OULU 2010
C 360

ACTA UNIVERSITATIS OULUENSIS

Ari Putkonen

MACROERGONOMIC APPROACH APPLIED TO WORK SYSTEM MODELLING IN PRODUCT DEVELOPMENT CONTEXTS

FACULTY OF TECHNOLOGY,
DEPARTMENT OF INDUSTRIAL ENGINEERING AND MANAGEMENT,
UNIVERSITY OF OULU

ACTA UNIVERSITATIS OULUENSIS
C Technica 360

ARI PUTKONEN

MACROERGONOMIC APPROACH APPLIED TO WORK SYSTEM MODELLING IN PRODUCT DEVELOPMENT CONTEXTS

Academic dissertation to be presented with the assent of the Faculty of Technology of the University of Oulu for public defence in OP-sali (Auditorium L10), Linnanmaa, on 18 September 2010, at 12 noon

UNIVERSITY OF OULU, OULU 2010

Acta Univ. Oul. C 360, 2010

Supervised by
Professor Seppo Väyrynen

Reviewed by
Professor John Abeysekera
Docent Hannakaisa Isomäki

ISBN 978-951-42-6236-4 (Paperback)
ISBN 978-951-42-6237-1 (PDF)
http://herkules.oulu.fi/isbn9789514262371/
ISSN 0355-3213 (Printed)
ISSN 1796-2226 (Online)
http://herkules.oulu.fi/issn03553213/

Cover design
Raimo Ahonen

JUVENES PRINT
TAMPERE 2010

Putkonen, Ari, Macroergonomic approach applied to work system modelling in product development contexts
Faculty of Technology, Department of Industrial Engineering and Management, University of Oulu, P.O.Box 4610, FI-90014 University of Oulu, Finland
Acta Univ. Oul. C 360, 2010
Oulu, Finland

Abstract

Product development (PD) has an important role as a key competitive factor in business environments. The capacity of designers and other stakeholders to perceive and process product related information is burdened by the increasing complexity of products and the high demands of working life. Therefore, companies need new human-centred perspectives and methods of balancing and enhancing their overall PD processes in order to develop successful products. The main motive for this research arises from the fact that ergonomics design research has been scarce from the process-oriented and systemic methods perspective. It has mainly focused on the methods, such as those needed in user interface design, and the usability and safety testing of products. The purpose of this dissertation is to consider the PD work system from the macroergonomics perspective.

Macroergonomics is a top-down sociotechnical systems approach that is concerned with the analysis, design and evaluation of work systems. Nowadays, the individual user context is the dominating source of product requirements, but the designers' work system has significant influence on its outcome as well. As an open work system, PD covers the use and design contexts of a product, not only at the individual, but also at the social and system levels. In this dissertation, the use and design contexts of products are examined through six individual studies, which were carried out during a demanding PD project of a new simulation game. In this design process, from the initial state to the goal state, macroergonomics was used as the main theoretical guideline.

In many companies, PD processes are considered and developed mainly from the project management or technological points of view. However, because of the increasing complexity and systemic nature of products, PD organisations, too, will have to become more participatory, more networked and more systems oriented.

As the main findings, this dissertation indicates that the macroergonomic approach can enrich the PD process and its outcomes by emphasising the balance between the technical and social subsystems of PD work system. The emerging complexity of products must be controlled from the entire PD work system, not the individual context of use only. The research introduces a new PD work system model that includes both the design and use contexts of products and demonstrates their analogical sociotechnical structures. The value of this dissertation for the industry is that companies can overcome certain emerging challenges of PD by applying the introduced macroergonomic principles. The findings of the research may encompass the re-designing of the current PD process in a company. Instead of shutting their eyes to the complexity of the surrounding world, companies should consider it as the macroergonomic PD work system and be more aware about the overall product requirements.

Keywords: design science, human interaction, human-centred design, macro-ergonomics, product development, system dynamics, work system

Acknowledgements

This research project was performed in close connection with an especially interesting product development project in which a new simulation game was designed and launched in the spring 2009. The project was supported by The Finnish Work Place Development Programme TYKES (2004–2009) aiming to enhance the productivity and quality of working life. I like to express my warmly thanks to all members of the TYKES team headed by Dr. Tuomo Alasoini.

I address my warmest gratitude to my supervisor Professor Seppo Väyrynen who gave me invaluable guidance in the multidisciplinary contexts of ergonomics, human-centred design and 'infected' me with macroergonomics as well. Many thanks to you Seppo, for your innovative, convivial and learned advice for my research. Your comprehensive approach and wide international academic network made it possible for me to consider many rousing project development subjects and participate in fruitful seminars. I wish also to acknowledge the entire staff at the Department of Industrial Engineering and Management. For instance, the scientific expertise of Dr. Juha Lindfros, Dr. Tauno Jokinen and Professor Harri Haapasalo and their ability to organise added value PhD seminars has been very advantageous for me. Besides I had my fellow doctoral students to thank for the easy atmosphere to study. This made me recall the old good times 30 years back when I started my master's degree in Department of Mechanical Engineering.

I would like to warmly thank my co-authors of the original publications included in this dissertation. I offer special thanks to Dr. Ursula Hyrkkänen, Dr. Juha Kettunen and Professor Matti Vartiainen who shared their extensive expertise in the fields of work psychology, distributed and mobile work, knowledge work and management. I am also deeply grateful to ProDesim project team and steering board members and especially to Mr. Markus Forstén, a co-author and workmate who shared the pains and celebrated the gains with me during the design process. Dr. Raimo Hyötyläinen from VTT also gave me very useful hints at the finalising stage of the work.

I wish to acknowledge the contributions of the official reviewers of this dissertation, Research Director, Docent Hannakaisa Isomäki from Faculty of Information Technology of University of Jyväskylä and Professor John Abeysekera from Work Science Academy, Sweden. Their careful review, valuable comments and recommendations improved the outcome.

The roots for this dissertation have been grown during a 15 year period when I was working for the Finnish export industry. Therefore, I would like to thank in particular the people who have motivated me as product developers. First of them are Mr. Kalevi Sjöholm, Mr. Reijo Kivelä and Mr. Heikki Kiiski and many others with whom I have been lucky to collaborate in various design projects.

This work took almost five years to complete. Without the co-operation with the above mentioned people and simultaneous everyday life with my family, the sacrifices would have been too much. First of all, I would like to thank my older parents Anneli and Eero who have always encouraged me in life. Many thanks to my brother Aki who has well focused 'R&D lenses' to talk about the product development issues from the holistic perspective. Thanks also to my sister Aija who showed a good example by her dissertation nine years ago. Finally, my deepest gratitude goes to my wife Marke and our daughters Raita, Ruut and Rosita who have been my muses in my 'hobby hall office' during the lonely night hours.

Counting my blessings in Merimasku on Whit Sunday 2010 Ari Putkonen

Abbreviations and definitions

IEA	International Ergonomics Association
ICT	Information and communication technology
NPD	New product development
PD	Product development
HCI	Human-computer interaction
UI	User interface
Artefact	is any object made by humans, e.g., a product.
Complexity	may appear when many components are involved, and these components, through links of different strengths, influence each other.
Design	as a noun is a plan that lays the basis for the constructing and making of every object or system.
Design	as a verb is to create, fashion, execute, or construct according to plan.
Design Science	is an outcome based information technology research methodology, which offers specific guidelines for evaluation and iteration within research projects.
Engineering	is the discipline, art and profession of acquiring and applying technical, scientific and mathematical knowledge to design and of implementing materials, structures, machines, devices, systems and processes that safely realise a desired objective, or inventions.
Human-centred design	is a design philosophy in interactive system development that focuses specifically on making systems usable. It is a multi-disciplinary activity which incorporates human factors and ergonomics knowledge and techniques. Human-centred systems support users and motivate them to learn. The benefits can include increased productivity, enhanced quality of work, reductions in support and training costs, and improved user satisfaction.
Product	is a thing produced by labor; all goods, services, and knowledge sold by an enterprise to its customer, the final result of engineering.

Product concept	is a clearly written and possibly visual description of the new product idea that includes its primary features and consumer benefits, combined with a broad understanding about the technology needed.
Product design	is a part of product development, the definition of the physical form of a product, the definition of product specifications from the product requirement, and includes engineering design and industrial design.
Product development	is the overall process of strategy, organisation, concept generation, product and marketing plan creation, execution, evaluation, and commercialisation of a new or improved product, converting product requirements into a working product.
Usability	The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.
User-centred design	is a part of the human-centred design focusing on the end users of an artefact only.
Work	is a sustained physical or mental effort to overcome obstacles and achieve an objective or result (Greek ergon).
Work system	is a system that involves two or more persons interacting with some form of hardware and/or software, internal organisational environment, external environment, and organisational design.

List of original publications

This dissertation is based on the following publications:

I Putkonen A & Hyrkkänen U (2007) Ergonomists and usability engineers encounter test method dilemmas with virtual work environments. In: Harris D (ed) Engineering Psychology and Cognitive Ergonomics. Berlin, Springer: 147–156.

II Hyrkkänen U, Putkonen A & Vartiainen M (2007) Complexity and workload factors in virtual work environments of mobile work. In: Dainoff MJ (ed) Ergonomics and Health Aspects of Work with Computers. Berlin, Springer: 85–94.

III Hyrkkänen U, Kettunen J & Putkonen A (2009) A participatory design project on mobile ICT. In: Cartelli A & Palma M (eds) Encyclopedia of Information Communication Technology. Volume II. Hershey, New York, IGI Global: 669–675.

IV Putkonen A & Forstén M (2007) The three-layer simulation game model for the computer-augmented board game. In: Mastik H & Mayer I (eds) Organizing and Learning through Gaming and Simulation. Proceedings of Isaga 2007. Eburon Delft, The International Simulation and Gaming Association: 303–311.

V Putkonen A (2009) Predicting the effects of time pressure on design work. International Journal of Innovation and Learning 6(5): 477–492.

VI Putkonen A & Forstén M (2009) Multiplayer interface for a computer-augmented learning game. In: Kankaanranta M & Neittaanmäki P (eds) Design and Use of Serious Games. Springer: 155–167.

The author of this dissertation has been the primary author in publications I, IV, VI and the single author in publication V. The researcher has been responsible for formulating the research problems and research questions, for the theoretical frameworks, the collection of empirical materials, analysing the materials, concluding and summarising the results, and finally being the primary author. The role of the co-authors in publications I, IV and VI has mainly been commenting and giving valuable feedback on the manuscripts. With regard to article II, the author has been involved for formulating the second research question, relating theoretical background and identifying workload factors as part of the contribution of the research. With regard to article III, the author was responsible for bringing participative design and macroergonomic perspectives for the research. The author had an important role in research design, literature review, and drawing future trends and conclusions. In publications II and III, the names of the authors are in alphabetical order. Articles I, II and IV were published in the referred proceedings of the international conferences, article V in the referred journal, and articles III and VI are chapters in the referred books.

Table of contents

1 Introduction

From the late 80's, one major challenge for product development (PD) organisations has been to keep development projects on schedule, as the delayed launch of a new product may mean losing a large part of its payback. That was the era when microelectronics brought added value for the first time for various industrial and consumer products, and caused a demand boom on the market. Efficient project management supported by a systematic PD process has been a very important success factor (Cooper 1996).

Today, rapid changes in the business environment are continuing. Short development times and the high technical quality of a product are still required, but they alone are not enough to be successful. New business models and delivery channels, shortened product life cycles, advanced ICT, and more diversified and flexible requirements of users are forcing management to reconsider the current ways of creating new products (e.g., Owens 2007). In addition, systems of innovation are nowadays global, and designers are therefore to a degree mobile and virtual workers. The management has new challenges in better understanding new virtual working environments and mobile designers' workload and well-being factors (e.g., Carayon 2006, Hyrkkänen 2006).

Knowledge workers are a crucial resource for PD, because their cognitive assets are the fundamental source of innovation (Nevala 2005). In the past, a highly competent group of engineers performed new product development, and knowledge about the product technology accumulated on an individual basis. Under the participatory approach (Kensing & Blomberg 1998, Olsson & Jansson 2005), many different stakeholders join the product development process. In this situation, individual knowledge is still important, but sharing the knowledge is crucial (Pentina & Strutton 2007). Therefore, team work skills (Akgün *et al.* 2007, Molleman 2005) are essential competencies among workers who are participating in the product development process.

Historically, the technology-centred approach has been very successful in PD (e.g., Pahl *et al.* 2007). But when the human-technology relationship is not completely understood and taken into account, various problems with products occur. Human-centred design (Norman 1998, Maguire 2001) is a PD approach emphasising that technology should fit users. This can be achieved by understanding the users' capabilities and limitations better during the design. In any case, the above mentioned approach does not guarantee the optimal product from the overall system point of view. The overall system can be for example a health care system, a transportation system or an information system.

Besides the advanced PD process, technology, and competent people, we need principles and methods for supporting the work of designers. They should be able to construct an overall picture of the system within which they are operating. Macroergonomics brings a wide systems perspective to work system design and development (Hendrick 2002), and therefore this study is interested in the macroergonomic approach to a PD work system, in order to find new opportunities to develop PD practices.

1.1 Background

This research project started in 2006 during the demanding PD project of a simulation method. Three research institutions, one PD association and several companies were participating in the project. The goal of the project was to create a simulation game for the collaborative training of PD skills. Industry and educational institutions were the targeted users of the simulation game.

Humans are the crucial intellectual resource for innovation and PD activities. PD as the fundamental theme of a business game was a new and challenging simulation system. Because of the demanding targets and the systemic nature of the problem, the decision was made to apply a macroergonomic approach in the project. Through the project, the theoretical and practical consideration of the PD work system was performed form the macroergonomic perspective. The project was finalised and the new simulation method launched in spring 2009. A more detailed description of the PD project case can be found in Chapter 4.1 and Appendix 1.

1.2 Motivation for the research

The focus of design science studies is still in the functions of artefacts, while the use contexts or social perspectives of the products are not discussed, even as products are more and more complex and their use environments are increasingly mobile and virtual. The ergonomics studies in the field of PD have also mainly focused on the microergonomic issues, such as user interface design, usability and the safety of products. Thus, the first motive for this research arises from the fact that a successful PD process seems to require more systemic and human-centred perspectives. The second motive arises from the need for new methods in order to consider and develop PD work practises and processes in companies.

By definition, macroergonomics brings a wide systems perspective to work system design and development (Hendrick 2002), but its applicability and usefulness in PD contexts is widely unknown. The third motive arises from the potential macroergonomics offers as a novel approach to improve product development process performance from the individual level to the organisational level, i.e., by applying systems thinking. Therefore, this dissertation explores the missing success factors of PD for these above mentioned motives.

1.3 Objectives of the research

The overall objective of this research is to bring new thinking into the discussion about innovations, especially innovation processes and PD work systems.

The main objective of this research is to examine whether macroergonomics is an applicable and useful methodology in a PD context. Macroergonomics brings a wide systems perspective to work system design and development, and thus one aim is also to highlight the importance of systems thinking in PD (Galanakis 2006), especially when products or their use environments are complex.

In practice, the last important aim of this research is to support the simulation game development project, introduced above, by offering a theoretical background for the tangible design challenges.

1.4 Dissertation structure

This dissertation consists of six individual articles and this summary. The summary is organised as follows: Chapter 2 presents the research design, including the description of the research problem, scope, perspective, approach, methods and process. Chapter 3 presents the formulation of the theoretical framework. Chapter 4 summarises the research contribution of the six articles. In Chapter 5, the overall conclusions of the research are discussed. Finally, Chapter 6 summarises the research work.

2 Research design

The main elements of a research are the purpose, research problem, methodology and materials. When they are relevant, and correctly selected and applied, the research will generate scientific contributions. The following chapters introduce the design of this research.

2.1 Research problem

Product development has an increasing role as a key competitive factor in business environments. The increasing sophistication and complexity of products require more collaborative skills among designers and other stakeholders in order to develop successful products. Companies are constantly decreasing the time and money spent on product development, but simultaneously the quality of the products should remain at a high level. Technology alone is not the solution to product success on the markets. Companies need new perspectives and concrete means to improve and streamline their PD processes.

Even though PD work includes many human related challenges, the role of ergonomics in product design has been limited. Traditionally, ergonomics has been applied to solving problems related to physiology or cognition in the human – tool or human – task domains (microergonomics). PD as a work system aims to produce usable, safe, healthy and efficient products for the users.

Pahl *et al.* (2007) have argued that design problems begin at the system level. This means that the whole problem has been understood and defined at the system level and then divided into subsystems and so forth, down to individual components that can be designed using the engineering knowledge and traditional analysis methods. The systems approach (Sterman 2000, Rodrigues *et al.* 2006) seems to be a missing perspective in many innovation processes.

Macroergonomics is known as a holistic work system design methodology, but its applicability and usefulness in PD contexts is widely unknown. However, Moro's (2009) study stresses that macroergonomics may increase the likelihood of information systems implementation success. Haro and Kleiner (2008) illustrate an integrative role for macroergonomics with respect to safety in organisations. Yasemin's (2004) study addresses the adoption of macroergonomics in order to improve management decision performance. Whilst there is a growing body of literature in the field of macroergonomics, there is less empirical evidence providing practical examples of how macroergonomics can be applied in PD. However, Palacios and Imada (1998) have described a macroergonomic analysis of workplace issues that drive end user needs. They emphasise the broader milieu where the product will be used.

Based on the exemplifications above, it can be supposed that latent PD success factors can be found by considering the work systems where the designers and users of the products are operating. The research problem this dissertation addresses can be formulated as follows:

Can the macroergonomic approach support PD work?

The research problem is studied from two complementary perspectives in the published articles. First, the *use context* is studied in Articles I, II and III, which introduce understanding about the complex use environments of products and bring out the macroergonomic viewpoints. The second phase of the research addresses the *design context*. This phase is carried out by selecting three cases that illustrate some design steps of a product development project. The design, modelling and realisation of a simulation game development are reported on in Articles IV, V and VI.

Each article is a case that provides a partial solution to the research problem that is considered from the above mentioned two perspectives. The research problem is divided into six research questions, which are deduced from the detailed research questions of the articles by raising the level of analysis. The research questions originate from practical targets when applying macroergonomics in the PD project case. It is obvious that the questions do not cover all of how the macroergonomic approach may support PD work, but they do, however consider many relevant macroergonomic viewpoints, such as, human resources (personnel), methods (technology) and systems design (organisation). The research questions, the articles, their PD context and the related macroergonomic viewpoints are summarised in Table 1. The research contributions of the individual articles are discussed in Chapter 4.

Table 1. Research questions and the related articles.

RQ#	Research question	Article	PD context	Macroergonomic viewpoint
1	What are the applicable ergonomic methods for macroergonomic intervention?	I	Use	Technology
2	What kind of workload factors occur in complex working environments?	II	Use	Personnel
3	What are the effects of a participatory approach on PD?	III	Use	Technology
4	How can the PD work system be modelled holistically?	IV	Design	Organisation
5	How can the effects of the designer's mental load factors on the performance be demonstrated?	V	Design	Personnel
6	How can the macroergonomic principles be applied in HCI design?	VI	Design	Technology

2.2 Scope and perspective of the research

Because the scope of this research is the PD work system, it is placed within the field of ergonomics (or human factors in U.S. literature). Ergonomics is the scientific discipline concerned with understanding the interactions between humans and other elements of a system, in order to optimise human well-being and overall system performance (IEA 2000). The PD process is a system that is considered from the macroergonomic perspective in this dissertation.

This study contributes to the product development activities in companies, and therefore its broader positioning is within the field of industrial engineering and management. Product development is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product (Ulrich & Eppinger 2004). When the word 'product' is used in this research, a tangible product is referred to. The findings may be also relevant for the development of intangible artifacts, such as services, but they have not been under particular consideration.

The position of this research is in the common ground between ergonomics and industrial engineering and management studies, as Figure 1 depicts. This dissertation contributes to the discussion about human factors, i.e., the ergonomics of PD work. PD belongs to the field of design science research (Järvinen 2004a, Hevner *et al.* 2004, Van Aken 2004, March & Smith 1995). Product development as an essential part of the innovation process is an important field of study in both the industrial engineering and ergonomics disciplines.

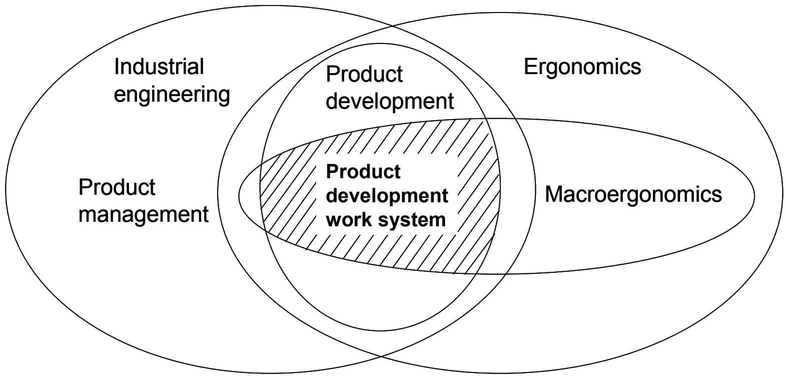


Fig. 1. Positioning the research in the field of engineering science.

Product development work as an object of modelling is a complex sociotechnical system and requires therefore consideration from the macroergonomics perspective. Macroergonomics is as a methodology of applying human-centred systems thinking to work system development.

2.3 Research approach

The main objective of this research is to consider whether macroergonomics is an applicable and useful methodology in PD. This viewpoint is novel, and thus the research is explorative in nature. The consideration is performed empirically by applying macroergonomics during the PD project case. This wide target requires versatile application of the technical and social sciences.

The theoretical framework for the research is constructed on the basis of macroergonomics and design science. Design science as a major scientific starting point for PD is an obvious element of the theoretical basis of this research. This definition is also supported by Karwowski (2005) who argued that ergonomics is a design-oriented discipline. The foundations of macroergonomics (Hendrick 2008) are in sociotechnical theory and general systems theory. From the design science perspective, macroergonomics can be seen as a method, i.e., a guideline, to perform a task, as March and Smith (1995) have defined.

In this sense, this research belongs to the category of ergonomics design and applied ergonomics. It is ergonomics design because it is interested in utilising the fundamental understanding about macroergonomics in the practical context of product development work. The theoretical perspective on ergonomics can be considered from the science, engineering, design, technology, and management of the human-systems points of view. They may have theoretical, practical or combined aims in ergonomics research. (Karwowski 2005.)

The design science paradigm is fundamentally a problem solving paradigm with its roots in engineering and the sciences of the artificial (Simon 1996). Design science creates and evaluates artefacts intended to solve identified organisational problems (Hevner *et al.* 2004). Design science research is also called constructive research (Järvinen 2004a). A constructive study is experimental by nature, following the pragmatic philosophy of science. The constructive research approach was originally developed in the field of management accounting in the 1980s (e.g., Kasanen *et al.* 1993).

The categorisations of Järvinen (2004a) and Hyötyläinen (2005) have been used as the frameworks for the selection of the scientific research approach. The constructive approach is close to the action research approach. Järvinen (2004a) argues that both building and evaluating the sub-processes of an artifact closely belong to the same process. He states that action research gives answers to the question: How to improve an artifact? Hyötyläinen (2005) expresses that action research can be seen as a method that supports ongoing change processes in the real context of an organisation, but in the field of traditional action research it is controversial whether the researcher may participate in formulating the solution.

In summary from the above consideration, the studied PD case followed the constructive approach when solving the practical design problems of the simulation game. The main objective of this research is to examine whether macroergonomics is an applicable and useful methodology for such design work. Thus the design science case study is a suitable approach for this research.

2.4 Research methods and materials

According to Eisenhard (1989), the case study is a research strategy which focuses on understanding the dynamics present within single settings. She also specifies that case studies can be applied in order to accomplish various aims: to provide a description, to test a theory or to generate a theory. In this study, macroergonomics as a method is tested by applying it to the PD project case.

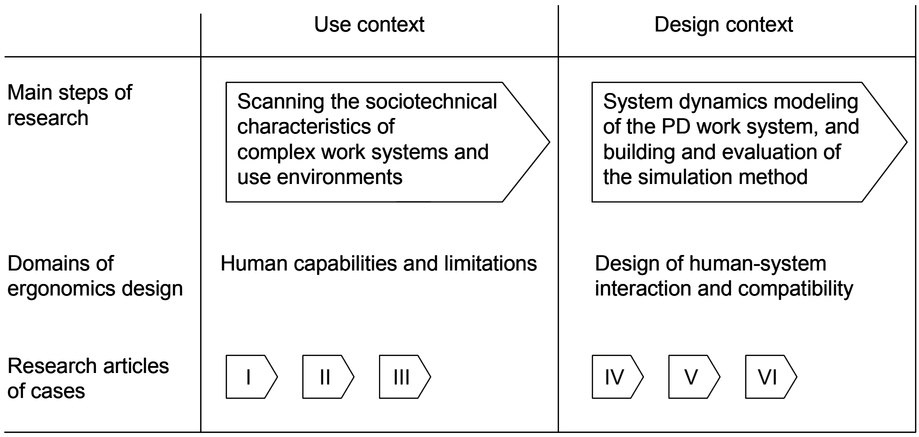


Fig. 2. The research process of the dissertation.

The research is qualitative in nature. Figure 2 depicts the two main phases of the design process of the simulation method. The first phase, with three cases, stresses understanding the sociotechnical characteristics in the *use contexts* of products. The second phase of the research is *design context* oriented by utilising the knowledge collected during the first phase for modelling a PD work system. Two domains of ergonomics design (Karwowski 2005) can be identified by examining the physical, mental and social capabilities and limitations of humans, and the design of human-system interaction and compatibility.

Case study designs can have either a single or multiple cases (Yin 2003). This research utilises a holistic multiple-case study with a single unit of analysis. The six studies and articles represent multiple cases from the PD work system. Several methods are applied for material gathering and analysis in the individual studies. These are introduced in the articles. However, the evaluation of the macroergonomic approach in PD, requires a higher level of analysis, where the single unit of analysis is a PD work system as whole.

First, the within-case analysis (Eisenhardt, 1989) is carried out by the identification of the relations between the sociotechnical work system elements. The results of this analysis are presented in Appendix 3 and interpreted in Chapter 5. Next, the role of the macroergonomic approach in the cases is analysed cross-case (Appendix 4) based on the contributions and the guidelines for macroergonomic intervention summarised in Table 2 (Hendrick & Kleiner 2001). This analysis helps to compress the empirical findings regarding the role of macroergonomics in the cases. The results of the analysis are summarised in Table 4.

Design science (Hubka & Eder 1987) is identified as a valid approach to widely consider PD. Therefore, the utility of the macroergonomic approach in the PD domain is analysed and discussed against the criteria of the design science research introduced by March & Smith (1995). This cross-case analysis (Eisenhardt 1989) combines the results of six studies that address to apply the macroergonomic approach in a PD project (Appendix 4). The results of this analysis are summarised in Table 6.

Finally, in order to highlight the systems perspective of the work system design, a new conceptual model about the macroergonomic PD work system was constructed by inductive reasoning. This part of the research follows the conceptual-analytical approach (Järvinen 2004b). Based on the earlier findings, the fundamental assumptions of the human-centred PD work system relate the needs: (i) to increase the designers' understanding about the use context in order to design optimal products, and (ii) to involve users in the design context in order to identify essential product requirements. The new conceptual model of the macroergonomic PD work system is justified in Chapter 5.3 against the design science guidelines offered by Hevner *et al.* (2004).

2.5 Summary of research design

Figure 3 summarises the main elements of the research design described above. The increasing sophistication and complexity of products require to considering the PD work systems from various viewpoints in order to develop optimal products. Macroergonomics is a holistic work system design methodology, but rarely mentioned in relation to PD activities. The primary objective of this study is to consider whether macroergonomics is also an applicable and useful methodology for PD. This viewpoint is fresh, and thus the research is explorative in nature. The theoretical framework for the research is constructed on the basis of macroergonomics and design science disciplines. This research utilises a holistic multiple-case study (Yin 2003) with a single unit of analysis, that is the PD work system. The empirical study is performed by using macroergonomics as an expedient in the actual building project of a simulation game. Thus, this part of the research can be classified as the design of artefacts as products (March & Smith 1995, Hevner *et al.* 2004, van Aken 2005). The case is studied from two complementary perspectives; the use context and the design context of the product. Within-case analysis and cross-case analysis are used to compress and combine the results of six studies. Based on the theoretical framework and the findings of the study, a macroergonomic PD work system model is introduced. This part of the research can be classified as the design of artefacts as processes (March & Smith 1995, Hevner *et al.* 2004, van Aken 2005). The usefulness of the macroergonomic approach in PD work is analysed against the guidelines of the design science research (March & Smith 1995, Hevner *et al.* 2004) in order to find the answer to the overall research problem. Finally, the contribution is summarised and discussed.

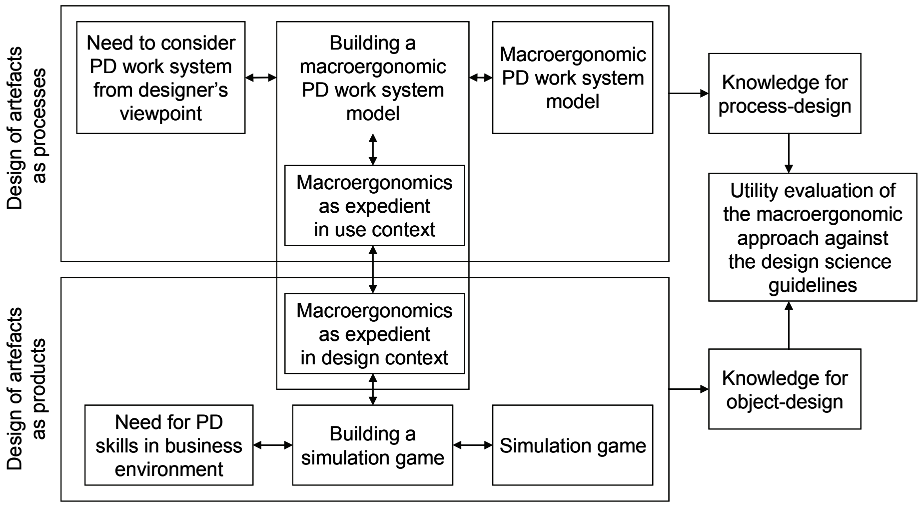


Fig. 3. The research design.

3 Theoretical foundation

In this chapter, the theoretical framework of the research is constructed based on the foundation of design science and macroergonomics. As a sub-discipline of ergonomics, macroergonomics focuses on the development of organisational structures. Therefore, the theoretical framework of this dissertation is created on the basis of these two disciplines.

3.1 Concepts of design science

Engineers apply their scientific and engineering knowledge in order to solve technical problems. The mission of design science is to develop knowledge for the design (process) and for realisation (implementing an innovation), and the utility of the innovation should be evaluated (van Aken 2004). Design knowledge concerns an object-design, a process-design, and a realisation-design. The typical object of design is an artefact; for process-design, a project plan, for problem solving and a realisation design, the building of an artefact. (Järvinen 2004a.)

A design can be defined as a model of an artefact or as an instruction for the creation process. The artefact can be an object or a process. The model can adopt various physical forms, e.g., a drawing, a scale model, a flowchart or a digital 3D-model. Usually, a model is an abstraction of reality, but when a design is concerned, it is a model of a possible reality in the future. (van Aken 2005.)

The building process of innovation consists of three fundamental stages; the initial state, the building process and the goal state (Järvinen 2004a). The purpose of the construction process is to achieve a movement from the initial state to the goal state. The problem is always unique and specific, and thus design knowledge must be translated to support the specific design case. March and Smith (1995) also emphasised the importance of the evaluation of design results. Thus, they see building and evaluating as separate research approaches in design science. A technology-based artefact is a typical example of the application of design theory, but organisational design activities, such as work practices and policies are also regarded as design science activities (Hevner *et al.* 2004).

The advantage of design theory for PD is that it covers the entire building process of an artefact from the concepts to the realisation. This may be enough for the design of traditional mechanical components, such as engines, valves, and switches. But the disadvantage is that it is all about the functions of artefacts (compare e.g., Suh 2005 and Maier 2008). The *use context* or social perspectives of products are not discussed, even though products are more and more complex and their use environments are increasingly mobile and virtual.

3.1.1 Methodology of design science research

The difference between design science research and routine design or system building is in the nature of the problems and solutions. Routine design is application using the existing best practice knowledge. Design science research addresses important unsolved problems in unique or innovative ways or solves problems in more effective ways. Thus, routine design and design science research make different contributions to the design knowledge base. (Hevner *et al.* 2004.)

The ultimate mission of design science is to develop design knowledge for the professionals in its fields (van Aken 2004). The design theory does not address a single problem or a specific artefact but a class of problems and artefacts (Walls *et al.* 1992 and 2004). The methodology of design science research emphasises both accuracy and relevance. Guidelines have been introduced on how to conduct, evaluate and present design science research (Hevner 2007, Hevner *et al.* 2004, March & Smith 1995, Walls *et al.* 1992 and 2004) in order to complete the knowledge base and produce valid and reliable technological rules (van Aken 2004).

Nunamaker *et al.* (1991) have classified the empirical methods of the design science research. Referred to by Järvinen (2004b) their multi-methodological approach consists of four research strategies: theory building, experimentation, observation, and systems development. The systems development follows the research process in the following way: (1) construct a conceptual framework, (2) develop a system architecture, (3) analyse and design the system, (4) build the system, and (5) observe and evaluate the system. Stages 2, 3 and 4 belong to system development itself. Stages 1 and 5 include similar methods as mentioned in traditional theory building, experimentation and observation approaches. Empirical methods such as case studies, survey studies and field studies can be used for observing the problem area. Methods such as computer simulations and field and lab experiments are possible methods for evaluation. Prototyping and PD are suitable methods for systems development. In multi-methodological thinking, systems development dominates and the other sub-strategies are used from the utility point of view.

The research referred to above about design research literature includes many ideas on how to conduct research. However, they do not provide process models that can be applied directly to the problem of design science research (Peffers *et al.* 2008). Certainly, March and Smith's (1995) and Hevner et al.'s (2004) design science research guidelines help in methodological choices and evaluation within the design science research process.

Design science research creates knowledge for design, and ergonomics is a discipline that considers design from the human perspective. The next sections address the concepts and methods of ergonomics.

3.2 Concepts of ergonomics

Ergonomics is the theoretical and fundamental understanding about human behaviour and performance in purposefully interacting sociotechnical systems. Ergonomics is also interested in the applications of that understanding to the design of interactions in the context of real settings. (Wilson 2000.) The objective in ergonomics is to apply scientific knowledge about human capabilities and limitations and other characteristics to the design of machines, tools, workplaces, and physical environments, in order to enhance usability, productivity, health, safety, and minimise human errors via design. (Hendrick & Kleiner 2001.)

The most often cited domains of specialisation within ergonomics are physical, cognitive and organisational ergonomics (Karwowski 2005). Physical ergonomics is mainly concerned with human anatomical, anthropometric, physiological and biomechanical characteristics (Dul & Weerdmeester 2001). Cognitive ergonomics is related to mental processes, such as perception, memory, information processing, reasoning and motor response (Hollnagel & Woods 2005). When ergonomics is concerned with human-machine interface technology or user-interface technology, it is often also referred to as microergonomics. In contrast, organisational ergonomics, i.e., macroergonomics, is concerned with the optimisation of wider sociotechnical systems, including their organisational structures, policies and processes (Hendrick & Kleiner 2001, Haro & Kleiner 2008).

In practice, the costs of poor ergonomics usually appear in terms of absenteeism, quality defects, decreased organisational performance, employee turnover and reduced productivity. Dul (2006) emphasises that the value of ergonomics for companies goes beyond health and safety. Significant cost reductions and quality improvements can be achieved by user-friendly products and well designed work processes. He has said that '*good ergonomics is also good economics*', but most organisations are unaware of this strategic value of ergonomics.

3.3 Product development methods

Engineers apply their scientific and engineering knowledge in order to solve technical problems. Various strategies, approaches and methodologies have been developed for enhancing the PD process and the integral component of engineering design. Among these are: structured, hierarchical design techniques (Pahl *et al.* 2007), methodologies emphasising user requirements (Maguire 2001), methods mapping user requirements to design attributes (Suh 1997) and gate reviews (Cooper 1996). Typically, the PD process has been divided into phases or stages in a timeline. This systematic process moves a PD project through the sequential stages from the idea to the launch. Each stage is designed to gather information and perform all the tasks necessary to progress in the project. (e.g., Ulrich & Eppinger 2004, Cooper 2004.) The difficulty with most of these processes is that they depict the phases of development at the high abstract level, without concrete links to the designers' everyday work. Implicitly they also postulate that there exists a 'design equation' for the perfect solution.

3.3.1 Product development processes

The product development process has been examined from several perspectives in previous studies. In many studies, finding an 'equation' for the optimal design seems to be the leading aim and motivation. In consequence, various PD approaches have evolved. We can recognise approaches to PD such as emphasising concurrent engineering (Swink 2003), creativity design (Hsiao & Chou 2004, Tuomaala 1999), teamwork and learning (Akgün *et al.* 2006 and 2007), networking (Apilo 2004), project management (Milosevic & Patanakul 2005), design for manufacture (Huang & Mak 1998), and recently, collaborative design (Détienne 2006), participatory design and ergonomics (Vink *et al.* 2008, Olsson & Jansson 2005, Sundin *et al.* 2004, Kensing & Blomberg 1998) and human-centred design (Maguire 2001, Kesseler & Knapen 2006, Jokela 2004). The purpose of all these different approaches is to show the direction towards the optimal product and an efficient development process.

Numerous different PD process models have been developed for moving a PD project through the various stages from idea to launch (Ulrich & Eppinger 2004). The approaches referred to above have affected the model concepts and their level of abstraction. Pahl *et al.* (2007) have defined four phases in the NPD process; (i) problem definition, (ii) concept planning, (iii) rough planning and (iv) planning of details. Cooper's (1996) second, further developed Stage-Gate-Model consists of five stages; (i) Preliminary investigation, (ii) detailed investigation, (iii) development, (iv) testing and validation, (v) full production and market launch. Each stage is designed to gather information and perform all the tasks necessary to progress in the project. Between the stages there are entry gates or decision points where the results of the actions of the previous stages (deliverables) are reviewed and the quality is checked.

The traditional movement of PD studies has emphasised the importance of understanding the product related requirements in order to be successful. The sources of these requirements can be, e.g., users, delivery chains, manufacturing technologies or authorities. Another section of the traditional PD studies is interested in the resources and limitations that are usually present in the PD processes. (e.g., Suomala & Jokioinen 2003.)

Cooper, the creator of one well-known stage-gate model, emphasises in his later studies (Cooper 2008) that applying a systematic approach with process phases is not the solution, but instead, better cooperation should be achieved in companies. Jespersen (2007) also argues that structuring the PD process is valuable for the screening of product ideas, but not for perfecting the PD process in a company. Thus, PD process models only give principles or templates on how the PD process should flow in the ideal word. Much effort is needed before an organisation is able to turn the theory into practice.

Most of the process models depict the phases of development at a highly abstract level, without concrete links to designers' everyday work. Even Cooper (2008), the respected developer of the stage-gate model, argued that applying a systematic approach with interacting phases is not the solution. The solution involves implementing the approach in work practices and larger domains.

Product design can be seen as a transformation process from an idea to a (technical) system, and the system is formed within the limits of the designers' cognitive and information capacities (Nevala 2005). Even though the literature includes a wide variety of models of design processes as referred to above, they rarely discuss anything the work system from the sociotechnical viewpoint at all.

All the PD process designs can be constructed from the basic input-output modules, where the requirements from the earlier phase are processed to the outcomes. In addition, the process is influenced by resources, limitations and uncontrollable disturbances. In this dissertation, the general PD process model is seen as depicted in Figure 4.

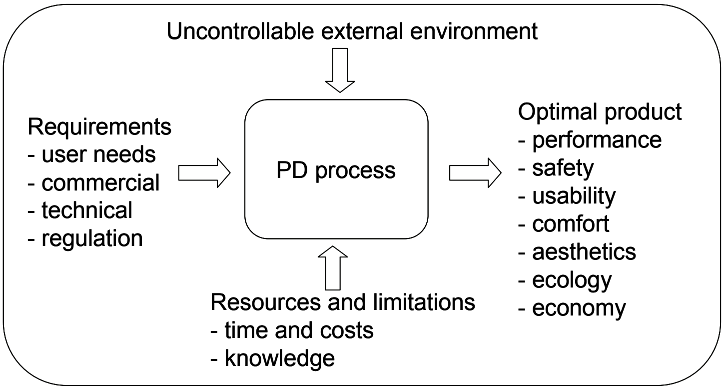


Fig. 4. The general PD process model.

The PD process can also be seen as a work system converting product needs and requirements into an optimal product. The PD process can further be seen as a bridge between the designer's and the user's worlds. Outcomes of the PD process depend on the process itself. In order to create optimal products, besides clarifying product related requirements, designers have to consider their own work processes and organisational structures. Referring to Senge (2006), they should see how their own actions create the problems they experience. In a learning organisation people should continually discover how they create their reality and how they can change it.

3.3.2 Human-centred design

The human-centred product development approach attempts to compensate for the weaknesses of the product functions focused approach. It is a process of product development that starts with users and their needs rather than with technology (Maguire 2001, ISO 1999). It requires developers who understand people and the tasks they wish to achieve. A favourable example is Kansei engineering that aims at the implementation of the customer's feeling and demands into product function and design (Nagamachi 2002).

Earlier studies exist where a holistic human-centred approach (Maguire 2001) has been applied to the field of PD. For instance, Väyrynen *et al.* (2006) reviewed 10 years of experiences with the PERDA method they have developed and used. PERA is an acronym of 'A participatory ergonomic research and development approach'. It is a user-centred design approach, which means that the concept of ergonomics and the basic ergonomic system model introduced by Pheasant (1996) are the key starting points. The user-centred design of products is opposed to technology-driven products (Ulrich & Eppinger 2004). Väyrynen *et al.* (2006) stated that the PERDA method always starts from the individual users or customer who uses the products to carry out the desired tasks. Later on, it considers user-product interaction in a larger context.

The need for a wider focus on PD has been recognised before with IT systems development, too, when the new systems did not meet user requirements. Hendrick (2002) describes how a waterfall type of PD process leads to focusing on defining technical solutions to information processing requirements rather than looking at the wider perspective of the user organisation. A wider perspective for human-centred systems design is also supported by the international standards. Their aim is to help in hardware and software design process management and to identify and plan human-centred design activities. For instance, the following standards complement existing design approaches and methods by the systems approach: ISO 13407: *Human-centred design processes for interactive systems* (ISO 1999), ISO/TR 18529: *Ergonomics – Ergonomics of human-system interaction – Human-centred lifecycle process description* (ISO/TR 2000), and ISO 6385: *Ergonomic principles in the design of work systems* (ISO 2004).

Collectively, research on user interaction and user orientation has provided valuable insights into the role of users in several key phases of the development process. This includes specifications, testing, requirements, and overall product feedback. Yet, such insights do not directly appear in the PD process models.

3.3.3 Participatory design

Participatory design is a specific field of participatory ergonomics and a widely used practice among professional designers (Kensing & Blomberg 1998). In participatory design, the end users are invited to cooperate with the developers in a product development process. Potentially, they are expected to participate in several stages of the development process. Among others, Olsson and Jansson (2005) and Kensing and Blomberg (1998) claim that a participatory design is essential for developing and testing new products. Earlier studies on participatory design have mainly focused on issues like the design process, concept communication, product specification, and prototype trials. Studies often focus on the importance of use contexts of products also, but they very rarely focus on combining macroergonomics to the process of design. Article III examines the participatory design process from the work context point of view by reporting a case study.

3.3.4 Collaborative group work in PD

In PD, overlapping and interdependencies between tasks are significant and collaboration is therefore a fundamental element of the design work. Détienne (2006) notes that in collaborative design, especially when team members work on specific subtasks, it is essential to understand that one's work is engaged in the work of another team member. For example, *A* relies positively on the quality and timelines of *B*'s work and vice versa. Thus, managing task interdependencies becomes crucial from the financial point of view.

Akgün *et al.* (2006) has stated that team information acquisition and sense-making within the team increase team intelligence, which helps the team members understand each other. It appears that understanding the sociocognitive processes in the team facilitates learning and the team's ability to convert the problems into more versatile solutions. Information sharing and collaborative sense-making aims to encourage team members to communicate and negotiate with others to ease decision making and problem solving.

The study by Owens (2007) shows that delay in PD projects is mainly due to poor understanding of customer requirements, insufficient knowledge about the product's technology and market forces. This indicates that poor internal communication between functions or team members makes it difficult to define product requirements and develop design specifications, which are the fundamental phases when developing a new product. The organisational key functions, such as research and development, marketing, engineering, production, financial accounting and management should be integrated into the PD process at an early stage to avoid the aforementioned pitfalls.

Cooperation between different functions of the company can have a significant effect on the end product of the development process and its ensuing success on the market. Cross-functional teamwork in product development has been studied by various authors. Kim and Kang (2008) identified, by means of a survey of team managers (N=243) at consumer electronics firms, some critical factors of cross-functional cooperation in design teams. The identified factors were: unified vision and goals, unified culture with partners, and building trust and cohesion. They argued that managers must consider the working climate and environment beyond technical systems or infrastructure in order to support design co-work.

In product development projects, the team must usually balance between time, costs, features of the product and quality. To find an optimal balance it is necessary for the team to communicate and collaborate successfully. Financial limitations are usually a dominant factor in these situations.

3.4 Concepts of macroergonomics

Larger work systems have to be considered when there is a need to better understand human–technology interaction, capabilities, and limitations. Macroergonomics (also known as organisational ergonomics) is an approach which attempts to achieve a fully harmonised work system at both the macro- and microergonomic levels by integrating principles and perspectives from industrial, work, and organisational psychology. (Hendrick & Kleiner 2001, Hendrick 2002, Kleiner 2006.)

Robertson (Robertson *et al.* 2002) clarified the origin of macroergonomics: sociotechnical system approaches historically did not directly address microergonomic issues and microergonomics failed to address the larger system's issues. Thus, there was a need for an approach integrating sociotechnical systems theory and microergonmomics. In this sense, macroergonomics also includes microergonomic issues.

Macroergonomics is concerned with the optimisation of sociotechnical systems, including their organisational structures, policies and processes. Examples of relevant macroergomonic topics include communication, human resource management, teamwork, participatory work design, community ergonomics, computer-supported cooperative work, virtual organisations and quality management. (Karwowski 2005.)

There are three criteria which are essential for an effective work system design: (i) a joint design purpose of the personnel subsystem and the technological subsystem, which should be developed simultaneously and supported by employee participation throughout the entire design process; (ii) humanised task approach concerned with human functions and tasks in the work system, prior to the decision to allocate tasks to workers or devices; (iii) consideration of the organisation's sociotechnical characteristics (personnel subsystem, technological subsystem, organisational design and external environment), which should be evaluated and integrated into the design process of the work system. When the selected development methodology fulfils the three criteria mentioned above, the design is human-centred and macroergonomic. (Hendrick & Kleiner 2001.) The guidelines on what is essential for an effective macroergonomic approach are summarised in Table 2.

Table 2. Guidelines for macroergonomic intervention.

#	Macroergonomic guideline	Description
1	Participatory design	Design is supported by employee participation throughout the entire design process.
2	Joint design	A personnel subsystem and a technological subsystem are developed simultaneously.
3	Human-centred design	Human functions and tasks in the work system are considered prior to the decision to allocate tasks to workers or devices. Apply ergonomic principles to fit work to human resources.
4	Systems design	Organisation's sociotechnical characteristics (personnel subsystem, technological subsystem, organisational structure and external environment) should be evaluated and integrated into the design process of the work system.

A characteristic example of the need for macroergonomic thinking is discussed by Abeysekera (1990). It concerns the link between the design and the use context of technology. Abeysekera emphasises that due to basic ergonomic differences, such as people's sizes, the physical environment, physical capacities and organisational and cultural differences, a technology may be found to be inappropriate, harmful, hazardous and unsuccessful if it is not designed or modified for use in the particular use context. For instance, a successful transfer requires that the technology is adapted or modified to take into account the technological, anthropological and socio-economic factors of the acquiring people.

System ergonomics is also an approach which is based on sociotechnical systems theory. It is suggested that macroergonomics distinguishes itself from system ergonomics by its special attention to organisational design and management factors within the multiple subsystems (Haro & Kleiner 2008).

Macroergonomics is an approach integrating sociotechnical systems theory and microergonomics (Roberston *et al.* 2002). It is a top-down sociotechnical systems approach for the design of work systems. In any case, there exist few studies where macroergonomics is the founding methodology on the PD work system design and development. One of the few is Palacios' and Imada's (1998) conceptual paper, where they identified the influences of macroergonomic variables on user needs and consequently on the design.

As a sub-discipline of ergonomics, macroergonomics brings a wide systems perspective to work system design and development (Hendrick 2002). In order to understand why macroergonomics is valued as a sub-discipline of ergonomics, we have to consider its origins in sociotechnical theory. Organisational design and management factors are best understood in a sociotechnical work systems context (Kleiner & Hendrick 2008).

3.4.1 Sociotechnical systems theory

Sociotechnical systems theory proposes a number of different ways of achieving the joint optimisation of the social and technical elements of an organisation. It was developed in the 1960's by Eric Trist and Fred Emery at the Tavistock Institute. Despite its beginnings in production line and mining case studies, the approach is as relevant today as it was 50 years ago. Sociotechnical systems theory is a theory stating that effective work sites have joint optimisation of their social and technological systems, and that work groups should have sufficient autonomy to control key variables in the work process. (Kleiner 2006.)

Carayon (2006) states that the margroergonomic design of sociotechnical systems in collaboration with both the workers in the systems and the customers requires increasing attention. In any case, principles of sociotechnical systems theory, like participation and usability, should be applied with care. Dillon (2000) argues that usability is a necessary but insufficient condition for technology acceptance, and the criteria for effectiveness, efficiency and satisfaction must be derived from the social and not the individual context of use.

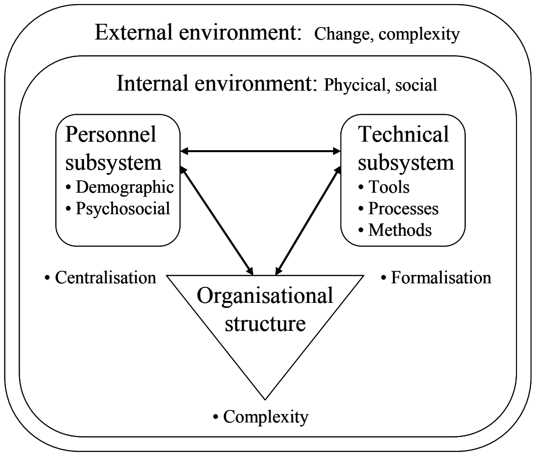


Fig. 5. A sociotechnical work system model (adapted from Kleiner (2006) and Kleiner & Hendrick (2008)).

A sociotechnical work system model is illustrated in Figure 5. It consists of four interacting subsystems: (1) The technical subsystem including tools, processes, methods, all the things required to perform the work. (2) The personnel subsystem comprised of the workers who are needed to do the work, including their demographic and psychosocial characteristics. The personnel subsystem interplays with the technological subsystem. (3) The environmental subsystem, which can be divided into two elements; external and internal. External refers to the elements outside the work system in focus, and internal refers to social and physical characteristics. Organisational structure and management processes belong to (4) the organisational subsystem, which is the fourth element of the sociotechnical work system, including core dimensions of centralisation, formalisation and complexity. All work systems operate within larger systems, and thus they are systems within systems and very challenging to analyse and design from the management point of view. (Kleiner & Hendrick 2008.) The number of organisational structure dimensions and their interrelations are high, and they are therefore presented in detail next.

3.4.2 Key dimensions of organisational structure

Organisational structure can be conceptualised by three core dimensions; centralisation, formalisation and complexity. In order to focus a macroergonomic intervention on the most essential factors, Kleiner and Hendrick (2008) have explained the commonly used measures to quantify the degree of these core dimensions. The measures of these dimensions are called macroergonomic variables.

A macroergonomic approach requires that the technological subsystem, the personnel subsystem, and the external environment are studied in relation to its effects on the three core dimensions of organisational structure (Kleiner & Hendrick 2008). In a balanced situation, the organisational structure supports the overall structure and goals of the work system. The optimal degrees of centralisation, formalisation and complexity of an organisation are not absolute, but dependent on, e.g., the organisation's strategic targets, technological level, personnel skills and education, and the external business environment.

Complexity refers to the degree of differentiation and integration. The increasing differentiation of a work system causes more complexity. Differentiation increases when the work system is segmented into parts. These differentiating parts are divided into vertical, spatial and horizontal differentiation. The number of hierarchical levels in an organisation is a factor of vertical differentiation. Geographic locations, distances of the locations from the headquarters, and the proportion of employees in separate locations are factors of spatial differentiation. Different goals and time orientations of work groups require a bigger number of specialised departments and therefore cause horizontal differentiation in the organisation.

Integration refers to the number and types of mechanisms that are used to integrate the segmented parts of the organisation. Thus, the integration of the work system is compensating for the impairing effects of differentiation on complexity. The number of integration mechanisms is a sum of all control, communication and coordination methods the organisation has in use. In practise, these can be information systems, regular meetings, and reports.

Formalisation refers to the degree of standardisation and flexibility of jobs within the work system. A highly formalised work system leaves the employee little room to decide what he or she does, how or when. The work system is characterised by explicit job descriptions, extensive rules and clearly defined work processes. With simple and repetitive tasks, standardised jobs of this kind may be effective. However, a too formalised work system may have impairing effects on employee well-being and engagement at work (Schaufeli & Backer 2004). In contrast, the more non-routine or unpredictable decision making is required, the more flexible job descriptions are necessary for the effective functioning of the organisation.

Centralisation refers to where formal decision-making occurs in the organisation. Basically, organisations make decisions of two kinds; strategic and tactical or operational. When the decision-making is concentrated with relatively few people, groups, or levels, we are talking about a highly centralised work system. The number of decision makers can be increased by the personnel's participation or by delegated decisions. However, a certain degree of professionalism in the organisation is a prerequisite for the delegation of decisions. The degree of professionalism also affects the autonomous functioning of the personnel. This decreases the need for hierarchical organisation levels, because a worker is able to have more control over his or her own work and fewer supervisors are needed. Delegated decisions concern tactical decisions more often than strategic decisions. (The author has illustrated the above described dimensions of organisational structure in Appendix 2 in order to clarify the complex relations of variables.)

3.4.3 Methodology of macroergonomics

In order to apply macroergonomics in practise, applicable and reliable methods are needed. Therefore, it is extremely important to look at what type of methods exist. Case examples are often a way to realise how the methods are used in real work systems. There are methods especially developed for margroergonomic interventions. In addition, several methods initially developed for microergonomics have also been applied to macroergonomic applications. The most common of these methods are analysed and classified from the work system development perspective by the author in Article I. In any case, it seems that magroergonomic methods for PD work interventions do not exist.

When addressing the macroergonomic approach, various holistic methods are called macroergonomic methods, such as human-centred design. It is important to identify the fundamental characteristics that distinguish macroergonomics as a different approach. Some indicators can be found: macroergonomics is concerned with the analysis, design and evaluation of work systems and is therefore in the central focus of management (Karwowski 2005). Another indicator is the level of analysis; macroergonomics is concerned with the structures, processes and policies of an organisation in social but not individual contexts (Zink 2000).

Macroergonomic Analysis and Structure (MAT) was developed by Hal Hendrick (e.g., Hendrick & Kleiner 2001 or 2002) to evaluate an organisation's key sociotechnical variables to determine the optimal structure for the work system. Macroergonomic Analysis and Design (MEAD) is a ten-step systemic analysing process of the work system's processes developed by Brian Kleiner (see Hendrick & Kleiner 2001 or 2002). CIMOP is a knowledge-base system for evaluating organisations and people who are designing or implementing Computer Integrated Manufacturing (CIM) systems (Karwowski *et al.* 2002). The System Analysis Tool (SAT) is also a method particularly developed for macroergonomic applications. It is designed for conducting systematic trade-off evaluations of work system intervention alternatives and to determine the most appropriate strategy for making changes in an organisation (Robertson *et al.* 2002).

Some traditional research methods have also been modified to fit macroergonomic studies. One example is the Macroergonomic Organisational Questionnaire Survey (MOQS) adopted by Carayon and Hoonakker (2001). Some specific methods such as Kansei Engineering (Nagamachi 2002) can also be applied to evaluating workers' affective responses to work system changes, even if their original fields of application are in product design. A primary methodology of macroergonomics is participatory ergonomics.

3.5 Theoretical framework

What is said before about the macroergonomic approach to work system design can be applied to PD work system design as well. Work systems are complex socio-technical systems (Carayon 2006) and PD work system can be seen as a typical example of this.

When the functioning of the PD process is under development, an individual designer or even a design team is not a sufficient subject. Instead, the entire work organisation and the use environment as a sociotechnical system has to be taken into consideration. The amount of information needed for successful product development is huge, and thus it is unfair to expect that an individual designer can manage all the relevant information and apply it during the design process. Instead, the management should organise the design in a way that supports teamwork and externalisation of the knowledge of the entire design team and the users. Still, individual creativity and intuition have a place among engineering methods when solving technical problems. There are, however, major challenges at higher abstraction levels, namely how to recognise and manage all the requirements products must fulfil during their lifespan.

Figure 6 illustrates the theoretical framework that aims to conceptualise the challenge described above to find out all the essential elements for the PD work system. The macroergonomic work system can be seen analogous to the microergonomic use system of a tool (i.e., a product). The personnel subsystem of the macroergonomic system is comparable to the user in the microergonomic system. The technical subsystem is similar to the tool that is available for the user. The organisational structure includes elements comparable to tasks of the microergonomic system. The external environments are equal in both systems.

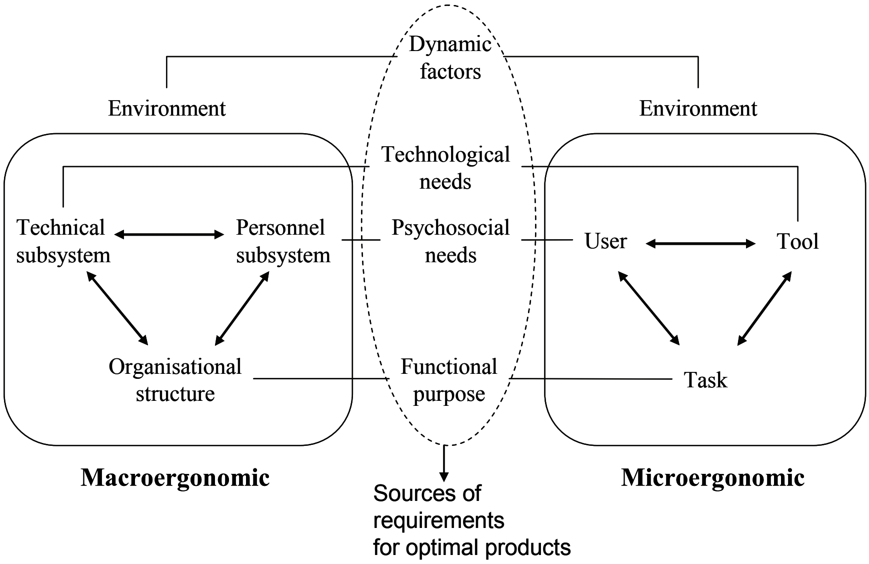


Fig. 6. The theoretical framework of the research.

Traditionally technical requirements are the major inputs from users to PD group. The framework supports a more comprehensive systemic approach in design. It supports designing better products, which fulfil the explicit technical requirements, but most importantly the tacit requirements caused by dynamic changes in the external environment, the psychosocial needs of users and the functional purposes of organisations. The better designers understand relations between the users and the personnel subsystem, the more they discover the psychosocial needs for the products. The better designers understand the relations between the tasks and the organisational structure, the more they realise the ultimate functional purpose of the product. Besides the technological needs, the environmental dynamic factors, users' psychosocial needs and the functional purposes of organisations are interesting sources of information for the better products.

Based on the constructed theoretical framework, it can be assumed that it is useful to increase the understanding about the analogous structures of the macroergonomic and microergonomic domains in order to identify essential product requirements and, consequently design better products.

4 Research contributions

The individual research contributions of the original articles are presented in this chapter, each article is one case. The research is divided into two phases: the first three cases reflect the macroergonomic approach in a use context, whereas the later three cases represent the macroergonomic approach in a design context. Each article includes a relevant literature review and a list of references. The PD project where the research was conducted will be described first.

4.1 Description of the PD project case

The empirical part of this research was conducted during a large three-year research and development project where a new type of business simulation game (called ProDesim) was designed. The simulation game includes the modelling of fundamental corporate areas such as marketing, manufacturing and logistics, but its focus is on the PD process. Simulations are procedural representations of isolated aspects of reality (Salen & Zimmermann 2004).

The main phases of the development process are depicted in Figure 7. The simulation game development process was iterative by nature, in which the designing, testing and re-designing phases alternated, as the final outcome could not be predetermined in the beginning of the project. Besides the design iterations, the feedback arrows in the process diagram illustrate the verification and validation activities of the final simulation game.

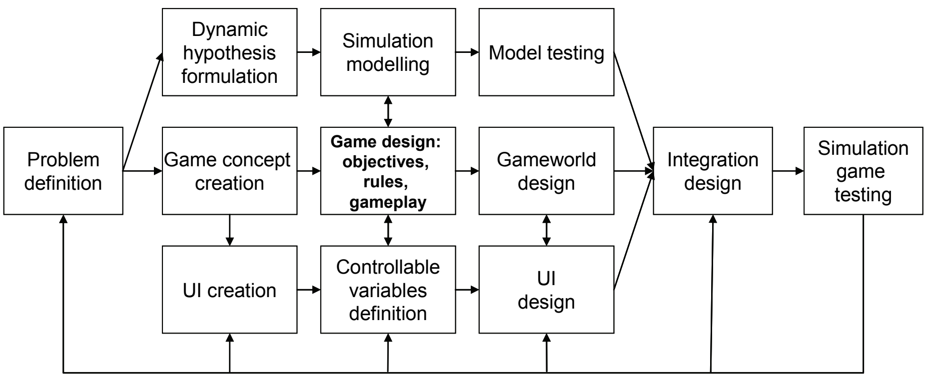


Fig. 7. Main phases of the PD project where the macroergonomic approach was applied.

The first stage was to structure and specify the problem, i.e., to identify the key areas of the PD work system for simulation gaming (Articles I, II and III). After the problem definition phase, three concurrent sub-processes started: simulation modelling, game design and UI design.

The simulation modelling (Article V) was based on the ideas of systems theory and the concept of system dynamics (SD) (Forester 1961, Sterman 2000). SD is an experimental, quantitative approach for designing structures of social systems and policies that can be made compatible with the social system's growth and stability objectives (Klabbers 2006). The developed system model consists of personnel, technical and organisational subsystems and the external environment, which support the macroergonomic approach in the design of the overall work system (Article IV).

In the game design sub-process, the interaction between players and the simulation model was defined. This refers to the way the players communicate and share knowledge and information in order to gain influence in relation to the model (Klabbers 2006). Players adjust parameters according to the rules of the game and control the system. In doing so, they develop strategies for steering resources. Gameworld design generates elements such as the artistic style and the background story of the simulation game. This way, games with computer simulation models provide an interactive learning environment for the participants.

During the UI design phases, there were numerous perceptual and cognitive aspects designers needed to consider. These were issues such as lighting conditions, text and symbol sizes, display resolutions, display placement, symbology, information layout, amount of information, assignment of tasks to players and the computer, and in particular what variables of the simulation model are controllable by the players. In this project, special attention was paid to the new multi-user interface concept and how it supports participants' collaboration and enhances their game experience (Article VI).

Before the simulation game testing phase, the simulation model and the gameworld design were implemented together with the designed user interface. During this integration design phase, a traditional board game concept and a computer simulation model were joined by means of electronic game board elements. RFID (Radio Frequency Identification) technology was implemented and RFID tags were attached to the moving game elements.

Game design was performed by following design science procedures (Hevner *et al.* 2004, Järvinen 2004a). The applicability of the solution has been tested by playing the various simulations, by data acquisition and by analysis of the data. The simulation game, developed during this project, can be seen as a product that is the outcome of the PD process described above. In addition, it is also a product that supports designers in considering, reflecting on and developing their own work practises. It offers participants a model for the business activities of a product development company by taking into account matters relating to personnel, customers, technology, business, production and competition. A more detailed product specification can be found in Appendix 1.

Table 3 summarises the research articles, materials, and the principal design science and macroergonomic guidelines applied.

Table 3. List of research articles, materials, and design science and macroergonomic guidelines applied.

Article #	Title	Materials	Design science guideline	Macroergonomic guideline
I	Ergonomists and usability engineers encounter test method dilemmas with virtual work environments	Article databases, maintenance group of a case company (8 employees),	Construct a conceptual framework	Systems design
II	Complexity and workload factors in virtual work environments of mobile work	41 employees in 6 groups	Construct a conceptual framework	Human-centred design
III	A participatory design project on mobile ICT	Maintenance group of 12 employees	Construct a conceptual framework	Participatory design, joint design
IV	Three-layer simulation game model for the computer-augmented board game	Findings of the above studies and PD related literature, game prototype	Develop a system architecture, Analyse, design, build and evaluate a system	Systems design, Human-centred design
V	Predicting the effects of time pressure on design work	Data from the simulation runs	Analyse, design, build and evaluate a system	Joint design
VI	Multiplayer interface for a computer-augmented learning game	Literature review, game prototype, participants' comments	Analyse, design, build and evaluate a system	Participatory, human-centred and joint design

4.2 Macroergonomic approach in use context

The following three chapters are related to the cases where the macroergonomic approach is applied in use contexts of products. The influence of the macroergonomic approach on each case is evaluated.

4.2.1 Ergonomists and usability engineers encounter test method dilemmas with virtual work environments

Designers, ergonomists and usability engineers need a broad understanding about the characteristics and demands of today's complex sociotechnical systems in order to develop optimal tools and products for workers and users. For this, they require appropriate ergonomics tests and evaluation methods to support the PD process. However, the large number of available methods is confusing for designers and ergonomists. An evaluation of 15 ergonomics methods was performed in Article 1. Applicable, potential and inapplicable ergonomics test methods for complex sociotechnical systems, such as virtual work environments, have been identified, based on the validity analysis and a case example. The introduced hierarchical top-down approach is a useful method selection guideline.

The systemic consideration of an organisation and the classification of the ergonomics methods also demonstrate that the majority of the methods are meant to be applied to issues at the human-device or human-task level. There are few methods for human-organisation considerations. Article I also introduces an example of how the work structure of an organisation (or the use environment of a product) can be described in an abstraction hierarchy matrix.

The study demonstrates interactions between the design contexts and the use contexts of products. The findings provide evidence that systemic, macroergonomic consideration of the technical subsystem (ergonomics methods) brings more understanding about the appropriate methods to explore the use context system from the sociotechnical perspective.

4.2.2 Complexity and workload factors in virtual work environments of mobile work

Article II concentrates on describing the complexity and work load factors of mobile work done in virtual environments. The mobility or virtuality of work are not the key topics of this dissertation as such, but they are typical examples of the emerging characteristics of the various use contexts of products, which the macroergonomic design approach should consider. Therefore, it is very important to understand the complexity and workload factors of such work and use environments of today.

A model of complexity factors was used in analysing the materials. To reduce the influence of the workload factors and to enhance well-being, fundamental requirements for the virtual work environment can be presented. At the levels of connection, device and application, the issue lies in the transfer capability of communication. Similarly, at the levels of the cognitive and cultural factors of the virtual space, the question is about the ability for the semantic transfer of the message.

Macroergonomics focuses on communication methods as one integration mechanism to decrease the complexity of the work system, as earlier explained in Chapter 3.4.2. The workers' message transfer ability as a well-being factor is thus explained by the macroergonomics theory.

4.2.3 A participatory design project on mobile ICT

Usually, in developing user-oriented communication and collaboration equipment, much attention has been paid to the tools themselves. When a newly developed tool is launched, the old and new practices collide and a number of conflicts may emerge. In the worst case, this leads to employees spending their time resisting the change. The fact that the development of new tools challenges the development of the entire work system has received little attention. The usability and reliability of the tools also affect the functioning of the work group, as well as the individual worker's well-being. Therefore, tool development should be expanded to include working concepts in which attention is paid to developing the entire work system.

The purpose of Article III was to describe a case where the users took part in the development of a new tool. The study describes and assesses the participatory development process of a palm computer with special software from the work system point of view by applying the macroergonomic approach. The benefits and drawbacks experienced by employees while testing, implementing, and using the new communication and collaboration tool were analysed. The macroergonomic model of the generic work system (see Fig. 5.) was used for analysing, coding and classifying the materials. The results were analysed and represented from the organisational, personnel subsystem and technical subsystem points of view.

Although the new tool faced many technical problems, the new participatory development concept had many benefits. The participation of the users in the tool development and the joint design of the whole work system proved crucial in committing the personnel to improvements. Article III shows empirical evidence that participatory tool and work system development supports ensuring relevant work related product features and solutions. Based on the results, it suggests that tool development should shift from technical issues to the development of work systems, where the technical tool development will be an integrated part. This is what the macroergonomics theory proposes about the balance between the technical subsystem and the organisational structure.

4.3 Macroergonomic approach in design context

The following three chapters are related to the cases where the macroergonomic approach is applied in the design context of products. The influence of the macroergonomic approach on each case is evaluated.

4.3.1 Three-layer simulation game model for a computer-augmented board game

In Article IV, based on the macroergonomic approach, an upper level work system model of the PD work system is constructed. The model is applied and preliminarily demonstrated through the prototype of a computer-augmented board game (for details, see the final product in Appendix I). The learning objectives of the simulation game are to understand the importance of collaboration, to learn the development process, to get familiar with the financial aspects, and to manage various PD related trade-off decisions.

The three-layer PD model consists of teamwork, the design process and the business layers. The business layer models the strategic goal setting and financial aspects of PD in order to support the managerial decisions of the employees. The design process layer functions as a bridge between the teamwork and business layers. The goal of the design process layer is to attain the target of the project. This layer models the process of the development project typically by a flowchart. Design data and an artefact are the deliverables of this layer. The teamwork layer models the interactions and roles among the personnel. The layer includes both individual and joint decisions. Designers learn how the consequences of their individual decisions affect the whole PD process. On the joint decision points the players are able to share their professional knowledge, debate and make decisions as a team. The organisational roles give an insight into different types of responsibilities and authorities inside the organisation. The other purpose of the teamwork layer is to help people from different backgrounds understand and share concepts of the design. The requirements of users, customers and authorities are representing the environment sub-system.

Phenomena that are possible to model and simulate by mathematics and computers have been the traditional area of simulations in engineering. Thus, simulations about mechanical construction or manufacturing processes are common. However, the increasing sophistication and complexity of products requires a more holistic simulation approach. People's collaboration and social skills should be taken into account as 'soft variables' in PD. Article IV makes a contribution to PD simulation development by introducing the three-layer PD model, where the personnel and their roles and social skills are playing important roles in addition to the business targets. This study also shows how the macroergonomic approach became evident in design.

4.3.2 Predicting the effects of time pressure on design work

Article V discusses job design in PD. It describes an approach to simulate and predict the dynamic effects of mental workload (caused by time pressure) on design work. Project management, work ergonomics and studies about occupational health were used as a theoretical framework for the study. The results of the simulation indicate that the mental workload of workers has a significant effect on the performance, quality and innovativeness of design work and, consequently, on the lead time of the entire project.

These effects can be immediate or delayed. First, the mental workload may have a positive effect on productivity in the short term, but a negative effect in the long term. Second, the mental workload leads to delayed mental fatigue, which has a negative effect on quality and productivity in the long term. Finally, mental fatigue decreases work engagement, thus having a negative effect on the innovativeness of the design group. Conventionally, project planning has been based on the constant work efficiency of the workers over the project timeline. As shown in this research, this fails to give a realistic prediction about the resource needs and, thus, may lead to overly optimistic predictions for completion. This is a significant managerial implication.

The study increases understanding about the dynamic effects of time pressure on design work. The human-centred and systems approaches, such as the macroergonomic guidelines, are used to demonstrate the effects of different job design alternatives (technical subsystem) on the designers (personnel subsystem).

4.3.3 Multiplayer interface for a computer-augmented learning game

The purpose of Article VI is to introduce an example on how the technological and social elements of the system can be fit together. An advanced multi-user interface (MUI) concept for a collaborative simulation game is used as a case example. In the conventional arrangement of a digital multiplayer simulation game, each player has their own keyboard and visual display. This is not an optimal solution from the natural collaboration point of view. This study introduces a new possibility for game designers to integrate a traditional board game concept with a computer simulation model to enhance collaboration and learning in simulation gaming.

The functionality and the physical elements of a traditional board game and the calculation performance of a computer simulation model were combined in the new MUI concept. Players' operations are mediated to the computer through the game board elements, not through the standard input devices of the computer. The key usability targets of the user interface have been identified. The research also provides evidence that the developed MUI supports the usability targets in terms of naturalness and collaboration.

Designers need a proper understanding about the use domain of the product, and the psychosocial factors of the users, in order to be able to design a user-technology balanced product. This research is a practical example of how macroergonomic design principles may have an effect on human–computer interface (HCI) design. Macroergonomic design principles such as participation, human-centrality and joint design were applied during the conceptual development of the MUI. They expressed themselves as a natural, flexible and collaborative UI solution. However, it can call into question, whether similar results had been gained with microergonomics only. For a closer evaluation of the simulation game and its UI design, see Forstén *et al.* (2009).

4.4 Research contribution summary

Above, the design variables and contributions of each separate case have been analysed and the role of the macroergonomics method evaluated. The six research questions, as formulated in Chapter 2, have been answered by the individual cases presented above. Table 4 presents a summary of the research contributions and the role of macroergonomics in achieving them.

Table 4. Summary of the research contributions and the role of macroergonomics in achieving them.

Article #	Contribution	Role of the macroergonomic approach
1	Classification of the ergonomics methods to consider them from the organisational structure and technological viewpoints. Hierarchical work system / use context model to select applicable methods.	Pointed out the interaction of the technical subsystem (methods) of designers and the organisational structure of users.
2	Identified complexity and workload factors in mobile and virtual work environments. Identified workers' message transfer ability as a well-being factor.	Further macroergonomic research topics related to decision-making in mobile and virtual work environments were identified.
3	The conceptual model and empirical evidence that participatory and simultaneous tool and work system development supports in ensuring relevant tool features and work design solutions.	Presented participatory design and joint design guidelines. Offered the sociotechnical work system model for the analysing framework of the materials.
4	Meta-level simulation model of the PD work system. Simulation game prototype based on the developed model.	Offered the concepts and systems approach for top-down modelling of the PD work system.
5	Understanding about the dynamic effects of time pressure on designers' mental and physical performance.	The human-centred and systems approaches as macroergonomic guidelines aided in connecting personnel subsystem with other work system elements.
6	Multiplayer interface concept for a computer-augmented simulation game. Usability criteria for a simulation game interface.	Supports in achieving an understanding about the use domain of the product and the users' psychosocial performance. However, the same results may be attained with the microergonomic approach only.

Based on the theoretical framework and the findings from the cases, a balanced macroergonomic PD work system model was constructed. It integrates the design and use contexts of the product by considering them as consisting of analogical sociotechnical system elements.

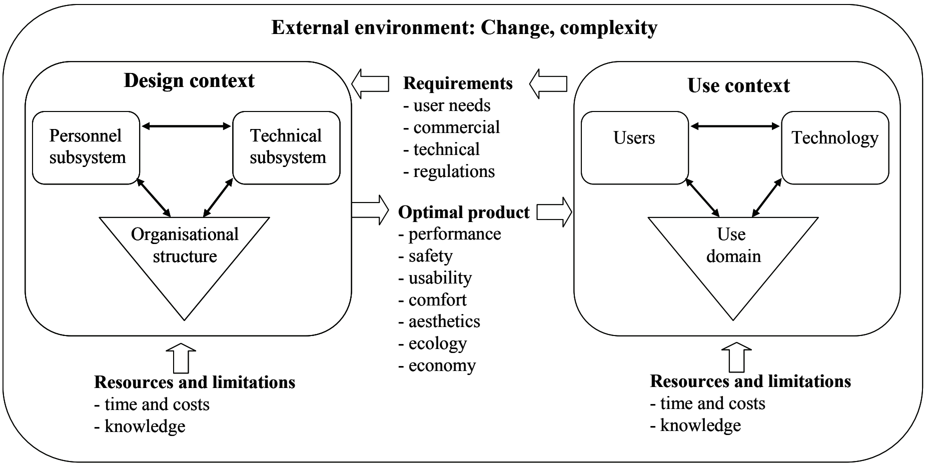


Fig. 8. A balanced macroergonomic PD work system model.

When the perception of the PD work system follows the model introduced in Figure 8, it may support the comprehensive systemic approach to design. It can support designing optimal products, which fulfil the explicit requirements, but most importantly the tacit requirements caused by the dynamics of use context elements. The better designers understand relations between the users, the technology and the use domain, the better they are able to consider, reflect on and develop their own work processes, and vice versa.

This is important because designers should understand the use context of the product comprehensively in order to identify the critical factors affecting its design. In addition, this consideration may include issues such as resources and limitations, as they may be different but still exist both in the design and the use context of the product. A changing and complex external environment is common for both contexts.

5 Discussion

The objective of this research is to figure out whether macroergonomics brings added value to solving design problems in the PD work systems. This research is believed to be unique because it is the first known attempt to theoretically and empirically apply the macroergonomic approach to the PD.

The research problem of this dissertation was examined from various viewpoints by the six articles and this summary. In this chapter, the contributions of the research are discussed with regard to the literature and the research problem: *Can the macroergonomic approach support PD work?* The conclusions will be made both from the theoretical and practical perspectives.

5.1 Theoretical and practical conclusions

Article I demonstrates interactions between the design contexts and the use contexts of products. Rasmussen's (2000) abstraction hierarchy was used as a method of describing the work system and the means and ends of an organisation in a compact form. The findings of the research provide evidence that a systematic approach, as one macroergonomic principle, brings more understanding about the appropriate ergonomics methods for work system studies. The research also demonstrates that the majority of the ergonomics methods are meant to be applied to human-device or human-task level issues, but there are few methods for human-organisation considerations. The valid level of analysis is an important issue when selecting design methods for macroergonomic interventions. Applicable methods are a prerequisite for gaining holistic product requirements, beyond the functional ones.

Article II concentrates on describing the complexity and work load factors of mobile work done in virtual environments. In the macroergonomic design approach, it is very important to understand the complexity and workload factors of many of today's work environments and use contexts of products. When the mobility and virtuality of work are in question, from the macroergonomic viewpoint, it is a question of the complexity of the organisational system. In this case, the complexity is caused by the spatial differentiation of the work system as Kleiner and Hendrick (2008) have specified (see Chapter 3.4.2). This kind of spatial complexity of the use environment causes product requirements that are not necessarily observable in the use context, but with the conceptual-analytic methods as introduced in Article II.

Article III introduces a case where the users took part in the development of a new tool. The benefits and drawbacks experienced by employees while testing, implementing and using the new tool were analysed. The macroergonomic model of the generic work system (Kleiner 2006) was used for analysing, coding and classifying the materials. The results were analysed and presented from the organisational, personnel subsystem and technical subsystem points of view. The findings demonstrate that there is an emerging need to carry the design requirements of the overall work system to the design of tools and human interfaces. The research proposes that overall work system development requires that work system development should be an integral part of tool development and vice versa.

In Article IV, a simulation game model (meta-level) is constructed based on the macroergonomic approach and the sociotechnical work system model. The three-layer PD simulation model integrates the characteristics of the conventional PD process model (see Fig. 4) with the sociotechnical work system model (see Fig. 5.). One of the most interesting features of the three-layer model concerns the workflow between work system elements. It is modelled by work packages including information, resources or material. These packages are typical PD tasks, such as goal setting, resource allocation and design decisions. The personnel subsystem as a 'soft element' was embedded into the PD process and the workflow through it was demonstrated. The study shows how the macroergonomic approach can become evident in work system modelling and gives ideas for further study.

Article V increases the understanding about the dynamic effects of time pressure on design work. Work planning has a crucial effect on the performance and well-being of designers, and consequently on the output of the design. By applying system dynamics methods (Sterman 2000), the effects of hypothetical variables, such as time pressure, in a PD work system can be examined, too. This is a common need in the macro-level analysis of design. Physical design factors are more straightforward to observe and measure in the product of design. Based on the experience of this research, the author points systems dynamics out as a promising macroergonomic method not mentioned in the literature (see Chapter 3.4.3).

In Article VI, macroergonomic design principles such as participation, human-centricity and joint design were applied during the development of the human-computer interface (HCI). They expressed themselves as a natural, flexible and collaborative UI solution, which supports the simulation of team based PD work. However, in such a human-interface design case, the results may be achieved with the microergonomics methods only, by applying the principles of cognitive and physical ergonomics to HCI design. In this sense, Kleiner's (2006) definition of macroergonomics as an approach which attempts to achieve a fully harmonised work system at both the macro- and microergonomic levels is somewhat contradictory. It would be clearer to define that macroergonomics theory doesn't cover microergonomic issues because both the methods applied and the level of analysis are different. A summary of the conclusions is provided in Table 5.

Table 5. Summary of the conclusions.

RQ #	PD context	Conclusion
1	use context	In the macroergonomic approach, the level of analysis for design methods has to be considered carefully. Article I gives an example of how to classify the ergonomic methods.
2	use context	The spatial complexity of the use environments of products is an important source of product requirements.
3	use context	Macroergonomic balancing of the technological and organisational subsystems requires the simultaneous development of the tool and the work system.
4	design context	Sociotechnical work system elements should be embedded into the PD process models.
5	design context	System dynamics is a promising method for macroergonomic interventions that also allows the examination of hypothetical variables.
6	design context	The concept of macroergonomics shouldn't include microergonomic issues because both the methods applied and the level of analysis are different.

Besides the conclusions discussed above, the macroergonomic approach to PD has to be discussed as a design method. However, macroergonomics is not a particular method, but rather a multi-disciplinary approach using various methods. Therefore, it can also be applied in different ways for solving design problems. This makes the utility evaluation difficult. The evaluation criteria can be founded on the 'universal' metrics described by March and Smith (1995). They have specified metrics for the evaluation of design methods (process) and outcomes (product). The data source for each evaluation is based on the case articles and the authors' subjective inductive reasoning. Table 6 summarises the utility evaluation of the macroergonomic appraoach in the PD domain.

Table 6. Utility of the macroergonomic approach in PD, evaluated by the criteria and outputs of design science research.

Evaluation criteria (March & Smith 1995)	Output of the design	Utility of macroergonomics in PD
Completeness, simplicity, elegance, understandability and easy to use.	Constructs	Macroergonomics offers a variety of concepts for a PD work system description, also including virtual working environments, but the organisational dimensions and related concepts are complex.
Fidelity with real world phenomena, completeness, level of detail, robustness and internal consistency.	Models	Macroergonomics offers conceptual models for work system development, such as design and use context scanning, but does not directly help in product modelling.
Operationality, efficiency, generality and easy to use.	Methods	Macroergonomics is a methodology rather than a single method, it does not guide the development process strictly. More specific process models are required when macroergonomics is applied in PD.
Efficiency and effectiveness and impacts on the environment and users.	Outcomes	Macroergonomics offers a systemic framework to consider product requirements, originating in their broad use context.

Macroergonomics is an approach which attempts to achieve a fully harmonised work system at both the macro- and microergonomic levels (Kleiner 2006). However, it is not always clear what a large system (macro) is and what a small (micro) system is. The author argues that this defined scope is too wide. The 'macro' refers to the upper level of analysis, but the definition of macroergonomics suggests applying it to the microergonomic issues, too. This is confusing and contradictory; it would be more logical to keep the macroergonomic level of analysis on the macro-variables only. The most important benefit of the macroergonomic approach for PD is the understanding about product requirements in broad sociotechnical context.

The first paradigm in PD was 'technology centred', the second wave was 'user-centred', and the present should be 'systems centred'. Figure 9 depicts the paradigm shift from the user-centred concept to the systems centred, i.e., the macroergonomic, PD concept. Macroergonomic PD starts from the systems level. It analyses the design context, the use context, the external environment and their interactions. These subsystems are analysed by means of the macroergonomic variables introduced in Chapter 3.4. This way, the design team gets a holistic view about the problem and solution space. The analysis also supports new innovations because it is not tightly linked to product functions or features and gives a broad pre-understanding about the problem and alternative solutions. The macroergonomic PD concept seems to answer the need Alter (2003) has brought out by arguing that, IT-reliant work systems should be better recognised in information systems practice and research.

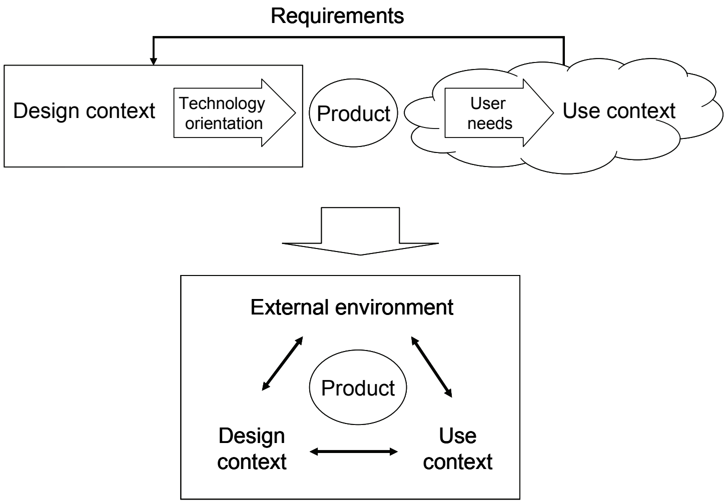


Fig. 9. The paradigm shift from the user-centred PD concept to the macroergonomic PD concept.

5.2 Managerial conclusions

This research emphasises that most of the current PD process models need to be revised by adding a macroergonomic perspective to them, in order to cover the larger domain of product requirements. This study is one of the first attempts to utilise the magroergonomic approach in PD. Therefore, the results are very preliminary and mainly at the conceptual level. In any case, some guidelines and conclusions can be drawn for management use.

The management, designers, ergonomists and usability engineers need a broad understanding about the characteristics and demands of today's complex design and use contexts in order to develop optimal tools and products for workers and users. They also require appropriate ergonomics tests and evaluation methods to support the PD process in such environments. The large number of available methods is confusing for designers and ergonomists, and therefore the introduced hierarchical top-down approach is a useful method selection guideline.

Many common PD process models (Cooper 1996, Ulrich & Eppinger 2004, Pahl *et al.* 2007) are limited because they only focus on the product functions and when to design them. Time line planning has been the starting point in many PD process models. A wider understanding about the PD work system, including the design and use contexts, would probably lead to better products in terms of economy, ecology, safety, performance and usability.

In a multi-professional design group, a shared mental model about the product development challenges is crucial in terms of information exchange, collaboration and speed of development. Leppänen (2000) has studied the metrics of conceptual management. She argued that the common concepts of team members are prerequisites for communication about observations, information and status of the development. Causal models of the project outcome related factors are especially useful. The macroergonomic PD work system model (Fig. 8) is a practical tool for a design team to discuss the sociotechnical factors and their effects on the PD.

Unexpectedly, the major problem with user centred design is related to the question: who is the user? When a designer answers this question from his individual perspective in the physical context, the answer is quite clear: all the people who use the product. However, there is an emerging risk that this perspective is too narrow. Besides user needs, we have to consider product requirements from the systemic perspective, as the product also has other interactions in the work/use system apart from the user-product interaction. Thus, the user requirements alone are not enough to develop successful products. Table 7 summarises the managerial conclusions discussed above in the form of guidelines. They also answer the six research questions.

The materials for this research was gathered during a PD simulation game project. Simulation games are promising methods of developing innovation systems in companies. Participants are able to share their ideas and concepts of the product and user needs. By a simulation, they can also consider their own work system and transform new ideas from the simulation environment to the real working environment. The macroergonomic objective of the game is to offer a new environment for designers and stakeholders to reflect on their own work and the PD process as a whole.

Table 7. Summary of the managerial conclusions as guidelines.

RQ #	Managerial guideline	Description
1	Implement new macroerconomics methods.	Companies should consider their ergonomics methods and evaluate whether they are applicable to macroergonomic (beyond human-task-tool) design problems. This study introduces an ergonomic methods classification in order to support practitioners in companies.
2	Analyse the use context and its external environment.	The use context of the product has significant influence on the users' performance and limitations and consequently on the product requirements.
3	Merge the design and use contexts, and tool and work system design.	Participatory design means that designers act as users and users act as designers. This causes deep understanding and commitment in design. Tool and work system design should be integrated and simultaneous processes.
4	Think systems.	System dynamics is an approach to understanding the behavior of complex systems over time. It assists in identifying reasons and consequences.
5	Consider designer needs.	User needs are overemphasised and designers' well-being underestimated as PD success factors.
6	Remember microergonomics.	Applying microergonomics in design is still increasingly important in order to fit the products for people. Macroergonomics does not substitute microergonomics.

Cooperation in design teams can only be trained in practise and this training can take a long time depending on the previous cooperation, experiences, values and motivations of the people at the starting point. This acquaintance period may be non-productive, because of misunderstanding the common goals or procedures being too incompatible to perform. Often, the risks in design and product development are realised when the design team do not understand the overall system and thus leave some important factors outside their considerations. A simulation offers a safe environment where a design team can develop their common and shared interpretations of the available information and consequently create alternative ways of solving the problems of complex systems or processes in real life (Ruohomäki 2003).

5.3 Reliability and validity

This research is qualitative and explorative in nature. Qualitative research is designed to operate well in areas that are complex, messy, causally ambiguous and where there is little exact knowledge (Johnson & Harris 2002). Research discussing the PD work system matches this pattern very well. This research focuses on understanding the PD work system from the macroergonomics viewpoint and constructing a new conceptual PD work system model. This model expands the product requirements domain from user centrality to the systems level, where the design and use contexts of the product are included. Multiple cases, related to the implemented PD project, are considered analytically, so we have a multiple-case study (Yin 2003). Every case has contributed to the overall picture of the answer to the research question.

First, this research can be evaluated against the design science research guidelines offered by Hevner *et al.* (2004). They argue that the artefact must be rigorously defined, formally represented, coherent and internally consistent. The designed simulation game and the balanced macroergonomic PD work system model as artefacts are created to address important organisational problems. They are described effectively and the game was implemented into use. The artefacts have been technology-based and they were developed to solve important and relevant business problems. The utility, quality, and efficacy of the game have been demonstrated. The utility of the macroergonomic approach is evaluated as well (see Table 6). The introduced macroergonomic approach to PD provides a clear contribution based on its novelty, generality and significance, even if the results are very preliminary. The methods used in both the construction and the evaluation of the artefacts have been careful. The level of analysis has not been very detailed, but appropriate for assessing the relevance of the macroergonomic approach in PD, which was unknown prior to this explorative research. The research has been conducted as an iterative search process in order to discover satisfying solutions (e.g., Fig.7). The research has been effectively presented both to academics and PD professionals through this dissertation work.

Second, Yin (2003) suggests four tests to establish the quality of any empirical social research: construct validity, internal validity, external validity, and reliability.

Construct validity establishes correct operational measures for the concepts being studied. To meet the test of construct validity, a researcher must be sure to cover two steps: (1) select the specific types of changes that are to be studied and relate them to the original objectives of the study and (2) demonstrate that the selected measures of these changes do indeed reflect the specific types of change that have been selected. (Yin 2003.) The original objective of the study has been to consider macroergonomics theory in PD context. The research problem of this study has been viewed from two different perspectives by six cases that were written and published as articles. The two perspectives selected were the design context and the use context of a product. The theory has been applied in practise in a PD project. This selection covers the wide domain of PD activities where the entire PD process is carried out and evaluated. This domain is larger than the conventional PD approaches and therefore it demonstrates the potential changes caused by the macroergonomic approach. The macroergonomic approach in PD has been reflected on from various perspectives: from the design methods point of view (Article I), explaining the complexity of work environments (Article II), as a participative method (Article III), supporting work system modelling (Article IV), in a systems simulation of the effect of management practises on designer performance (Article V) and applied to HCI design (Article VI). The explorative nature of this research means that the selected measures could be selected in many ways. Harrison (2002) states that it is difficult to get the measures right the first time and so multiple sources of evidence are favourable.

Yin (2003) argues that *internal validity* is only a concern for causal case studies where the researcher tries to determine whether event x led to event y. If the researcher incorrectly concludes that there is a causal relationship between x and y without knowing that a third factor z may actually have caused y, the research design has failed to deal with some threat to internal validity. However, this logic is inapplicable to descriptive or explorative studies, which are not concerned with making causal claims. The other concern about internal validity relates to the broader problem of making conclusions. A case study involves a conclusion every time an event cannot be directly observed. The researcher can also be a source of the conclusion. Yin (2003) recommends some analytic tactics to address internal validity: pattern-matching, explanation-building, addressing rival explanations and using logical models. This research has been exploratory in nature and its aim has not been to make causal claims. However, one of the articles (Article V) modelled designer performance by a system dynamics method that is based on causalities. The internal validity of this research has been separately evaluated at the end of the paper. All the cases have been analysed, explained and discussed from the macroergonomics perspective earlier in this summary.

External validity deals with the problem of knowing whether the research findings can be generalised beyond the immediate context of the research (Yin 2003). The six research cases where macroergonomics have been considered were unique and the macroergonomics theory was not tested by replicating the findings.

In that sense, the research findings cannot be generalised. However, the effects of the macroergonomic intervention on the cases have been generalised and theorised within each research paper and in this summary.

The objective of testing *reliability* is to ensure that if some other researcher followed exactly the same procedures described by the researcher and conducted the same study all over again, he or she would arrive at the same findings and conclusions. The goal of reliability is to minimise errors and biases in the research. (Yin 2003.) This research and the PD project of the simulation game as a case have been unique in nature and it is impossible to conduct exactly the same research: there is no need to develop a similar product again, the working organisations are changing, people are learning new things, and so on. However, the research protocol, the documented PD project and the published articles are convincing external reviewers of the reliability of this research.

Third, the results of qualitative studies can be evaluated in terms of different methods of triangulation (e.g., Hoepfl 1997, Golafshani 2003). In this research there can be found 1) methodological triangulation, because the macroergonomic approach for the PD work system is investigated with multiple methods such as modelling, interviews, simulation and participatory evaluation, 2) theoretical triangulation, when this phenomenon is studied from the viewpoint of design science and macroergonomics, and 3) data triangulation, when material from six case sources have been used. This gives some more credibility to the transferability of the results. In addition to the different methods of triangulation, the credibility of the research results in the qualitative studies is achieved by careful case descriptions and analysis as described in the Articles, and Chapters 4 and 5 in this summary.

5.4 Limitations and further research

This research has certain limitations that need to be taken into account when considering the research and its contributions. However, some of these limitations can be seen as opportunities for future research among the theme of PD. This wide and complex area has been studied in this research from a rather limited empirical perspective. The selection of a case study design always brings some limitations as far as the generalisation of the results of the study is concerned. The design research case selection includes these limitations as well, because the design research is premised on the basis of the artefact building, what is unique by nature. Thus, the empirical setting around one PD project, can only be seen as a pilot context of this explorative research. On the other hand, this is the particular idea to apply the case study approach, in order to test or create new theory about the not well known enough phenomena.

The conclusions as well as the limitations of this study also highlight some interesting possibilities for future research. The most important possibility lies in developing new PD process models based on the combined macroergonomic and design science research approach. Such the new PD process models should cover the technical and social elements of the PD work. The other interesting possibility for the further research is to study new organising models of the PD work systems, where the emerging virtual working environments and the need for the participatory design would have been taken into account. However, in this research the decision was made to focus on finding evidences that the above mentioned research subjects would be relevant from the industry viewpoint.

The intangible products, such as services, fall outside the specified scope of this research. However, based on the findings of this study, it can be assumed that the booming area of service design requires new methods and tools beyond customer centrality as well. The customer-centrality is alone not enough to develop innovative services on the always changing market, where new business models, ICT solutions and virtual environments are present. The complex service systems cannot be developed only by bottom-up methods; there is a need for the more comprehensive systemic methods. Further research is needed to develop new concepts and models to support human service design in practice. The theoretical macroergonomic PD framework presented in this research offers a proper starting point for the all human related design activities. Thus, macroergonomics should be considered further as a promising complementary methodology for design science.

6 Summary

Product requirements are considered mainly from the users and technology points of view, but this is not enough to be successful on the market. We have plenty of knowledge about the factors of economic success, managerial success and technical success, but we do not know enough about the effects of human interaction on PD success. Macroergonomics, i.e., the harmonisation of human-organisation and human-environment interaction seems to be a missing component when the sources of PD performance are listed. This research highlights this missing component in order to also achieve success on the markets, where the use and design environments of products are increasingly complex.

If the focus in PD is on micro-scale solutions, it tends to result in technology-centred designs, as many authors have argued. Therefore, design should start from the systems i.e. macroergonomic perspective. This makes it possible to release a design process from the technology focused, function emphasising design. Moreover, all the product requirements are not observable in the use context of a product, as these tacit requirements can be, e.g., caused by dynamic changes in the environment, users' psychosocial needs and the functional purposes of organisations.

Another philosophy and mental model behind the current PD process models seems to be the ambition to simplify problems as soon as possible in order start the design of product functions and features. On the contrary, this research emphasises that we should not shut our eyes to the complexity of the surrounding world. Instead, we should consider it as the macroergonomic PD work system and increase the complexity around the product idea as much as possible during the first phase of the PD project. If the idea survives through this dissection, the technical design specification can be formulated and the project can continue towards the first milestone. This approach may also support innovations, because a larger problem and solution space is discovered.

During the feasibility phase, this research suggests the simultaneous consideration of the design and use contexts. This is important for two reasons: (i) designers should understand the use context of the product comprehensively in order to identify the critical factors affecting design, and (ii) designers should reflect on their own work, because the design context as a work system has direct effects on the outcome. The working methods should be considered from the macroergonomic guidelines perspective; are they participatory, human centred, joining human and technological components, and systems oriented.

The macroergonomic approach can enrich PD work and its outcomes by offering new concepts for a broad systems approach as a starting point of design. This framework helps discussions about the holistic product requirements beyond the functional and user originated ones. Applying this, the existing PD processes in companies need to be revised by taking into account the characteristics of the macroergonomic PD work system model introduced in this study. Macroergonomics can also be considered as a promising complementary methodology for design science that focuses on human and work system related issues. The compatibility of macroergonomics with design science has not been discussed before this research, and therefore, hopefully plenty of further research will appear.

References

Abeysekera JDA (1990) Ergonomics and technology transfer. International Journal of Industrial Ergonomics 5(2): 181–184.

van Aken JE (2005) Valid knowledge for the professional design of large and complex design processes. Design Studies 26(4): 379–404.

van Aken JE (2004) Management research based on the paradigm of the design sciences: The quest for field-tested and grounded technological rules. The Journal of Management Studies 41(2): 219–246.

Akgün AE, Byrne JC, Lynn GS & Keskin H (2007) Team stressors, management support, and project and process outcomes in new product development projects. Technovation 27(10): 628–639.

Akgün AE, Lynn GS & Yılmaz C (2006) Learning process in new product development teams and effects on product success: A socio-cognitive perspective. Industrial Marketing Management 35(2): 210–224.

Alter S (2003) 18 Reasons why IT-Reliant work systems should replace the IT artifact as the core subject matter of the IS field. Communications of the Association for Information Systems 12(23): 366–395.

Apilo T (2004) Management of Networked R&D processes. In: Proceeding of the 5th International CINet Conference, 22–25 September 2004. Sydney, Australia: 490–499.

Carayon P (2006) Human factors of complex sociotechnical systems. Meeting Diversity in Ergonomics. Applied Ergonomics 37(4): 525–535.

Carayon P & Hoonakker P (2001) Survey design. In: Karwowski W (ed) International Encyclopedia of Ergonomics and Human Factors. London, Taylor & Francis: 1899–1902.

Cooper RG (2008) Perspective: the Stage-Gate® idea-to-launch process – update, what's new, and NexGen systems. The Journal of Product Innovation Management 25(3): 213–232.

Cooper RG (2004) Product Leadership. Pathways to Profitable Innovation. 2nd ed. New York, Basic Books.

Cooper RG (1996) Overhauling the new product process. Industrial Marketing Management 25(6): 465–482.

Détienne F (2006) Collaborative design: Managing task interdependencies and multiple perspectives. Special Theme Papers from Special Editorial Board Members. Interacting with Computers 18(1): 1–20.

Dillon A (2000) Group Dynamics Meet Cognition: applying socio-technical concepts in the design of information systems. In: Coakes E, Willis D & Lloyd-Jones R (eds) The New SocioTech: Graffiti on the Long Wall. Springer Verlag Series on CSCW. London, Springer: 119–125.

Dul J & Weerdmeester B (2001) Ergonomics for Beginners. 2nd ed. London, Taylor & Francis.

Dul J (2006) The business value of ergonomics. In: Saarela KL, Nygård C- & Lusa S (eds) Promotion of Well-Being in Modern Society. 38th Annual Congress of the Nordic Ergonomics Society 24–27. 9. 2006. Hämeenlinna. Proceedings of NES 2006: 14–18.

Eisenhardt KM (1989) Building theories from case study research. Academy of Management Review 14(4): 532–550.

Forrester JW (1961) Industrial Dynamics. Cambridge Massachusetts, The MIT Press.

Forstén M, Putkonen A & Li X (2009) Collaboration with a multi-user interface – Case: Product development simulation game. In: Blashki K (ed) IADIS Multi Conference on Computer Science and Information Systems. Proceedings of Game and Entertainment Technologies 2009. Algarve, Portugal, June 17–23, 2009 IADIS: 11–18.

Galanakis K (2006) Innovation process. Make sense using systems thinking. Technovation 26(11): 1222–1232.

Golafshani N (2003) Understanding reliability and validity in qualitative research. The Qualitative Report 8(4): 597–607.

Haro E & Kleiner BM (2008) Macroergonomics as an organizing process for systems safety. Applied Ergonomics 39(4): 450–458.

Harrison A (2002) Case study research. In: Partington D (ed) Essential Skills for Management Research. London, SAGE Publications: 158–180.

Hendrick HW (2008) Applying ergonomics to systems: Some documented "lessons learned". Applied Ergonomics 39(4): 418–426.

Hendrick HW (2002) An overviw of macroergonomics. In: Hendrick HW & Kleiner BM (eds) Macroergonomics: Theory, Methods and Applications. Mahwah NJ USA, Lawrence Erlbaum Associates: 1–23.

Hendrick HW & Kleiner BM (eds) (2002) Macroergonomics: Theory, Methods and Applications. Mahwah NJ USA, Lawrence Erlbaum Associates.

Hendrick HW & Kleiner BM (2001) Macroergonomics: an Introduction to Work System Design. Santa Monica, Human Factors and Ergonomics Society.

Hevner AR (2007) A Three cycle view of design science research. Scandinavian Journal of Information Systems 19(2): 87–92.

Hevner AR, March ST, Park J & Ram S (2004) Design science in information systems research. MIS Quarterly 28(1): 75–105.

Hoepfl MC (1997) Choosing qualitative research: A primer for technology education researchers. Journal of Technology Education 9(1): 47–63.

Hollnagel E & Woods DD (2005) Joint cognitive systems, Foundations of Cognitive Systems Engineering. USA, CRC Press, Taylor & Francis Group.

Hsiao S & Chou J (2004) A creativity-based design process for innovative product design. International Journal of Industrial Ergonomics 34(5): 421–443.

Huang GQ & Mak KL (1998) A survey report on design for manufacture in the UK furniture manufacturing industry. Integrated Manufacturing Systems 9(6): 383–387.

Hubka V & Ernst Eder W (1987) A scientific approach to engineering design. Design Studies 8(3): 123–137.

Hyrkkänen U (2006) Analysis of work load factors and well-being in mobile work. In: Vartiainen M (ed) Workspace Methodologies: Studying Communication, Collaboration and Workspaces. Report 2006/3 Espoo: Helsinki University of Technology, Laboratory of Work Psychology and Leadership: 63–79.

Hyötyläinen R (2005) Practical Interests in Theoretical Consideration. Constructive Methods in the Study of the Implementation of Information Systems. Espoo, VTT Publications.

IEA (2000) International Ergonomics Association. URI: http://www.iea.cc/browse.php?contID=what_is_ergonomics.

ISO 13407 (1999) Human-centred design processes for interactive systems.

ISO 6385 (2004) Ergonomic principles in the design of work systems.

ISO/TR 18529 (2000) Ergonomics – Ergonomics of human-system interaction – Human-centred lifecycle process descriptions.

Jespersen KR (2007) Is the screening of product ideas supported by the NPD process design? European Journal of Innovation Management 10(4): 453–466.

Johnson P & Harris D (2002) Qualitative and quantitative issues in research design. In: Partington D (ed) Essential Skills for Management Research. London, SAGE Publications: 99–116.

Jokela T (2004) Evaluating the user-centredness of development organisations: conclusions and implications from empirical usability capability maturity assessments. Interacting with Computers 16(6): 1095–1132.

Järvinen P (2004a) On Research Methods. Tampere; Opinpajan kirja.

Järvinen P (2004b) Research Questions Guiding Selection of an Appropriate Research Method. University of Tampere, Department of computer sciences, Series of publications D. D-2004–5: 3–10.

Karwowski W, Kantola J, Rodrick D & Salvendy G (2002) Macroergonomics aspects of manufacturing. In: Hendrick HW & Kleiner BM (eds) Macroergonomics, Theory, Methods and Applications. Mahwah New Jersey, Lawrence Erlbaum Associates: 223–247.

Karwowski W (2005) Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems. Ergonomics 48(5): 436–463.

Kasanen E, Lukka K & Siitonen A (1993) The constructive approach in management accounting research. Journal of Management Accounting Research 5: 243–264.

Kensing F & Blomberg J (1998) Participatory Design: Issues and Concerns. Computer Supported Cooperative Work 7(3–4): 167–185.

Kesseler E & Knapen EG (2006) Towards human-centred design: Two case studies. The Journal of Systems and Software 79(3): 301–313.

Kim BY & Kang BK (2008) Cross-functional cooperation with design teams in new product development. International Journal of Design 2(3): 43–54.

Klabbers JHG (2006) The Magic Circle: Principles of Gaming & Simulation. Rotterdam, Sense Publishers.

Kleiner BM (2006) Macroergonomics: Analysis and design of work systems. Fundamental Reviews. Applied Ergonomics 37(1): 81–89.
Kleiner BM & Hendrick HW (2008) Human factors in organizational design and management of industrial plants. International Journal of Technology and Human Interaction 4(1): 113–127.
Leppänen A (2000) Työprosessin mallintaminen tukemaan työn ja osaamisen kehittymistä. Helsinki, Työterveyslaitos.
Maguire M (2001) Methods to support human-centred design. International Journal of Human-Computer Studies 55(4): 587–634.
Maier JRA (2008) Rethinking design theory. Mechanical Engineering 130(9): 34–37.
March ST & Smith GF (1995) Design and natural science research on information technology. Decision Support Systems 15(4): 251–266.
Milosevic D & Patanakul P (2005) Standardized project management may increase development projects success. International Journal of Project Management 23(3): 181–192.
Molleman E (2005) The multilevel nature of team-based work research. Team Performance Management 11(3/4): 113–124.
Moro F (2009) Macroergonomics and information systems development. International Journal of Human - Computer Interaction 25(5): 414.
Nagamachi M (2002) Kansei engineering as a powerful consumer-oriented technology for product development. Applied Ergonomics 33(3): 289–294.
Nevala K (2005) Content-based design engineering thinking. In the search for approach. PhD thesis. Jyväskylä Studies in Computing, University of Jyväskylä (60): 64.
Norman DA (1998) The Invisible Computer. MIT Press.
Nunamaker JF, Chen M & Purdin TDM (1991) Systems development in information systems research. Journal of Management Information Systems 7(3): 89–106.
Olsson E & Jansson A (2005) Participatory design with train drivers: A process analysis. Interacting with Computers 17(2): 147–166.
Owens JD (2007) Why do some UK SMEs still find the implementation of a new product development process problematical?: An exploratory investigation. Management Decision 45(2): 235–251.
Pahl G, Beitz W, Feldhusen J & Grote KH (2007) Engineering Design – A Systematic Approach. 3rd ed. Berlin, Springer-Verlag.
Palacios N & Imada AS (1998) A macroergonomic approach to product design. In: Vink P, Koningsveld EAP & Dhondt S (eds) Human Factors in Organizational Design and Management. Amsterdam, Elsevier: 439–444.
Peffers K, Tuunanen T, Rothenberger MA & Chatterjee S (2008) A design science research methodology for information systems research. Journal of Management Information Systems 24(3): 45–77.
Pentina I & Strutton D (2007) Information processing and new product success: a meta-analysis. European Journal of Innovation Management 10(2): 149–175.
Pheasant S (1996) Bodyspace : Anthropometry, Ergonomics and the Design of Work. 2nd ed. London, Taylor & Francis Ltd.

Rasmussen J (2000) Human factors in a dynamic information society: Where are we heading? Ergonomics 43(7): 869.
Robertson MM, Kleiner BM & O'Neil MJ (2002) Macroergonomics methods: Assessing work system processes. In: Hendrick HW & Kleiner BM (eds) Macroergonomics: Theory, Methods and Applications. Mahwah NJ USA, Lawrence Erlbaum Associates: 67–96.
Rodrigues LLR, Dharmaraj N & Rao BRS (2006) System dynamics approach for change management in new product development. Management Research News 29(8): 512–523.
Ruohomäki V (2003) Simulation gaming for organizational development. Simulation & Gaming 34(4): 531–549.
Salen K & Zimmerman E (2004) Rules of Play : Game Design Fundamentals. Cambridge, The MIT Press.
Schaufeli WB & Bakker AB (2004) Job demands, job resources, and their relationship with burnout and engagement: a multi-sample study. Journal of Organizational Behavior 25(3): 293–315.
Senge PM (2006) The Fifth Discipline: The Art and Practice of the Learning Organization. London, Random House Business Books.
Simon HA (1996) The Sciences of the Artificial. 3rd ed. Cambridge MA, MIT Press.
Sterman J (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill.
Suh NP (2005) Complexity in engineering. CIRP Annals Manufacturing Technology 54(2): 46–63.
Suh NP (1997) Design of systems. CIRP Annals Manufacturing Technology 46(1): 75–80.
Sundin A, Christmansson M & Larsson M (2004) A different perspective in participatory ergonomics in product development improves assembly work in the automotive industry. International Journal of Industrial Ergonomics 33(1): 1–14.
Suomala P & Jokioinen I (2003) The patterns of success in product development: A case study. European Journal of Innovation Management 6(4): 213–227.
Swink M (2003) Completing projects on-time: how project acceleration affects new product development. Journal of Engineering and Technology Management 20(4): 319–344.
Tuomaala J (1999) Creative engineering design. Acta Universitatis Ouluensis C 128. Oulu, University of Oulu.
Ulrich KT & Eppinger SD (2004) Product Design and Development. 3rd ed. New York, McGraw-Hill Companies Inc.
Väyrynen S, Rönning J & Alakärppä I (2006) User-centred development of video telephony for servicing mainly older users: review and evaluation of an approach applied for 10 years. Human Technology, An Interdisciplinary Journal on Humans in ICT Environments 2(1): 8–37.
Vink P, Imada AS & Zink KJ (2008) Defining stakeholder involvement in participatory design processes. Applied Ergonomics 39(4): 519–526.

Walls J, Widmeyer GR & Sawy OAE (1992) A methodology for developing dependable information systems. Omega 20(2): 139–148.

Walls JG, Widmeyer GR & Sawy OAE (2004) Assessing information system design theory in perspective: how useful was our 1992 initial rendition? Journal of Information Technology Theory and Application 6(2): 43–58.

Wilson JR (2000) Fundamentals of ergonomics in theory and practice. Applied Ergonomics 31(6): 557–567.

Yasemin CE (2004) Successful adoption of macroergonomics in manufacturing: Using a multicriteria decision-making methodology – analytic hierarchy process. Human Factors in Ergonomics & Manufacturing 14(4): 353–377.

Yin RK (2003) Case Study Research, Design and Methods. 3rd ed. USA, Sage Publications Inc.

Zink K (2000) Ergonomics in the past and the future: from a German perspective to an international one. Ergonomics 43(7): 920–930.

Appendix 1

ProDesim – Product Development Simulation Game, Product specification

1. Introduction

The development of products and services demands an increasing amount of multifaceted know-how. In such a working environment, the complexity of development increases, the relative importance of technical skills decreases and emphasis is placed on team work skills. Product development work is often disorganised, consisting of constant problem solving and leaving financial rewards to chance. The quality and through it the productivity of product development can be improved by developing the tools and operating procedures used. The product development process is a key component affecting the quality of product development. It has to support the process as a whole, where the employees, customers, business, production and competitors are all taken into consideration at the same time.

2. Overview of the product

ProDesim is a business simulation designed for work communities and teaching organisations operating in the field of product development. With the simulation, expertise on collaborative product development can be enhanced quickly and in an exciting manner.

ProDesim simulates the activity of a product development company for a five-year period. During that time, the participants develop multiple products according to their interpretation of the current market situation.

ProDesim combines elements from computer simulations and traditional board games in a new, innovative way. It offers a comprehensive model for the business activities of a product development company by taking into account:

- personnel
- customers
- technology
- business
- production and
- competition.

2. Roles and teamwork

ProDesim is designed for a group of 8–16 people. The participants have role-specific responsibilities with regard to their own activity in the company, but achieving success in the simulation requires collaboration. The need for cooperation is emphasised by the simulation's shared interface, which is jointly utilised by the whole group.

The simulation also illustrates the individual obligations of distinct parties within the company, which enables the participants to appreciate the different organisational sectors outside their own educational background.

The participants of the simulation are responsible for different activities according to distinct roles, which include:

- Managing Director
- Marketing Manager
- Personnel Manager
- Product Manager
- Testing Manager
- Project Manager
- Design Manager
- R&D Manager

Teamwork supported by the game board design.

4. Feed-back parameters

ProDesim's simulation model is based on the laws and interrelations of product development and business. The results of the participants' decisions and actions are visible either immediately or with delay on the projector screen. This feedback information can be classified into three categories and among others it includes the following facts:

Business

- product portfolio
- total sales and sales by products
- stock and production capacity
- market shares by products
- total expenses
- reclamations
- profit and loss statement
- capital gains of investments

Projects

- project expenses vs. budget
- project time line
- progress of pre-study, product definition, design and testing phases
- estimated workloads by phases
- progress of endurance test
- customer satisfaction
- R&D expenses
- R&D progress

Personnel

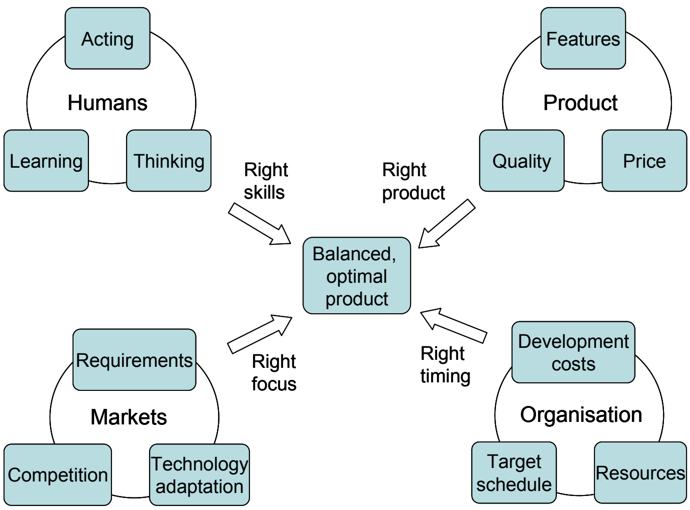
- amount and type of human resources
- experience of personnel
- productivity
- well-being
- skill level

3. Learning target

The objective of ProDesim is to demonstrate the varied challenges of product development in order to bring forth the whole to which the participants' own work is connected. Thus, they are able to better appreciate the significance of different phases of development and the origins of varied product development expenses. In-depth knowledge of the system as a whole facilitates improving their own work and identifying possible complications within the product development process.

Participants have to make various trade-offs during the game as the figure below illustrates. Participating in the simulation improves product development expertise as well as cooperation skills, while making it easier to isolate factors relating to a successful product. The participants of the simulation learn and get feedback about:

- the economic results of their investments in product development
- market dynamics
- project management
- personnel management
- scheduling and
- issues concerning interaction and the expertise levels of the development group.



The PD trade-offs in order to achieve an optimal product.

5. Adaptability to different environments

ProDesim can be tailored to correspond to the needs of both business and educational organisations. Extensive possibilities for adaptation ensure extremely varied simulations with regard to the nature of the experience and the challenges it offers. With ProDesim, it is possible to regulate numerous variables as a result of which the simulation can be adapted for all kinds of businesses operating in all kinds of different environments.

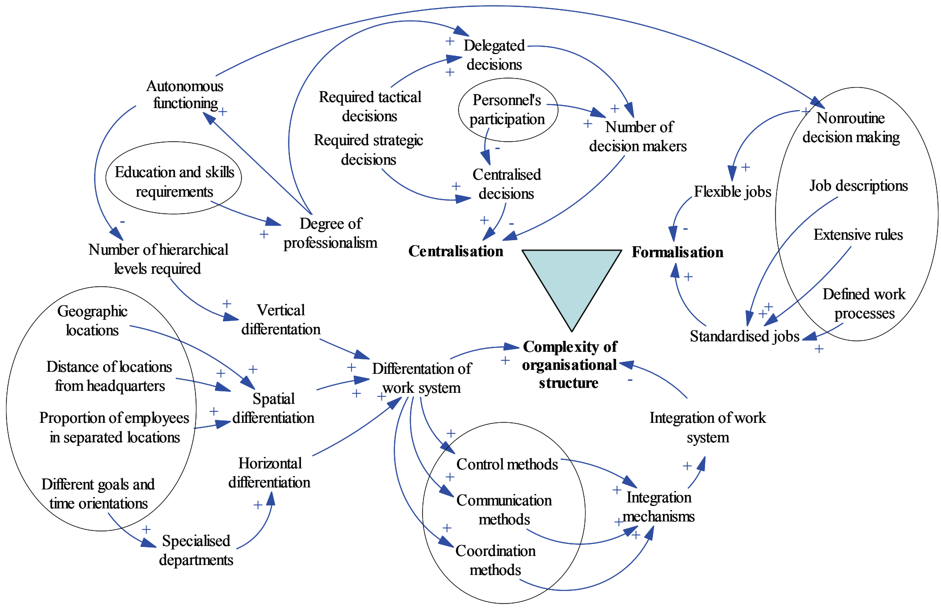
6. Contact information

ProDesim – Product Development Simulation
Turku University of Applied Sciences
Research & Development Center
Joukahaisenkatu 3 A
FI-20520 Turku, Finland

Email: prodesim@turkuamk.fi
Web site: www.prodesim.fi

Appendix 2

Dimensions of organisational structure and related macroergonomic variables.

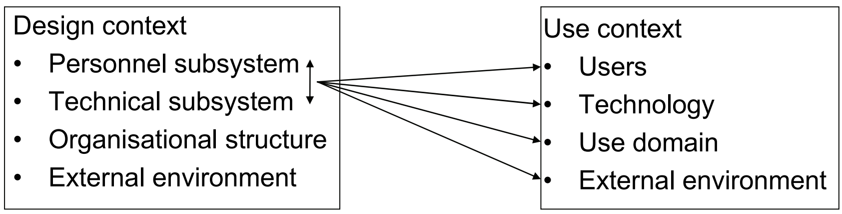


Appendix 3

Within-case analysis

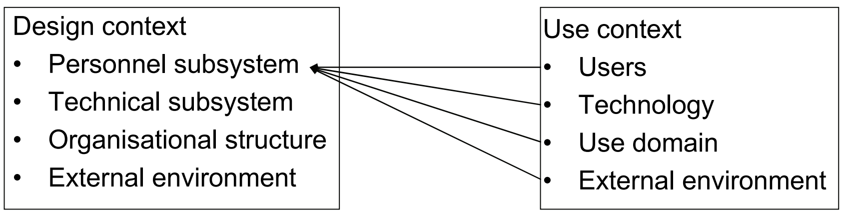
The relations between the sociotechnical work system elements of the design and use contexts of a product in six cases. The unit of observation is the relation between two sociotechnical work system elements.

Case I



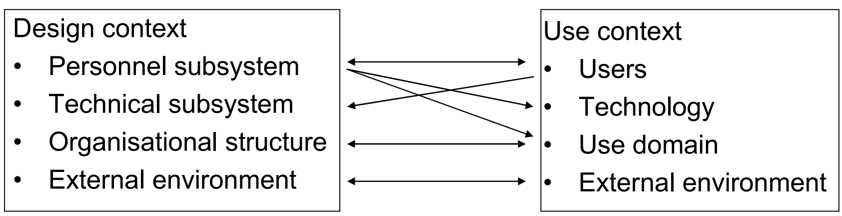
The relations between the sociotechnical work system elements from a designer's viewpoint when the ergonomic methods are concerned.

Case II



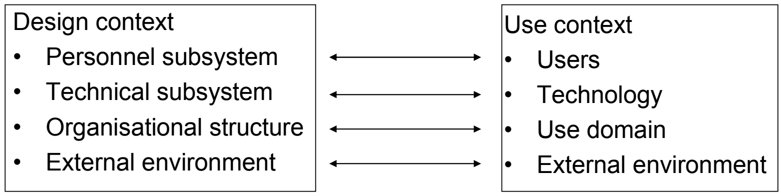
The relations between the sociotechnical work system elements from a designer's viewpoint when the characteristics of the entire use context is concerned.

Case III



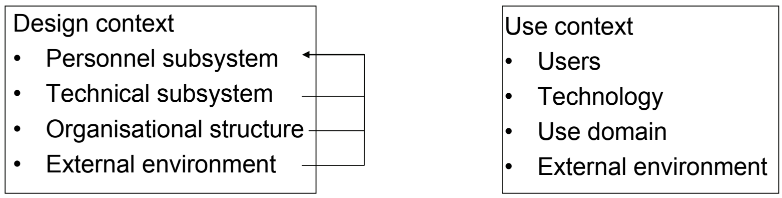
The relations between the sociotechnical work system elements from a designer's viewpoint when the participatory design is concerned.

Case IV



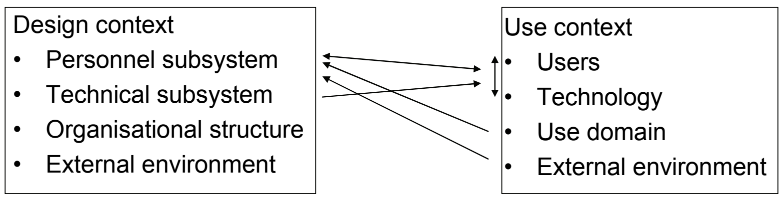
The relations between the sociotechnical work system elements from a designer's viewpoint when the modelling of the PD work system is concerned.

Case V



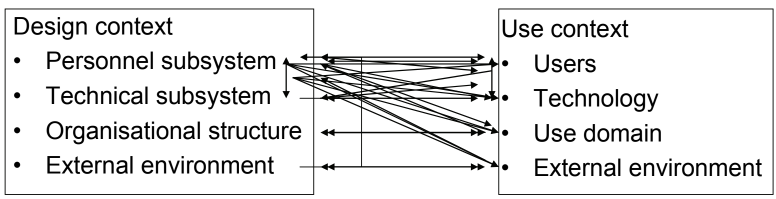
The relations between the sociotechnical work system elements when the effects of the mental load factors on designer's performance is demonstrated.

Case VI



The relations between the sociotechnical work system elements from designer's viewpoint when the HCI design is concerned.

All cases in one



The relations between the sociotechnical work system elements from a designer's viewpoint in the PD project case.

Appendix 4

Part 1 of 2: Case analysis of the macroergonomic approach in the use context.

	Use Context		
Case features	**Case 1**	**Case 2**	**Case 3**
Problem area	Data acquisition from use context	Workload factors in complex work/use environment	Tool development
Phase of the PD process	Problem definition	Problem definition	Concept creation
Microergonomic perspective			
Domain	Methods to collect information for design	Human performance	Tool development
Objective / Problem to solve	Confusing ergonomics methods	Identification of complexity and workload factors	New tool for maintenance men
Source of requirement	Practitioners	Worker / User	Maintenance work
Type of requirement	Technical	Psychosocial	Technical
Unit of analysis	Ergonomics method	Complexity and workload factor	Tool
Method / Guideline	Classification	Interview	Participation, interview
Outcome	List of ergonomics methods	Identified complexity and workload factors	Revision needs
Utility	Informative for practitioners	More understanding about a complex work environment	Software development
Macroergonomic perspective			
Domain	Technical subsystem and virtual work/use environment	Personnel subsystem in virtual work structure	Technical subsystem of an organisation
Objective / Problem to solve	Ergonomic design in virtual work environment	Understanding of tacit product requirements	Paperless reporting in an organisation
Source of requirement	Emerging virtuality	Emerging virtuality	Company
Type of requirement	Ext. environment	Sociotechnical	Technological
Unit of analysis	Work system	Work system	Work system
Guideline	Systems design	Systems design	Participatory design, joint design
Outcome	Hierarchical classification of applicable methods	Decision making in virtual work environments as the important subject of study	Need for the integration of tool and work system development
Utility	Classification of the ergonomics methods related to abstraction and organisational levels of work system	Further research	Personnel's commitment to tool development
Design science perspective			
Target of design	Process	Process	Process
Constructs	Abstraction hierarchy (AH), Organisational structure	Complexity, virtual work	Participation
Model	AH model	Mediated communication	Joint design
Method	Classification	Construct	Construct
Instantiation	Classification of ergonomics methods	Communication model of virtual work	Model of simultaneous tool and work system development

Part 2 of 2: Case analysis of the macroergonomic approach in the design context.

	Design Context		
Case features	**Case 4**	**Case 5**	**Case 6**
Problem area	Modelling of PD work system	Simulation modelling	Multiplayer UI design
Phase of the PD process	Development	Development	Development
Microergonomic perspective			
Domain	Game design	Game design	User interface design
Objective / Problem to solve	Modelling of PD process	Calculation of designer's performance	Integration of a board game and a simulation model
Source of requirement	Type of the game	Features of the game	Users
Type of requirement	Technical	Technical	User needs
Unit of analysis	PD process	Factors of performance	HCI
Method / Guideline	Modelling, prototyping	System dynamics	Human-centred design process
Outcome	Game prototype	Software module for the game	Multiplayer interface concept
Utility	Testing of the simulation game	A feature for the game	Integration of a board game concept and a simulation model
Macroergonomic perspective			
Domain	Personnel subsystem and organisational structure	Personnel subsystem	Technical subsystem and personnel subsystem
Objective / Problem to solve	Modelling of PD work system	Effects of time pressure on designers' work	Interaction between simulation model and users
Source of requirement	Project target	Importance of designer as knowledge worker	Users
Type of requirement	Sociotechnical	Psychosocial	User needs
Unit of analysis	Work system	Work system	HCI
Guideline	Systems design, Human-centred design	Joint design	Participatory design, Human-centred design
Outcome	Meta-level simulation model of the PD work system	Understanding about the effects of time pressure on design work	Multiplayer interface concept
Utility	Integration of personnel subsystem into the simulation model	Supports management in project planning	Supports collaboration in gaming
Design science perspective			
Target of design	Product	Product	Product
Constructs	Holistic PD work system	Mental workload	Multiplayer interface
Model	Sociotechnical work system model	Job Demands-Resources Model	Simulation game related usability criteria
Method	Construct	System dynamics	Construct
Instantiation	Three-layer simulation model	Model of the dynamics of design work	Multiplayer interface concept of the simulation game

Original publications

I Putkonen A & Hyrkkänen U (2007) Ergonomists and usability engineers encounter test method dilemmas with virtual work environments. In: Harris D (ed) Engineering Psychology and Cognitive Ergonomics. Berlin, Springer: 147–156.

II Hyrkkänen U, Putkonen A & Vartiainen M (2007) Complexity and workload factors in virtual work environments of mobile work. In: Dainoff MJ (ed) Ergonomics and Health Aspects of Work with Computers. Berlin, Springer: 85–94.

III Hyrkkänen U, Kettunen J & Putkonen A (2009) A participatory design project on mobile ICT. In: Cartelli A & Palma M (eds) Encyclopedia of Information Communication Technology. Volume II. Hershey, New York, IGI Global: 669–675.

IV Putkonen A & Forstén M (2007) The three-layer simulation game model for the computer-augmented board game. In: Mastik H & Mayer I (eds) Organizing and Learning through Gaming and Simulation. Proceedings of Isaga 2007. Eburon Delft, The International Simulation and Gaming Association: 303–311.

V Putkonen A (2009) Predicting the effects of time pressure on design work. International Journal of Innovation and Learning 6(5): 477–492.

VI Putkonen A & Forstén M (2009) Multiplayer interface for a computer-augmented learning game. In: Kankaanranta M & Neittaanmäki P (eds) Design and Use of Serious Games. Springer: 155–167.

Reprinted with the permission from Springer (I, II, VI), IGI Global (III), Inderscience (V) and the authors (IV).

Original publications are not included in the electronic version of the dissertation.

344. Chung, Wan-Young (2009) Ubiquitous healthcare system based on a wireless sensor network

345. Väisänen, Tero (2009) Sedimentin kemikalointikäsittely. Tutkimus rehevän ja sisäkuormitteisen järven kunnostusmenetelmän mitoituksesta sekä sen tuloksellisuuden mittaamisesta

346. Mustonen, Tero (2009) Inkjet printing of carbon nanotubes for electronic applications

347. Bennis, Mehdi (2009) Spectrum sharing for future mobile cellular systems

348. Leiviskä, Tiina (2009) Coagulation and size fractionation studies on pulp and paper mill process and wastewater streams

349. Casteleijn, Marinus G. (2009) Towards new enzymes: protein engineering versus Bioinformatic studies

350. Haapola, Jussi (2010) Evaluating medium access control protocols for wireless sensor networks

351. Haverinen, Hanna (2010) Inkjet-printed quantum dot hybrid light-emitting devices—towards display applications

352. Bykov, Alexander (2010) Experimental investigation and numerical simulation of laser light propagation in strongly scattering media with structural and dynamic inhomogeneities

353. Kannala, Juho (2010) Models and methods for geometric computer vision

354. Kela, Lari (2010) Attenuating amplitude of pulsating pressure in a low-pressure hydraulic system by an adaptive Helmholtz resonator

355. Ronkainen, Sami (2010) Designing for ultra-mobile interaction. Experiences and a method

356. Loikkanen, Mikko (2010) Design and compensation of high performance class AB amplifiers

357. Puikko, Janne (2010) An exact management method for demand driven, industrial operations

358. Ylioinas, Jari (2010) Iterative detection, decoding, and channel estimation in MIMO-OFDM

359. Tervonen, Pekka (2010) Integrated ESSQ management. As a part of excellent operational and business management—a framework, integration and maturity

Book orders:
Granum: Virtual book store
http://granum.uta.fi/granum/

UNIVERSITY OF OULU P.O.B. 7500 FI-90014 UNIVERSITY OF OULU FINLAND

ACTA UNIVERSITATIS OULUENSIS

ISBN 978-951-42-6236-4 (Paperback)
ISBN 978-951-42-6237-1 (PDF)
ISSN 0355-3213 (Print)
ISSN 1796-2226 (Online)

UNIVERSITY of OULU
OULUN YLIOPISTO