HUMAN-CENTRED COLLABORATIVE SYSTEM SUPPORTING JIT DELIVERY IN MANUFACTURING

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Abstract: The study presented in this paper is part of a wider research into practical testing and further improvement of methods and tools for human-centred design and evaluation of complex socio-technical systems and advanced technology-based products. A computer-aided collaborative system supporting just-in time (JIT) delivery of components in the manufacturing of electrical energy meters was evaluated by means of criteria for human-centred design. For this purpose, the existing KOMPASS method was extended for use in evaluation of service-type socio-technical systems. Results show, first, that the extended KOMPASS method is appropriate for evaluation of collaborative systems, and second, that the evaluated system has the greatest potential for improving its working efficiency and cost-effectiveness in a more flexible allocation of functions between humans and machines.

Keywords: Human-centred design, Communication systems, Manufacturing systems, Evaluation, Cost-Oriented Automation, Socio-technical systems.

1. INTRODUCTION

In searching for efficient measures to boost their competitiveness on global marketplaces, many successful companies introduce various collaborative systems supported by advanced technology. Among other reasons, the purpose of technology in these systems is to help mastering their complexity. This is usually done by automating the procedures of collaboration as much as possible, in order to reach greater overall effectiveness of working. Indeed, currently available information and communication technology (ICT) systems, including control systems, offer a huge potential for this purpose. Unfortunately, it is not easy to exploit this potential by currently prevailing approaches to system design and implementation.

The idea of this paper is to show how this huge potential of ICT-supported collaborative systems can be better exploited by available approaches to Human-Centred Design of complex socio-technical systems (STS). It is reported how a collaborative system supporting just-in time (JIT) delivery of components in manufacturing was evaluated by means of the method KOMPASS (Wäfler et al., 1999).

The aim of this study was twofold: first, to test the viability of this method for design and evaluation of service-type socio-technical systems, and second, to explore the possibilities for improving the working efficiency of the collaborative system supporting the manufacturing of electrical energy measurement and management systems in the Slovenian enterprise Iskraemeco.

This paper is structured as follows. The second chapter gives an introduction to human-centred design and the method KOMPASS. The third chapter is a brief description of the evaluated system. Finally, the procedure and results of evaluation are given in the fourth chapter, followed by conclusions mentioning the main implications of work presented in this paper.

2. HUMAN-CENTRED DESIGN AND THE "**KOMPAS**S" METHOD

2.1. Some background of Human-Centred Design

In order to understand the meaning of the work presented here, it is good to know something about the background of Human-Centred Design (HCD). The first obvious question is usually: Why should system designers, or managers planning to invest into advanced technology, or even its prospective users bother about this issue? Maybe the best arguments for this question are given by the famous "**ironies of automation**" written by Lisanne Bainbridge (1983). They were meant originally for the area of automation, but can be readily extended to the wider context of socio-technical systems, such as for example the collaborative systems dealt with in this paper.

In such a wider context, the essence of automation ironies is the following: the idea of introducing advanced technology is to make selected work processes as much as possible independent of humans. This is because humans are often perceived as "sources of trouble" in (technology-based) work systems, due to their inclination to make errors, or casual absenteeism, or requests for better working conditions or higher wages. Following this line of reasoning, the introduction of automation is often meant to be "justified" in terms of lower (labour) costs and greater working efficiency which is not difficult to "prove" in financial terms.

On one hand, it would be fine to eliminate the human "sources of trouble" and replace them as far as possible by advanced technology which is never tired, is working repeatedly the same way, has no "requests" or syndicates and has also many other desirable features. On the other hand, it is a fact that humans are badly needed in more or less rare cases when technology somehow comes out of order.

Exactly this is the point of irony: in contrast to the tendencies for eliminating humans from work systems, they are urgently needed for "manual" intervention when things become tough and dangerous, specifically in cases that were not foreseen or were not programmed into technology. There are many factual proofs available for this important statement, most of them related to more or less severe accidents with advanced technology (see, e.g. Field, 2003). So it becomes obvious that some other - more balanced - solutions for cost-effective systems must be found. In the context of the Human-Centred paradigm, economic consideration of efficiency is augmented by criteria for efficient co-operation between humans and technology.

It is good news that such solutions are available for some time. Conversely, it is bad news that these solutions are by far not so widely accepted as it would be logical and needed. Therefore the aim of the study presented here is to make wider promotion of practical solutions in the area of human-centred and socially acceptable systems, in order to contribute to their greater acceptance among system designers as well as users of ICT.

In the following, a couple of principles are mentioned on which these solutions are based. The **first principle** specifies the main entities to be considered during the deployment of technology. Almost any technology today is both, designed and used with implicit or explicit relations between the following three important entities: People, Organisation and Technology. These relations are often presented in a triangle, like that one depicted in Fig. 1 (Brandt and Černetič, 1998). This triangle is a useful reminder that almost any (advanced) technology today is embedded in a sort of socio-technical system.

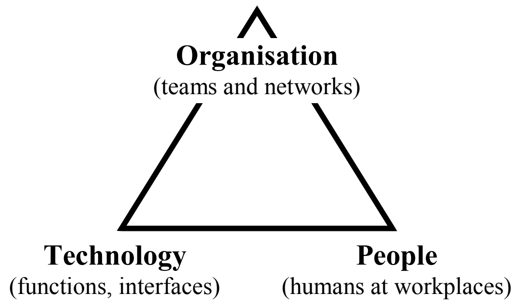

Fig. 1. Basic relations in socio-technical systems.

The **second principle** important in design of socio-technical systems (STS) is the priority of dealing with the entities in Fig. 1. As advocated recently by Brandt (2003) and many others previously, the correct succession is: first – People, second – Organisation, and third – Technology. The **third principle** important in STS design became the hallmark of the so-called Dual Design Approach (Henning and Ochterbeck, 1988; later extended by Fuchs-Frohnhofen, 1994). The Dual Design principle (Fig. 2) states that the design of an automated STS should proceed from two different directions or viewpoints at the same time:

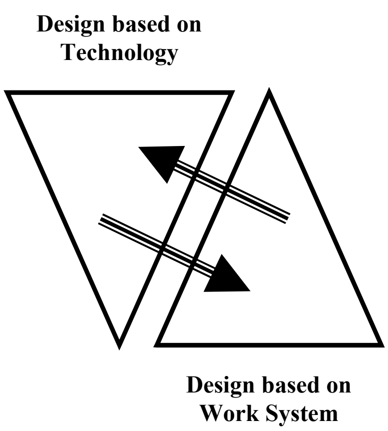

Fig. 2. The Dual Design principle

- Design based on technology (led by engineers) and
- Design based on the system of working (led by specialists for work organisation and work psychology).

Most importantly (and this is the **fourth principle**), these two design sub-processes (i.e. their actors) must have intensive mutual interaction, as also indicated in Fig 2. Thus, in the continuum between the technology-based design and work-based design, the following four important design parameters in the new system can be chosen in an optimal way:

- degree of work automation,
- degree of change dynamics,
- degree of networking complexity, and
- degree of formalisation in the communication, co-operation and relations between machines and humans.

This optimum is determined according to specific criteria which allow finding a best combination between:

- the possibilities of technology,
- the capabilities, competencies and needs of humans, as well as
- the objectives and requirements of the work system.

The **fifth principle** of STS design specifies the hierarchy as well as the direction in which the particular levels of detail are considered during the design and implementation (deployment) of the new system (Fig. 3). Due to its appearance, this principle of STS design is sometimes called "the onion model".

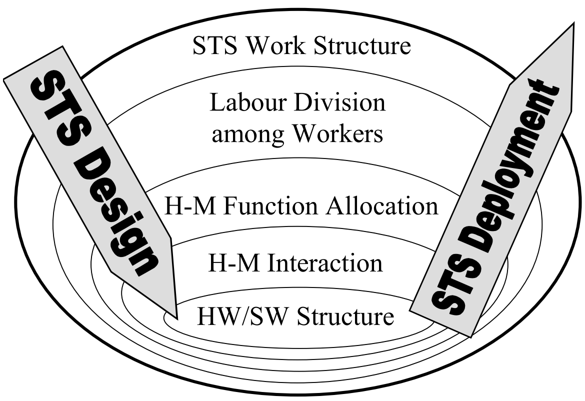

Fig. 3. Hierarchy and consideration of details during STS design and deployment.

2.2. <u>The basics of the KOMPASS method</u>

The KOMPASS method is based on the long tradition of research into STS, HCD and work psychology. It was developed at the Institute for Work Psychology, Technical University (ETH) in Zürich, Switzerland as a pragmatic, but strongly theory-based, guideline for human-centred analysis, evaluation and design of automated production systems (Wäfler et al., 1999). The approach of the KOMPASS is called "complementary" as it considers complementarities and synergy between technology, humans and the work system, essentially according to the Dual Design principle (Fig. 2).

The KOMPASS method is using three different perspectives, which means that the "onion model" from Fig. 3 was a bit simplified:

- the perspective of the entire work system,
- the perspective of individual human work tasks,
- the perspective of function allocation between humans and machines.

These three perspectives are mirrored in the main tool of the KOMPASS method – its STS analysis/ evaluation/ design criteria (Grote et al., 1995). These criteria enable systemic and detailed consideration of all important factors which make people, together with automated (production) machines, a smartly integrated, synergetic and efficiently operating unity. A short summary of KOMPASS criteria is given in Table 1.

The KOMPASS approach and method in themselves are holistic and systemic in the sense of HCD and STS design principles discussed before. They can be used for the design of new as well as for the evaluation of existing systems; the latter with the idea to get extensive recommendations, either for their improvement or complete redesign or reconstruction.

The KOMPASS method supports the design team in changing its eventually narrow technical considerations with a holistic picture of people collaborating with machines efficiently and in truly synergetic ways. The aim of this support is to design technology in such a way that, on one side, it compensates for human deficiencies and limitations, but on the other side, it purposefully supports humans in preserving and even in further developing their specific strengths. The advocates of the HCD paradigm call this ideal situation "Human-Machine Symbiosis" (Gill, 1996).

Although it is not often mentioned in the context of Human-Centred design, it may be logical to infer that socio-technical systems working according to the principles of human-machine symbiosis have a serious potential for achieving not only better efficiency regarding lower costs and higher productivity, but also potential for overall enterprise optimisation in the sense of (business) excellence (see, e.g. http://www.efqm.org/). Some further reflections to the point of cost-effectiveness in Human-Centred and socially acceptable automation systems are given by Černetič (2003).

Table 1. Summary of KOMPASS criteria

Level 1: Entire System of Working
1.1. Completeness of work functions in the organisational unit
1.2. Independence of the unit regarding fluctuations and disturbances
1.3. Adaptation of requirements and possibilities for control
1.4. Polyvalence and mutual support of co-operating workers
1.5. Organisational autonomy and joint decision making
1.6. Control of boundary conditions by supervisor
Level 2: Individual Working Tasks
2.1. Completeness of work tasks
2.2. Requirements for thinking and planning
2.3. Requirements for communication and collaboration
2.4. Possibilities for learning and skill development
2.5. Variety of requirements for working
2.6. Transparent (clear) working procedures
2.7. Possibility for planning work and working conditions
2.8. Flexible working time
Level 3: Allocation of Functions between Human and Machine
3.1. Transparent process of working, with sufficient feedback from the machine
3.2. Dynamic coupling of working options regarding time, place, procedure and necessary attention
3.3. Available information from machine, with variable filter for information flow
3.4. Execution authority of human with his active control of working process
3.5. Flexible function allocation

2.3. Modifications and extensions to the method

As mentioned previously, the KOMPASS method was developed specifically for analysis and design of automated production systems. Nevertheless, it was felt by the authors of this paper that the method has also a great potential for other instances of advanced technology embedded in wider socio-technical contexts, particularly in cases with higher levels of complexity, such as typically found in collaborative systems. After initial testing of the method in simpler systems, it gradually became clear that it is meaningful to make some modifications and extensions to the KOMPASS methodology.

But before the method could be used on a wider scale in Slovenia, it was necessary to perform the translation of the materials into the domestic language. This was important due to a couple of reasons. First, the understanding of the original German-language materials is very limited in Slovenia. Second, it appeared that it is not only a more or less direct translation that had to be made, but the materials had to be adapted to both, the specific local thinking and language patterns as well as to keywords known from the materials (papers, books, etc.) written in English. Third, as the evaluation interviews have also to be made with people without any (scientific) degrees and foreign language knowledge, all foreign words and less familiar concepts have to be simplified, explained and/or exchanged by more familiar ones.

After that initial preparatory work, the idea was to use the method in some ICT-supported systems. As these mostly have the characteristics of collaborative and/or service-type systems, it was also necessary to adapt the materials to their specific features.

Another major methodological improvement came from the practical use of the KOMPASS criteria in system evaluation. Due to the usual time limitation and consequent pressure during the interviews with technology users, the person leading the interview needs pragmatic support for explaining some methodological concepts and details behind the particular criteria. Showing the (translated) materials on the spot was found to be only a provisional solution. Therefore the essential methodological explanations were condensed into a brief but meaningfully structured document, called “the extended KOMPASS questionnaire”. Its essential structure for a selected criterion in a shortened version is shown in the Appendix 1. Normally, each criterion is presented on two A4 pages and in a transparent, clearly understandable structure.

3. THE OBSERVED SYSTEM

The introduction of the collaborative system (being evaluated in this study) into the company Iskraemeco (http://www.iskraemeco.si) some years ago represented a vital part of measures for achieving its greater competitiveness on the international markets. This highly successful company with a number of associated companies in Europe and on other continents has over 2.000 employees, almost 100 million EURO yearly revenues and is investing about 1/8 of this sum into innovating its production system, based on its policy for continuous improvement.

In essence, the observed collaborative system is supporting direct supply and just-in-time (JIT) delivery of about 360 production components from both, 35 outside partners and eight internal suppliers (the latter are from inside the company). With about 90 delivery requests per day, small local component storage in production and with very tight delivery deadlines, this collaborative system is so complex that it would be impossible to manage it by

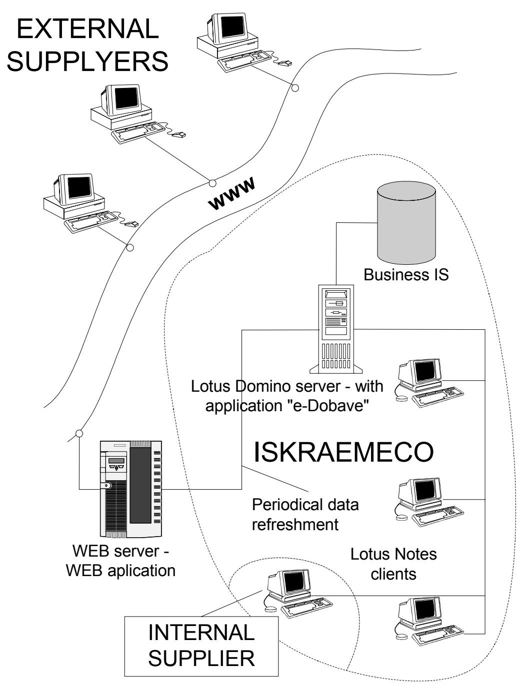

Fig. 4. Hardvare and software for the observed collaboration system

conventional communication procedures and old technology.

The new production control, communication and information system enables direct delivery of components to workplaces in production, almost exactly where and when these are needed. Through this, the organisation of work is simplified, essential quality control of components is made by suppliers themselves and the overall costs of production are greatly reduced. Fig 4 gives an impression about system hardware and software.

The motivation for performing this study came from three origins of interest: research, economy and development. The aim of researchers was to test the extended KOMPASS method in a real-life situation. The management of Iskraemeco wanted to get some new insights for improving their production control system. Finally, the software development company Genis where initial prototype of this collaborative support system (called "e-Dobave", meaning "e-Delivery") was initially designed, was interested to see suggestions about how they could make their software tools more user-friendly.

4. THE EVALUATION AND RESULTS

The evaluation of the observed collaboration system involved a number of people and was performed in several phases extending over more than a year. Involved were: developers of the basic application from the Slovenian software development company Genis, developers and current maintenance staff of the final application in Iskraemeco, and finally, four researchers from the J. Stefan Institute. The *de facto* evaluation was preceded by a couple of extensive introductory steps which were necessary in order to understand the essential features of this pretty complex collaboration system. The essential phases performed were the following.

- Study of Lotus Notes - the basic application platform.
- Analysis of the JIT component delivery work system was made in the research laboratory by setting up and running a simple "component delivery game" by means of the real application software.
- Analysis of the real work system was performed through a couple of visits to the production facilities of the company and by several meetings with the application development and maintenance staff.
- The final evaluation was made through an extended interview with the application development and maintenance staff at the company site. Results of the final evaluation are given in Table 2.

In reading the results, it should be noted that the numerical result of evaluation for each evaluation issue is a product: (weight)x(value). For the <u>weight</u>, the evaluator had three choices: "very important" (2), or "important" (1) or "not important" (0). For the <u>value</u>, there were five possibilities: "excellent" (5), "very good" (4), "good" (3), "acceptable" (2) and "bad" (1). The results in table 2 show on the average that – seen through the eyes of the evaluators - the human-centred orientation of the observed collaboration system was perceived as: fairly good at the work system level, very good at the level of individual working tasks and good at the level of human-machine function allocation. This means that this system has the greatest potential for improvement at the lowest level of its socio-technical structure, in particular with a more flexible allocation of functions between the humans and machines.

5. CONCLUSIONS

The main message of this paper is that pragmatic use of Human-Centred Design principles and criteria can significantly help in finding meaningful suggestions for improving synergy between humans and machines in complex socio-technical systems. The results of this synergy are visible not only in greater cost-efficiency of these systems (processes and key performance results), but also in an increased level of other (business) excellence indicators, as measured by the human-related criteria: leadership, people, partnerships and resources, and people/customer/ society results. The reported study has also shown that the existing methodology (in this case the KOMPASS method) is flexible enough to be adapted for evaluation or design of collaboration systems which is a very important segment of service-type

Table 2. Results of final evaluation.

Level 1: Entire System of Working	
1.1. Completeness of work functions	4
1.2. Independence of the unit	5
1.3. Adaptation for control	2
1.4. Polyvalence of workers	4
1.5. Organisational autonomy	4
1.6. Control of boundary conditions	3-4
Level 2: Individual Working Tasks	
2.1. Completeness of work tasks	4
2.2. Thinking and planning	2
2.3. Communication and collaboration	8
2.4. Learning and skill development	4
2.5. Variety of work requirements	4
2.6. Transparent working procedures	4
2.7. Possibility for planning	4
2.8. Flexible working time	5
Level 3: H/M Function Allocation	
3.1. Transparent work process	3
3.2. Dynamic coupling	3
3.3. Available information	4
3.4. Execution authority	3
3.5. Flexible function allocation	2

systems. On the other hand, the study can encourage ambitious companies, having their work systems heavily supported by advanced technology, to seek further innovations for improving their competitiveness through the potential of the Human-Centred Design paradigm.

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Appendix 1.

Structure of the "Extended KOMPASS Questionnaire" for a selected criterion.

Code	*Keyword*	*Evaluation result*
3.2.	**Dynamic coupling**	
Question: Has the human any possibilities for selecting by himself time, space, procedure and degree of his/her attention during the execution of particular working steps?		
Aim: humans who are able to handle appropriately, according to the specific current situation. *Short explanation*: The human should have possibilities to decide: when, where, how and at which level of his/her attention he/she will perform a working step, all depending on the specific working/ handling situation.		
Aspects: coupling of time, place, procedure, attention (with further more detailed explanations ...)		
More detailed questions: …		
Guidelines for evaluation: …		
Justification of evaluation result: (room for comments of the evaluator) …		
Definition of the problem and how it can be solved by design: (detailed explanation in small font)		
SUMMARY of design recommendation: Design of technology is assuring dynamic coupling when it offers possibilities to the human for choosing time, place, procedure and degree of his/her attention during the execution of particular working steps.		

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