HTO – A complementary ergonomics approach

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Abstract

The field of human factors and ergonomics constitutes a strong potential in systems analysis, design and improvement. However, it is difficult to communicate its potential value. This paper addresses how the human-technology-organization (HTO) concept can be defined and supports the understanding, communication and development of the systems' character and potential of human factors and ergonomics. Empirical examples from the authors' experiences of working with the HTO concept in R&D and teaching are illustrated, including its usefulness as: 1) a conceptual model; 2) an analysis framework; 3) a meta methodology; 4) a pedagogical tool; and 5) a design tool. The use of HTO provides guidance on how the system can be designed to better support health, individual and systems performance. It is further suggested that there is a strong potential for developing the theory, applications and methodological aspects of HTO.

1 Introduction

As the aim of the human factors and ergonomics discipline is to provide safety, well-being and systems performance, it necessarily includes a mix of knowledge from fields such as engineering, medicine and behavioural sciences. Therefore, the discipline provides a strong basis for analysing, designing and creating high-quality work situations for the individual as well as beneficial systems performance in operations of different kinds. At the same time, because the discipline is broad, there is a risk that the focus and the content are perceived as unclear and superficial. This makes it difficult to communicate its potential value to different stakeholders, and difficult to promote the education of human factors and ergonomics specialists, as pointed out by Dul et al. (2012). These dilemmas are discussed within the human factors and ergonomics scientific society. They are further discussed in the *Applied Ergonomics* special issue 'Systems Ergonomics/Human Factors', where Wilson (2014) argues that the focus should be on the interaction between the systems' components rather than on the components themselves. Hollnagel (2014) claims in a corresponding way that there should

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be an emphasis on what the system does rather than what it is. This suggests the idea of a dynamic system in which there are ongoing activities that continue to transform the system itself. These properties are highly important characteristics for identifying and communicating the human factors and ergonomics (HFE) discipline. Consequently, systems orientation is inherent within the HFE discipline, which to a great extent originates from the socio-technical systems theory (e.g. Wilson, 2000; Noy et al., 2015). The socio-technical systems theory focuses on the interactive interdependent influences of social and technological factors shaping how work is performed. As stated by Hollnagel: ‘The idea of a socio-technical system is that the conditions for successful organizational performance – and conversely also for unsuccessful performance – are created by the interaction between social and technical factors’ (2009, p. 19).

The Swedish human-technology-organization (HTO) concept was established in the nuclear power industry, as described below. The concept is based on a systems view and emphasizes interactions and interdependencies between the three included elements. The HTO concept has been used and elaborated by researchers and practitioners and by the authors of this paper. It is a useful approach for the application of human factors and ergonomics as well as an approach for understanding complex systems (Carayon, 2006).

The aim of this paper is to further describe the HTO concept, its background and basis, and to demonstrate how it can support the understanding, communication and development of the system character of human factors and ergonomics. Empirical examples from the authors’ experiences of working with the HTO concept in R&D and teaching are used to exemplify the potential for using the HTO concept in a number of ways.

The paper is organized as follows. Section 2 discusses the development of the human factors and ergonomics fields. In Section 3, the development and characteristics of the HTO concept are elaborated. Section 4 presents the authors’ experiences of working with the HTO concept in different settings in research, development and teaching. Finally, the benefits and disadvantages of the HTO concept are discussed and concluded in Sections 5 and 6.

2 Human factors and ergonomics development

Human factors and ergonomics have multidisciplinary roots and to a large extent started to develop during the Second World War. The scientific discipline became recognized in the late 1940s. The term ‘ergonomics’ was predominantly used in the UK, and its development led to the formation of two research fields, namely anatomy/physiology and experimental psychology. During the 1960s, ergonomics in the UK also came to include a systems view due to increased automation and the need to understand the influence of management, technology and human-machine aspects on work (Waterson and Eason, 2009). In parallel, the term ‘human factors’ or ‘human factors engineering’ was predominantly used in the United States, strongly influenced by the disciplines of psychology and engineering. In Scandinavia, Germany and the Netherlands, the basis for the discipline evolved from medicine and functional anatomy, while in Eastern Europe it largely developed from the industrial engineering profession (Singleton, 1982; Wilson, 2000). People in general associate the term 'ergonomics' with physical aspects and individual factors, while the term 'human factors' is often associated with cognitive aspects (Wilson, 2000). The terms 'ergonomics' and 'human factors' are now considered more or less synonymous, although they were derived from partially different research traditions. The discipline of human factors and ergonomics is frequently referred to as HFE (Wilson, 2014), and this acronym will be used for the remainder of this paper to denote the discipline.

The need for a holistic view as a complement to the reductionist research approach, dividing a system into separate elements, became apparent in the 1950s and led to the development of systems theory associated with efforts to manage increasingly complex systems. Understanding the whole system necessitates an understanding of the parts and their interactions (von Bertalanffy, 1972; Checkland, 1981). Systems theory has largely influenced research in, for example, biology, engineering, organizational development and HFE (Wilson, 2014). The system view and a holistic perspective are included in the organizational development and management (ODAM) field within ergonomics.

As described by Carayon et al. (2015), various approaches relating to socio-technical systems with different foci have evolved over the years – e.g. a) macro-ergonomics (Hendrick and Kleiner, 2001); b) activity-related ergonomics (e.g. Daniellou and Rabardel, 2005); c) user-centred approach (Booher, 2003); d) systems approach to HFE (Moray, 2000; Wilson, 2000). These approaches differ somewhat in the view of the human role in terms of individual or individual performance, human systems design/performance or human capacities and limits in the centre. They also differ regarding the main focus – e.g. sub-systems included, elements of the work system, interaction characteristics and system levels. Furthermore, they have different methodological and application approaches – e.g. regarding how to structure and

analyse the system, such as MEAD (Kleiner, 2006) and activity analysis (Guerin et al., 2007).

Moreover, research groups with different research traditions have developed HTO related models over the years. Examples of such models are Porras and Robertson (1992) from the OD tradition; Rollenhagen (1997) analysing systems' safety; Eklund (2003) highlighting interactions within human activities in relation to processes; SEIPS for patient safety (Carayon et al., 2006; Holden et al., 2013) and the Swiss CIM model (Ulich and Schüpbach, 1991) analysing businesses on company, organization, group and individual levels (Latniak, 1999).

3 Development and characteristics of the HTO concept

The HTO concept is today a well-established unifying concept within the Swedish nuclear power industry (Strålsäkerhetsmyndigheten, 2014). The concept was initially developed for improving nuclear power plant safety (e.g. Skjerve and Kaarstad, 2014), but has over time acquired a wider application. Today it includes an extensive range of aspects of the interactions between the H (human), T (technology) and O (organization) sub-systems in different operations and settings, and it is also related to systems performance and health issues, not only safety (Ahlin, 1999; Grote et al., 2000; Berglund and Karltun, 2007; Eklund, 2003; Karltun, 2011).

By focusing the interaction between the three major interdependent sub-systems human, technology and organization, rather than the sub-systems themselves, the HFE system performance becomes more obvious. Further, this indicates ongoing activities in a dynamic system, which implies that the relationship between well-functioning activities and organizational processes and system performance as a whole is easy to detect (compare Hollnagel, 2014; Wilson, 2014).

The conceptual idea of HTO is that work activities can often be described, analysed and understood by describing the interactions between the three sub-systems – human, technology and organization – each of which it is possible to describe as a system on its own. 'H' can be defined as the description of the human at four levels, namely: 1) a biological energy processing system; 2) an information processing system; 3) a psychic subject with a unique history; and 4) a member of social groups and cultures (Daniellou, 2001). Drawing on these distinctions, human interactions involve a combination of physical, cognitive, psychological and social aspects. 'T' in socio-technical theory was defined by Mumford (2006) as the technology itself, including the work system. This view was further specified and enhanced by Porras and Robertson and can be defined as the means of transformation of input to output using artefacts, procedures and methods, including know-how and the physical setting (1992). Finally, 'O' can be generally defined as a consciously coordinated social entity, with a relatively identifiable border, which works relatively continually with the purpose of reaching common goals (Robbins, 1990), but is here more suitably described as formal organizing arrangements and informal social structures (Porras and Robertson, 1992). It may be noted that these definitions of 'T' and 'O' include what is sometimes called the internal environment.

The HTO concept builds on the socio-technical systems theory. There is, however, an important difference in that the human is considered as an equal and separate sub-system and HTO includes the interactions between an organizational system, a technical system and a human system, all inseparable in a certain activity. We thus use a redefinition of the social system as an organizational system posing formal organizational and informal social requirements and affordances to the human, just as the technical system does. While the human sub-system of the HTO concept relates to the individual activities carried out in a business and how the business at large impacts on individuals as persons, the 'O' component relates to individuals at a collective staff level, focusing on, for example, how staff categories or roles affect operations and processes (Westlander, 1999a). It is important to discuss the 'H' subsystem in an equivalent manner to that of 'O' and 'T' in order to understand what is actually going on in the system and how it will affect processes and outcomes for the individual as well as the system. We have found some HFE models explicitly addressing the human as a separate sub-system – e.g. the 'balance model' (Carayon, 2009).

In all organizations, processes cannot be accomplished without activities performed by humans: this is what systems do (Hollnagel, 2014). By highlighting the human as a separate sub-system, the influence of the individual is not hidden when incorporated into the social system. This becomes more important as organizational and technological complexity increases and roles change, which requires better understanding of the individual human as a system – e.g. regarding stress reactions, cognitively demanding work or work-related musculoskeletal disorders. This means that the activity in the HFE system is viewed as the core of the HTO conceptual model, and the result of an activity is considered dependent on the conditions for the single individual performing it and dependent on the interactions of this individual. This also makes it possible to view the involved human from different perspectives. For example, a human can be viewed as an actor in the system, as exposed to the system, as cooperating in the system or as learning in a technical organizational context (Westlander, 1999a). Such views in turn affect both analysis and results and open up new opportunities to understand conditions that otherwise would not be apparent (Karltun, 2007).

4 Applying the HTO concept

The authors of this paper have used and applied the HTO concept in several contexts, constellations and with various stakeholders, as well as with varying objectives. Four R&D projects, as well as the development and execution of a Master's programme in ergonomics and HTO, are presented. An overview of these cases is displayed in Table 1, followed by a description of the Master's programme.

The case descriptions below illustrate examples of R&D and teaching where the HTO concept has been applied and used in different ways. The R&D issues have broad disciplinary coverage from individual to societal level with project periods lasting from four to ten years. In the last case, a Master's programme in ergonomics, which has been developed towards a clear HTO focus, is introduced. Each case is presented by: a) case description; b) application of the HTO concept; and c) experiences of using the HTO concept.

4.1 Identifying improvements for forklift truck drivers

The background to this study was that a forklift truck manufacturer intended to develop its products in order to improve the driver-forklift system, so that better ergonomic solutions for the drivers would result in better efficiency for the user organizations. The company contacted ergonomics researchers and an agreement was reached on how to collaborate in a joint development project. Several sub-studies were performed, which included different types of forklift. The first sub-study aimed at identifying problems in the interaction between the driver and the forklift. The second sub-study aimed at proposing solutions to the problems identified, and the third sub-study aimed at evaluating the effects of the improvements. The methods included observations of driver work activities, measurements of ergonomic risk factors and performance, and interviews with drivers, other warehouse personnel, designers and marketing personnel. Difficult work activities were focused on – e.g. those demanding

Table 1. Overview of cases applying the HTO concept in research, development and teaching

Domain	Research project	Aim	Project length and research approach	No. of researchers and project workers	No. of sites and participants
International forklift truck manufacturer	Identifying ergonomics improvements for forklift truck drivers	Improving the design of forklift trucks regarding ergonomics, safety and productivity	10 years; university-industry collaboration project	10 researchers, 8 project workers/ students	3 sites; over 50 participants from the company
Swedish woodworking industry	Understanding production planning work	Understanding the real tasks performed by planners	4 years; case studies, activity analysis	2 researchers	4 companies; 20 industrial participants
Swedish postal service	Improving postmen's work	Identifying and developing HTO measures to improve health and productivity	5 years; interactive research project	4 researchers, 11 project workers/students	16 primary mail delivery offices; 1100 postal participants
Meat cutting industry in Sweden	Improving meat cutters' work	Identifying potentials for improving health and safety, also considering productivity	7 years; interactive research project	5 researchers, 4 project workers/ students	10 primary production sites; more than 100 participants
Teaching the HTO concept	The Master's programme in 'Ergonomics and HTO' is taught at the Royal Institute of Technology (KTH), Sweden. It is managed and continuously developed by three main teachers who have collaborated in the programme since 2007. Their competences and research areas cover complementary multidisciplinary areas, such as mechanical engineering, physical ergonomics, cognitive ergonomics, human factors and ergonomics in general, work organization, group dynamics, and industrial management and engineering. About 25–30 students with backgrounds in health science, behavioural science and technical science are admitted every second year.				

time, causing errors, demanding recurrent corrections, giving rise to near accidents, or those that were exerting, tiring or uncomfortable. Literature reviews and analyses of official work injury statistics were performed. Competitor forklifts were benchmarked.

4.1.1 Application of the HTO concept

The driver, the forklift and the warehouse together were seen as forming an HTO system, in which the sub-systems interacted with one another. The application of the HTO concept was inspired by the interaction framework proposed by Nolimo-Solman (2002), the HTO model proposed by Eklund (2003) and participative ergonomics (Noro and Imada, 1991; Wilson, 1991). The framework demonstrated how the interaction between the sub-systems was decisive in the performance of the system – i.e. the drivers' ability to perform their work, and the health and well-being of the drivers. Work activities that caused problems for the drivers and performance losses were identified. Indicators of deficient interaction included long learning times, high performance variability, goods damage, accidents, incidents, discomfort in the neck, shoulder, wrists and back of the drivers, and negative driver feelings regarding drivability and control of the forklift truck. Factors that supported or counteracted a smoothly functioning system and design features that could improve the system were identified.

The HTO analysis showed several indicators of insufficient interaction concerning productivity, quality of the work result, safety risks, physiological and adverse mental effects on the drivers, perception of discomfort and drivability. For the reach truck, the major problems were handling loads high above the floor in the pallet racking and positioning the forks in a pallet on the floor, perpendicular to the aisle. These tasks demanded substantial time to learn and perform, in particular for inexperienced drivers. There were injury risks, and the tasks gave neck and shoulder strain to the drivers. The work injury statistics confirmed the HTO analysis.

4.1.2 Experiences of using the HTO concept

The use of the HTO concept enabled sources of deficient interaction to be identified. Since one aim of the research was to improve forklift truck design, the interactions between the driver and technology were dominant. There were also obvious interactions with the environment, such as light and noise conditions. Interactions with organizational factors were less prominent, since these interactions were dependent on each user organization. The HTO concept illustrated the mutual influence within the single sub-systems. One example was the contradiction of narrow aisles being regarded as more economical when built, but causing more strain for the drivers and causing reduced productivity. The analyses pointed to improvements of several design aspects, such as driver seat comfort, a tilting driver cabin to improve vision and neck posture, a height indicator for the forks to decrease the time in adverse postures and a small steering wheel, together with a 360-degree steering technology to decrease shoulder load and to make job performance quicker. Other elements were developed and tested, such as TV monitors in the forklifts. Improvements were proposed regarding education and training of the drivers, design recommendations for the warehouses, improved scheduling for more varied tasks and improved lighting. The HTO analyses confirmed that some improvements for the forklifts had positive effects on productivity, others on quality, and still others on the health and well-being of the drivers. An economic evaluation showed that normally it was profitable for companies to buy an ergonomic forklift truck in spite of the higher purchase price.

4.2 Understanding production planning work

The background to the project was an identified need in the Swedish woodworking industry to learn more about and develop their production planning processes. In the project, planning work was studied in four companies: one sawmill, one parquet floor manufacturer, one furniture manufacturer and one wooden house manufacturer. The overall method used was work activity analysis (Guerin et al., 2007), which focuses on the distinction between work as prescribed and as carried out in practice. The data collection consisted of initial interviews and document studies, which served as the authors' pre-understanding during five full days of observation of real work activities in each company. Observation protocols were used, and the observation data were analysed from several perspectives, from a qualitative and quantitative perspective, to obtain an understanding and a multifaceted picture of planning work. After the observations, a second set of interviews was carried out with those who were identified during the observations as having close contact with the studied planners.

4.2.1 Application of the HTO concept

The data collection resulted in a rich set of data, and it was clear to the researchers that a systems approach could be useful for a part of the analysis. The HTO concept was chosen as an analysis framework to explore its usability in developing a holistic ergonomic view of production planning work, which had not been done in earlier research. Initially, the researchers thoroughly discussed how to define the concept in this case – i.e. what perspective to take on the H, T and O sub-systems, respectively. With regard to the specific aim of the overall research project, the H sub-system included a cognitive, social and psychological perspective (Daniellou, 2001), the T sub-system was defined as consisting of both a primary (controlled) and a secondary (controlling) technical system (Waefler, 2001), and the O sub-system comprised how work was organized formally (job definitions, responsibilities, policies, etc.) and informally as practised in real work activities (Westlander, 1999b).

4.2.2 Experiences of using the HTO concept

Using the HTO concept as a model for analysis demonstrated the complexity of the planning work (Karltun and Berglund, 2010), and how the sub-systems H, T and O interacted with one another (Berglund and Karltun, 2007). For example, the analysis showed that the cognitive load on the planners emanated from uncertainties and limitations in the technical system, but also from the organizational structure in which the planners had to deal with several functions within and outside the companies and understand their specific logics. Using the HTO concept proved to be successful in describing planning in a structured way to obtain a systems view. After the initial discussions to define the different H, T and O sub-systems, it was fairly clear what part of the studied work belonged to what sub-system. There were no main challenges to using the HTO concept to analyse the planning work, except that it was not possible to describe and analyse all interfaces to the same extent as there were richer data collected regarding some areas than others. The O-T interface was one example where only a little data could be collected within the chosen method.

4.3 Improving mail distribution service and postmen's work situation

The background to this study was that a standardized rationalization method for mail distribution, ‘Best Method’, with the goal of increasing productivity, was introduced in the 700 delivery offices in the Swedish Postal Service during 2000. However, the calculated productivity gains were not achieved as planned. Union representatives, along with the Swedish Work Environment Authority, were greatly concerned that the method would create an increase in occupational injury risks.

During 2001, the Swedish Postal Service invited researchers in ergonomics to investigate 1) the entire work situation for postmen in the country and 2) how the characteristics of the implementation process had affected the outcome of the ‘Best Method’, which varied between mail delivery offices. The investigation was conducted on a stratified sample of 15 local mail delivery offices. It was initially based on participant observations; 60 semi-structured interviews with managers, union representatives and postmen, including safety representatives; questionnaires from 452 postmen; and physical measurements of postmen during work. This became the foundation of a five-year researcher-supported change process that led to new designs that were developed, implemented and evaluated in all local mail delivery offices in Sweden (Karltun, 2007, 2008).

4.3.1 Application of the HTO concept

It was apparent from the investigation that a lack of systems thinking lay behind the problems with ‘Best Method’ per se, but also shortcomings in the implementation process. The HTO concept inspired by the OD framework by Porras and Robertson (1992) was used in the analysis. The framework emphasizes how the design and function of system components affect the interactions in the system and the individuals' ability to perform their work. The T sub-system was defined in terms of the technical design of equipment, tools and work procedures, as well as the physical setting of the work areas. The O sub-system was defined as formal organizational arrangements and informal social factors, and the H subsystem was studied at a physical, physiological, cognitive, psychic and social level (Daniellou, 2001). The focus of the analysis was to find out how the design of the T and O sub-systems affected the individuals' (H) ability to perform their work in order to suggest improvements. The HTO concept was further used as a pedagogical tool to educate managers and postmen in systems thinking and systems performance (Karltun, 2011). Moreover, it helped to identify improvement measures that inspired management to arrange specific sub-projects in the business to improve the design of HTO elements. The T sub-system, for example, was improved by the redesign of labelling and lighting of the sorting racks and ancillary spaces, the O sub-system by improving the overall organization of indoor work processes, and the H sub-system by training the postmen's individual skills in work techniques.

4.3.2 Experiences of using the HTO concept

As the H sub-system was raised as an equivalent to T and O, it also emphasized the importance of individuals as active players through participation in the process of change (Westlander, 1999a). By concentrating on the three main sub-systems, H, T and O, it was comparatively easy to keep focused on the interactions between factors that affected the entire work situation for the postmen. The HTO analysis also supported managers and employees in understanding and accepting what measures needed to be designed, developed and implemented to address the problems at hand. The findings led to a unique way for the Swedish Postal Service organization to manage the design and development of improvement measures by involving postmen as active participants in seven subprojects led by line managers and supported by researchers (Karltun, 2011). These improvement measures were then evaluated and implemented in all mail delivery offices in the country, which substantially increased postmen's well-being as well as the business's productivity. It further satisfied the requirements posed by the Swedish Work Environment Authority and brought scientific contributions to the fields of ergonomics and interactive research (Karltun, 2008; Karltun and Eklund, 2008).

4.4 Improving meat cutters' work

Meat cutting and deboning work is physically demanding, both in terms of general workload and risks for musculoskeletal disorders and accidents. After a period of inspections and dysfunctional communication between the Swedish Work Environment Authority and the meat industry regarding the level of work-related injuries, an injunction was issued to the largest firms with a five-point programme to reduce the risks for meat cutters. A group of researchers was involved in trying to solve the problematic situation and a project was organized, led by the CEO of the industry association. The project searched to integrate ergonomics, organizational development and the triple helix concept (Etzkowitz and Leydesdorff, 2000), where industry, academia and the state are active parts of the innovation system, with an interactive research approach. The aim was to increase, or at least preserve, the competitiveness of the industry and at the same time reduce health and safety problems. A steering group was created with representation of three industry managers and three union representatives, with one researcher as ordinary and another two researchers as adjunct members. The steering group was responsible for decisions regarding the progress of the project, to create and support contacts between companies/employees/stakeholders and the researchers. The interactive character of the project enabled the steering group to adapt the project to the process of development and to adjust the focus when deemed advantageous.

4.4.1 Application of the HTO concept

The project was initially set up in phases, whereof the first was a diagnosis comprising an initial study of the situation in the industry, done through interviews and visits, and a literature review. In the second phase, the work was organized according to the HTO concept. Four work groups were formed, each of them with management, union and research representatives. The groups focused on human and individual aspects, technological aspects, work organization aspects and cross-company work environment improvements. The groups then made inquiries about the status and developments in each of the first three foci (HTO). The last group collected examples of how different practical problems related to the work environment or how health and safety issues had been solved in different companies. A catalogue was produced with more than 40 problems described in detail and how they had been solved. The other three groups produced written overviews of each area and possible development opportunities that could most likely contribute to diminishing the addressed problems of the industry. In the subsequent phases, these opportunities were the foundation for a number of detailed studies, including Vogel et al. (2013, 2015) and Karltun et al. (2016).

4.4.2 Experiences of using the HTO concept

In retrospect, a number of advantages can be identified. By using the HTO concept, a systems approach to the operational problems in the industry could be introduced and accepted. This led to a wide view of the problems: different aspects could be openly discussed in the steering group by combining the results of the different groups regarding, for example, the influence of pay systems or chosen technical solutions. The HTO concept also aided in finding appropriate detailed foci for sub-projects and studies contributing to the main aim of the project, improving both competitiveness and the work environment. Finally, together with the interactive research approach, where the steering group could successively decide on what to focus on, access to workplaces and the industry environment was secured and simplified. The overall results of the project were highly appreciated by the industry as well as by the Swedish Work Environment Authority and academy (Karltun et al., 2014).

4.5 Teaching the systems perspective of HTO

Teaching the HTO concept was initially developed by the authors to educate engineering students in HFE in a separate course. Positive experiences from the course for engineering students and other undergraduate student groups led to an elaboration of the HTO concept and its integration into a Master's programme in ergonomics. This programme started in 1997, with a new group of students being admitted every two years. Since 2007, a clearer HTO focus has been developed in the programme, which is why it is now titled Ergonomics and HTO.

4.5.1 Application of the HTO concept

The Master's programme begins with a six-credit[2] course in human, technology and organization. This is followed by the four six-credit courses: research methods and study design; cognitive ergonomics; organization, change management and work environment legislation; and physical ergonomics. Each course has some overlap with the next course and the HTO concept recurs like a thread throughout the other courses, and ties the other courses together in the HTO approach. This trains the students in systems thinking, which permeates their entire education. When the first five courses are finished, the students carry out a project work and their final degree project in ergonomics, in which they are ready to apply the HTO concept and models further.

4.5.2 Experiences of using the HTO concept

In the HTO course, different established HTO-related models are brought forward, applied and discussed in lectures and seminars to stimulate systems thinking. In some of these models, each HTO sub-system is clearly defined, in others not. Regarding the definitions of H, T and O, the students are encouraged to reflect on what facets of each sub-system are in focus and their relevance to different cases. This guides them in choosing suitable HTO-related models in assignments and thesis work. By using the HTO concept as a consistent theme that permeates the entire Master's education, the main focus is on the importance of a systems approach, its consequences for understanding a user or customer, a product and/ or a service, and their contexts. The HTO concept supports the students in creating a relatively clear basis for systems thinking, where focus on the interaction between the H, T and O sub-systems facilitates the understanding of dynamics and improvement potential in real work settings. This is also confirmed by the students' comments in course evaluations. Some of the comments are exemplified below:

'I consider myself to be more equipped to take on work-related issues within the work environment and sustainability with a clearer HTO concept' (graduate in behavioural science).

'I've learned a whole new mind-set about the systems, ergonomics and HTO' (graduate in health science).

'From an engineering perspective, I see an enormous advantage in being able to pay attention to H, T and O in a system, to see that there is not any scapegoat in a problem. It is all about interaction' (graduate in engineering).

Our experience is thus that the HTO concept has resulted in facilitating students' understanding of the HFE systems discipline (Berglund and Karltun, 2015). Mixing the core of the teacher team from different HFE domains and students' various backgrounds regarding educational domain, profession and experience has further enforced the systems view. In

[2] European Credit Transfer and Accumulation System (ECTS): 60 ECTS credits – one year of full-time study.

particular, the HTO concept is very helpful in making students understand that they need to consider a holistic system that includes the human being on equal terms with technological and organizational aspects of operation systems, and perhaps this is especially evident in the case of the engineering students, who often develop a very narrow technology focus.

5 Analysis and discussion

The aim of this paper is to describe the HTO concept and how it can support the understanding, communication and development of work system characteristics.

The concept is based on the view that human object-oriented activity (Daniellou and Rabardel, 2005) is at the core of all tasks in organizations, that this work activity ultimately produces the added value of the system and that this value is the basic reason for work. Such activities form processes and constitute the organization's operating system. In order to facilitate and emphasize the analysis of human interactions, we argue that the human should be introduced as a separate sub-system to complement the technical and social sub-systems inherent in socio-technical theory.

There is an important point to equating human aspects with the technical and organizational aspects of an operation system. The individuals' ability to do a good job, given the organizational and technical conditions, is often not explicit in reductionist approaches and not always easy to grasp in HFE models.

Waterson et al. (2015) provide some interesting challenges and implications regarding socio-technical systems (STS) methods, such as STS meaning different things for different users, the large number of methods – which often are difficult to use – boundary problems and system level problems.

The HTO concept does not explicitly address these problems but offers some clear advantages. The initial understanding of the systems approach taken, where the human, the organization and the technology are all given distinct attention as parts of the interaction, provides an apparently simple model to start with for further investigations. The difficulty in using it depends more on the investigator and the aim: the higher the demands for a valid result, the more complex the system and the higher the methodological demands on the investigator. The HTO concept thus offers a holistic starting point for investigation, design and change, not least for complex systems.

This suggests that the HTO concept has the potential to improve understanding of the importance of the interactions that are necessary for sustainable system performance, productivity and healthy and rewarding jobs, aspects that otherwise might not be evident. As the complexity increases in society and in various operations, so too does the need for knowledge among students to handle balanced systems analyses.

5.1 Advantages using the HTO concept in R&D and education

By using the HTO concept represented by the cases above, we have identified a number of advantages. Applying the HTO concept has proved useful in gaining an understanding of what factors influence human activity in a work system, as well as how individual human activity contributes to the overall system performance.

In the case of studying planning work, the application of the HTO concept in the analysis facilitated a systematic analysis of data. It also showed that there were important HTO components that influenced the planners' work activities. The activity focus also required a redefinition of the social system into the organizational system, including parts (colleagues) with whom one interacts and the interacting individual who performs the activity, which in turn requires capabilities regarding both technology interaction and social interaction.

The forklift truck system, regarded as an HTO system, gave many new insights which were not previously recognized. For each technology solution, effects were identified on, for example, productivity and quality of performance affecting the human system in terms of errors, mistakes, learning, postures, injury risks, usability, subjective feelings and safety. A few improvements were related to organizational aspects – for example, the communication equipment for the logistic planning. Some effects were pronounced positive, others were small and some were negative. Using the HTO concept, the different effects on the system could be identified for each of the designed technology solutions, thus confirming the usefulness of the approach.

By investigating and analysing the work system within the mail delivery offices through the HTO concept, the researchers were aided in discerning problematic patterns of interaction and suggesting supporting development of HTO improvements. Management responsible for implementing the new work concept with the main focus on ‘rationalizing technology’ were totally unaware of the HTO interactions that gave rise to negative effects on the individual and thus system performance. The HTO concept was therefore further used as a comprehensible model to educate management and postmen about the importance of a systems perspective to create healthy and productive workplaces. This was an eye-opener for management and postmen that gave a boost to the development, design and implementation of the improvement measures in all mail delivery offices in Sweden, which resulted in a substantial positive impact on productivity, quality and postmen's health.

Sometimes the term ‘ergonomics’ is associated with costly measures to adapt the work environment rather than inferring investment and increased systems performance. This seems to be a deeply culturally rooted connotation of and attitude towards ergonomics that is difficult to change. By attracting managers, access is also granted to organizational layers with more powerful mandates to make decisions regarding HTO measures. This was also the case when working with the meat cutters, where the initial state of the industry was characterized by conflicts of interest between meat cutters and managers. However, separating the problematic situation into technical, organizational and human issues helped to create genuine interest from the parties in working towards potential new solutions that would improve the situation.

In these cases, we have found that describing the HTO subsystems makes it easier to approach the elements that are not within one's special domain and to acknowledge the need to bring knowledge of the other sub-systems into a thorough analysis. The HTO concept highlights the interactions that take place through activities and processes. The seeming simplicity helps users of the concept become more aware of the different interaction dynamics that exist as a key to understanding the system. Since the interaction is highlighted in the concept in an apparent and systematic way, stakeholders seem to perceive it as more tangible and better understand that human interaction with products and work systems is far more than 'common sense' and may be handled in a structured way from a systems perspective. Moreover, stakeholder groups such as managers and technicians are easier to attract because the HTO concept conveys functionality and systems performance and thus relates to their responsibilities and duties to a greater extent than health and well-being benefits.

When comparing the use of the terms 'ergonomics' and 'HTO' among engineering students, it has become obvious that they consider that it will not be their responsibility to work with ergonomics in their future working life. However, they consider that their task might be broader than simply having responsibility for the technology – i.e. responsibility for systems performance. In such a view, the HTO concept is more attractive by its apparent emphasis on systems and how performance is affected by the interaction between the different sub-systems.

Since the HTO conceptual model is comparably easy to visualize (Fig. 1), it offers a pedagogical tool for conveying a way of structuring work systems, a way of analysing those systems, as well as a basis for improving or redesigning the systems. As such, it can be viewed as a meta methodology that provides an approach or philosophy where the human is focused as an additional sub-system in the socio-technical systems theory. This applies to both R&D, as exemplified above, and traditional education, as described in the Master's programme in Ergonomics and HTO. In discussions with organizations or students regarding aims, applications or benefits, HTO has served as a tool to understand the complexity of the studied issues.

The difficulty in communicating the value of HFE to different stakeholders (Dul et al., 2012) was in several of the described cases facilitated by using the HTO concept. This thus facilitates the description of ergonomics as a more integrated part of strategy, planning and implementation 'by moving from a health ergonomics paradigm to a business ergonomics' (Dul and Neumann, 2009).

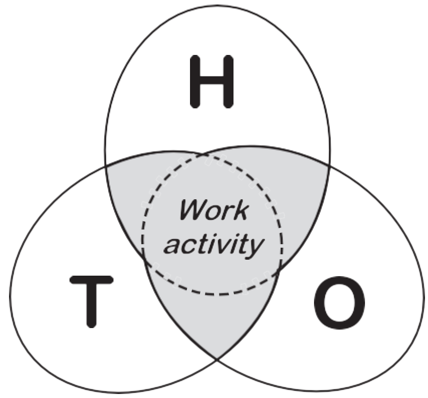

Fig. 1. Illustration of the relationship between the H, T and O sub-systems and the work activity in the HTO conceptual model.

Our experience is that the awareness of HTO interaction is increasing in many fields, such as healthcare, traffic systems, process industry and among complex computer systems. Students with this education are attractive in the labour market. Students in several disciplines are not used to regarding a work system from a holistic view, so the HTO concept thereby promotes integrative and holistic learning, and it supports the students in seeing their role in the larger system in which they are active.

5.2 Challenges and potential in using the HTO concept

As for all concepts and models, there are challenges and disadvantages related to the HTO concept. Firstly, understanding the full potential of the systems view may lead to frustration, since it is normally not possible to influence the whole system. A project may become too large if the holistic approach is applied in all stages of the project. This necessitates making conscious delimitations, such as not including changes to or development of all aspects of the system. It may not be obvious that the HTO approach allows for choice regarding units of analysis. However, systems or subsystems (Siemieniuch and Sinclair, 2014) may be chosen for the analysis, even the interactions between humans. It is the privilege of the investigator to choose system boundaries. In this way, different HTO models and other supplementary models may be used in complementary ways and the analysis may be adapted to each situation. The work environment can, for example, sometimes be included in the technology sub-system, but in other situations be analysed as a separate component displaying interactions with the human, the technology and the organization. Analyses of interactions between individual humans – e.g. a manager and an employee – are often preferably performed by using other more specific theories and models.

Furthermore, the systems view may be in contradiction with the way organizations are structured, and the way the education system is organized. Advocating a holistic systems view may therefore evoke resistance in organizations as well as in the education system.

In cases where a thorough understanding of complex interactions between the human at work and the technical and organizational systems is not required e.g. regarding human capabilities in a limited situation – the HTO concept might not be a suitable choice.

The minimalism of the HTO concept could be regarded as a limitation but also a strength, as discussed above. As researchers within the field of ergonomics, we need to have a broad palette of HFE models and methods of various complexity to choose from depending on focus and objectives. The HTO concept is a contribution to this palette.

6 Conclusions

This paper describes the use of the HTO concept in the human factors and ergonomics discipline. Experiences in applying the HTO concept where a work activity is analysed and developed using the interaction between the three sub-systems human, technology and organization demonstrate that it provides a number of advantages. Firstly, by including the human as a separate sub-system at the same level as technology and organization, interactions with the human will be emphasized as being at the core of the total system's performance though the human activity. Secondly, the contributions and restrictions imposed by the human, with abilities and shortcomings, become more apparent in the performance of the total system. Thirdly, when the human as such is more apparent, the human well-being and health aspects are more easily introduced into the analysis. Fourthly, the concept indicates that the total system cannot be designed, analysed and understood satisfactorily unless the interactions with the human are included in the analysis.

The HTO concept can be used in various businesses and in academic teaching to enhance communication and comprehension during interventions. It can be applied in investigations, analyses, design, implementations and as a pedagogical tool to increase understanding of systems performance. Further, it gives benefits when applying an HFE systems approach in operations.

In summary, the HTO concept has been shown to be useful when dealing with work systems and is suggested as: 1) a conceptual model to easily grasp an initial understanding of work activities by emphasizing the human, the organization and the technology as three sub-systems of fundamental importance; 2) a framework presenting the three sub-systems to be analysed regarding their features and interactions; 3) a meta methodology providing a holistic ergonomics perspective for subsequent method use regarding work activity investigations and interventions; 4) an attractive pedagogical concept to visualize and communicate with stakeholders and students – e.g. through a more ‘neutral connotation’ focusing on investment gains; and 5) a design tool by emphasizing the needs of the human, pointing to how the technical and organizational systems can be designed to better support individual performance, health and systems performance.

Building on socio-technical systems theory, our intention is that the HTO concept can facilitate non-ergonomists in understanding how the H sub-system affects and is affected by interaction with the T and O sub-systems in the work system. Furthermore, the work activity is visualized at the centre of the conceptual model as it is the fundamental reason for work, well-being and efficiency, producing value adding output for any business. The focus on interaction between the HTO sub-systems also elicits the fact that the outcome of such a dynamic process as a whole becomes more than the sum of its parts.

There is a strong potential in further developing the theoretical underpinning of HTO as well as in developing its practical usefulness through building experience from its use in different application areas and developing analysis tools.

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