HELIX
Working Papers

# HTO – A Concept of Humans, Technology and Organisation in Interaction

Martina Berglund
Anette Karltun
Jörgen Eklund
Johan Karltun

**HELIX Rapport**
**20:002**

HELIX COMPETENCE CENTRE
**LINKÖPINGS UNIVERSITET**

# HTO – A Concept of Humans, Technology and Organisation in Interaction

Martina Berglund
Anette Karltun
Jörgen Eklund
Johan Karltun

**HELIX Rapport 20:002**

HTO – A Concept of Humans, Technology and Organisation in Interaction

Martina Berglund, Anette Karltun, Jörgen Eklund, Johan Karltun

2020

HELIX working papers 20:002
ISSN: 1654-8213



HELIX Competence Centre
Linköping University
SE-581 83 Linköping
Sweden

http://liu.se/helix

Printed by: LiU-Tryck, Linköping 2020

# Preface

Humans, Technology, Organisation (HTO) is a concept for understanding, analysing and developing human work systems. It is a concept related to several similar models (and in some contexts called MTO – Man, Technology, Organisation). These models are used for different purposes and within a variety of domains.

Based on the authors' experiences from working with HTO interactions within research, teaching and consulting, the idea behind this report is to present our view of the HTO concept, how it can be understood and used in different domains.

This report is a further development of the chapter "HTO - A Concept on Humans, Technology, and Organisation in Interaction" in the free online course "Work and Technology on Human Terms" published at Prevent, Sweden (https://www.prevent.se/onhumanterms/) and the research paper "HTO – A complementary ergonomics approach" published in Applied Ergonomics in 2017.

We would like to express our gratitude to Ulrika Harlin, RISE Research Institutes of Sweden, for valuable feedback and comments on a draft version of this report.

*The authors*

# Abstract

Working life of today faces challenges. There is a fast pace in technical and organisational development and continual demands for increased performance. In order to manage the increasing complexity in work systems, there is a need to take a holistic view on operations. One such view is the systems concept of Humans, Technology and Organisation (HTO). The aim of this report is to describe the HTO concept, how it was developed, and how it can be used to develop work and work systems, understand humans at work, and understand contributing factors to organisational performance and individual well-being. The core of the HTO model is human work activity and how it is carried out within a work system consisting of humans, technology and the organisation. Focussing on human work activity generates knowledge about work conditions, needed competences and collective interaction, but also understanding about outcomes of the activities – the systems performance. H, the Humans in the work system, can be understood from different perspectives, for example as biological systems, information processing systems, individuals with unique personal traits and experiences, or as members of social groups. The H can thus in itself be regarded as a sub-system within HTO. In a similar way, T, Technology, includes several facets, such as tangible tools and machinery, intangible IT systems and software, and environmental characteristics that are technologically designed. The same applies for O, Organisation, consisting of both formal aspects (e.g. written work instructions and follow-up systems) and informal aspects (e.g. organisational culture and informal work practice). Applying HTO in practice generates several types of outcomes: 1) HTO to design products shows that it can be beneficial for productivity, quality and individual safety; 2) HTO to analyse and understand complex work may shed light on complex work in practice, the influences between the individual and the work system, and gaps between prescribed, standard work and how it is carried out in practice; 3) HTO to understand safety shows that it is achieved through systems thinking, thus technology needs to be designed to match human capabilities, and HTO barriers should be in place to prevent accidents; and 4) HTO to improve health and productivity may result in workplace redesign, increased individual well-being and business productivity. HTO has several uses, such as a theoretical framework, an analytical tool, and a method for a holistic view on human work, but also as a tool for visualisation and design.

# Contents

# Figures

# 1 – Introduction

Working life today faces challenges. There are continual high demands on increased performance of work systems in terms of productivity, efficiency and quality. The rapid technical development, such as the quick expansion of digitalised solutions and products connecting different parts within and outside a work system, creates business opportunities for organisations and new ways of organising operations. However, it also requires relevant organisational structures, work procedures and employees that are prepared to manage and interact with the technology. New technology may open up opportunities to work independent of time and geographic location, but it may also contribute to increased complexity in working life. In addition to that, there is an overall emerging need for organisations to strive for ecological, economic and social sustainability.

To understand what is at stake for an individual, group or overall operations, there is a need to take a systems view. We argue that this view is a fruitful way to continue improving working conditions for many people with the aim to provide system performance, well-being, health and safety. Such aspects are often today described as ingredients of social and economic sustainability.

The aim of this report is to describe our interpretation of the concept of Humans, Technology and Organisation (HTO), how it was developed, and how it can be used to develop work and work systems, understand humans at work and understand contributing factors to organisational performance and well-being.

The HTO concept captures how interactions between humans, technology and organisation are involved in work activities, see Figure 1. It is useful for all who try to understand complex systems and work systems where humans perform tasks, by emphasising that performing tasks is always done in interaction with the technology and the organisation. The performance of the work activity is at the core of the model and the activities performed provide the outset of analysing work systems. Regardless of technology development and increasing complexity, most operations will remain dependent on human work activities within the foreseeable future. As a consequence, the need for understanding the conditions for involved humans in such work activities increases as the demands change.

The HTO concept is multidisciplinary, related to human work activities and consequently includes integrated knowledge from disciplines such as engineering, medicine and behavioural sciences. There is also a focus on design and improvements for individuals and for the entire work system. Therefore, we think that those who have learned about the HTO concept have many advantages when they analyse, visualise and design work systems. They can also better contribute to high-quality work situations for the individual as well as high performance for the organisation.

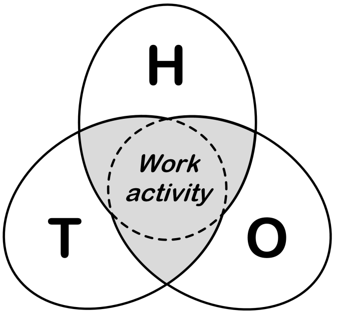


*Figure 1* *The sub-systems Humans, Technology and Organisation with grey-marked fields representing the interaction during different activities. Parts of the H, T and O are involved in different ways and to varying extents in different activities.*

The idea behind HTO is to design the technology and the organisation engaged in an activity iteratively taking into consideration the needs, abilities and limitations of the humans when designing work systems. It is not to have the starting point be developing the technology first, adapting the organisation to the technology and then using humans to compensate for the design limitations and shortcomings.

In the following chapters, the need for a holistic view on operations is described and how the HTO concept first was developed to improve safety and later also applied in other domains. Thereafter, the sub-systems H, T and O are described and the importance of understanding their mutual interactions. The relation between the business or organisational mission and HTO is also highlighted. Some examples of how HTO is applied in practice are then presented. These include HTO for design of products, HTO to understand complex work, HTO for safety, and HTO to improve health and productivity. The report ends with a reflection on the need for cooperation between different areas of expertise to use HTO for improving work systems.

# 2 – A holistic view on operations

The need for a holistic view on operations has become more and more important in order to manage the increasing complexity in work systems. Already in the 1950s the increased technical complexity indicated that it was no longer enough to think in terms of individual machines to be managed. Increased competition in the world market also called for a wider systems view on production systems. It then became apparent that understanding a system as a sum of separate parts was insufficient; their interrelations also needed to be taken into account. This led to the development of systems theory, which was associated with efforts to manage increasingly complex systems. The rapid changes of today, such as technology development and societal challenges with impact on work activities, reinforces the need for systems approaches.

Training in systems thinking is important as humans are not well equipped for dealing with complexity. To get a grip on the overall picture, we try to treat it as if it were made up of independent parts, but this is bound to partly fail because the reality is a whole. As described, the key feature of systems is that their parts are affected by each other through interactions that determine the systems' functionalities, which may be difficult or even impossible to discern and/or predict. In tightly coupled systems, a failure in one or more parts can lead to cascading failures which may have long-term or catastrophic consequences on the functioning of the system as a whole. Another problem that commonly occurs is that parts or sub-systems are optimised, but the total system will not function in an optimal way. A holistic view is needed in order to create the best possible situation for the total system to perform in the desired way.

The HTO concept is one example of how a work system can be regarded. When HTO is used for analysis of a system, it can reveal deficiencies in some interactions, but it can also reveal that other interactions work perfectly well. This can enable the planning of measures to be taken to improve system performance and individual well-being.

# 3 – Development of the HTO concept

The Human, Technology, Organisation (HTO) concept was coined in the Swedish nuclear power industry. When this industry began to develop, a strong emphasis was put on technology development in order to improve safety. In this first phase of improving safety in the complex nuclear power industry system, engineers developed more elaborate methods to calculate reliability and to predict failures of machine components and sub-systems in order to improve the design of these components. Statistical methodology and other methods such as Failure Mode Effects Analysis were applied. After some time, the engineers learned to make more advanced calculations that also included complex machine systems. This resulted in a safer and more reliable technology with fewer failures. However, other types of errors now appeared which required focus on an additional system part.

This gave rise to a second phase to improve safety, where the role of humans was highlighted. Operators did not always react as expected. This could be due to many reasons, for example lack of education or training, insufficient information from the user interface to the operators, or too high/too low mental load of the operators. Other examples could be when operators were tired due to shift work or had low levels of attention, so that they missed signals that they were expected to react to. Such situations have often been referred to as influenced by 'human factors'. Some managers started to treat humans as unreliable due to that, but in fact this was mainly a problem of lack of knowledge of human nature. Humans are better at some tasks than machines (e.g. strategy development and predictions based on experience), but machines are better than humans at other tasks (e.g. performing tasks demanding high force and exact repetition during sustained surveillance). The solution is having knowledge about these differences in abilities, so that the tasks can be correctly allocated to humans or to machines. The humans should perform what they are best at, and the machines what they are best at. In the nuclear power industry in that period, emphasis was put on the humans in the system, in order to minimise incidents and near-accidents. These efforts included education and training as well as improvements of the control rooms and user interfaces of instruments, displays, and controls. But there were still problems left which revealed the need to develop the view of the system.

In the third phase of development of the nuclear power industry, the organisation was found to be insufficient in some situations. Not only the formal organisation but also informal ways of working regarding safety were such examples. The concept of ´safety culture´ is often used to describe how an organisation deals with safety issues. A well-known example is when the organisation punishes workers for errors that they make, which will lead to a situation where errors are denied and/or hidden. Fellow workers protect their friends and colleagues from being punished. This consequence is an example of an inadequate safety culture where incidents are not identified and discussed openly. If instead the incidents could be thoroughly investigated and worked through for the purpose of finding better ways of working so that the incidents are not repeated, safety would improve. Other organisational examples that create risks are e.g. insufficient organisation of maintenance, which could increase risk of breakdowns. Another example is organisations that have 'forgotten' to give newly hired employees the training that they should have.

The experiences that were learned in the nuclear power industry led to the concept of HTO (in Swedish *Människa, Teknik, Organisation – MTO*) being coined in Sweden (Rollenhagen, 1997). The examples in this report show how valuable it is to consider the humans, technology, and organisation as sub-systems, and in particular the interactions between these sub-systems.

The concept of HTO is used for managing safety. The Swedish Radiation Safety Authority (2020) expresses on their website that:

> *No technical safety systems can work without the close involvement of people and the surrounding organisation. This is why our regulatory supervision is based on how people work and the fact that quality and safety hinge on people, the specific context and organisation, alongside the technology itself. We always have this perspective when we review all aspects of nuclear power plant operations, from the design and layout of control rooms to the safety culture and management systems.*

Such examples can also be found elsewhere in contexts characterised by complexity or being safety critical. In an examination of several severe accidents and incidents in health care, HTO analysis arguably brings much more thorough and relevant knowledge regarding responsibility and improvement of safety than previous, more limited analyses. The focus is on the acting operator, what is his/her responsibility and what is built into the other sub-systems, the organisation and the technology used. Here, the HTO analysis might elucidate aspects that previously have not been considered.

The HTO concept has been shown to be useful not only for handling safety issues, but also for considering quality output, performance of the whole system, and the work environment of employees. Industries have gained the experience that incidents, near misses, accidents, quality deficiencies and production losses often have the same causes. One important cause is variability of input to the system and disturbances that occur for every system. Such disturbances lead to deviations from normal work procedures and thereby new unpredicted risks occur. Through an HTO analysis, it can be understood and explained how disturbances, incidents and deviations from planned and normal work procedures lead to safety risks, more stressful work situations, higher demands, health risks, quality deficiencies, and productivity losses.

**Box 1**

The HTO concept was first developed to improve safety within the nuclear power industry, but it has also been shown to be useful to improve quality, system performance, and the work environment in various industries.

With an increasing fast pace of change within work systems, it is increasingly relevant to consider HTO to create good conditions for work activities.

# 4 – Understanding work activity and H, T, O

In order to take an HTO view of any human work activity, it is necessary to understand each sub-system H, T and O as well as the work activity itself.

## 4.1 – THE WORK ACTIVITY

The HTO model requires an identifiable activity for its relevance, whether it be a single task (e.g. something difficult to perform), a typical task (several of the examples included in this report) or a set of related tasks that can be identified within a system boundary. The work activity at the core of the model and most often what you are interested in has some characteristics that different theories on activities agree on (Daniellou & Rabardel, 2005).

- Individuals perform activities using objects and resources in order to achieve one or several goals. These goals are not always clear but do exist, and the goals during work are related to the task as well as to the overall goals of the organisation and its mission or business model.
- The conditions for performing the activity are mediated by the technology and the organisation as well as by the characteristics of the individual.
- Activities are unique due to individual diversity and variability as well as due to the variability of the context. Activities can thus be seen as responses to unique situations.
- Activities have roots in the past as they are designed and performed using the experiences and skills of the individual and the history of the context. This also includes the fact that activities are constantly developing, taking into consideration the evolution of the individual and the context.
- Studying the activity requires cooperation between the analyst and the individual and the analysis is mostly a joint production.
- Activities are integrational taking into consideration both the individual and the contextual conditions. Understanding activities generates knowledge about:
    - the physiological and psychological work conditions
    - how the individual's abilities are used and the costs that may entail

- the tacit competences activated and
- forms of collective interaction.

It can be noted that what takes place in an activity in practice is not always the same as what is prescribed in procedures or processes by managers or designers. Prescribed work consists of predetermined conditions and expected results, i.e., information. Information can be defined as the description of what the employer prescribes the operator to do. Work performed, the work activities, consists of real conditions and actual outcome. Work activity can therefore be regarded as a strategy for adapting to the real work situation, and it is the work activity that will generate the actual outcome of the task.

**Box 2**

A work activity is the way in which a prescribed task is performed in reality. However, the actual conditions and the actual results often differ from the prescribed tasks and the expected results. It is the real-time activity that determines the actual outcome, i.e., the performance of the system.

## 4.2 – THE H SUB-SYSTEM

The H stands for human dimensions needed to be considered related to work activity. One attempt to summarise the various aspects of the H sub-system has been made by Daniellou (2001), who argues that the human at work can be described at four levels:

- *A biological energy processing system*, which is related to all our movements and includes all physiological aspects as well as our physical ability to withstand forces and loads. It is this system that makes it possible for us to control our body and move regardless of whether it is about threading a needle, using a keyboard or performing hard physical work like digging, running, lifting, etc.
- *An information processing system*, which is related to our cognition including e.g. sensory interpretation and decision making. This is the system that controls and provides guidance to the other systems and is also often referred to as our mental abilities. We experience the environment and its information content with our senses and the brain processes the information and creates e.g. action strategies, which control the other systems of the body.
- *An individual with a unique history*, which is related to personality and experience. These will guide a great deal of our emotions,

values, reactions, skills and priorities.
- *A member of social groups and cultures*. Human beings are social creatures, belonging to several groups like family, work groups, groups related to personal interests, etc. We constantly shift between groups and the different demands posed by these groups and our behaviour is also formed by the groups.

The described four levels could all be taken into consideration to explain the human efforts to perform work activities. The approach of looking at the human from several perspectives is also needed to understand and deal with for instance stress reactions. It is also clear that all aspects of a human are rarely involved in an activity and some aspects thus could be seen as contextual.

There are also other ways of thinking about the human at work, depending on what issue is in focus for an HTO analysis and related to the content of the activity. Westlander (1999) suggested that the human can be regarded from the following perspectives reflecting participation and influencing factors at work:

- The human as *exposed* to a number of factors at work, such as the physical environment, high mental workload or stress. This is a perspective that is common within health and safety at work.
- The human as a *cooperative* being where characteristics of cooperation depend on the choice of technology and organisational form.
- The human as a *learning* being, a perspective that is useful for e.g. competence development.
- The human as an *actor*, a perspective that can be used within change management.

**Box 3**

The human at work (H) can be viewed from different perspectives which can be useful to understand the work activity. Examples of these are:
- A biological energy processing system
- An information processing system
- An individual with a unique history, personality and experience
- A member of social groups

## 4.3 – THE T SUB-SYSTEM

The T in HTO stands for technological aspects with impact on the work activity. Technology ranges from simple tools to advanced technical systems, including IT systems and software, which are part of the work system. Several attempts have been made to define technology in a work system and this can be done in each case where the HTO concept is used. Referring to the interaction during the activity, technology could be defined as the means for transformation of input to output using things like tools and machinery, from very simple like a pencil to the most advanced like computers as well as the design of the physical setting. It is evident that some technology is directly involved in the interaction with humans. Other technology is often more related to the environment where the work is performed, such as design of buildings, ventilation, background noise, lighting, etc. Such aspects do influence the work activity, by providing more or less favourable conditions for the human. A further example of how technology influences human work is the ongoing digitalisation. Information technology also strongly influences the organisation. It breaks up borders, can short-circuit hierarchies, provides less dependence on spatial and timely synchronisation and influences how decisions are made in a work system.

**Box 4**

Technology (T) consists of technical aspects influencing the work activity:
- Tangible tools and machinery
- Intangible tools, such as IT systems and software
- Environmental characteristics (noise, etc.) that are technologically designed

## 4.4 – THE O SUB-SYSTEM

Finally, the O includes aspects related to how the work is organised and structured, such as who does what, responsibilities, and roles. Robbins (1990) defined O as a consciously coordinated social entity, with a relatively identifiable border, which works relatively continually with the purpose of reaching common goals, or in short, a social system to reach certain goals that all activities are expected to contribute to. Applied in a workplace there are formal aspects of the organisation, which usually are documented, such as vision, goals, policies, strategies, hierarchical positions and powers, and systems for follow-up. These formal aspects also include job definitions, formal obligations, written instructions, etc. The formal aspects are thus related to prescribed work (Westlander, 1999; Guérin et al., 2007) as described earlier.

Another term used is “work-as-imagined” (Hollnagel, 2015). There are also informal organisational aspects related to organisational cultural issues, management style, informal work practices, etc. These informal aspects are also influenced by individual attributes and related to the work activities described earlier. This actual work activities (Guérin et al., 2007) is similarly expressed as “work-as-done” (Hollnagel, 2015). It is important to understand both the formal and the informal sides of the sub-system O.

It can also be said that organisational aspects are sometimes directly involved in the interaction and sometimes offer an environment, just like the other sub-systems.

**Box 5**

The organisation (O) is a coordinated social system with specified goals. It consists of aspects that influence the work activity:

- Formal aspects, such as goals, hierarchy, written instructions and follow-up systems
- Informal aspects, such as organisational culture, management style, and informal work practice
- Both the formal and informal sides of the organisation need to be investigated when performing an HTO-analysis

# 5 – Interactions in systems

A systems view is however not reached by only understanding the subsystems involved, in this case H, T and O, but also their interactions. A systems view means that the analyst is trained to see the whole, the parts and how the interaction of the parts creates the whole. Furthermore, there is a need to understand how a change in one part affects the process in the entire system. The whole is thus created by the parts and the interaction between the parts and change in one part or interaction will affect the entire system.

*Example:* An orchestra performing a piece of music can be used as a metaphor to describe these relationships. In order to achieve a good result, the individual musicians are required to master their different instruments cognitively and physically and they also must master their individual part in the specific piece of music. The orchestra performs in a given physical setting – a concert hall – that creates special conditions for the performance, such as acoustics, ventilation, light, and placement in relation to other musicians and the conductor. The instruments need to be of good technical quality and well maintained. Other equipment like chairs, the notation itself and the position of the notes also affect the performance. Each musician can be highly professional regarding his/her own instrument and part in the piece of music but unless these can be integrated into a whole through the conductor's ability to direct the parts, the music will not be enjoyable. This requires that all musicians can see and have good contact with the conductor who coordinates the pieces to a whole. When the conductor perceives that something is wrong in the interaction or timing, it is adjusted until the interaction provides the desired outcome. It is the quality of the parts and their coordinated interaction that produces the whole which has its own characteristics separate from the parts, and the audience experiences the music from a holistic viewpoint.

Systems theory has largely influenced research in various areas, for example in biology and engineering. In human factors and ergonomics, the systems view comes from socio-technical theory where work systems are viewed as being composed by a social system, involving people, and a technical system in continuous interplay.

Various approaches within human factors and ergonomics relating to socio-technical systems have evolved over the years, for example macro-ergonomics, activity-related ergonomics, and user-centred methods. The differences between these approaches are that they vary somewhat methodologically, in the view of the human work activity and the main focus, but they all emphasise the importance of taking into account the interacting human more clearly than in socio-technical systems theory.

HTO is considered a generic concept since it can be applied to any operation. The applied science behind HTO frequently spans a wide field between theory and practice, with interactions embracing different knowledge and research areas as shown in the examples in Figures 2 to 4.

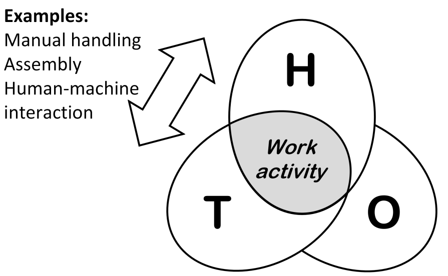


*Figure 2* *The interaction between H and T is about design of human-machine interface (HMI), embracing cognitive ergonomics but also physical ergonomics.*

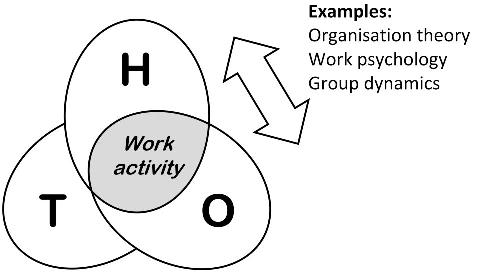


*Figure 3* *The interaction between H and O represents the research on organisational models in practice in the areas of organisational theory and work psychology*

.

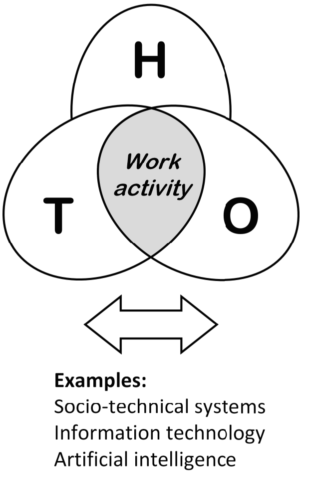


*Figure 4* *The interaction between T and O has put its mark on the socio-technical tradition and research areas are to be found in computer science and information systems.*

# 6 – Applying HTO in practice

In the following, four different cases exemplify how to apply HTO in practice. The cases describe how HTO can be used to 1) design products; 2) understand complex work; 3) improve safety; and 4) improve health and productivity.

## 6.1 – HTO TO DESIGN PRODUCTS

The background of this case was that a forklift manufacturer wanted to develop the design of their forklifts. It was anticipated that in order to improve the driver-forklift system, better ergonomic solutions for the drivers were needed, which would result in better efficiency and quality output for the system. It would also be easier for the forklift drivers to perform their tasks. Moreover, it would result in work environment improvements for the drivers, which would contribute to better safety, health and well-being for the drivers. An agreement was reached with researchers to collaborate in a joint development project based on the HTO concept.

This case started with several sub-studies performed on different types of forklifts. The first step aimed at analysing the present situation and identifying existing problems in the interaction between the driver and the forklift. The second step meant proposing ideas to solve the problems identified. In the third step the effects of the solutions were evaluated. When identifying the existing problems, the methods included observations of driver work activities, measurements of ergonomic risk factors, measurements of performance in terms of time needed for different tasks, and finally interviews with drivers, other warehouse personnel, designers and marketing personnel. Problematic work activities were in focus. Examples of such activities were those demanding much time and recurrent corrections, but also those causing errors, giving rise to near accidents, and those that were perceived as requiring exertion, tiring or uncomfortable. Furthermore, official work injury statistics were analysed. To some extent competitor forklifts were also benchmarked.

*Applying HTO:* The driver, the forklift and the warehouse with its organisation formed an HTO system, where the sub-systems interacted with one another. The application of the HTO concept was in this case based on the interaction framework proposed by Nolimo-Solman (2002) and the HTO model proposed by Eklund (2003). The framework was used in the analysis of the interaction between the sub-systems of the system and indicators of interaction quality were identified (Nolimo Solman, 2002):

- Productivity (time needed for task, time needed for learning, variability, disturbances)
- Quality (errors, deficiencies, adjustments, rework, precision, variability)
- Safety (accidents, near misses, injuries, unplanned events)
- Physiological and mental effects (pain, disease, discomfort, effort, well-being)
- Experiences (comfort, feeling, tiredness, usability)

These indicators enabled identification of work activities that caused problems for the drivers and performance losses for the organisation. Indicators of deficient interaction also included measures of goods damage, which is a specific indicator of quality of the tasks performed. For forklift drivers, discomfort from the neck, shoulder, wrists and back are relevant, but also drivers' feelings regarding inferior drivability and control of the forklift.

The HTO analysis identified several work activities in which indicators of insufficient interaction were present, e.g. productivity, quality of the work result, safety risks, physiological and mental adverse effects on the drivers, perception of discomfort and drivability. For the reach truck, one major problem identified for the drivers and for driver performance was handling loads high above the floor in the pallet racking. Another problem was to position the forks in a pallet on the floor, perpendicular to the aisle, forcing the driver to make a 90-degree turn with the reach truck. These two tasks demanded substantial time to learn, and they also took a long time to perform for inexperienced drivers. There were injury risks when handling loads high above the reach truck, and the tasks were stressful for the driver's back, neck and shoulders. The work injury statistics confirmed the HTO analysis.

Different technology solutions had been developed earlier, such as height indicators for the forks, video cameras for a better view of the fork and goods, and a steering by wire system. These solutions supported a smoothly functioning system, in terms of better quality work, higher productivity and a better work situation for the driver. The HTO analysis identified design features that could improve the system further.

*Outcome:* The use of the HTO concept and identification of deficient interactions made it possible to identify sources of disturbance. One aim of the project was to improve the forklift design (the technology). The forklift design included the interface between the machine and the driver, and therefore the interactions between the driver and technology were dominating. The case also identified obvious interactions with the environmental features, such as light, temperature, noise conditions, and slippery floor. Interactions with organisational factors are important, but these differ between different companies. In this case, those interactions were less prominent since the user organisation was not in focus.

The application of the HTO concept also illustrated contradictions within the work system. One example was when narrow aisles were regarded as more economic to build, but more stressful for the drivers and causing reduced productivity.

The case showed that improvements of several design aspects were profitable, such as a tilting driver cabin to improve vision, neck posture and ease of work, a height indicator for the forks to decrease the time in adverse postures and increase productivity, and a small steering wheel together with a 360-degree steering technology to decrease shoulder loads and to enable quicker performance. Other solutions were developed and tested, such as laser guidance of the forks. Improvements were proposed regarding the education and training of the drivers, design recommendations were given for the warehouses, improved scheduling was discussed for more varied tasks, and improved lighting was proposed for the warehouses. The HTO evaluations of the solutions confirmed that some improvements of the forklift design had positive effects on productivity, others on quality, and still others on health and well-being of the drivers. Some solutions improved all effects in a positive way.

**Box 6**

HTO in product design resulted in:

- Improved product design with positive effects on
  - Productivity
  - Quality
  - Driver safety, health and well-being
- Recommendations regarding
  - Training of the drivers
  - Scheduling of the drivers' work
  - Change in the warehouse design
  - Improved lighting
- A new systems solution including technology, the human and to some extent organisational factors due to discovered insufficiencies in the HTO sub-system interactions.

## 6.2 – HTO TO UNDERSTAND COMPLEX WORK

The background to this case was a research project to study production planners' work within the Swedish woodworking industry. Although there are logics and mathematical algorithms to calculate how production should be planned to reach high productivity, planning in practice was considered a challenge. In the research project, planning work was studied in four companies that represented different types of production in the woodworking industry. These companies were one sawmill, one parquet floor manufacturer, one furniture manufacturer and one wooden house manufacturer.

The planners' work was studied with work activity analysis (Guérin et al., 2007). It is a method that is used to study human work and under what conditions it is carried out. The planners were observed during five full working days. Their work activities, search for information, use of tools, communication with others, and physical placement were noted in observation protocols. These were later analysed, both from qualitative and quantitative perspectives to get a detailed picture of planning work in practice. In the final phase of the project, there were follow-up interviews with the planners and other internal and external people who had been in close contact with the studied planners during the observations. The topics during these interviews were identification of good planning, expectations on the planners, influences between the interviewees and the planners, and improvement suggestions.

*Applying HTO:* During the studies, it became clear that a systems approach could be useful for an overall analysis. The HTO concept was selected to explore if it could add new knowledge to earlier reported research on production planning work in practice. It was decided to use the generic HTO model. H, the planner, was then analysed regarding cognitive, social and psychological aspects (Daniellou, 2001). T was separated in a primary technical system, the physical production system, and a secondary technical system, the planning software system (Waefler, 2001). Both these technical systems were part of the planners' everyday work. Finally, O included both the formal organisation (job descriptions, responsibilities, policies, etc.) and the informal organisation in terms of how the planners carried out real work activities.

*Outcome:* One aim of this research project was to gain understanding of planning work in practice. HTO proved to be suitable for describing the complexity of the planning work (Karltun and Berglund, 2010) in a structured way, and how the different aspects of H, T and O interacted with one another (Berglund and Karltun, 2007). For example, the analysis showed that the planners had high cognitive workload due to the need to handle several parallel activities, dealing with uncertainties due to the outcome of the technical system, and having to understand several functions with different specific logics within and outside the company. The analysis further showed that the planners succeeded in their work due to social skills to handle different groups within the company, but also due to their individual backgrounds with long work experience and high legitimacy among other employees as well as from management. Moreover, the analysis showed the strong influence of technology on the planners' daily work and how the planners needed to deal with challenges. This also included the need for them to go beyond standard work procedures to be able to take responsibility for and carry out their work tasks. Using the HTO concept was successful in describing the complexity in planning work and to reach a systems view in a structured way.

**Box 7**

HTO to understand complex work resulted in:

- A thorough description of the complexity of production planning work in practice and under what conditions work is carried out
- The possibility to highlight the interactions between different parts of the work system
- An understanding of how the work system influenced the planners' work and how the planners influenced the work system
- An explanation for the gap between standard work and how it was carried out in practice

## 6.3 – HTO FOR SAFETY

This case describes an error in radiation treatment in healthcare (Lim, 1998). The patient, a 33-year-old oil field worker, underwent radiation therapy because of cancer in his left shoulder. This treatment occasion started just as the others, with the patient lying face down on the treatment table. The nurse positioned the radiotherapy machine and went into the control room. The radiation unit was operated by a terminal that was connected to a computer. The video and audio between the patient room and the control room was out of commission on this occasion.

The radiation unit had two modes. In the first mode, a high-power x-ray dose of 25,000 rads was used to radiate tumours. Command 'X' was chosen. At this state, a metal plate was automatically inserted between the radiation unit and the patient. In the other mode, a low-power electron beam of 200 rads was used for subsequent treatment. This state was chosen by giving the command 'E', meaning low-power electronic beam. This was the treatment that was to be given to the patient on this occasion.

The nurse entered the command 'X' and realised immediately that it was wrong. She corrected it and changed the command from 'X' to 'E'. This was also confirmed on the screen whereupon the nurse pressed the 'return' key. The correction was quick – less than eight seconds. The nurse got the next message from the system 'E-Beam ready'. She pressed the key to start the treatment and received the message 'Malfunction 54' from the machine. She was surprised and tested again.

In the treatment room, the patient lay on the table and waited. Used to the earlier treatments he was calm and relaxed. Suddenly he experienced an excruciating stabbing pain in his left shoulder. He lost his breath and did not manage to move enough until the pain hit him again, this time in his neck. The patient then screamed to the nurse but as the connection between the treatment room and control room was broken, she could not see him or hear him screaming. Before the patient managed to leave the treatment table a third dose went through his neck and shoulder. He rushed out into the corridor shouting that there was something wrong with the machine. Nobody understood what had happened. When they examined the machine, it reported that the patient had received the prescribed dose of 200 rads but in fact he had received 75,000 rads. The patient directly became ill and died six months later.

*Applying HTO:* An initial HTO analysis of this case highlighted the interaction between the human (the nurse) and technology, in this case the radiation unit as well as the video and audio equipment between the patient room and the control room. Regarding the radiation unit, the nurse and her colleagues had not understood what had happened and why the first message of malfunction appeared. This is an example of a shortcoming in the interaction between the human and the technology. Another example of insufficient interaction is that the video and audio equipment between the patient room and the control room was out of order. Looking at organisational aspects, this case showed the lack of regulations and safety rules at the healthcare unit. One such safety rule could have been to not perform the treatment if there was any message on the screen that the operator, in this case the nurse, did not understand or if the machine behaved strangely in any way. Another example of lack of safety rules is that it should not have been allowed to perform the treatment if the video and audio unit was out of order. These types of safety rules are often part of the formal organisation and should be executed in everyday work practice to ensure good safety.

*Outcome:* Eventually a thorough investigation of the radiation unit was carried out. It was then found out that when an error was corrected – changing from ‘X’ till ‘E’ too quickly (less than eight seconds), the program that controlled the function in the radiation unit went astray. It then executed a compromise between the two states – the high power level remained but the metal plate was removed. Consequently, what had happened to the patient was that he had received high power level radiation directed towards his unprotected body without the metal plate in between.

The engineers who had designed the machine had not believed it possible to correct an error as quickly as the nurse had done. They had not tested and investigated how quickly such actions could be performed by an operator at work. Except for identifying the poor design of the technology, the radiation unit software including the human-machine interface, this analysis also showed the importance of having thorough knowledge about the cognitive aspects of the human operator and his/her work tasks. The analysis also showed that lack of organisational barriers to stop the chain of events before it led to fatal consequences was a contributing factor to the outcome of the accident.

**Box 8**

HTO for understanding safety showed that:

- Safety is obtained by thinking in systems terms, taking into account how humans, technology, and the organisation interact in certain situations
- Technology should be designed with thorough knowledge about the human capabilities of the operators as well as their work activities
- Design for safety should include suitable barriers (human, technical and organisational) to prevent near-misses and accidents

## 6.4 – HTO TO IMPROVE HEALTH AND PRODUCTIVITY

The background to this study was the introduction of a standardised method for mail distribution, ‘Best Method’, in 700 delivery offices in the Swedish Postal Service. The overall aim was to rationalise work and increase productivity, but the calculated productivity gains were not achieved. At the same time, union representatives and the Swedish Work Environment Authority were greatly concerned that ‘Best Method’ would lead to increased occupational injury risks.

The Swedish Postal Service therefore invited researchers in ergonomics to investigate 1) the whole work situation for postmen in Sweden and 2) how the different processes of implementing ‘Best Method’ had influenced the outcome. The investigation was carried out at 15 local mail delivery offices. At first, the postmen’s work was observed. This was followed by 60 semi-structured interviews with managers, union representatives and postmen, including safety representatives. Furthermore, 452 postmen responded to questionnaires about their work, and physical measurements of postmen during work were conducted. This became the basis of a five-year change process supported by researchers in the Swedish Postal Service (Karltun, 2007).

*Applying HTO*: The investigation clearly showed that the problems with 'Best Method' were caused by lack of systems thinking, but also by shortcomings in the way it had been implemented. The HTO analysis was inspired by the Porras and Robertson (1992) framework, which highlights how the design and function of sub-systems affect the interactions between these and how this influenced the postmen's ability to perform their work activities.

In this study, the humans were studied regarding physical, cognitive, psychological and social aspects. Physical workload was measured through biomechanical calculations, wrist movements, activity analysis and estimation of effort during daily work. Cognitive, psychological and social aspects were measured through questionnaires, self-assessments and experiments. These methods were combined with interviews in different phases of the project to allow for a deeper understanding of the whole work situation, the implementation of 'Best Method', and how to deal with the problems at hand. The results revealed an exceptionally high daily workload.

Technology was defined as the technical design of equipment and tools, but also the design of the physical environment of the work areas. It became apparent that the technical sub-system was poorly adapted to the human conditions in a number of aspects, and the interaction with the organisational and logistical planning was not properly considered.

The organisation, finally, was considered in terms of formal organisational arrangements as well as informal interactions and forms of collaboration, which emerged in everyday work activities. Contradictions were found in the organisational arrangements (formal as well as informal) and the interaction with the technical and human sub-systems which created the problems at hand. It was further found that the degree of participation in planning and implementing 'Best Method' at each office, i.e., cultural aspects of the organisation, affected the productivity outcome. The higher the assessed degree of participation, the better outcome of 'Best Method' related to e.g. how postmen had been able to influence and locally adapt different aspects of the new method for mail distribution. These results were statistically significant.

In order to suggest improvements, the analysis focused on how technology and organisational aspects could be redesigned to improve the postmen's work situation. In this study, the HTO concept further proved to be a useful pedagogical tool to facilitate understanding and learning about systems thinking and systems performance among managers and postmen (Karltun, 2011).

*Outcome:* As the H sub-system was considered equally important as technology and organisation in the HTO analysis, it showed the importance for postmen to participate as individual actors in the change process (cf. Westlander, 1999). By focussing on the three main sub-systems, H, T and O, it was easier to identify how their interactions influenced the postmen's work situation. It also facilitated the identification of possible improvements, which inspired management to organise specific sub-projects to redesign HTO sub-systems and their interaction. Technology was e.g. redesigned regarding labelling and lighting of the sorting racks as well as regarding additional spaces. Concerning the O sub-system, the postmen's indoor work processes were reorganised and improved. The postmen were e.g. trained in individual skills in different work techniques. Overall, the HTO analysis supported both managers and employees in understanding and accepting that measures needed to be designed, developed and implemented to deal with the identified problems. As a result of the HTO analysis, the Swedish Postal Service organisation started a unique development of improvement measures by involving postmen as active participants in seven subprojects led by line managers and supported by researchers (Karltun, 2011). After evaluation, these improvement measures were found successful and were thereafter implemented in all mail delivery offices in Sweden. This resulted in positive outcomes regarding postmen's well-being, which satisfied the Swedish Work Environment Authority, as well as increased business productivity.

**Box 9**

HTO to improve health and productivity resulted in:

- Facilitated understanding of factors that influenced the postmen's work among postmen as well as managers
- Identification and acceptance of necessary improvement measures
- Implementation of extensive redesign of the workplace for all Swedish postmen
- Improved postmen's well-being as well as increased business productivity

# 7 – HTO for improving work systems

Using the HTO concept for improving work systems requires deep knowledge of the work context as well as different aspects of the human involvement, the technology and the organisation. This implies that different areas of expertise within a business are needed to develop an HTO systems thinking. A continuous dialogue about the systemic effects regarding the interactions between H, T and O should be integrated in everyday practice. This is a greater challenge than the cooperation itself as different professions often have different educational backgrounds and thereby are trained in a certain way of thinking. There may also be strict departmental or organisational boundaries preventing the flow of information, knowledge and learning within the organisation.

The complexity of using an HTO systems view has implications for how development and change will be operated within a business. Today, the technological development is a strong driving force in the light of business development opportunities, and it is often the key driver of business change. Awareness of this makes it an important task to balance the technology with consideration of humans involved and the organisation of work in order to avoid less productive and sustainable operations. One way is to ensure that the individual is made visible in development and change management work. Conscious effort is therefore needed to discover individual contributions, roles, and needs in the larger context in production and operations. This becomes more important as organisational and technological complexity increases and roles change. The organisation must thus also be taken into consideration. An organisation is a multidisciplinary field in itself where there is a risk that popular management consultant models and organisational philosophies have an impact that may not be in harmony with the human and technical conditions, so these patterns of interaction must also be taken into account.

It has been argued that the mission or the business model of a company must be incorporated in an HTO analysis as this is the driving force in many organisations. However, the activity at the centre of the HTO model implies a goal for the work activity that in turn is related to the mission or the business model. As a senior manager in an operation, knowledge about the interconnection between the mission or the business model and the HTO concept might be useful for strategic work in a company. Then HTO aspects need to be related to and integrated with the company's strategies and linked to overall performance.

There are several HTO-based models which have been developed for certain applications. Some models have been mentioned in this report: Porras and Robertson (1992) from the organisational development (OD) tradition, Rollenhagen (1997) for analysing system safety, and Eklund (2003) for highlighting human activities in relation to processes. Other useful models for different applications are e.g., the Swiss CIM model (Ulich and Schüpbach, 1991) analysing businesses on company, organisation, group and individual levels, SEIPS for patient safety (Carayon et al., 2006; Holden et al., 2013), and TOP to support co-design of technology, organisation and people (Boy, 2020).

The aim for this report is to describe how HTO can be used to understand human work activities from a systems perspective, how important it is to have knowledge about the interactions between H, T, and O, and how HTO can contribute to improvements regarding human well-being and operations performance (Karltun et al., 2017). Involving people with different disciplinary backgrounds is necessary to deal with HTO issues, which is why it is important to learn about and train in cross-disciplinary collaboration and systems thinking. Having an understanding of the HTO interactions, and how they affect systems performance regarding efficiency, effectiveness, well-being as well as productivity, is thus important knowledge for operations management.

**Box 10**

To sum up, HTO can be used as:

- A theoretical framework describing the HTO system in terms of three mutually dependent sub-systems (H, T and O)
- A conceptual tool to obtain initial understanding of human work activities
- An analysis tool for identifying characteristics and interactions within the HTO system
- A methodology for a holistic ergonomics view in investigations and interventions
- A visualisation tool to communicate a systems view to stakeholders
- A design tool that demonstrates the need to design the technical and organisational tools to human needs to support individual health and well-being as well as individual and system performance

# References

Berglund, M., Karltun, J. (2007). Human, technological and organizational aspects influencing the production scheduling process. *International Journal of Production Economics*, 110, pp. 160-174

Boy, G., A. (2020) *Human–Systems Integration: From Virtual to Tangible*. CRC Press, Boca Raton FL.

Carayon, P., Hundt, A. S., Karsh, B., Gurses, A., Alvarado, C., Smith, M., Brennan, P. F. (2006). Work system design for patient safety: the SEIPS model. *Quality Safety Health Care,* 15(1), 50-58.

Daniellou, F. (2001). *Epistemological issues about ergonomics and human factors.* In: Karwowski, W (Ed.) International Encyclopaedia of Ergonomics and Human Factors, Part 1. London: Taylor & Francis, pp. 43-46.

Daniellou, F., Rabardel, P. (2005). Activity-oriented approaches to ergonomics: some traditions and communities. *Theoretical Issues in Ergonomics Science*, 6(5), pp. 353-357.

Eklund, J. (2003). *An extended framework for humans, technology and organisation in interaction*. In: Luczak, H., Zink, K.J. (Eds.), Human Factors in Organisational Design and Management – VII. Re-designing Work and Macroergonomics – Future Perspectives and Challenges. Santa Monica, CA: IEA Press, pp. 47-54.

Guérin, F., Laville, A., Daniellou, F., Duraffourg, J., Kerguelen, A. (2007). *Understanding and Transforming Work. The Practice of Ergonomics*. Lyon: ANACT.

Holden, R.J., Carayon, P., Gurses, A.P., Hoonackker, P., Hundt, A.S., Ozok, A.A., Rivera-Rodriguez, J. A. (2013). SEIPS 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients. Ergonomics 56 (11) pp. 1669-1686.

Hollnagel, E. (2015). *Why is Work-as-Imagined Different from Work-as-Done?* In R. L. Wears & E. Hollnagel (Eds.), Resilient Health Care, Volume 2 (pp. 279–294). CRC Press.

Karltun, A. (2007). Researcher-supported Work for Change in Real Service: Improving the Work Situation of 15,000 Postmen. Doctoral dissertation. Linköping University (in Swedish).

Karltun, A. (2011). *Developing HTO systems thinking for organisational and technological change*. In: Proceedings of 10th International Symposium on Human Factors in Organisational Design and Management. Grahamstown, South Africa, April 4-6, 2011.

Karltun, J., Berglund, M. (2010). Contextual conditions influencing the scheduler's work at a sawmill. *Production Planning & Control* 21, No. 44, pp. 359-374.

Karltun, A., Karltun, J., Berglund, M., Eklund, J. (2017). HTO – A complementary ergonomics approach. *Applied Ergonomics*, 59, pp. 182-190.

Lim, J. (1998). *An Engineering Disaster: Therac-25*. Retrieved from http://www.bowdoin.edu/~allen/courses/cs260/readings/therac.pdf (Accessed 17-12-2020).

Nolimo-Solman, K. (2002). Analysis of interaction quality in human-machine systems*:* applications for forklifts*. Applied Ergonomics* 33, No. 2*,* pp*.* 155-166.

Porras, J.I., Robertson, P.J. (1992). *Organisational development: theory, practice, and research*. In: Dunette, M.D., Hough, L.M. (Eds.), Handbook of Industrial and Organisational Psychology. Palo Alto: Consulting Psychologist Press Inc,, pp. 719-822.

Robbins, S. P. (1990). *Organization Theory, Structure, Design and Applications* (Third ed.). Englewood Cliffs, New Jersey: Prentice Hall.

Rollenhagen, C. (1997). *The Relationships between Humans, Technology, and Organisation: an Introduction.* Lund: Studentlitteratur (in Swedish).

Swedish Radiation Safety Authority (2020). *Man-Technology-Organisation*. Retrieved from https://www.stralsakerhetsmyndigheten.se/en/areas/nuclear-power/our-regulatory-supervision/man-technology-organisation/ (Accessed 09-12-20).

Ulich, E., Schüpbach, H. (1991). Im Spannungsfeld von Mensch, Technik und Organisation. *Technische Rundschau*, 83(28), 52-56.

Waefler, T. (2001). *Planning and scheduling in secondary work systems*. In: MacCarthy, B.L., Wilson, J.R. (Eds.), Human Performance in Planning and Scheduling. London: Taylor & Francis, 411-447.

Westlander, G. (1999). *Focus on the human in research on operations development*. In: Ahlin, J. (Ed.), Forskningsperspektiven. NUTEK, Stockholm, 20-33 (in Swedish).

Additional literature that provided inspiration for this report and that also can be read for further depth in systems thinking and HTO-related models:

Bohgard, M., Karlsson, S., Lovén, E., Mikaelsson L-Å., Mårtensson, L., Osvalder, A-L., Rose, L., Ulfvengren, P. (red.) (2015). Arbete och teknik på människans villkor, Prevent, Stockholm

Booher, H.R. (2003). *Handbook of Human Systems Integration*, vol. 23. Hoboken. NJ: John Wiley & Sons.

Carayon, P. (2006). Human factors of complex sociotechnical systems. Applied *Ergonomics* 27(4), 525-535.

Checkland, P.B. (1981). *Systems Thinking, Systems Practice*. Chichester, UK: John Wiley & Sons.

Cherns, A. (1976). The principles of sociotechnical design, *Human Relations* 29(8), 893-792.

Hendrick, H.W., Kleiner, B.M. (2001). *Macroergonomics: an Introduction to Work System Design*. Human Factors and Ergonomics Society, Santa Monica, CA.

von Bertalanffy, L. (1972). The history and status of general systems theory. *Academy of Management Journal*, 15(4), 407-426.

Wilson, J.R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics* 30(1), 557-567.

Wilson, J.R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics* 45(1), 5-13.

Ödegård S. (Ed.) (2007). In the name of justice: responsibility, guilt and safety in healthcare. Stockholm: Liber (in Swedish).

Martina Berglund
Assistant Professor
Quality Development and HTO
martina.berglund@liu.se

Anette Karltun
Associate Professor
Work Organisation
anette.karltun@ju.se

Jörgen Eklund
Professor Emeritus
Ergonomics
jorekl@kth.se

Johan Karltun
Associate Professor
Work Organisation
johan.karltun@ju.se

HELIX Competence Centre is a multidisciplinary research program at Linköping University, conducted in partnership between five sectors - *universities, industry, the public sector, labour market organisations and civil society*. The main goal of HELIX is to develop knowledge of how good working conditions in terms of learning, health and gender equality can be combined with efficiency and the ability to innovate. The knowledge created in collaboration between practitioners and researchers from different disciplines is based on an interactive research model where research results can be implemented directly in the partner organisations.

Together with the partnership, research is conducted in four main areas

- Sustainable development in industrial production systems
- Growth and development in small businesses
- Sustainable, innovative and coordinated health and welfare services
- Inclusive workplaces

HELIX competence centre is financed by VINNOVA together with Linköping University and partner organisations and it is a 6-year research program ending in 2022.

More information about the centre can be found at

**www.liu.se/helix**

HELIX

LINKÖPING UNIVERSITY