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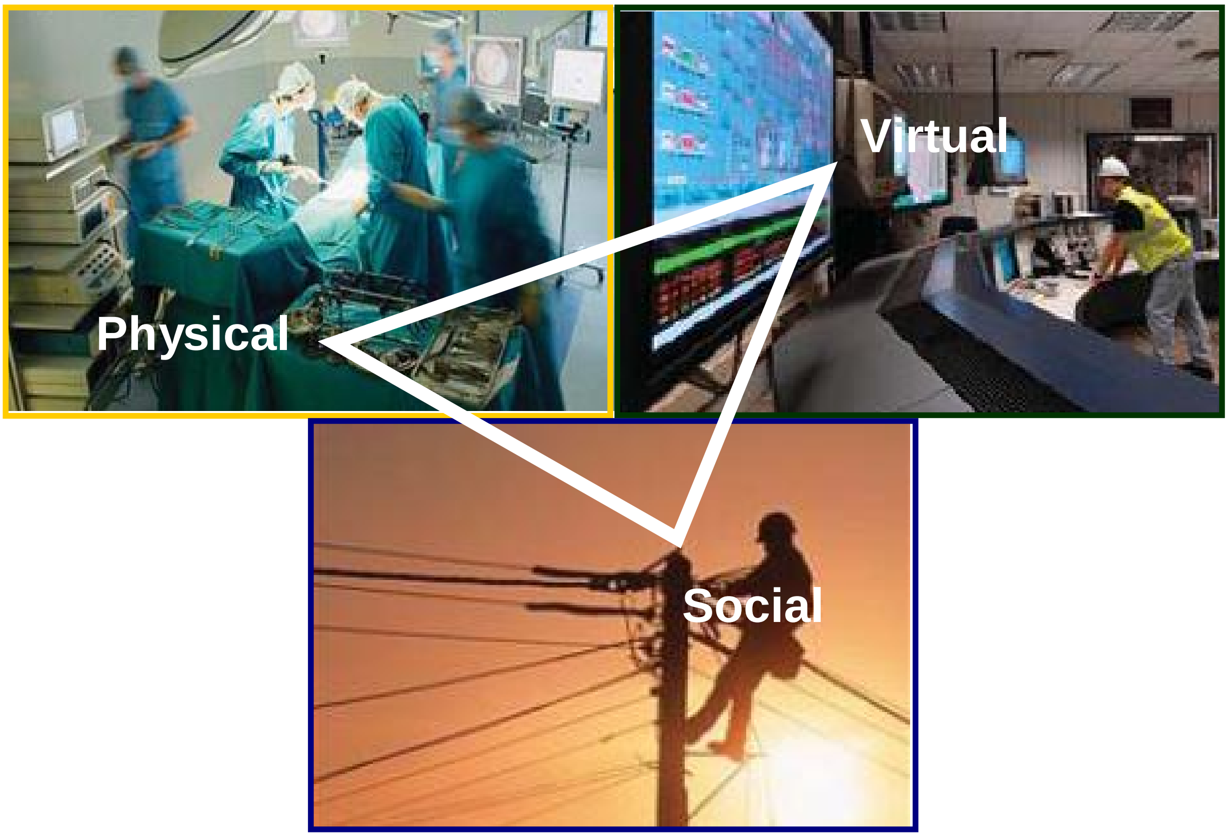

Expanding control room – a new frame for designing spatial affordances of control places

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Summary

TILAVA (SPACIOUS) - project is carried out as a part of Tekes (The Finnish Funding Agency for Technology and Innovation) Tila (Spaces and Places) research program. The target of the project was to study spaces that are designed and used for monitoring and controlling industrial processes or other kind of complex systems. Spaces dedicated for such activities are typically called control rooms. In this project we urged to extend the concept of control room to be more than just a room *space* dedicated for monitoring and operating tools. Instead we proposed that control rooms are comprehensive human-system interfaces and *places* in which the operating personnel accomplish their work and that are incorporated with cultural norms and social meaning. In order to fulfil the demands of work the operators need at all times to understand the state of the process. Situation awareness, sense of control and sense of presence are experiential states that reflect this understanding. We assume that those spatial features of control rooms that support the formation of places facilitate these functionally significant user experience qualities. We conceptualised spatial affordances of control rooms on the bases of three spatial aspects: physical space, social space and virtual space. Paring these aspects we developed three control room metaphors: the Illustrative control room, the Interactive control room and the Boundless control room. These metaphors were used as conceptual design elements around which three empirical user-involving case studies were constructed. The cases involved control of electrical grid (illustrative), development of interactive surfaces for complex operations (interactive), and co-creation of future control room conceptions by diverse experts of a design company (boundless). The results of the three case-studies were synthesized into a proposal for a design frame for future control rooms. The frame conceptualises the main generic activity demands that control rooms should enable. Drawing on the case study results, different spatial affordances are relevant in different types of control spaces. These spatial affordances were interpreted as dimensions that need to be considered in the design of new solutions or that enable analysis of existing control spaces. The position of a certain solution along the different dimensions is in the next step of development of the frame intended to be used as basis of construction of profiles that demonstrate the extent of *placeness* that the solution would enable. User experience concerning situation awareness, sense of control and sense of presence could be used as sign of achieved placeness. In the future the conceptual frame will be tested and developed further by utilising it in different design-oriented studies.

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Contents

1 Introduction

1.1 Background

TILAVA (SPACIOUS) - project is carried out as a part of Tekes (The Finnish Funding Agency for Technology and Innovation) TILA (Spaces and Places) - research program. Within the Spacious –project we have been interested to study “spaces” that are designed and used for monitoring and controlling a particular industrial processes or other kind of complex systems. Spaces dedicated for such activities are typically called control rooms. In this project we consider the concept of control room to be more than just a “room space” dedicated for monitoring and operating tools. Instead we see that the control rooms are comprehensive human-system interfaces and *places* through which the operating personnel receive huge amount of situational process data and create an understanding of the state of the system and each others activities.

Due to the employment of the modern information and communication technologies (ICT) the control room environments are going through major changes. When designing the future control rooms it will be important to understand how the new technological enablers change and form the different functions of the control room and the work activities carried out within it. Intelligent monitoring, operation and awareness of the system are needed in order to supervise and control the state and course of the process appropriately. Therefore the aim of the research done in TILAVA-project is the development of the future intelligent control room concept and elicitation of user requirements for it by involving expert users. The central objective for designing such environments should be that the control space promotes the creation of shared situational awareness and that the human-system interface is as efficient and intuitive as possible. These objectives drive for better integration of the different elements of the control room and creates insights of the directions that the design of the future control environments may take.

1.2 Challenges of the enabling ICT technologies

We are living and working in a word that is coming more and more dependent on computers and the use of digitalized information. This development that once started from the interest of a small group of specialists is turning out to have significant role in everyone’s everyday life. People are constantly interacting with this digital computerized world, more and more often without even noticing the presence of computer. The new digital way of being connected and interacting with our surrounding environment also challenges the tradition of human-computer interaction design. We should be able to better address and understand whether and how the way we are used to do things will be transformed when we learn to act in the computerized world. We believe that it is necessary to apply a more holistic view and see that the new environment in which the human-technology interaction takes place has novel structures and features. It provides new kinds of possibilities that are meaningful for human and shapes the stream of interaction.

The vision of a digitalised environment relies on diverse technological enablers. According to Kaasinen et al. (2007) the vision of future smart environments is founded on at least on three technological pillars: The first one is *algorithmic intelligence* that contributes profoundly by enabling automatic functions that have features like context sensitiveness, learnability or anticipation. The second technological pillar is *advanced interaction*, including intuitive interface technologies, high level (visual) concepts, and constructiveness. The third technological pillar is *ubiquitous technologies* composed of elements like embedded information and communication technologies, comprehensive networks and mobile technologies. The extent of exploitation of these enabling elements depends on the application domain and the needs of the users whose activities the environment should enforce and support.

The vision of smart environments also involves conceptual innovations what regards the way human cognition and activity are comprehended. Over the years of research and practical work the human factors community has identified restrictions in the classical information processing approach in comprehending human behaviour in real contexts. It has become evident that the circumstances, i.e. aims and constraints of behaviour shape the content and structure of cognitive processes. Moreover, it is becoming common place to consider that cognitive resources are distributed in various ways. Cognition is in a way distributed between the human actor, the instruments or other cultural artefacts used, and the environment in which activity takes place. Moreover, bodily functions and physical presence and engagement in the environment are part of the comprehensive ability to make sense of the world, and to act appropriately. (see e.g. Kaptelinin and Nardi, 2006). Functionally seen human actor and certain parts of the environment constitute one system. These descriptors of human cognition are highly relevant for our attempts to understand peoples' meanings and ways of acting in digitalized environments.

1.3 Challenges of the development of control rooms

The trend towards comprehensive use of digital technology does not only refer to people's everyday environments. Digitalization and increased use of modern ICT based tools also challenges the development of process control systems and control rooms. Our interest is, by applying a broader view, to analyze the control room as an intelligent environment and a comprehensive human system interface that provides process information and from where the process can be controlled.

Traditionally control rooms have been seen as a *place* that has been designed for certain *actors* for the *control* of some *process* (Hollnagel and Woods 2005). Today there is however a pressure for change with regard to each of the main components (in italics) of the above control room definition:

- *Remodelling of control room structures*. There is a clear shift in the definition of the control room. The control room was earlier definitely a stationary and single room space but recently possibilities have been created and pressure emerged to create mobile or also spatially distributed control spaces.

- *Changes in the allocation of operative tasks*. Also the concept of an operator has changed. Earlier the actor was always comprehended as a single person. Today the actor is comprehended in plural and it typically refers to a team of people or, more recently, also to a joint human-technology system, composing e.g. of automatic agents that collaborate with human actors.

- *Enlargement of the focus of the process*. When thinking about the process we may identify shifts in temporal focus. When the operators were formerly mainly oriented towards the present situation there is more and more pressure and possibilities today to consider both the past events and the expected future behaviour of the process.

- *Enlargement of the control room focus*. There is also a tendency to enlarge the focus of control from operations to maintenance, design, production planning etc.

2 Goals

The nature of the one-year project was exploratory. The target was to improve understanding of what kind of a space a control room is, what kind of developmental needs there might be, and what could the role of ICT-technologies be in the design of new control room functionalities. It was thought that such an exploration would require conceptual tools and theoretical frames. It was also clear that the exploration needs to be a joint effort involving researchers, control room designers and end-users e.g. control room operators. Three main goals were defined for the project:

- Finding novel possibilities and technologies to communicate the process
- Identifying operators central needs in improving the control of the process
- Testing conceptual means to facilitate end-user input in the design process

2.1 Finding novel possibilities and technologies

As already mentioned before, the development of technology has caused major changes in the complex control environments over the years. The changes have challenged operators' earlier experiences and ways of work. In conventional control rooms based on analogical technology the monitoring and controlling activity was done by observing and physically manipulating the control devices of the wall-mounted control panels and consoles. In this kind of control room setup the whole control room environment and its elements (e.g. structures, walls and objects) was taken advantage of and the entire room space constituted a comprehensive interface for monitoring and controlling the complex system. However, today's control environments are furnished with variety of digital technology applications. The capabilities of these technologies have increased enormously in recent decades, and the digitalization of control systems has made it possible to collect and present more detailed information from the process than earlier. As a part of the digitalization process the physical control panels and consoles are transformed into their digital counterparts i.e. a keyboard and mouse controlled displays on which a vast amount of process information is graphically presented.

Due to the rather small-size of the display screens, hierarchical structuring of information is necessary and, as a consequence, increased navigation within this structure is required. Workstations based operation have been experienced to create restrictions for displaying and managing the growing amount of process information. In this kind of desktop based control system only a very small fraction of the information space can be observed at a time. Instead of feeling of being surrounded by and having a good view to the controlled system the operators easily feel that they are observing the system from outside through a small hole. That is why this phenomenon is also called as a “key-hole” effect. The digitalization process has also argued to diminish the role of a control room space as an essential element of the human-system interface as well as weaken the operators ability to maintain awareness of the prevailing situations.

These challenges have lead designers and developers to seek ways to improve the information presentation and operators' possibilities to better "grasp" and control the system. The concept of affordance that rises from the field of ecological psychology is used for describing the action possibilities of an environment (Gibson 1979). The term is now widely used to describe those things that an environment offers or furnish to an animal through interaction and further a key to understanding behaviour for him was an analysis of the ecology. (We shall return to this concept in Chapter 3.2). In the context of complex process control the control room environment is perceived directly by means of what kind of possibilities it can offer to operators' actions.

Developments of ICT based interface technologies has brought about the possibility to integrate and update the spatial qualities of earlier control room designs in new designs and in this way facilitate more intuitive representation and control of the process. Multimodal (e.g. integrated use of visual, audio, speech and tactile based information) interfaces can be developed in order to support operators' interaction through various communicational channels. This makes it possible to mediate more qualitative information and so called "weak signals" without overburdening vision. These kinds of environmental cues that human partly subconsciously perceive by acting in an environment might play an unexpectedly important role. These space related interaction qualities should not be undervalued in future control room designs. Nowadays it is also possible to embed and integrate interface technology/ elements into control space structures (walls, floor, movable wall screens and units). As a result the future control room environments can be built to be more flexible and their structures can even be changed according to the prevailing situations.

However, with the integration of interface elements into the structures of the control room environments and with the use of novel interface technologies a number of challenges arise. These are both technical as well as human-technology interaction related ones. Therefore one of the goals of this project was to examine the possibilities to improve the control space's ability to communicate the process behind by better acknowledging the control room's spatial affordances and how the use of these possibilities could be supported through the introduction of new technology

2.2 Identifying operators' central needs

From the process control point of view it is essential that operators of the process have a feeling of being control of events and the situation, and, that they have a clear picture of the situation-related constraints and their own possibilities to take appropriate actions. A term situation awareness (SA) is used for describing this generic operational purpose (Endsley 1995). Situation awareness is defined as the degree to which human operators are aware about what is happening and how their own situation is related to the surrounding context. Many human actors take part of the process control and monitoring activity and therefore the establishment of a common ground of understanding is essential to support through control room designs. Forming and maintaining shared understanding of the process is dependent on many things such as awareness of actors' prerequisites and possibilities to monitor and operate the system. Situation awareness can be said to be good when an individual or a group understands the nature of the current situation, the reasons leading to the situation and the consequences that the situation might have to the process. Maintaining situation awareness also enables operators to solve problems and take decisions as well as act in an efficient and effective manner.

Designing a system that supports forming and maintaining situation awareness is not straightforward. Endsley, Bolte ja Jones (2003) have listed a group of factors that create difficulty for forming and maintaining SA. These factors are following:

- Attentional Tunneling: the user fixates on specific elements of information while becoming blinded to other elements.
- Requisite Memory Trap: Some designs tax working memory to the point where SA is decreased due to overload.
- Workload, Anxiety, Fatique, and Other Stressors: Psychological and physical stressors can negatively affect information intake by making it less systematic and more error prone.
- Data Overload: The way data is processed, stored and displayed all affect how data is organized and presented to the user. These factors can contribute to overload.
- Misplaces Salience: Salience may help or hinder SA depending on the context of use. Designers must be careful to use it appropriately.
- Complexity creep: this phenomenon may undermine the user's ability to correctly interpret information presented and to project what is likely to happen.
- Errant Mental Models: Lack of standardization and use of modes can activate errant mental models in user's minds and cause them to misinterpret the meaning of cues.
- Out-of-the-loop Syndrome: Too much automation can push the user out-of-the-loop, causing them to lose SA in regards to the status of the elements under systems control.

The above mentioned factors can lead individuals or teams to have false understanding of the situation or narrowed focus of attention. These kinds of difficulties are typical for human decision making, and in an industrial setting the consequences of this misconception of the situation might be severe. The operators' experience of feeling of being control of the system is closely related to the concept of situation awareness as well as the decisions made on the level of automation in the system designs. Increasing awareness of oneself, others and the functioning of the automation systems can be used to promote new understandings by expanding the shared frame of reference which the control room environment is part of.

Thus one of our goals is to study how the control room as a space or environment enables operators to understand and control the system under their supervision.

2.3 Testing conceptual means to facilitate end-user input in the design process

Traditionally control rooms have been considered mainly from the technical and user interface point of view. In this project the control room is seen as a comprehensive operating environment. Control room is an environment in which variety of technical equipments and tools are utilized and in which many people and professions are working together. These people might collaborate in physically same room space or distantly by being virtually connected to each others. The variety of elements of the control room environment can be merged differently depending on what activity it is strived for. Similarly, the tasks carried out and the ultimate goals of the work, as well as the quality and performance demands that are imposed on the activity, affect how well the control room space functions and how operators' situation awareness is supported. (Savioja and Norros 2008) The control room space constitutes a kind of information ecology in which the human – technology interaction takes its place and forms. (Kaasinen ja Norros 2007) This is a new and broader view to the human-technology interaction than the traditional approach that typically focuses on investigating the use of single tools in some defined tasks and use context. In this project we are trying to find suitable combinations of control room elements for human – technology joint functioning.

Especially in the design of complex environments aimed for professional use the involvement of expert knowledge of a particular use context is important. The integration of this operational experience into the development process early as possible would be beneficial and profitable. It is, however, often so that the developers of the system do not have the required skills and methods for collecting and integrating the usage-related information into the design. And, respectively, the expert users lack the means to express their needs and influence the design process. Thus, in this project we aimed to develop and test user involving design methods. Users are needed as co-designers and their expertise is valuable for the design process. This form of design can also be called *immediate design* (Keinonen 2007, Kuutti et al. 2007).

Further, as we see that the development of future control room environments should be an evolving and continuous process instead of being just an embodiment of some particular user group's wishes and expressions, it is important that solid and generic base for design activity is created. This enables the development of control room concepts and elements that can be adapted and structured according to the different use contexts and veins of work activities. For this more generic aim of the design the concept of *remote design* was introduced (Keinonen 2007, Kuutti et al. 2007).

In this project we aim to combine these two design practices (immediate and remote design) in the realization of three case studies exploring and prototyping the possibilities of the future control room environments. We aim to create a future control room concept and develop methods for early expert user involvement in design and elicitation of user requirements.

3 Theoretical bases of the study

3.1 Three views to space

3.1.1 The "three views approach" to space in the Tila program

In the Tila programme description provided in the programme website (http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/Tila/fi/etusivu.html) the idea of three types of spaces, i.e. the *physical space*, the *social space* and the *virtual space* is proposed. Physical space refers to different types of physical environments, like home, workplace, school or hospital. The social space focuses living environments. This may be interpreted to refer to places from the point of view of different activities that take place in them. Finally, virtual environments refer to the virtual worlds enabled by information and communication technologies. The three views approach to space is very descriptive and only a visual model is provided but no conceptual elaboration. However, we found the distinction of the three space qualities relevant. Hence, we developed it into a generic tool with which we could characterise those spaces that we were particularly interested in. In the next section we describe how we interpreted the three space qualities in the context of control room spaces. Later in Chapter 5 we shall extend the usage of these space qualities into a conceptual method we used in our empirical study.

3.1.2 Adaptation of the “three views approach” to control room context

The present study focuses on a specific work space i.e. the control room of a complex process or system. The definition of three types of spaces proposed in the programme documents was taken as a conceptual tool for further definitions and organisation of the project.

The *physical space quality* of a control room is often thought to be related to the physical structure of the control room (i.e. walls, roof, objects), but it also includes aspects that supports operators’ physical activities and control operations. The constant interplay between the physical control room environment and operators’ physical actions provides possibilities to some actions while hinders others.

The *virtual space quality* deals with an idea that the control room is a representation of the complex object of an activity. Therefore the control room should provide the operators with a realistic and an understandable picture from the prevailing process state. The digitalization of the control rooms is thought to bring operators apart from controlled process. By utilizing technological solutions that support and make effective use of the virtual space quality users may be provided with new kinds of views to the controlled entity. New technological solutions also extend the “natural” senses of the human being and enable perceiving and exploring of objects that earlier were out of reach of the operators (e.g. reactor core in nuclear power plants).

The *social space quality* of the control room is created in the activity of the operating crews. The different actors in the control room and in the entire plant work towards same main goals, cooperate and communicate with each other and complement each other in many ways in achieving the goals. The control room environment can be considered as a framework in which the activity and cooperation takes place and through which the operational information is mediated. In the control room space the social space quality plays an important role in the process of creating shared understanding of the process state and in the coordination of the crew’s activities.

3.2 Exploitation of the concept of affordance in defining spatial possibilities

After deciding to utilise the above described three space qualities as basic descriptors of control room spaces we identified the need to conceptually define what possibilities such space qualities would offer to the human operator. The conceptual tool that we exploited there was the concept of *affordance*. In this chapter we shall provide a short introduction to this concept and explain how it was adapted to develop the targeted framework.

3.2.1 The concept of affordance

<u>The origin</u>

An American psychologist James J Gibson (1979) introduced the concept of affordance, and it played an important role in his theory of direct perception. A central idea in this theory is that meaning is inherent in the organism–environment system, and an actor can directly pick it up without further mental processing. The term “affordance” refers to the complementary interaction between an organism and an ambient environment (Gibson, 1979). It is used to describe those things that an environment offers or furnishes to an actor through interaction. The mutuality that characterizes the relationship between actors and their surroundings is a key feature of the affordance concept. According to this point of view, an affordance is not a property of an environment or the actor, but it becomes evident when organisms are actively living in a particular environment.

The design interest

An important contribution to the development of the concept of affordance was made by Donald Norman (1988) who introduced this notion to the design community. Norman urged to direct the designers’ attention to certain key aspects of interfaces and artefacts in general. Norman’s definition focuses on how an *artefact can be used* by a user. He uses the concept of affordance in a narrower sense than Gibson, and he concentrates on physical man-made objects. According to Norman, the term affordance refers to the perceived and actual properties of things. Norman identifies two kinds of affordances, real affordances and perceived affordances. Real affordances refer to physical characteristics of a device that allow its operation, whereas perceived affordances are those characteristics in the appearance of a device that provide cues of its operation and use. Affordances reveal to the user what can be done with the artefact. Norman’s interpretation has been adopted with enthusiasm by designers; on the other hand, it has also lead to confusion among them.

Rex Hartson’s and his colleagues’ work is based on Norman’s and Gibsons’s work. Working in a design context Hartson classified affordances into three categories: the role they play, the cognitive mechanisms they use, and the actions they correspond (Hartson 2003): A *sensory affordance*, helps and facilitates users with their sensory actions and emphasizes design attributes related to auditory, visual, tactile/haptic or other sensations. Sensory affordances play a supporting role for cognitive and physical affordances. A *cognitive affordance* refers to a design feature that helps us to know about something, that is, it is associated with semantics. According to the idea of product semantic meaning is cognitively constructed in the user’s mind based on the information perceived by the senses. The interpretation that a user creates can depend greatly on cultural conventions and personal experiences. A *physical affordance*, in turn, enables a user to do something physically. It is associated to “operability”. For example, a physical affordance can be an adequate size or form of an object. The fourth class of affordances is *functional affordances*. Users do things to accomplish their goals, and functional affordances are design features that aid us to accomplish different types of activities. The notion of functional affordance may be seen to highlight the functional core idea of the affordance concept. Functional affordance goes beyond user interfaces to the larger context of overall system design. It is a question about user enablement in the work domain.

Affordance as interaction between an organism and environment

Affordance refers to the *interaction* between an organism and environment. This interaction may be taken to refer to a function that the organism and the environment may jointly realise. In accordance to this original idea of Gibson, William W. Gaver (1991) defines affordances as properties of the world that are compatible with and relevant for people’s interactions, that is, affordances are *links between perception and action*. Moreover, Gaver states that our environment is, perceived directly by means of what kind of *potential* it can offer to our actions (Gaver 1991). This idea of affordances as potential for interaction in the environment reflects the basic idea of Gibson that affordances exist in the environment regardless of whether they are actualised or not. Still affordance by nature is something that is defined by an organism as a perceiver and potential user of that feature of the environment. In this way the concept refers to a property that characterises the relationship between the environment and organism, not to a property of the environment as such.

The relational character of the concept of affordance has brought up the idea of distinguishing between the levels of usage of affordances. One example of this is the above-mentioned distinction by Norman between real existing affordances and those that human users perceive. Those who consider the distinction between real (objectively existing) and perceived (subjectively comprehended) affordance to be contradictory to the original idea of Gibson that an affordance defines the relationship between environment and human, and, hence, does not contrast objectiveness to subjectiveness, use slightly different distinctions between affordances. For example Kyttä (2003) by drawing on Greeno (1994) distinguishes between *potential* and *actualized* affordances. She continues by identifying different levels of actualization. The analysis of the actualisation of affordances brings the concept of affordance to a more concrete level and refers to people's real actions in certain situations. This is useful for Kyttä because she is interested in analysing children's outdoor environments empirically. She considers actualised affordances either being as *perceived*, *utilized* or also as been *shaped* by people. Peoples' intentions or other individual, social and cultural factors determines how deeply the potentials of the environment are been exploited.

3.2.2 Affordance concept in the Nase project

In the VTT project NASE (Novel affordances in smart environments) (see Urhemaa et al. 2010, Laarni et al. 2007) we also utilised the concept of affordance as a starting point. Drawing on the above referred references we made an attempt to develop the concept further so that it could even better suit to design of complex work environments.

The above-mentioned classification by Hartson (2003) between sensory, cognitive, physical, and functional affordance was seen to provide a framework to analyze and design smart environments (e.g., for production environments). We made an elaboration of this classification due to the observation that in many application domains, not least in work domains, it is typical that several people are interacting simultaneously with the same technical system and with each other. Hartson's concept of affordance is, however, based on the view that one person is interacting with one device. Therefore, the term social affordance was introduced. It was defined as a relationship between the properties of information technology and the characteristics of a group of people that enables particular kinds of interaction among them. It is thus a property that facilitates and supports collaboration and communication.

With the above extension of the Hartson classification, a model concerning the characteristics of affordance was constructed as is seen in Figure 1. Leaning on the idea of Hartson that the different characteristics of affordance refer to different cognitive processes, it was proposed, further, that the characteristics can be ordered to different levels of primacy (see Figure 1).

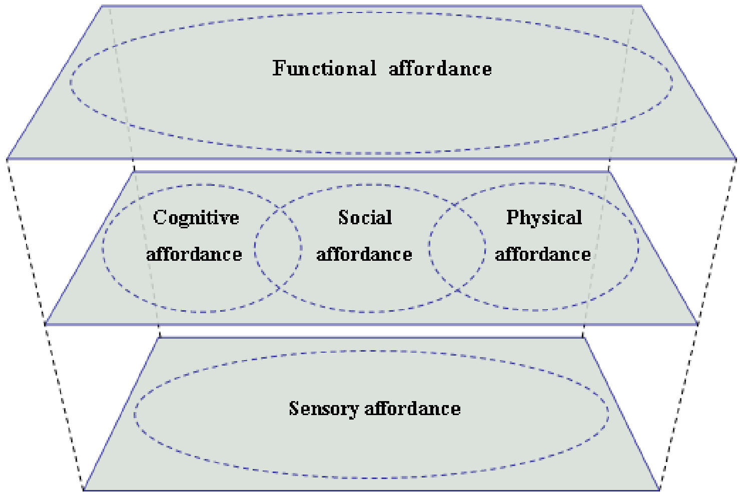

Figure 1. The levelled affordance concept of the VTT NASE project). Sensory affordances forms the primary level on the bases of which cognitive, social and physical affordances are build. Functionl affordance connects to the environmental features to the intentions of the users in an activity context. (Bradner 2001, Hartson 2003)

The sensory affordance is the fundamental level of people interacting in the environment and provides a basis for the physical, cognitive, social activities of people. The sensory affordances provide sensory feedback like visual feedback (information of, e.g., colour, shading, texture, depth, 3-D structure and motion of real and digital objects), auditory feedback (information of, e.g., loudness, pitch, timbre and location of real and digital objects), and physical feedback (tactile and haptic information, movement, physical constraints). The *physical* affordances in the environment that support direct operative interaction with a space augmented with smart digital tools. They can be touchable objects, moving real objects or digital objects, or environments or objects that are aware of the user's movements, gestures and facial expressions. The affordances that are relevant in each case are dependent on the details of the smart environment. *The cognitive* affordances help users to conduct several types of cognitive activities, and they provide information of what the user should do in a particular situation, and by which way he/she should do it. They should also provide feedback of whether the user's actions have been successful. *Social* affordances support communication, coordination and cooperation between people. *Functional* affordance is connected to the purposes that integrate and provide meaning to these activities (modified based on Urhemaa et al. 2010). All these forms of affordances and actions that they support are relevant in the design of control spaces.

3.2.3 Linking the concept of affordance with human-environment interaction models

In order to develop the affordance concept into a practical tool for analysis of activity in a smart environment we felt necessary to emphasize that the way in which the affordances of a system are perceived by an actor depends on the goals and intentions of that person (Laarni et al. 2007, Urhemaa et al. 2010). A connection between different aspects of the environment and the different types of human decision making was made in a well known model of Jens Rasmussen (1986). According to Rasmussen, an environment or a system to be acted upon may be described with the aid of a means-end hierarchy with five levels ranging from high-level value properties to low-level physical properties. The two lowest levels in the abstraction hierarchy (physical form and physical function) answer to the so-called "how" questions: how to act or accomplish tasks in certain conditions. The next level is related to the problem of defining goals and tasks. It relates to "what" questions of actors: what does this mean? The highest level is related to "why" questions. It concerns the overall purposes of the activity and the fundamental physical laws of the environment.

While a user interacts with an environment the above described levels of abstraction become relevant descriptors of the type of interaction he is involved with. When an event occurs in the system the user may observe it, identify the present state of the system and launch a learned action. Such behaviour is described by Rasmussen as skill-based (Rasmussen 1986). It may be connected to the above mentioned "how" questions and corresponding affordances, i.e. to physical and sensory affordance.

When a situation is less clear and a further interpretation becomes necessary, typically also the action to be performed needs to be selected. In this way of interacting with the environment, which is labelled as rule-based by Rasmussen, the "what" level interaction takes place. The corresponding affordances, i.e. the cognitive, sensory and social affordances become relevant.

If there is even more ambiguity about the situation and acting properly may need even considering the ultimate goals and definition of tasks to be accomplished. This is knowledge-based acting according to Rasmussen and can be characterised by "why" questions. These are mainly supported through functional affordances. Functional affordance could be interpreted to refer to the overall purpose of the activity that requires all the other aspects of affordances, i.e. the physical, sensory, cognitive and social affordances. We illustrate the human-environment interaction process and the corresponding affordances as is depicted in Figure 2.

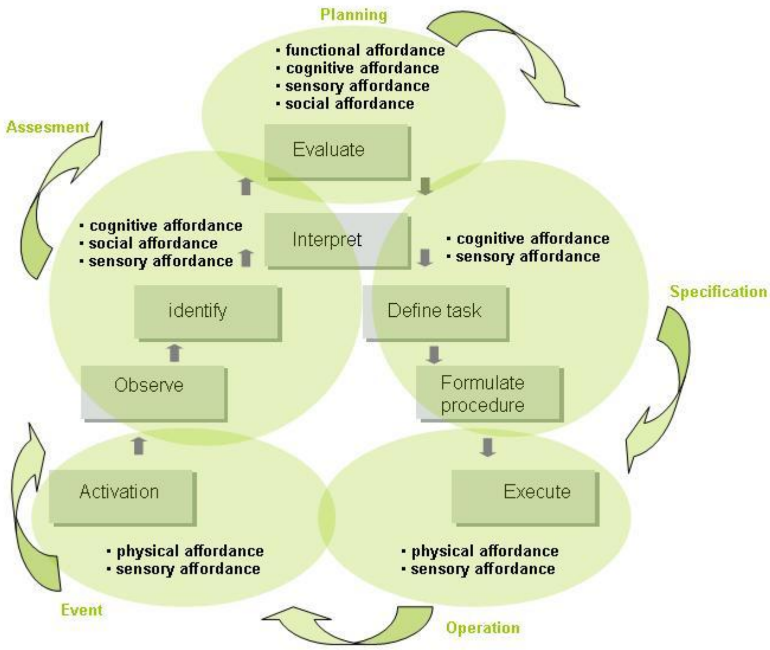

Figure 2. Affordances that plays prior role in different action sequences set into the human-machine interaction model (cf. Rasmussen,1986)(adapted from Urhemaa et al. 2010).

In the present project we sought new ways of approaching the control room as a design object. Adopting the concept of affordance was one step in the development of a conceptual framework. With this notion it is possible to comprehend the features of the control room environment from the point of view of the activity that this environment should support. The more the potential features of the environment could be actualised by the users, the more appropriately the control room would support the aimed activity and reaching of the purposes of that activity.

3.3 Designing spaces or places?

The next step in the creation of the design approach we realised that it was necessary to focus even more on the fact that control room is not only an instrument or tool but also a place in which the process control work takes place. Hence, it is necessary to seek ways to define the control room in spatial terms.

3.3.1 The distinction between space and place

According to Steve Harrison and Paul Dourish (1996) it has been commonplace in the design of collaborative systems to observe and analyse the way that *space* structures actions and interactions. Spatial models and metaphors have been used to capture the features of spaces that influence action and interaction. The authors summarise the most important properties of spaces in four characteristics: The first one is the “relational orientation and reciprocity”. Most frequent spatial dimensions are “up” and “down”, “front” and “back” or “left” and "right". These and other equal spatial characteristics provide people a common orientation to the physical world. This invaluable resource enables mutual communication, understanding and acting in the world. For example pointing to objects, e.g. on the "top of the shelf" enables a joint spatial reference and, hence, joint operations. The second characteristic the authors identify is "proximity and action". It is typical to pick up objects that are near or talk to people who are closest. When we see people gathered around a table we may understand something of the activity they are involved in. The third characteristic named is "partitioning". By this the authors refer to the lack of proximity. Distance between objects may be used to separate actions or objects or to reduce interaction. The final, firth main spatial characteristic is "presence and awareness". By this characteristic the authors refer particularly to the fact that spaces do not only include objects but also other people and their activities of which people become aware and take into account in their own actions.

The point Harrison and Dourish make is that the above listed characteristics are characteristics of *space*. *Space* is "the structure of the world; it is the three dimensional environment in which objects and events occur, and in which they have relative position and direction. The claim further that in architectural or collaborative system design one needs what is called "appropriate behavioural framing" in order to create functioning *places.* In more concrete terms what is needed in the design of places is attention to the activities, purposed and shared understandings, norms and ways of behaving that people connect to these places. "A *place* is generally a space with something added – social meaning, convention, cultural understandings about role, function and nature and so on" (Harrison and Dourish 1996; italics added). Important for the design of places is to understand that places are created and sustained in patterns of use, not designed in directly by applying spatial physical characteristics of places.

When the intention is to facilitate formation of places for certain activities the characteristics of places may be used to create the important features of *connectedness* and *distinction*, which features need to be balanced. We interpret that by connectedness Harrison and Dourish mean fitting-in to the whole environment or into the situation. When something new is ntroduced or takes place it should not appear to be "out of place". Yet, a place is not a place if it does not distinguish from the environment. We interpret that it must have features that enable identifying it to be a place for certain activities and separable from the environment.

On the basis of the features of connectedness and distinction, and taking into account the idea that placeness needs to be facilitated but can not be designed in, three targets for design of places may be defined. These relate to supporting of certain patterns of behaviour. These ar*e support for adaptation* (of places), *support for appropriation* (learning in places) *and support for participation* in the activity in the place. All these features facilitate improvement of placeness and development of activity.

3.3.2 Developing placeness as actualization of spatial affordances

In distinguishing space and place Harrison and Dourish (1996) make a connection to the concept of affordance just in passing when they take distance from those authors who simply focus on space characteristics and spatial modelling. In this context they refer to spatial structural characteristics as "affordances of space". The authors do not return to the concept of affordance in the context of discussing "place" and its characteristics, even though they see that space "is the opportunity" and place the "understood reality". Those characterisations may be seen as a clear connection to the ideas of the levels of actualization of the potential in the environment (see reference to Greeno1994, and Kyttä 2003 in section 3.2.1). We may also see that the concept of place, that is said to be defined by the purposes and activity that take place in the place, has parallels to the idea of functional affordance (see Figure 1). Moreover, the idea of Harrsion and Dourish that the exploitation and shaping of spatial features in acting in the environment produces place, i.e. extends the placeness of spaces. We may, further, interpret that Kyttä in her attempt of identifying levels of actualization of affordances was denoting the same principle of making spaces more and more places.

3.3.3 Creating placeness through use

In the present study we draw on the distinction between space and place made by Harrison and Doursih (1996). We also see that the design intention should be to find ways of improving the placeness of control rooms. We interpret the creation of placeness as a more and more comprehensive exploitation of the spatial affordances of the environment when acting in the environment by the development of habitual patterns of use. The process is affected simultaneously by spatial possibilities (bottom-up) and culturally and societally defined motives and purposes of the activity (top down).

In addition to what has been expressed so far we also hypothesize that that there are certain important “experiential indicators” of the development of the placeness of an environment. These are *situation awareness, sense of control* and *sense of presence*.

An experience of *situation awareness* emerges via working in the control room together with fellow operators. Situation awareness is manifested as an improved interpretation of the process state and accomplishing actions that are in place in the situation. Situation awareness is an active product of experience in work and the operators’ own moulding of the control room environment.

In the context of authoring the proposal for the frame work we decided that beyond situation awareness we also need two other relevant experiential qualities (see also the Results chapter 6.2.2): *Sense of control* may be seen as the feel by the operators that the control room place provides them with necessary means to act appropriately in the different situations that they might encounter during the work. Sense of control is also connected to understanding one’s own role with regard to fellow actors and automation.

Sense of *presence* may in our connection be interpreted as a feel by the operators that the process is actually in operation. The operators feel that what is currently happening is not repetition of something previously experienced, and that they themselves have had and can have an effect on the behaviour of the process.

All above mentioned qualities of operator experience support the operators of a complex process to stay in the loop of an often highly automated process, help them to comprehend the significance of different events in the process with regard to the safety and productivity envelope, and support their role and motivation.

4 Research questions

In the TILAVA project the set research questions to be tackled in the study are following:

1. How do the users comprehend the demands of the process control activity in different contexts of use?
2. How does the employment of novel user interface solutions and technologies affect the control room environment and how do these innovations further promote work activity and situation awareness (sense of control and sense of presence)?
3. How to apply user-involving and dialogic design methods in the concept development of complex operating environments?

The set questions are very challenging and must be understood as a set of basic questions that we shall be analysing in our future control place design work that this study was supposed to give direction to.

5 Methods and data collection

Our assumption is that making broadly use of the space qualities (physical, virtual and social) in control room designs it is possible to develop control room settings that facilitates users to maintain situation awareness and act appropriately. Applying the research approach introduced above we aim answer the set research questions and realize user involving case-studies on the future control room environments. The chosen case based method values the expert users' opinions and expressions as an essential development and research input. The case studies are built according to the same format which makes it possible to synthesize the findings in the end as a comprehensive user requirements' structure.

5.1 Utilisation of the Katve virtual environment

VTT has built a virtual environment (Katve) in one of its buildings at Otaniemi. Katve virtual environment provides rich research facilities for studying human-technology interaction. In this project we use Katve as a "playground"/ "testing field" where the elements of the future control room environments are tested and prototyped together with the users.

Katve virtual environment provides rich possibilities for studying and testing novel user interface solutions and technologies:

- Multi-touch tabletop
- Interactive wall mounted large screen displays
- AR/VR applications and presentations
- Multimodal user interface tools and technologies
- Process simulations (APROS connection/linkage)

5.2 Exploring the CR's space qualities in three case-studies

Traditionally, the control room and interface elements in it are considered from the point of view of a variety technical equipments that are needed for the process control and monitoring. The changes in the control room composition are mainly driven by economic and technology related issues. At the same time, the mainstream interface development is still largely relying on the graphical user interface based equipments and representation. Today, we are quickly moving away from the situation where the operators' focus is on the content of a single workstation screen as our work environments are equipped with networked computers and more actors are involved in the operation of the complex system. The traditional human-computer interaction design to support operation of a more comprehensive networked control system confronts a difficult challenge.

In this project we tackled this methodological challenge by applying a view where the control room space is thought to be an integrated wholeness in which all components and human actors are interrelated to each other. In this kind of control room setting the elements can merge differently depending on what activity it strives for. The control room space constitutes a kind of information ecology in which the human – machine interaction takes its place and form.

As a *methodical framework* we used three control room *metaphors* (representing the remote design element, see chapter 2.3) and built around them three case studies to be explored together with the *expert users* in *design workshops* (representing the immediate design element, see chapter 2.3). The idea in these workshops is to discuss with the users the meaning and essence of the three space qualities in control room environment and test new interface technologies in order to assess their potentiality to support such qualities. The third part of our methodical framework is to form a conceptual synthesis of the result of the three case studies.

The idea in these workshops was to discuss with the users the meaning and essence of the three space qualities in control room environment and test new interface technologies in order to assess their potentiality to support such qualities. Our aim was not only to study the applicability of some specific technological solutions in control rooms as such but also more generally the meaning and the role of different space modalities for the work and creation of situation awareness.

Three space qualities of a control room are the *physical-, the social- and the virtual space* quality. Each quality provides a specific type of affordances that are more or less present in real control room environments. In order, however, to articulate more clearly their features, describe what is already there, we *combined the three space qualities in pairs* of two and developed three control room metaphors, which are following (see figure 3):

- The Illustrative control room,
- The Interactive control room
- The Boundless control room.

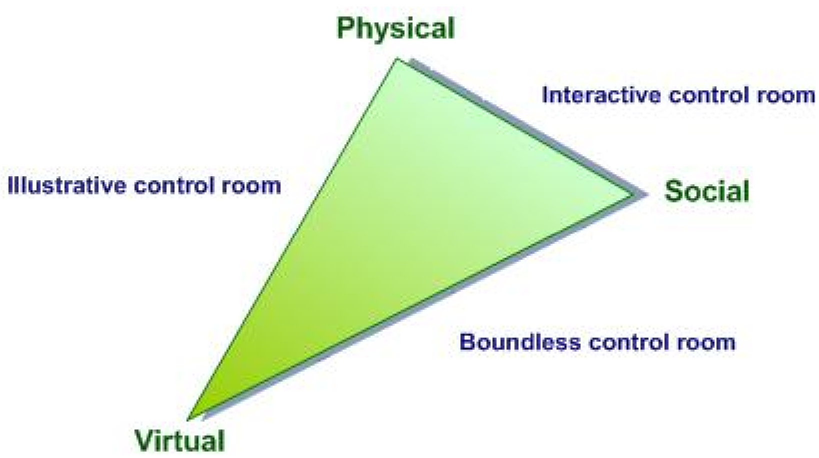

Figure 3. The three space qualities (physical, virtual and social) and the three control room metaphors that were formed by combining the space qualities in pairs of two.

As Figure 3 demonstrates, combining the three space qualities pair wise we created three control room metaphors: Illustrative-, Interactive- and Boundless control room. In Tilava-project we build three case studies around these metaphors.

5.2.1 Case 1: Illustrative control room

In the *Illustrative control room* the physical and virtual space qualities are combined in order to explore how complex and sometimes even invisible object of control activity could be made understandable and perceivable for human operators.

Use context and user activity: Monitoring and control of the electricity transmission system

Space qualities and situation awareness: The challenge that arises is how information is presented to the operators. Control room space can be seen as a representation of a complex process behind. It should mediate an overview of the status of the process in understandable and illustrative way. Operators should be able to obtain a picture from the object of their supervision and follow the progress of the process even in some processes the area of supervision is extensive or the observed magnitudes might not be visible (e.g. voltage). In order to be able to better illustrate the relationship between pieces of data and the supervised object new kind of digital pictures representing the state and the nature of the process situation has to be developed. This is because some representations are significantly easier to work with as the representational form of the problem makes visible to most relevant constraints implicit in the problem. The relevance for improving process comprehension and situation awareness is expected by facilitating operators' seeing connections between elementary data and higher level functions. In the Illustrative control room, it should also be important not to restrict too much the presentation elementary features of the process that serve as background for implicit building of meaningful patterns of process states.

Technological possibilities: We expect that the illustrative qualities of control room environments could be facilitated by employing new visualization techniques and philosophies as well as through innovative use of advanced AR/VR solutions and multimodal interface technologies.

Data collection: Audio and video recordings from the user interviews (within themes: general work and context description and operators' earlier operational experiences), design workshops and training simulator excursion.

5.2.2 Case 2: Interactive control room

Interactive control room metaphor is a combination of the physical and social space qualities.

Use context and user activity: Complex energy production process monitored and controlled by operating grew from the main control room.

Space qualities and situation awareness: In Interactive control room case the focus is on possible use of different kind of interactive surfaces in control room environments as a crew's cooperative tool. For example, in a digitalized control room the control operations are done by using keyboard and mouse control. Thus, the place of execution and the physical form of control operations (physical space quality) has changed when compared to the conventional analogue control room setting where the control operations were done through the wall-mounted control panels and consoles. With the computerized graphical user interface (GUI) that is controlled with a mouse and a keyboard, there is no mechanism to be aware of the practices of other crew member as all their actions look the same (social space quality). This makes it also harder to reflect others activities in relation to own activity and realize what their control operations (gestures) are referring to. The control room space should be able to mediate information about the development of the situation, operators' activities and use of available resources within the control room. According to our conception of the human cognition these improvements in physical and social space qualities should support comprehension of process overview and situation awareness because the bodily bases of cognitive functions are used more extensively and these are further used to facilitate the collaborative resources of cognition.

Technological possibilities: Our assumption is that through innovative use of interactive surface technologies, i.e. multi-touch displays, digital tangible objects and large screen displays, in control room environments, the control room's physical and social space quality can be promoted.

Data collection: Audio and video recordings of the design workshop/ testing session concentrating on the use of combined 3D large screen displays and multi-touch tabletop system and user interviews (within themes: qualities and potential usefulness of tested technologies and user experience). Questionnaire data summarizing users' evaluations on user interface features and experience of presence.

5.2.3 Case 3: Boundless control room

In the last case study, *Boundless control room*, the combination of the virtual and social space qualities are explored.

Use context and tasks: Monitoring and control of complex industrial production process in cooperation between the main control room and field "probes"/operators. The focus is on especially the challenges of distributed operation and maintenance and field work extending the view on operating crew.

Space qualities and situation awareness: Controlled entities are becoming increasingly complex in size, dynamic and functionality with the advent of new technological advances. Nowadays, it is possible to collect and more widely represent information from the controlled process. However, in order to enable this amount of specified process information more local and detailed data from the process needs to be collected. This challenges the cooperation and communication between the personnel in the main control room and the ones working in the field. It can be said that the control room in a way spreads over the whole supervised area and employs actively also the recourses in the field. In this kind of setting it is essential that the control room functions as a mediating surface between the operative parties and helps them to maintain a shared understanding of the current status of the plant and its relation to potential future states. As a result, the control room space comes flexible and it can adapt its functions and structures according to the prevailing process situation and the needs of the human operators as well as the whole operative organization.

Technological possibilities: By exploiting the network and mobile technologies it is possible to support collaboration and enable communication that is needed for creating more global awareness of the significance of complex process phenomena. The Boundless control room diminishes the persistent division between blue and white collar work by abolishing the white collar workers' monopoly over higher level information.

Data collection: Audio and video recordings from the design workshop. Future control room conceptions and operational stories (written and visual form of presentation) produced by pairs of designers from the Metso Automation design organization.

6 Results

6.1 Case based-results

6.1.1 The illustrative control room

The *illustrative control room* metaphor was defined to be one in which the physical and virtual space qualities are combined in order to explore how complex and sometimes even invisible object of control activity could be made understandable and perceivable for human operators.

The case chosen to demonstrate the Illustrative control room metaphor was Fingrid. Fingrid is the electricity transmission system operator in Finland. From the Fingrid's control rooms the nationwide grid is monitored and operated and they are responsible for the functioning and the development of the grid system in Finland. The operators that monitor and take care of the transmission of the electricity are responsible of an activity that is also socially significant. Thus also the question of how usable and intuitive the control systems are from the operators' point of view is essential.

Fingrid's motivation to participate in the Illustrative control room case study was driven from the survey that was internally made in Fingrid in order to recognise the development and visualization needs in their current control rooms and interfaces. Therefore, they found the Illustrative control room case a potential way to find new ideas and solutions to the visualization question of the electricity grid. Questions that rose from Fingrid side were the possible use of more geography based presentation (e.g. maps), the possible new illustrations from the magnitudes that so far has been presented numerically and possible use of new visualization techniques (e.g. animation, 3D).

The user-involving design method
The Illustrative control room case was build upon two parts: The *literature review* and the *user-involving study* of the activity of electricity grid operations and of the control room environment.

The *literature review* covered three different areas: 1. Power grid operation work, 2. currently used and possible future visualization techniques for representing electricity grid and, 3. information visualization principles. The literature review answers to the second research question (2. What kind of new visualization solutions there are and how they could be applied to support power grid operation? (See details in Koskinen, H . Järvinen, P. Valli, S. and Norros, L. 2010: Tilannetietoisuutta edistävä älykäs valvomo - Havainnollinen valvomo: Case Fingrid. VTT-R-01902-109).

The *user-involving* study of the operator activity was carried out with Fingird's operative personnel during the winter 2009. All together 5 operators took part to the interviews, from which 3 operators came from Fingrid's Power Systems Control Centre and 2 operators from the Network Control Centre. The method composed of operator interviews and two design workshops with those operators who had participated in the interviews.

The interviews took part at the work place of the operators, who were interviewed individually. The interview had two major parts: The first part concentrated on the generic psychological work demands i.e. core-task demands of the work as well as more general nature of the electricity grid operation environment. The second part was more situation-centred and it used Critical Decision Making CDM method (Crandall et al. 2006) to reveal more detailed what kind of operational situations interviewed operators had experienced especially challenging. Based on operators' situational descriptions 5 scenarios were formed. These scenarios were further discussed in the next phase of the study in design workshops (examples of the scenarios can be found in Koskinen et al 2010).

Design workshops followed the interviews. Two design workshops were arranged at VTT Virtual laboratory in the spring 2009. The same operators who were interviewed participated also at the design workshops. The design workshops were targeted to especially to give answers to what kind of information requirements and demands for information presentation the operators recognise.

The content of the workshop was organised according to the challenging operational situations that operators had described during the interviews. The situations had been transformed into a form of scenarios. We prepared 5 different scenarios, which were presented to the operators in a form of a table that captured the order in which the events had occurred, the information available at the situation and the actors and recourses that had been involved in the operation of the situation. The scenarios were then discussed through once at a time with all operators. The table was complemented during the discussion.

<u>Design issues</u>
The results of the discussions of the workshops with regard to each scenario were synthesized into major design issues.

As the focus of this case study was the *Illustrative control room* metaphor it was natural that the subjects discussed most those themes that were related to the question of information presentation:

- The operators expressed that there is a clear need for the use of *more visual and more illustrative representations* to complement and compensate the numerical information that the operating system provides at the moment. Also, related to the form of presentation of information *more systematic approach to* the use of colours and other visual design solutions within the system interfaces was suggested.

- Operators also wished the systems to support them to acquire *multiple and alternative views* to the process information. This includes the system to support *effective navigation* (e.g. easily move from one view to the other), *scalability* so that it could be possible to get closer view to the items/elements of the system that they wish to know more about and *filtering* in order to quickly reach the specific information needed at the situation.

- Operators also recognised the need for *geographical information* and *map based representations* but the benefits of those seamed to be tightly coupled to some specific operational situations. In many quickly evolving disturbance situations operators could make use of more detailed and local geographical information to effectively locate source of the problem. However, in normal operation the benefits of geographical information presentation were not thought to be so evident.

- In addition to the presentation of information that *dynamically evolves* from the events of the present, operators wished to be provided with recordings of the *history of operations.* They thought that these recordings could be useful to give insights to the situations and tasks that they are presently handling. However, this kind of information should be more *easily and quickly accessed* than it is the case at the moment.

During the case study, also many subjects related to the *Boundless control room* metaphor were raised on the discussion. Many different actors participate to the activity of power transmission operation and supervision.

- According to the operators the *communication and cooperation between the different parties* could be supported by introducing new tools (e.g. mobile tools for field workers) that could mediate relevant information across the whole operative organization.

- In this kind of highly networked power grid operation activity *the successful integration of the interface elements* of the systems plays an important role. This was mentioned several times in the workshop discussions and operators expressed it to be one of the most critical areas of development to meet the challenge of managing and exploiting the control space effectively.

The *Interactive control room* metaphor was also though to be relevant in the context of operating the grid. There are a lot of interactions between operators, the two main control rooms and with the recourses and materials in the field.

- One function that the control room space should fulfil is to support and enable interactions that are meaningful for the operation. In Fingrid’s control rooms the *large screen displays* has already been used for some time and they were seen as an integral part of the transmission operating system. On the large screen display operators prefer to show pictures that help them to get an *overview from the functioning of the grid system and its key elements*. Also having a *display from the phone system* on large screen display was perceived useful as it provided operators assistance for the coordination of the tasks and handling of the phone traffic. However, it was thought that developing the usage practices of large screen displays and content that is specially designed for being presented on large screens should be pursued as this was seen a way to offer more comprehensive picture of the grid system and a way to effectively mediate the interactions within the system.

6.1.2 The interactive control room

Interactive control room metaphor is a combination of the physical and social space qualities. The case study carried out within the Interactive control room metaphor was intended to explore the possibilities of the new interactive surface technologies in the context of control and monitoring of the energy production process.

The interactive control room case study was done in close cooperation with Nase (Novel Affordances of Smart Environments) –project. In the Nase-project the focus had been to develop interaction concepts and prototypes for more efficient and intuitive usage of smart environments. Within the Nase-project the research efforts related to two different application areas. One was to yield new ways to support work in complex industrial processes. The other was to develop tools and platform to support multimodal and multi-device user interaction in smart environments generally.

The motivation to cooperate in the Interactive control room case study was driven from the shared interest to explore the potential of the interactive surfaces for the support of industrial process control work. The central element of the Nase-project was "Affordance Table" that has been developed for supporting collaborative management of industrial processes. The Affordance Table is a metaphor of a collection of smart tools augmenting the monitoring and control of the power production process. A concrete result of the Nase-project was the development of the multi-touch supportive tabletop surface. For further development of the tabletop and for its acceptability among the aimed professional users it is essential to involve expert users and their knowledge to the design process early enough. This was the motivation that drove these two projects, NASE and TILAVA, to hold a user testing session/ design workshop together on interactive surfaces and especially on multi-touch interaction.

<u>The user-involving design method</u>
The Interactive control room case study was build upon a design workshop/ user interface testing session that was aimed to involve users to the development of the three-wall large scale display and multi-touch tabletop system.

The *user-involving* study of the potential usefulness of the interactive display system was carried out with Nase-project and a group of potential users of the system in the autumn 2009. All together six participants took part to the *testing session*/ *design workshop*. The participants had little or no experience in the use of multi-touch or large screen displays, at least in the connection of process control activity. The method composed of *user interviews* and two kind of *testing sessions*, one concentrating on exploring the users' preferences and associations on multi-touch / gesture based interaction with the tabletop and the other concentrating on usage of the display system as whole in navigational search tasks.

The case study was realized in the Katve virtual environment at VTT's Digitalo-building. All the six participants were interviewed individually. The *interview* had two major parts: in the beginning of the workshop participant were made familiar with the goals of the workshop followed by *a short background interview.* After the main testing session *a debriefing interview* was carried out to gather more specified information about 1) the potential usefulness of multi-touch technology; 2) user experience on the tested navigation techniques and the multi-touch display itself; and 3) the perception of the 3D virtual environment (presented on three large scale displays) and the use of the integrated virtual reality wall display and multi-touch tabletop system.

The *testing session* had two major parts: training phase, in which the participants could make themselves familiar with the use of multi-touch tabletop and the basic interaction gestures that were designed for it as well as practice the use of the introduced navigation methods. The second part was the main testing phase during which the usefulness of the designed display system was test by using twelve search scenarios. During the testing session participants were also asked to complete two kinds of questionnaires (assessment of the tested interaction qualities and the experience of presence while using the system).

Design issues

In the design workshop the use of the multi-display system was demonstrated and tested by using the scenarios and a functioning prototype system. The scenarios/ operational situations developed for the testing session were aimed to help users to experience the display system through a meaningful and realistic use situation. The idea behind the use of these scenarios was that the users would be able to better address the specific aspects of the interaction and get realistic feeling about the functions and the performance of the system.

The results of the discussions and the testing phase were synthesized into major design issues. As the focus of this case study was the *Interactive control room* metaphor it was natural that the subjects discussed most were related to the use of the multi-touch screen and other interaction related qualities:

- All the *basic manipulations and touches* serving functions like moving, zooming, selecting and rotating were experiences intuitive and easy to learn. But when testing the different *interaction techniques* while performing a variety of scenarios differences started to came out. The interaction method where the objects were manipulated directly by touching them was experienced easiest to apply. And the method where the object was manipulated by using separate control elements on the tabletop was experienced most difficult to use.

- While performing the scenarios the participants needed also to do fine-grained manipulations on the touch screen. This aspect of interaction became an issue with all of the tested interaction techniques. *Performing accurate and fine-grained operations* was not supported in a satisfactory way. Particularly when designing for the purposes of the process control activity this aspect should be paid careful attention.

- The multi-touch tabletop was not designed to give *tactile feedback* from the executed operations. This aspect was also mentioned in many of the discussions and evolutions as a lacking feature in the interaction. It caused difficulties and operation mistakes (e.g. manipulating accidentally wrong interface object) especially when the tabletop and large scale displays were used together.

- The interaction qualities of the multi-touch tabletop were considered most suitable for *navigation and browsing* purposes. It was also suggested that the multi-touch supportive tabletop could be used for problem solving tasks when it is necessary to view larger document and pictures/drawings or manipulate large scaled 3D objects.

During the case study, participant also brought up subjects that were related to the *Illustrative control room* metaphor.

- Participants imagined that in an industrial process control context, the multi-touch tabletop and the large screen displays could *complement* each other, and the combined interactive display system could have potential for providing an overall medium for the navigation and information presentation in these industrial environments. The kind of presentation format (virtual reality) and way of interacting (multi-touch) was thought to be useful in situations in which there is a need for monitoring places and objects that are not approachable, observable or visible.

- In addition, it was found out that the system provided participants with *multiple and alternative presentations* to the supervised entity. The tabletop provided 2D presentation of the layout of the building where the search task was performed whereas the wall displays provided 3D presentation of the same building. Therefore it was possible to easily navigate between the presentations and change the point of view just by raising the sight from the tabletop to the wall display and wise versa.

The *Boundless control room* metaphor was also thought to be relevant especially when the virtual reality presentation on the wall displays were able to provide participants with a view to physically distant place.

- The *combined display* system was also considered to be useful in a context of remote operations.

6.1.3 The boundless control room

In the last case study, the *Boundless control room*, the combination of the virtual and social space qualities were explored. The Boundless control room metaphor extends traditional view of the operating grew and aims to involve the whole organization more tightly to the process control activity. The focus is on especially the challenges of distributed operation and maintenance and field work.

The case chosen to demonstrate the Boundless control room metaphor was Metso Automation. Metso Automation is a company which produces control systems and automation solutions for the purposes of different industry sectors.

The motivation for Metso Automation to participate in the realization of the Boundless control room case study was their interest on developing information applications and interface elements that enable all the members of an organization to access and share the operative actions. The ongoing trend towards more distributed and networked operation of complex systems challenges the cooperation and communication between the personnel in the main control room and the ones working in the field and other parts of the organization. The aim to explore and provide solutions to support these processes droved Metso Automation participation.

<u>The user-involving design method</u>
The Boundless control room case study was realized in a form of cross-disciplinary design workshop.

The *user-involving* design workshop was carried out with group of diverse experts of Metso Automation design department at autumn 2009. All together 18 experts took part to the workshop, from which 2 participants were invited from the other TILAVA project company party, Fingrid and the rest of the invited participants represented different expertises of Metso Automation design department.

The *design workshop*, underneath the theme of “future control room concept” took place at the Metso Automation design department auditorium. The workshop had three major parts: The first part was dedicated for facilitating presentations in which the goals of the project were introduced and the participants’ mind settings were tuned to the future by demonstrating the possibilities of the novel user interface technologies. In the second part the workshop participants were working in pairs of two. During this group working phase the pairs were producing operational stories and conceptions of future control room environments into the online working space (Wiki-format). Participants were asked to co-create and describe the essential elements of the future control room concept and build an operational story around it. The format (e.g. written, pictures) in which the concept should be presented was leaved open. In the last part of the design workshop the pairs were introducing and explaining the basic ideas of their conceptions and the others had possibility to comment and ask questions.

<u>Design issues</u>
In the end of the design workshop the operational stories and concepts created by the pairs of participants were described and discussed in detail. The idea behind the use of these imagined operational stories was that it would be easier for the participants to address the important elements and features of their concepts when they were able to place it to some specific use context and operational situation.

The results of the workshop were then synthesized into major design issues. As the starting point for the case study was the *Boundless control room* metaphor it was natural that in many of the stories and concepts created during the workshop the focus was on highly distributed and collaborative process control and monitoring work:

- As said in the many of the operative stories and control room conceptions the work was thought to be highly distributed and collaborative. In this kind of context the *fluency and effectiveness of the communication and change of operational information* is essential. In many of the described concepts participants made use of the social media applications (e.g. instant messaging, online communities)

- It was also thought that the *online communities and other social media applications* could be effectively used for problem solving and operating support. For example some specific problem occurred in the process could be discusses and solved with the other experts by contacting the online expert forum/ advisory group.

- The use of new technologies could also other ways to ease remote work and operation. *Mobile communication* applications and *wireless connections* were also considered to be useful in a context of remote operations.

During the design workshop, participant also brought up ideas and concepts that were related to the *Illustrative control room* metaphor:

- The participants expressed that there is a clear need for the use of *more visual and more illustrative representations* in control room environments. Numerical and text-based information should be complement and compensate with presentations that are in visual form. In their concepts participants were for example exploring the possibilities to present alarms and events lists more visually.

- Participants also imagined the future systems to support operators to acquire *multiple and alternative views* to the process information. Also in many of the conceptions the interface was described to be formed according to the *hierarchical abstraction levels*. This form of presentation would provide the operators with easy access both to the high level overview information as well as the more detailed lower level elementary information.

The *Interactive control room* metaphor was also though to be relevant in the context of complex process control activity:

- Many of the pairs had recognized the need for better navigational solutions. When the amount of information that the system can provide is increasing constantly operators must be equipped with better tools to manage and navigate within the large amount of data. The *levelling strategy of interface* presented above was also considered to be part of the solution how the system could support *effective navigation* (e.g. easily move from one view to the other)

- Touch interaction was not discussed greatly but for interface to be able to provide effective *scalability* of information (so that it could be possible to take closer view to the items/elements of the system) participants for example suggested the of use *gesture based interaction techniques*.

6.2 Concept results

The challenging goal of the present study was to develop bases for and propose a conceptual framework for the design of future control rooms. As was explained in Chapter 3 the idea was to work towards this goal via design cases during which the needs of the end-users and experience from earlier design practice could be exploited effectively. At the same time we urged to create conceptual tools to facilitate the comprehension of the end-users' and designers' experiences. Hence, theoretical concepts concerning the targeted design object, the control room were introduced. The concepts were, in the last phase of the study, used further to synthesize the case results and to form the aimed design framework. The result is presented in this chapter.

The framework to be presented in this chapter includes two parts: the "Placeness profile" and the "User experience of placeness "("UX'Place"): situation awareness, sense of control and sense of presence.

6.2.1 Placeness profile of the design solutions

The "Placeness profile" is a design tool that could be used by the designers to draw attention to the spatial characteristics of control room systems that are important for the appropriate functioning of the control room in its future usage. The intention is to inform the designers of such spatial features that have psychological, social and cultural implications. In other words the "Placeness profile" aims at supporting the designer to create such a control room space that would later, when used by the operators, be developed in to a *control room place*.

<u>Activity demands</u>
The "Placeness profile" tool is depicted in Table 1. The tool is structured according to two basic dimensions. The first dimension refers to the generic *activity demands* of process control work. In order to become a place the control room needs necessarily to support fulfilling these demands. In the Table 1 five central process control demands are included.

The control room space is required to “enable monitoring the process and detecting deviations”, “enable diagnosis of process state”, “enable operations” , “enable collaboration and coordination”, and finally to “enable learning and design of instruments”.

Spatial functions

The second dimension of the “Placeness profile” tool refers to the spatial metaphors that we created by combining the physical, social and virtual space characteristics. In the framework we name these spatial metaphors in more general terms changing the term “room” to “space”. Hence we call them as the “Illustrative control space”, the “Interactive control space” and the “Boundless control space”. Each of these metaphors describes a certain *function* that a space should serve. In a real room all functions are present to smaller or larger degree. In other words, we see that in order to become a work place for process control the control space should, to necessary degree, illustrate well the on-going process and the situation, it should serve interaction with the process and within the operators, and finally it should serve remote and mobile control.

Spatial affordances

The three different control space functions are relevant to the activity demands in different ways and to different degree. This is manifested in the framework by introducing spatial dimension under the spatial functions. The dimensions represent *spatial affordances* that the control room should have in order to support the activity demand. The present dimensions were drawn from the empirical material we collected in the three case studies. We also utilised our theoretical sources, in which features relevant to the process of forming places were mentioned. It is clear that the presently available dimensions must be considered as tentative. In the present form of the tool we have included 20, 21 and 14 dimensions to illustrative, interactive and boundless control spaces, respectively (see Table 1).

	Illustrative control space	Interactive control space	Boundless control space
Enables monitoring the process and detecting deviations	Real-time information Trend information Illustration of change Illustration of parameter relations Functional purpose Structural relations Spatial relations Transparency of automation Degree of granularity (layers)	Control of set points Sharing monitoring task Modifiability of monitoring view Availability of multiple views	Remote information access Mobile information access Multi-unit connections
Enables diagnosis of process state	Predictive information Accumulated information Design basis Degree of granularity (layers)	Availability of multiple views Availability of shared problem solving	Remote expert advice
Enables operation	Direction of change Transparency of operations Transparency of duration	Operability of UI element Accuracy of operation Feedback of operation Information of achieved effect Control of operation sequences Shaping of modes of operation	Mobile operations Remote operations Multi-unit operations Information of achieved effect
Enables collaboration and coordination	Proximity of objects Transparency of on-going action	Number of co-workers Allocation of tasks Ease of communication Rhythm of communication Availability for participation Synchronization of operation within physically same space Spatial relations	Availability for communication Transparency of co-workers Rhythm of communication Synchronization between physically distant operations Allocation of tasks
Enables learning and design of instruments	History of events Record of operations	Possibility for testing Feedback of success	Operational experience

Table 1. Placeness profile.

For the frame to be useful for the design there is a need to define the dimensions and their poles more concretely. At the present we see possible that instead of concretizing the dimensions already in the method, this process of characterising the dimension could be seen as step of the design process itself. Finding the appropriate level of defining the dimensions requires some testing in our further research work. Another issue that should be tested in our further work is how best to support the designer to find forms of presentation or interface technology to addresses the aimed spatial affordance most appropriately.

The further idea is that particular design solutions may manifest the spatial affordances to different degree. The design solutions may take, or may be targeted to take, certain position at certain dimensions. As a result a profile could be drawn of the solution. This profile portrays a potential for “placeness” of the control room solution. Hence, we coined the tool the “placeness profile”.

The above described first part of the proposed framework i.e. the “placeness profile” is constructed on conceptually defined characteristics that may be reflected upon. This tool supports an analytical observer’s point of view to the designed solution. Designers together wit end-users can use the frame to reflect on the spatial features of the control room.

6.2.2 User experience of place (UX’Place)

The second part of the proposed framework takes clearly the users’ point of view as it focuses on the experience gained of the use of the solution, or of earlier corresponding solutions.

The idea of considering user experience (UX) as an indication of appropriate design of control room spaces, and to include UX as part of the targeted framework emerged during the work. In the beginning, thanks to our reading of relevant literature and our own previous work it was already clear that in process control the operators’ need to have a good situation awareness, i.e. to comprehend the process situation in order to act appropriately. As a matter of fact, appropriate action is an indication of good understanding of the requirements in the situation.

Later, we first adopted the idea of Harrison and Dourish (1996) of the distinction between space and place and that placeness should actually be the targeted “good” that the design products for collaborative work should manifest. It also became clear, as the cited authors also state, that placeness emerges during the use of the environment or system. During this process the users, in our case the operators, perceive, use, appropriate, resonate, adapt, and change the affordances of the environment. Through this process also the human operators themselves change: operators learn the ability to act and create patterns of acting in the environment. This mutual process of formation may partly be consciously comprehended and reflected by the operators. Yet, much of this process runs on a pre-reflective level. The point we want to make is, that creating “placeness” reflects this mutual moulding process. Moreover, we see that capturing the non-reflected events of this process may require considering the emotionally laden experiences.

In the Chapter 3.3 we already proposed the experiential qualities that we consider relevant for evaluating the emergence of placeness. As we wrote, three “experiential indicators” of the development of the placeness of an environment could be proposed. These are *situation awareness, sense of control* and *sense of presence*.

An experience of *situation awareness* emerges via working in the control room together with fellow operators. Situation awareness is manifested as an improved interpretation of the process state and accomplishing actions that are in place in the situation. Situation awareness is an active product of experience in work and the operators' own moulding of the control room environment.

Sense of control may be seen as the feel by the operators that the control room place provides them with necessary means to act appropriately in the different situations that they might encounter during the work. Sense of control is also connected to understanding one'sown role with regard to fellow actors and automation.

Sense of *presence* may in our connection be interpreted as a feel by the operators that the process is in actually in operation. The operators feel that what is currently happening is not repetition of something previously experienced, and that they themselves have had and can have an effect on the behaviour of the process.

All above mentioned qualities of user experience support the operators of a complex process to stay in the loop of an often highly automated process, help them to comprehend the significance of different events in the process with regard to the safety and productivity envelope, and support their role and motivation.

It is the target of our future work, first, to test the above ideas and, second, to propose with the aid of which kind of measures these three qualities should be considered.

7 Conclusions

The leading goal of this project was to propose a conceptual framework to facilitate design of future control room design. This was an ambitious target for a one year project. On the one hand, the idea was to work closely together with experienced designers and end-users in case studies, and on the other hand, seek relevant theoretical bases to conceptualise the control room in a new way.

More *focused aims* of the project were, via the case studies to

- acquire experience and find novel possibilities and technologies to improve spatial characteristics of control rooms,
- acquire empirical evidence of the central need of the operators, and finally, to
- test by conceptual means possibilties to facilitate end-user input in the design process.

Presently we may state that the three concrete aims were at least tackled and partially also fulfilled via the case studies. In the first case study that was accomplished together with Fingrid Oyj and that focused on the illustrative space function we were successful with regard to all three goals. Hence, via a literature review and by exploiting VTT expertise concerning visualisation technologies it was possible to define new technological solutions for visualisation. We also accomplished plenty of experience concerning user demands in grid control. This new knowledge completes international literature, which is rather scarce with regard to descriptions of work in electric grid control. In the first case study we worked intensively with the end users, and we also found useful the methods created for a user-involving process.

The second case study was accomplished in collaboration with the VTT NASE-project. It focused on testing possibilities that new types of interactive surfaces could provide. The interactive function of spaces was the special focus of this study. In this case study the first aim was fulfilled very well and internationally new results were achieved concerning the use of interactive surfaces. In this case study user needs were tested with regard to challenges that haptics put as a new interface modality in complex control tasks. More context- related requirements were not considered in this case study. The VTT Katve virtual environment was used in this project as a means of creating an environment for user-involving design.

The third case study was accomplished together with Metso Automation Oyj. The company provided a possibility to work together with a diversity of experts in the design organisation on issues relevant for future innovative control room design. The boundless control space i.e. remote and mobile control were the particularly challenging topics, but also other issues were considered both from the technological and end-user demand point of view. Also in this case all the three goals of the project were tackled. Beyond these results, the third case study contributed in an important way to the more synthetic goal of the project, i.e. to the design frame work.

The proposing of a *design framework* is certainly the most important result of the project. The framework focuses on the development of spatial aspects of smart work environments, in particular the control rooms. We formulated a theoretically and empirically founded proposition of how to improve control room design. In this we proposed how the formerly separate design areas, i.e. the interface design and the control room layout design, can be integrated by emphasizing the functions and meaning of space for activity. The TILA program gave us a good start by proposing that in the projects of the program space are considered from physical, social and virtual space point of view. We took this advice as our challenge, and proceeded by developing a new conceptual framework that would integrate these three aspects in a conception of space. The central idea of this framework is that instead of focusing on spaces and their physical characteristics only, the design should be targeted to facilitating places in which people act. We also identified affordances of space that could be relevant to support creation of places. Placeness is the targeted “good” in the design of control spaces. A novel idea that also emerged was that good control spaces, i.e. those having the character of a place, will probably be experienced by the operators as supporting situation awareness, sense of control and sense of presence.

The framework proposed in the project is tentative. Our hope is that it will serve as a source for good hypotheses and design ideas to be tackled in our own and our colleagues´ further work. In order to receive comments and feed back the project group published results of this project on international forums.

During the project we created a *number of new connections* with researchers in Finland and abroad. Human factors experts worked together with experts from different fields of engineering during the case studies. The case studies also created new connections between researchers and designers and end-users from the participating companies.

New *possibilities and ideas for future work* were created during the short time of the project. There are good prospects that the work will be continued in the Tekes-driven SHOK research programmes. We have also established connections with OECD Halden Reactor Project with regard to innovative control room design. Design companies from France and Denmark have also shown interest in collaborating with the Tilava-project to develop the proposed ideas further.

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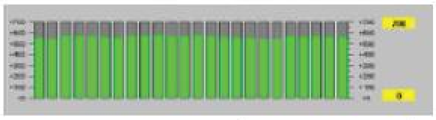
Attachment 1 : Control room metaphors - Illustrative control room

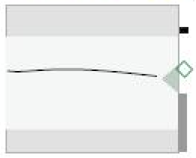
Havainnollinen valvomo

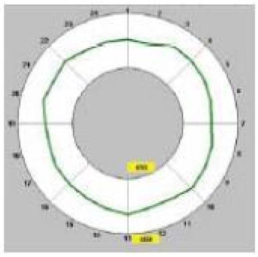
Havainnollinen valvomo

Taustalla oleva tilaominaisuuksien yhdistelmä on fyysinen ja virtuaalinen tilaominaisuus.



Valvomotila on representaatio edustamastaan monimutkaisesta kohteesta. Sen tulisi pystyä viestimään kohteen tilaa mahdollisimman todenmukaisesti, luotettavasti sekä operaattoreille ymmärrettävässä muodossa. Joitakin valvottavia kohteita (esim. laaja alue) ja järjestelmän ominaisuuksia (esim. jännite) ei ihmissilmin pysty havaitsemaan ja kuitenkin operaattoreiden olisi pystyttävä muodostamaan kuva kohteen tilasta ja ymmärtämään kohteessa vallitsevia suhteita. Näiden havainnollistamiseksi ja "näkyväksi tekemiseksi" valvomotilaan on luotava uudenlaisia järjestelmän tilaa ja luonnetta ilmentäviä kuvia.





Ratkaistavia kysymyksiä

- **Minkälaisia kohteita Havainnollisesta valvomosta valvotaan?**
- **Minkälaista työtä siellä tehdään?**
- **Miten hallinnan tunnetta tuetaan Havainnollisessa valvomossa?**
- **Mitä eri ominaisuuksia Havainnollisella valvomolla tulisi/ voisi olla?**
  - **Tarjoaa havainnollisen yleiskuvan valvottavasta kohteesta**
  - **Helpottaa kohteessa vallitsevan tilanteen hahmottamista**
  - **Tukee poikkeamien aikaista havaitsemista ja selvittämistä**
- **Minkälaisia teknologioita voitaisiin käyttää ja kehittää tukemaan työtä Havainnollisessa valvomossa?**
  - **Visualisointi tekniikat ja filosofiat**
  - **Multimodaaliset käyttöliittymät**
  - **Lisätty- ja virtuaalitodellisuus tekniikat**

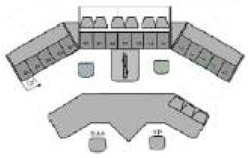
Attachment 2 : Control room metaphors - Interactive control room

Vuorovaikutteinen valvomo

Vuorovaikutteinen valvomo

Taustalla oleva tilaominaisuuksien yhdistelmä on fyysinen ja sosiaalinen tilaominaisuus.

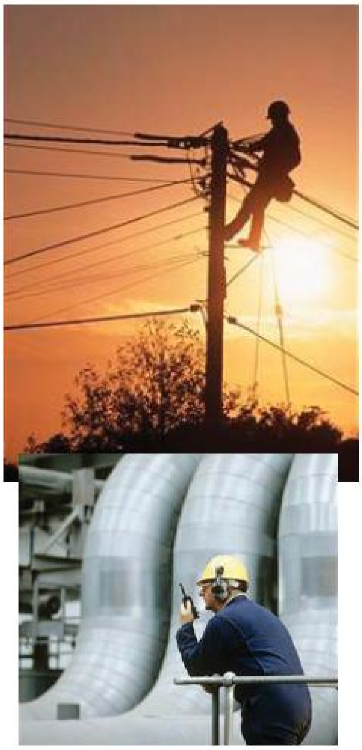
Digitalisoitumisen myötä operointitoimenpiteet nykyvalvomossa suoritetaan työasemanäytöiltä hiiriohjauksella. Vaikka periaatteessa operoitava kohde on pysynyt samana, operoinnin fyysinen muoto ja sijainti valvomotilassa ovat muuttuneet. Operaattorit ovat raportoineet ongelmaksi sen, että he eivät enää pysty monitoroimaan valvomotilassa toisten tekemiä operointitoimenpiteitä ja punnitsemaan niiden merkitystä omaan toiminnan kannalta (sosiaalinen tilaominaisuus). Myös navigointi monimutkaisessa hierarkkisessa näyttöjärjestelmässä saattaa aiheuttaa tilanteita, joissa operaattori hetkellisesti tuntee olevansa ”eksyksissä” kun informaatio ei enää sijaitsekaan staattisesti tietyssä paikassa valvomotilassa (fyysinen tilaominaisuus).



Ratkaistavia kysymyksiä

- **Minkälaisia kohteita Vuorovaikutteisesta valvomosta valvotaan?**
- **Minkälaista työtä Vuorovaikutteisessa valvomossa tehdään?**
- **Miten hallinnan tunnetta tuetaan Vuorovaikutteisessa valvomossa?**
- **Mitä eri ominaisuuksia Vuorovaikutteisella valvomolla tulisi/ voisi olla?**
  - **Tukee tiimin ja vuoron yhteistoimintaa**
  - **Mahdollistaa nopean järjestelmään vaikuttamisen**
  - **Tukee tehokasta navigointia käyttöjärjestelmässä**
  - **Tukee luonnollista vuorovaikutusta ympäristön kanssa**
  - **Toisen operaattorin huomion ja toiminnan kohteen ilmaiseminen**
- **Minkälaisia teknologioita voitaisiin käyttää ja kehittää tukemaan työtä Vuorovaikutteinen valvomossa?**
  - **Interaktiiviset näyttöpinnat**
  - **Multimodaaliset käyttöliittymät**

Attachment 3 : Control room metaphors - Boundless control room



Rajaton valvomo

Rajaton valvomo
Taustalla oleva tilaominaisuuksien yhdistelmä on fyysinen ja sosiaalinen tilaominaisuus

Valvottavasta kohteesta voidaan kerätä ja esittää tietoa entistä kattavammin ja monipuolisemmin. Tämän mahdollistamiseksi tarvitaan kuitenkin myös paikallista, kohteen yhteydessä toimivaa ja usein liikkuvaa valvontaa. Valvomotilan voidaan nähdä laajenevan ja haaroittuvan verkkomaiseksi, ja valvomotilan tavallaan voi nähdä siirtyvän kohteen sisälle tai ainakin lähemmäksi sitä. Samalla syntyy kuitenkin tarve kommunikointiin paikallisten ja keskitettyjen toimipisteiden välillä. Yhteistä kohdetta ja valvonta- sekä operointitoimintaa koskeva tieto tulisi pystyä välittämään ja jakamaan kaikille käyttötoimintaan osallistuville, ja käsitystä kohteesta muodostaa yhdessä. Tuloksena olisi joustava valvomotila, jonka rakennetta ja toimintaa voitaisiin esimerkiksi muuttaa ohjattavan kohteen tai sen tilanteen (esim. huoltoseisokki) tarpeiden mukaan.

Ratkaistavia kysymyksiä

- **Minkälaisia kohteita Rajattomassa valvomossa valvotaan?**
- **Minkälaista työtä Rajattomassa valvomossa tehdään?**
- **Miten hallinnan tunnetta tuetaan Rajattomossa valvomossa?**
- **Mitä eri ominaisuuksia Rajattomalla valvomolla tulisi/ voisi olla?**
  - **Tiedon välittäminen kaikille toimijoille yhteisen tietoisuuden muodostamiseksi**
  - **Päävalvomon ja kentän välisen kommunikoinnin edistäminen**
  - **Tukee joustavaa ja tilanteen mukaista toimintaa ja liikkumista**
- **Minkälaisia teknologioita voitaisiin käyttää ja kehittää tukemaan työtä Rajattomassa valvomossa?**
  - **Mobiiliteknologiat**
  - **Sosiaalinen media**
  - **Paikannus ja sensoriteknologiat**