HFC

HFC – forum for human factors in control

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RAPPORT

TITTEL

Visualisering og grensesnitt
Resultater HFC Forum, 6. til 7.april 2011, møte #13

FORFATTER/REDAKTØR

Johnsen S. O.

OPPDRAGSGIVER(E)

HFC forum

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SAMMENDRAG

Denne rapporten dokumenterer presentasjoner, relevante artikler, agenda og deltakerliste fra HFC forum møtet den 6. til 7.april 2011 i Oslo, møte nummer 13. De vedlagte presentasjonene er:

G.A. Jamieson	Coping With Automation with Future Human-System Interfaces
B. Hove	Interaction Design - Toolbox Talk
K. Husøy	Beyond Best Practices - Concepts for Future Operator Interfaces
A.Clark	Design of visual facilities within collaborative decision environments
K. Lukander	Novel Interaction with Computers
Besøk hos ABB	
P. Ø. Braarud	Human Factors Integrated System Validation
P. Holter	User Centric Design for Professional Applications
Workshop – Fordeler og ulemper med storskjerm	
C. Skorup	Intelligent Visualization of Alarm Information
S. Kvalheim	Collaboration Between Onshore and Offshore Supported by Video

STIKKORD	NORSK	ENGELSK
GRUPPE 1	Menneskelige Faktorer	Human Factors
GRUPPE 2	ISO 11064	ISO 11064
EGENVALGTE	Sikkerhet	Safety

INNHOLDSFORTEGNELSE

1 Evaluering av møtet og innspill

1.1 Innledning

I denne rapporten gis en samlet oversikt over HFC møtet den 6.-7.april i Oslo, med presentasjoner, relevante fagartikler (”papers”), oppsummering av evaluering fra deltakerne, og liste over alle deltakere.

I det nedenstående har vi oppsummert fra de evalueringene som deltakerne leverte inn.

1.2 Evalueringer

Generelt synes det som om de fleste er godt fornøyd med HFC møtene og formen som benyttes, med samling over to dager. Kommentarene vi får er generelt konstruktive og positive, med gode tilbakemeldinger på det faglige og sosiale utbytte. Forumet er bredt med mange forskjellige deltakere, og utfordringen er å gi alle noe, både forskere, konsulenter og industrideltakere. Vi får derfor et bredt sett av innspill med forskjellige meninger.

Tilbakemeldingene gikk i hovedsak ut på at programmet var vellykket og foredragene fikk generelt meget god tilbakemelding. Det var gode foredrag, god servering og interessante deltakere som gjør det mulig å få til konstruktive diskusjoner.

1.3 Formen på HFC møtene

Tilbakemeldingene er generelt positive til formen på møtene. Det ble påpekt at det var viktig med tid til debatter, og opphold mellom de forskjellige innleggene.

1.4 Samarbeid med HFN i Sverige

HFN nettverket fra Sverige vil fortsatt gjerne delta og bidra inn i møtene, men ber samtidig om at vi fra Norge deltar inn i de seminarer og møter som HFN arrangerer.

1.5 Tema og forelesere til de neste HFC møtene

Vi har i tidligere plannotat skissert følgende grove møteplan for HFC møtene, ref tabell-1.

Tabell-1: Tema og forelesere i HFC forum foreslått tidligere

Periode	Forslag til tema og forelesere
Vår 2011	HF i endringsprosesser, ”Design for resilience”, Perspektiver som Actor-network theory (ANT) i HF granskninger.
Høst 2011	Inntog i det globale: Språk, kultur, tidsforskjell, HF i global setting.
Vår 2012	Fokus på HF i andre land, som USA og Sørøst Asia – erfaringer, muligheter og trusler

Av tema som ble trukket frem som spesielt interessante til neste møte, kan nevnes:

- Sammenlikning av Human Factors arbeid og standarder rammeverk i ulike bransjer som fly, kjernekraft eller helsevesen.
- Human Factors design av arbeidsprosesser.
- HF utforming av sikkerhetskritisk utstyr, ref ”Operasjonell HF” (i mangel av et bedre begrep), dvs HF i prosessanlegget / der hvor det fysiske arbeidet skjer. Forslaget er

inspirert av denne hendelsen: http://www.aftenbladet.no/energi/olje/1364020/Miljoefarlig_tabbe_av_Statoil_.html
- Praktiske utfordringer med Human Factors inne offshore – hva er organisatoriske, tekniske og menneskelige utfordringer?
- Human Factors design av håndholdte enheter?

Av forelesere ble følgende nevnt (eller har vært trukket frem tidligere uten at de har fått plass):
- Ronald L. Boring (Human Reliability Analysis), C. Weick eller J.Reason, K. Haukelied, Cato Bjørkli, E.Hollnagel.
- Fra følgende miljøer hadde det vært spennende: Fraunhofer FKIE(Tyskland), MIT User Interface Design Group (USA).
- HFS – Dr. Jørgen Frohm, Frode Heldal, Ingrid Danielsson – ønskes mht interaksjonsdesign. J.Frohm eller K.Gould – Automasjon eller lean production.
- M.Endsley (Situational awareness), G.R. Hockey fra Univ of Leeds, Mark Young.
- Interessant å utvide HF mot community of practice og praksisfellesskap som J.S.Brown, P.Duguide – eks. hvordan mobiliserer man et praksisfellesskap?

1.6 Kurs og forelesninger innen human factors

Ved UiS har de et kurstilbud innen MTO (menneske, Teknologi, Organisasjon), se www.kursguiden.no/kurs/Allmennfag-etter-og-videreutdanning/Samfunnsfag/MTO-Menneske-teknologi-og-organisasjon/

Ved NTNU arrangeres innføringskurs innen human factors, se: http://videre.ntnu.no/pages/doc2894700.xml

1.7 Kontakt opp mot Human Factors fagnettverket i Europa og USA

For de som er interessert i faglig kontakt opp mot Human Factor nettverket i Europa og USA viser vi til: *hfes-europe.org* – som er den europeiske Human Factors and Ergonomics Society. Beskrivelse: ”*HFES - The Human Factors and Ergonomics Society, Europe Chapter, is organised to serve the needs of the human factors profession in Europe. Its purpose is to promote and advance through the interchange of knowledge and methodology in the behavioural, biological, and physical sciences, the understanding of the human factors involved in, and the application of that understanding to the design, acquisition, and use of hardware, software, and personnel aspects of tools, devices, machines, equipment, computers, vehicles, systems, and artificial environments of all kinds*.” HFES er tilknyttet den internasjonale Human Factors and Ergonomics Society, Inc. Se *www.hfes.org*.

1.8 Lenke til hovedoppgave

Stud. M. Hessaroeyeh ved UiO, presenterte sin masteroppgave i forrige HFC forum. Vedlagt er lenken til oppgaven: "HF/HMI challenges in modern control system design in the Norwegian oil and gas industry": http://www.duo.uio.no/sok/work.html?WORKID=105770

1.9 Mindre oppdatering av CRIOP

CRIOP metoden har blitt oppdatert med referanser til det nye HMS regelverket som trådte i kraft fra 1/1-2011. Siste versjon av metoden er tilgjengelig som word og PDF versjon fra www.sintef.no/Projectweb/HFC/CRIOP/.

2 Agenda og deltakerliste

2.1 Agenda for HFC møtet den 6.-7.april

Vedlagt ligger justert agenda for HFC møtet den 6.- 7.april 2011, oppdatert med korrekte forelesere.

Dag 1		Foreleser
11:00-11:30	Registrering	
11:00-12:00	Lunsj	
12:00-12:30	Velkommen og presentasjonsrunde blandt deltakerne	
12:30-13:15	Coping With Automation with Future Human-System Interfaces	G.A. Jamieson/CEL
13:15-13:45	Diskusjon/Pause	
13:45-14:15	Interaction Design - Toolbox Talk	B. Hove/HFS
14:15-14:30	Diskusjon/Pause	
14:30-15:00	Beyond Best Practices - Concepts for Future Operator Interfaces	K. Husøy/ABB
15:00-15:30	Diskusjon/Pause	
15:30-16:00	Design of visual facilities within collaborative decision environments	A.Clark/EPSIS
16:00-16:15	Diskusjon/Pause	
16:15-16:45	Novel Interaction with Computers	K. Lukander/FIOH
17:00-18:30	ABB – Bedriftsbesøk	
20:00	Middag	
Dag 2	Innlegg med spørsmål etter	
09:00-09:30	Overview of and Experiences from Human Factors Integrated System Validation	A.Bye/IFE
09:30-10:00	User Centric Design for Professional Applications	P. Holter/Halogen
10:00-10:15	Diskusjon/Pause	
10:15-11:30	Introduksjon til workshop Workshop - Fordeler og ulemper med storskjerm	A.Bye/IFE
11:30-11:45	Diskusjon/Pause	
11:45-12:15	Intelligent Visualization of Alarm Information	C.Skorup/ABB
12:15-12:45	Collaboration Between Onshore and Offshore Supported by Video Conferencing Solutions	S. Kvalheim/Safetec
12:45-13:00	Avslutning og oppsummering	
13:00-14:00	Lunsj	

2.2 Påmeldte og deltakere

Nedenstående tabell lister opp påmeldte og deltakere i HFC møtet den 6.-7.april.

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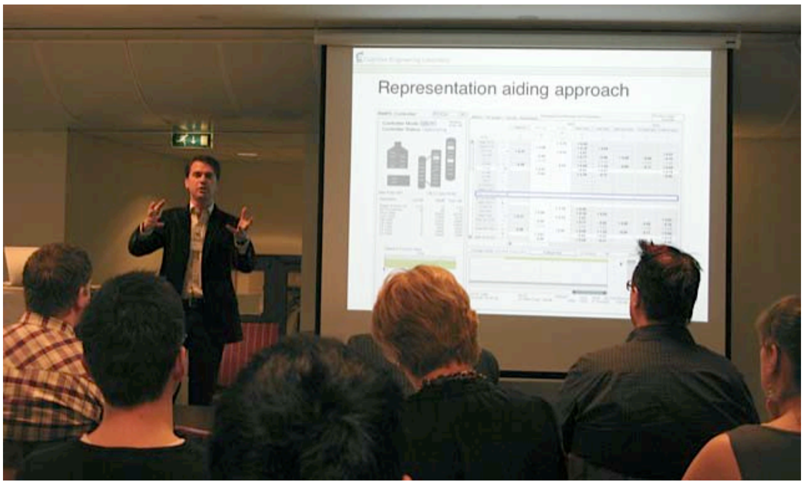
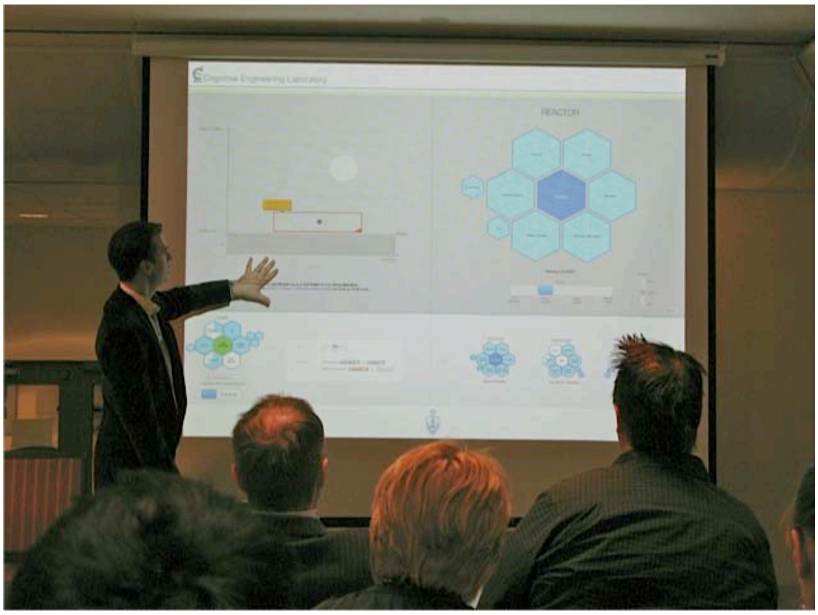
2.3 Fotografier fra HFC møtet

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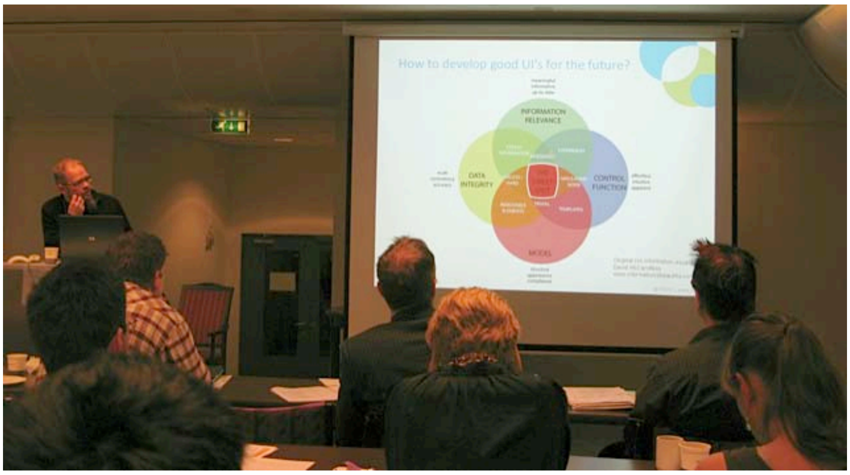
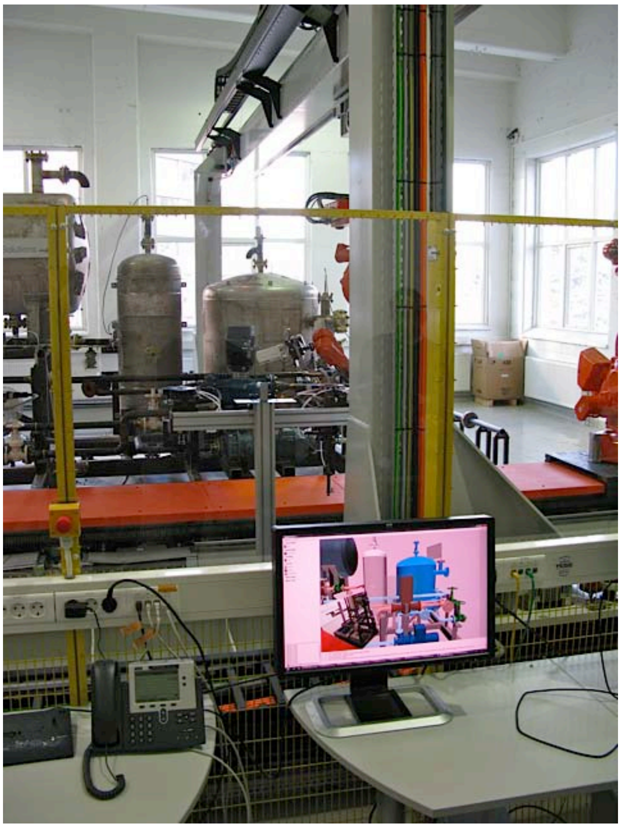
REACTOR


How to develop good UI's for the future?
INFORMATION RELEVANCE
DATA INTEGRITY
CONTROL FUNCTION
MODEL




Automation
TC
Navigation
DP

HFC

Coping With Automation with Advanced Human-System Interfaces

G.A. Jamieson

Mere informasjon:
http://cel.mie.utoronto.ca/publications/conference-papers.htm

Coping With Automation with Advanced Human-System Interfaces

Greg A. Jamieson, PhD, P.Eng.
Cognitive Engineering Laboratory
University of Toronto

Chemical process equipment is basically the same now, as it was in the 1930's, or at least the 1950's. The trays, [knock-out] drums, compressors, heaters, steam systems have not - and probably will not change. The fundamental nature of process equipment operation has been well established for a very long time. Modern methods of computer control, and process design have not, and cannot, change the basic performance of the bulk of process equipment. **These tools just seem to have made learning about the working of the equipment more difficult**. (Lieberman and Lieberman, 1997, p. xv)

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Human-automation interaction challenges

- Out-of-the-loop unfamiliarity
- Clumsy automation
- Automation-induced errors
- Inappropriate trust
- Behavioural adaptation
- Skill loss and skill shift

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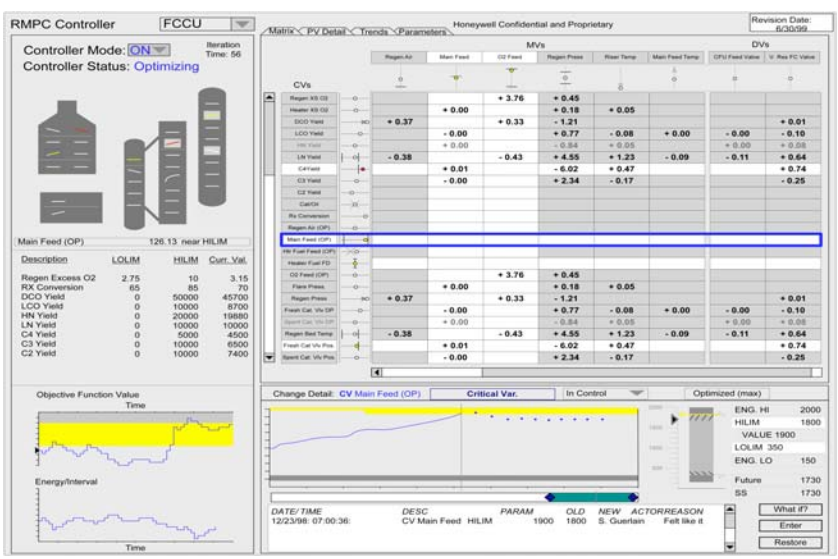
The envisioned world

- Substantial increase in the scope, autonomy and authority of automation
- Joint human-automation control
  - Human monitoring during normal ops
  - Human solving problems during abnormal ops
- Design challenges:
  - How will operators **think about** automation?
  - How will operators **interact with** automation?

Two design perspectives

- Representation aiding
  - Automation as machine
  - Opaque – needs to be made visible (transparent)
  - E.g., Guerlain, Jamieson, Bullemer & Blair (2002)
- “Team player” metaphor
  - Automation as agent
  - Isolated – need to be made directable
  - E.g., Christoffersen & Woods (2004)

Representation aiding approach



To be a team player, an agent must:

1) Agree to work together with other agents and operators
2) Be able to model other participants' intentions and actions
3) Be mutually predictable
4) Be directable
5) Be able to make their status and intentions obvious to their teammates
6) Be able to observe and interpret signals of status and intentions
7) Be able to engage in negotiation
8) Enable a collaborative approach
9) Be able to participate in managing attention
10) Help to control the costs of coordinated activity

Klein, Woods, Bradshaw, Hoffman & Feltovich (2004)

"Making automation a team player in complex work settings has proven to be considerably harder to do than to imagine." Cook, Nemeth & Dekker (2008)

Coping With Automation with Advanced Human-System Interfaces

Lars Hurlen, Christer Nihlwing, Gyrd Skraaning,
Arild Teigen, Håkon Jokstad, Greg A. Jamieson

Halden Reactor Project

Design premises and decisions

Premises

- Central control room
- Single plant
- Automation suite
- Operating crew
- Agents

Decisions

- Integrated/Separated automation and process representations
- Allocation of agent interaction tasks
- Types of automation to include

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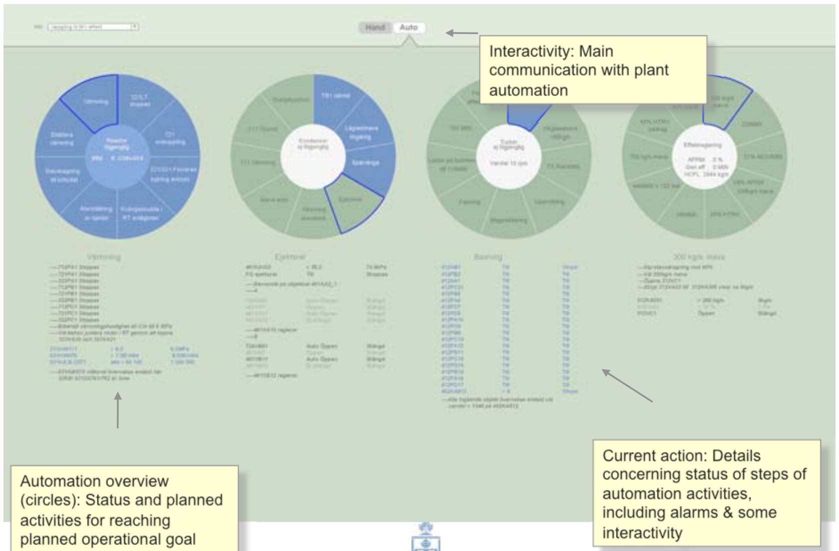
Automation Overview Display



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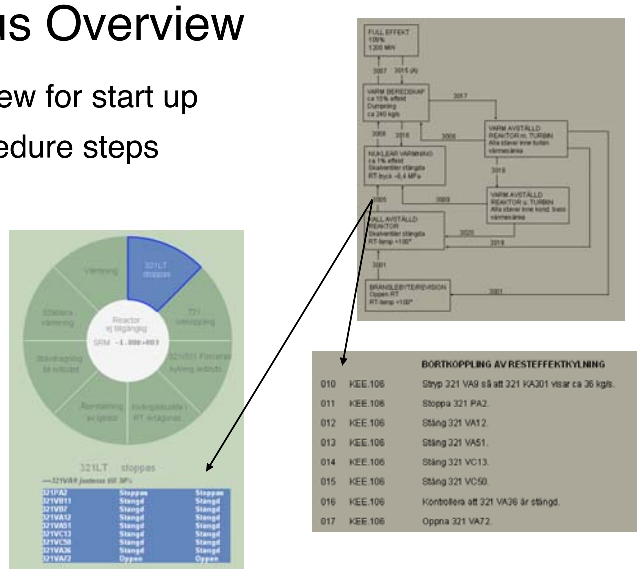
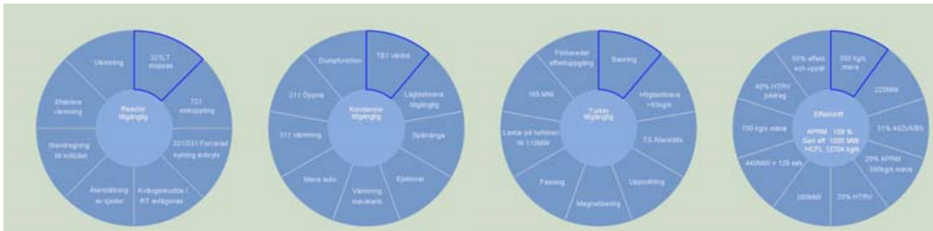
Plant Status Overview

- Provide overview for start up
- Visualise procedure steps

Each sector represents part of the start up procedure



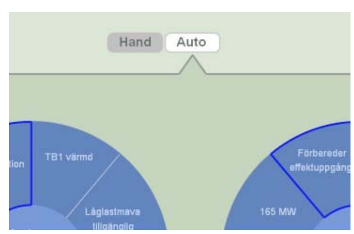


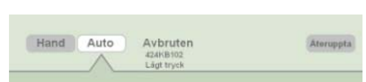
Full power

Cold start-up

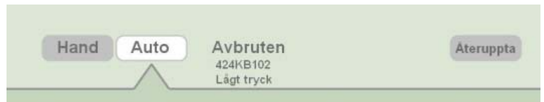
Plant Automation

- The Plant Automation (PA) agent is controlled from the Plant Status display
- Manual (”Hand”): PA is not active
- Auto: PA is active and working to reach the goal of 50 % reactor power
- If a problem occurs the PA pauses, maintaining current plant status
- When the operator decides, he/she can press ”Continue” and the PA resumes task execution





Example: PA is on hold due to a problem with seal steam, and waiting for operator action to resolve the problem and issue the ”Continue” order.



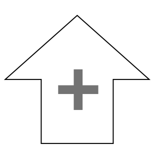
Evaluation

Main findings:

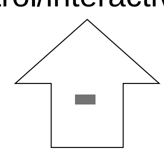
- Overall task performance with PA not different from no PA condition; detection performance impaired
- Displays increased trust in automation
- Design was generally much appreciated by operators

Usability issues:

- Good overview
- Supports prediction

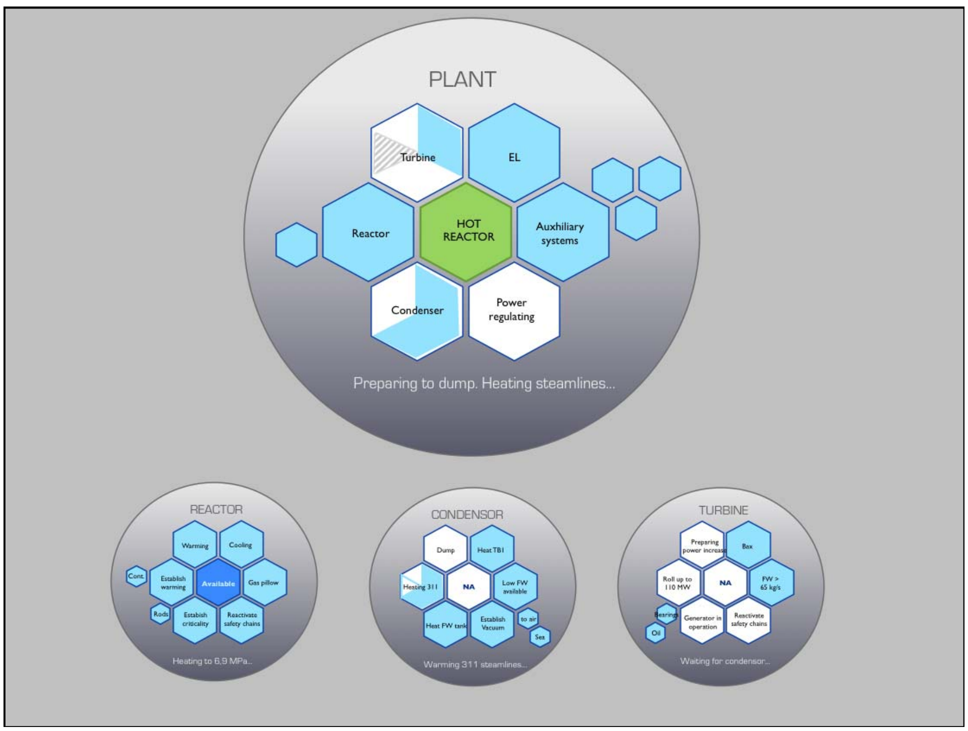


- Unclear strategy when PA paused/on hold
- Operators want more control/interactivity



What aspects of agents to control?

- Autonomy (a.k.a. level of automation)
- Task execution speed
- Error handling behaviour



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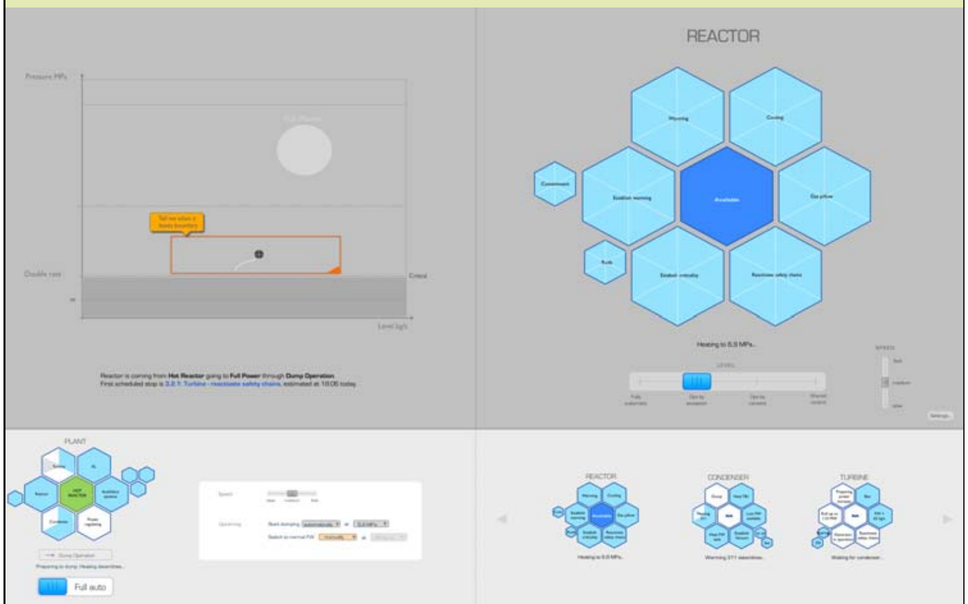

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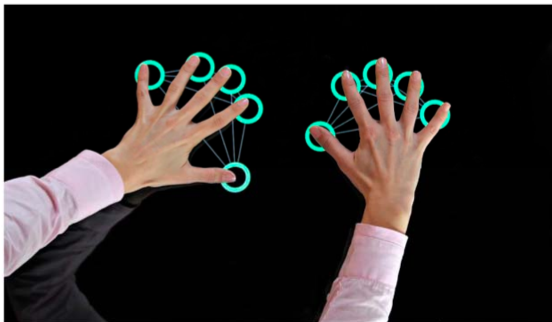
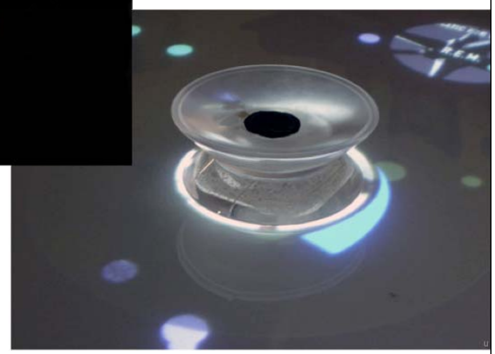
Limitations and extensions

- To date, a procedure execution agent
- Lingering doubts about “design basis” line of thinking
- Re-think operator roles and competencies

Future HSI





Multi-touch
Tangible UI

The MPC Elucidator: A Case Study in the Design for Human–Automation Interaction

Stephanie Guerlain, *Associate Associate Member, IEEE*, Greg A. Jamieson, Peter Bullemer, and Ronald Blair

***Abstract*—In this paper, we describe the design of a decision support system for operators of model-based predictive controllers (MPC). MPC is a form of advanced automatic control that is increasingly common in process operations due to its ability to control and optimize large sections of a process. A cognitive task analysis revealed that current operating displays, which rely on displaying tables of numeric information across several display pages, do not effectively support human operator monitoring, diagnosis, and control of MPC. This case study shows how we applied representation aiding and workspace management design principles to better support the human–automation interaction requirements of monitoring, understanding, and adjusting these complex, semi-autonomous process controllers. We show how effective user interface design can significantly reduce the complexity of operating with advanced automation, and can lead to improved understanding of how the automation works.**

***Index Terms*—Automation, design methodology, display, graphical user interfaces, human factors, industrial plants, knowledge representation, process control, process monitoring.**

I. Introduction

THE many challenges of human–automation interaction have been well documented. For example, automation can sometimes make easy tasks easier, while exacerbating hard tasks [1], [49]; automation can be "brittle," only working well for the situations for which it is designed [15], [50]; and it may be difficult for operators of automation to maintain situation awareness [4], [10]–[12], [31], [32], maintain vigilance [31], or effectively calibrate the automation's capabilities or current state [27], [33]–[35], [45], [50], [53]. Despite these issues, automation plays a clear role in improving the throughput, efficiency, and safety of many complex and dangerous operating environments. Empirical research is making steady inroads to understanding how human–automation interaction can be better supported (see e.g., [16], [17], [19], [23], [26], [29], [36]–[38]).

As advanced automation use proliferates in transportation, communications, and process control, familiar human–automation interaction problems tend to arise. In general, these can be stated as problems of how best to monitor the automation, diagnose any problems, and make effective control changes (see [31]). Moreover, it is becoming increasingly necessary to predict the future behavior of highly autonomous controllers [12].

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In this paper, we discuss the design of a user-interface for model-based predictive controllers (MPC), a class of automation technology that is being employed with increasing frequency in refining, pulp and paper, and grinding operations worldwide. We first identified human–automation interaction issues using a cognitive task analysis methodology. We then created a redesign based on the principles of 1) providing representational aids to show the constraints and interrelationships of the controller algorithms and 2) providing a coherent workspace that minimizes the amount of window manipulation and cognitive data integration required to support operators' information needs. These techniques have rarely been applied to elucidate the workings of a highly automated system (although see [42] for a notable exception).

Designing an effective user interface for these types of controllers was extremely challenging due to the complexity of the controller algorithms, the amount of information that is potentially relevant, and the complex interactions of the underlying process. It is hoped that the presentation of this case study will be useful to other researchers and practitioners interested in applying representation aiding and workspace management to effectively support human interaction with highly automated systems.

In Sections II and III, we discuss the design strategies of representational aiding and minimizing workspace management requirements. We then move on to descriptions of model-based predictive control (MPC), the refining environment in which it is often employed, and the current state of the operator interfaces. Following this domain description, we relate the findings of a cognitive task analysis of MPC use in petrochemical refining, as well as a cognitive work analysis of the automation technology itself. The largest section of our paper is devoted to a case study of the design of the MPC Elucidator, a user interface designed to support human–automation interaction with MPC. We discuss in detail how the design addresses the information requirements more effectively than the original user interface design.

II. Representation Aiding

The goal of representation aiding, broadly speaking, is to represent relevant domain, task, and system constraints through visual properties of the display, and thus encourage people to perceive these relationships with little cognitive effort (see [2], [3], [5], [7]–[9], [13], [18], [20], [21], [24], [25], [37], [39]–[41], [44], [46]–[48], and [55] for some examples and discussion). The representation of domain constraints and relationships through graphical user interface components is based largely on the work of Gibson [14]; who argues that people can be attuned to invariant relationships in the environment without having to compute those relationships. Thus, if one can map the structure of such invariant domain properties onto a visual form, it may be easier for humans to recognize abstract concepts or relationships. These and various related concepts have been studied under the headings of representation aiding [52], ecological interface design [48], and the semantic mapping principle [2].

A. Representation Aiding Strategies

One strategy in representation aiding is to map higher-order relationships onto emergent features of the display that can be perceived by the viewer. Conversely, if no corresponding domain relationship exists, then one should avoid using a visual representation that has an emergent feature, as the visual representation has no corresponding meaning. Thus, extraneous use of graphics can be misleading and should be avoided.

A second representation aiding strategy is to represent the dimensional properties of a variable appropriately [55]. For example, object shape is a categorical representation. If one uses shape to represent an interval property such as magnitude, the observer must relate the meaning of a shape to the magnitude of the variable. It is more appropriate to use object size to represent such a variable, because the observer can directly perceive that a larger object is greater than a smaller object, which has direct relationship to the ordinal dimension of the variable being represented.

A third representation aiding strategy is to put data into its appropriate context. For example, in assessing the value of a parameter, one needs to know the current values versus the expected values, e.g., to know if a value is within normal constraints or exceeding constraints. Displaying a number without reference to expected ranges and setpoints takes the data out of context, and requires that people remember the setpoints and ranges of interest and make mental calculations to determine if a variable is "normal" or not. Often, displaying a value in analog form makes it easier to directly see how a variable is performing relevant to regions of interest.

Appropriately designed representational aids can significantly minimize the cognitive complexity of a task. Representations can be quite powerful, and very effective, if the information that is being represented accurately maps to the relevant information in the domain of interest. Zhang and Norman [55] have studied the *representational effect*, showing that people can easily solve a problem that is informationally equivalent to the normally difficult Tower of Hanoi problem if the constraints on the problem are represented externally through equivalent physical constraints, thereby making wrong moves impossible to perform.

B. Advantages

The major strength of analog representations of data as opposed to text-based display is that many relationships can be conveyed directly using visual properties of the display. In doing so, access to the embedded knowledge is granted through perception of the display, as opposed to doing mental calculations to infer the desired information. For example, in monitoring a process, people are often interested in such higher-level questions as: How is the process behaving? Are key parameters increasing, decreasing, going out of safe limits, or operating normally? Sometimes, this kind of information can be mapped directly into a graphical form, so that the user can obtain relevant information by simply glancing at the display.

Visual representations are also good at preserving the spatial, topological, and geometric properties that are important for certain kinds of reasoning tasks, such as in solving physical or geographic problems. In trying to understand the representational benefits of a diagram, Larkin and Simon [25] noted that object properties could be indexed by their location, rather than by an explicit label. Furthermore, many properties can be represented simultaneously in the same location, and these properties may all be relevant to the problem.

In a text-based display that only shows raw data values in numerical form, the viewer must remember the set points and relationships of interest, compare those values with others that may or may not be displayed, and perform mental calculations to determine the required information. Over-reliance on digital forms makes it difficult to put data into context, makes it difficult to highlight events, creates the problem of fleeting data, and increases the need for the user to navigate through virtual data space to collect and integrate related data [30], [51].

C. Potential Challenges and Limitations

Despite the strengths of the representation aiding approach, there are several challenges to applying this technique. One potential problem with a representation aiding approach is that, whereas the designer of the display may be able to encode properties of the domain into properties of the display, users may have difficulty decoding that display, i.e., not knowing how to properly interpret the display [52]. Each representation makes some information about a problem salient while making other information more difficult to see [20], [26], [28]. Thus, we run a risk of highlighting some information at the expense of hiding other information.

A second issue is that, in many complex domains, the number of potentially important relationships is very large; sometimes too large to be represented with only one visual representation. In these situations, representation aiding can be preceded by modeling efforts that parse the information space in context sensitive ways [30]. The results of such analyses can be used to highlight important relationships as they become relevant for a given task situation. In this approach, one develops a set of representations that are sensitive to the person's problem solving context, and makes more detailed data available as a person narrows down the search space.

A third limitation is that visual representations are not necessarily the best means to portray all types of information effectively. For example, procedural information may be better represented with a message-based display [38] or a hybrid display that uses both text and graphics [23]. Thus, the designer must be aware of when the use of representational aiding is appropriate given the information presentation requirements.

Finally, the design and implementation of effective representations takes considerable skill and insight. It is often difficult even for experienced designers to develop effective representations and many of them require specialized, nonstandard programming techniques to implement. Thus, representational aids are often difficult to include in a design because they are too difficult and expensive to develop.

D. Conclusion

The preceding discussion demonstrates that there are many potential advantages and limitations to the use of representational aiding. It is important to point out that, in many cases, good design practice can lead to an exploitation of those advantages and avoidance of the limitations. Presenting successful design evolutions of representational aids is a valuable step in helping others to develop these design skills. This is particularly true in the case of representational aids for complex automation, because very few examples exist in the literature (cf. [39]).

III. Workspace Management

Workspace management refers to the window manipulation, command input, and navigation activities required when working with computer-based systems [54]. Workspace management activities take away from the primary task (e.g., process monitoring and control), as users must ask themselves, "What information do I need, where is it located, and how do I call it up?" Due to the large amount of potential information that can be displayed on the screen and the generally fixed screen area, users must manage their workspace carefully. This involves making decisions as to what information to call to the forefront, at the expense of potentially missing important information on screens that are not being displayed [17], [30]. Woods and colleagues have likened this to looking through a "keyhole," as only a small portion of the big picture can be viewed at a time [51].

There is a tradeoff between having more information available on one screen and preserving spatial separation between data elements. In the former case, the designer risks cluttering the display, while in the latter case, the designer risks forcing the user into excessive navigation as well as imposing a memory load. If the task does not require parallel access to the data, then having it spread across screens is not as problematic as when the task requires that the data be integrated by the user. Therefore, one design strategy is to determine what corresponding information needs to be viewed in parallel and group that information on the same screen. In general, the goal is to minimize workspace management as much as possible. A recent study by Burns showed that subjects were able to perform diagnoses better with an integrated display that overlapped all the required information in the same spatial area, than with a display that spread the same information onto separate windows [5]. The extreme density of information in Burns' integrated display challenges commonly held notions about what is considered "cluttered." Given that effectively combining related information into a coherent "picture" is one of the goals of representation aiding discussed above, these two design strategies should be complementary.

IV. Refinery Operations and Model-Based Predictive Controllers

In Sections II and III, we discussed two design techniques for building interfaces for complex systems. In this section, we shift our attention to a description of one particular class of such systems and an increasingly common form of advanced control employed there.

A. Refinery Operations

Refineries and other process plants typically encompass a large physical area, with scores of multi-storey towers, hundreds of pumps and vessels, and thousands of sensors, controllers, instruments and valves. Such plants are typically subdivided into functional units. Operations teams comprised of field operators and board operators are tasked with controlling one or more units of the plant. Field operators are responsible for physical interaction with the unit (e.g., making rounds, taking readings and samples, and adjusting manual valves). Board operators use schematics, trend graphs, and alarm pages to monitor and control the process from a control room via a distributed control system. A board operator can change the setpoint of variables under regulatory control (e.g., flows, levels, pressures, or temperatures) within his/her unit. The operator can trend each variable, evaluate its associated alarms, and potentially see where that variable is in a schematic display.

B. Model-Based Predictive Control

Model-based predictive controllers (MPC) are multi-input, multi-output automatic controllers that take over much of the monitoring and control responsibility for a section of the process [22]. They are designed to optimize the process (e.g., maximize production variables or minimize utility costs) subject to various process parameter constraints. Well-designed MPCs can keep the process running smoothly and push production as well as, or better than, most operators. Because of its high profit potential, this advanced automation technology is being introduced into petrochemical, pulp and paper, and grinding operations throughout the world.

MPC uses an empirical process model to predict how changes in one process variable will affect others. There are three types of variables contained in the model, namely controlled variables (CVs), manipulated variables (MVs) and disturbance variables (DVs). A midsize MPC might have 20 to 30 CVs, 6–8 MVs, and 2–3 DVs.

1) *Controlled Variables (CVs)* are the process variables that MPC is trying to keep within constraints or at setpoint.
2) *Manipulated Variables (MVs)* are the variables (usually control valves) that MPC can adjust in order to keep all the CVs within their constraints while trying to meet optimization objectives.
3) *Disturbance Variables (DVs)* are those variables that have an impact on the process and can be measured, but not controlled (e.g., ambient air temperature). Knowledge of these independent variables can help MPC act to offset CV excursions before they take place.

Once installed, MPC is monitored and adjusted by board operators. The operator's primary responsibility is to set high and

TABLE I
SAMPLE SITE VISIT AGENDA

1 hr.	Site control engineer(s) brief us on their process, indicating where MPC controllers have been being installed, and why.
1 hr.	Site control engineer(s) review current MPC operator interface(s) in use at their plant.
4 hrs.	Interviews with, and observations of, control engineers and operators to understand: • How training occurs and how effective it is. • How the introduction of MPC has changed operators' jobs. • How MPC failures are detected and diagnosed. • The changes and adjustments that should and should not be made. • The ease/difficulty of predicting the effect of controller changes. • User likes and dislikes and Frequently Asked Questions (FAQs)

low limits for each variable within a range specified by the process engineer. MPC then decides what the target value for each MV and CV should be based on its empirical model of the process, the constraints as defined by the engineers and adjusted by the operator, and optimization objectives. Thus, MPC is relying primarily on *range* control, delivering setpoints to the lower level regulatory controllers. Relieved of this lower level control task, the operator is theoretically available to control larger sections of the process. However, in addition to the traditional process schematics, trend, and alarm pages, the board operator must also monitor the MPC, using an additional set of display pages that are installed when the MPC is introduce to the unit.

V. Cognitive Task Analysis

A. Method

We conducted a cognitive task analysis [43] to understand how and when operators currently interact with, and ideally should interact with, MPCs. We performed a second analysis on MPC itself to understand how this control technology is engineered. This second analysis followed the premises of cognitive work analysis [47], although the modeling frameworks normally associated with that approach were not employed. Both of these analyses were based on data gathered via on-site interviews with seven control engineers and observations and targeted interviews with ten operators, for a total of 45 hours of on-site data collection. Multiple operators at several different units were interviewed to get a cross-section of user experience with MPC, and to understand how different MPC characteristics (robustness, size, etc.) affected their use. A similar agenda was followed at each site (see Table I).

In addition to the on-site activity, our team extensively reviewed the MPC documentation and spent approximately ten hours working with designers of the automation to gain insight into the engineering foundations of MPC. Throughout the design process, these domain experts critiqued the new interface in terms of its faithfulness to the automation technology.

B. From Cognitive Task Analysis to Information Requirements

We did not explicitly use a formal modeling technique (such as GOMS, abstraction hierarchy, or the operator function model, [6], [28], [30], [48]) in performing our cognitive task analysis/cognitive work analysis (CTA/CWA). Rather, we developed a comprehensive set of information requirements based on the activities described above. We conducted several iterative reviews of the information requirements with control engineers and operators to ensure completeness.

Next, we analyzed the information available in the current displays to support these activities. We found several deficiencies in information availability or information aggregation (i.e., either the information was not available at all or it was cumbersome to gather and integrate as required for task demands). Finally, we used these information requirements to develop design requirements for the novel interface. The design itself served as our only formal "model" of the operator-relevant domain information properties. Section VI describes this design process in more detail.

C. Issues With the Use of MPC

The cognitive task analysis revealed that it is very difficult for operators to interact effectively with MPC. Specifically, operators have difficulty *monitoring*, *diagnosing*, and *controlling* these advanced controllers. This is due to a combination of the complexity of the controller algorithms, the complex coupling of the large number of variables contained in the controller, and the dynamic nature of the controller's interaction with the process. However, the current user interface is also not well designed to assist operators in these primary tasks. Table II shows the relationship between generic human–automation interaction needs, several MPC-specific examples of those information needs, and the means by which the operator could get that information (if at all) with the current displays. The purpose of this table is to show how our cognitive task and work analyses led to information requirements, which in turn led to the identification of deficiencies in the current user interface. We can see how poorly the current displays meet information requirements by analyzing the number of steps and mental calculations necessary in order to gather the information necessary to make informed decisions.

1) Monitoring: During normal operations, an operator needs to periodically monitor the controller to determine if it is running effectively. Operators refer to this as establishing the 'health' of the controller. This is difficult to ascertain with the present displays for two reasons. First, information about the controller is spread across multiple display pages. One Summary page (or set of pages in the case of a large controller) lists the current value, predicted value, and high and low limits for each of the MVs. A second Summary page lists similar information for each of the CVs, and a third shows the current value for DVs. Fig. 1 shows a sample of one of the CV Summary pages. The effect of this organization is

TABLE II
HUMAN–AUTOMATION INTERACTION WITH CURRENT MPC DISPLAYS (EXTENSIVE NAVIGATION AND DATA INTERPRETATION REQUIRED)

GENERIC HUMAN-AUTOMATION INTERACTION QUESTION	SPECIFIC INFORMATION THAT HELPS ADDRESS GENERIC QUESTION	HOW INFORMATION NEED IS MET (OR NOT) WITH CURRENT DISPLAYS
Monitoring		
What are the automation's objectives?	Which variables are being optimized (either minimized or maximized or targeted)?	For each CV, DV and MV listed, navigate to corresponding detail page. If LINEAR OBJ COEF is negative, variable is set to be maximized, and vice versa. If QUAD OBJ COEF is nonzero, number displayed is the targeted value.
How well are the automation's objectives being met?	Are optimized variables near optimum?	After performing above steps, check each optimized variable compared to target.
What is the current state of the automation?	Which MVs and CVs are at their limit?	For each CV, DV and MV listed, compare value to Lo and High Limits.
	Is MPC currently making large moves? If so, why?	Can possibly be inferred by trending the setpoint of variables in the controller.
	Are an abnormally large number of MVs at their limit? This is an indication that the controller is losing control.	For each MV, compare Value to Lo and High Limits. Count number of MVs at a limit. Compare to "normal" count, if known.
Diagnosis		
Why is the automation performing poorly? What factors are constraining the controller? Is it possible to relieve the automation's constraints?	What is limiting the controller? e.g., What is preventing it from increasing feed?	Look at Gain/Delay Page to determine which variables are influencing feed. Navigate to corresponding MV, CV, and DV pages to see which of these variables are limited, as described above. If limited, decide if this is what is limiting the controller. If nothing found, navigate to regulatory pages to see if a valves is "wound up".
Control		
How do I make adjustments, taking into account system constraints and objectives of previous operators?	What is the widest allowable range for this variable (as defined by plant engineers, process constraints or best practices)?	Found on detail pages rarely viewed by operators, and not viewable while making control changes.
	What are the delta soft "cushions" set by the engineer?	Found on detail pages rarely viewed by operators, and not viewable while making control changes.
	What recent limit changes have been made for this variable and why?	Not displayed.

that relevant information is highly distributed throughout the displays, resulting in a "keyhole effect" [51].

The second reason that it is difficult to assess the health of the controller is that the data are presented in discrete elements. In order to assimilate higher level information about the controller, users must navigate through the displays to see what variables are currently at a limit, if a particular variable is predicted to be outside its limits, and to note which variables are set to be optimized. Because the current and predicted values of a parameter are displayed in numeric format next to the high and low limits for that variable, operators must do mental calculations to determine if a variable is closer to one limit or another, and to infer how wide the allowable range is.

Noting which variables are being optimized is a particularly intensive task. Operators must select each variable in turn to call up its detail page to see if a nonzero linear or quadratic optimization coefficient is set for that variable (see Fig. 2). To do this, the operator would have to navigate to each CV and MV Summary Page and then click to see the detail page for each CV and MV. Once on these detail pages, the operator needs to check if the LINEAR OBJ COEF is nonzero. If so, then the operator needs to know that a negative value means that the variable is being maximized, and a positive value means that the variable is being minimized. Further, if the QUAD OBJ COEF is set to nonzero, the operator needs to know that the number displayed is the targeted value. These are a large number of steps, each requiring mental processing by the operator. For a controller with 36 variables, at least 40 screens would have to be viewed, with a minimum of 75 workspace navigation activities.

To get a sense of how the controller has been behaving over time, the user's only option is to call up a trend of one or more variables contained in the controller. There are no summary statistics or graphs that the operator can consult. Consequently, operators often rely on alarms or anomalous changes in the more

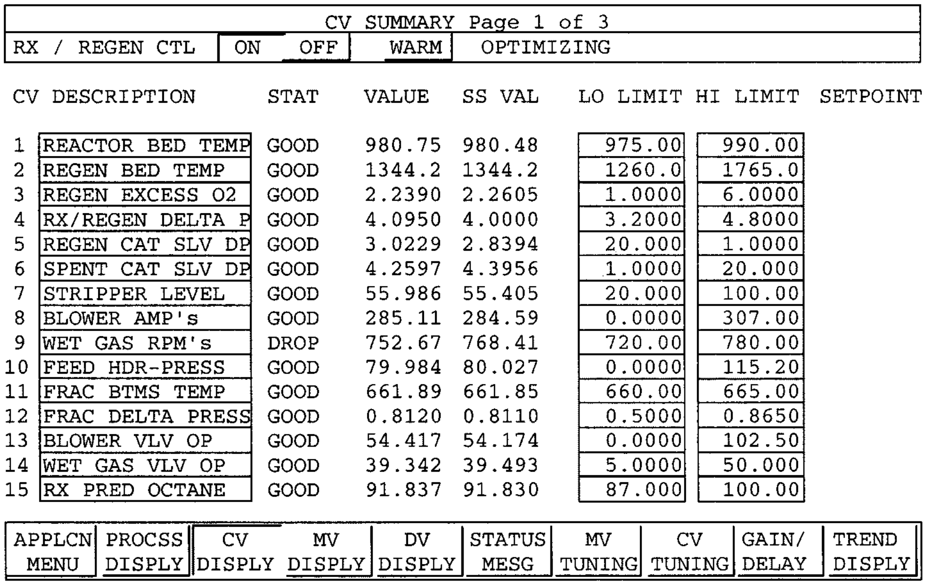


Fig. 1. Example CV summary display.

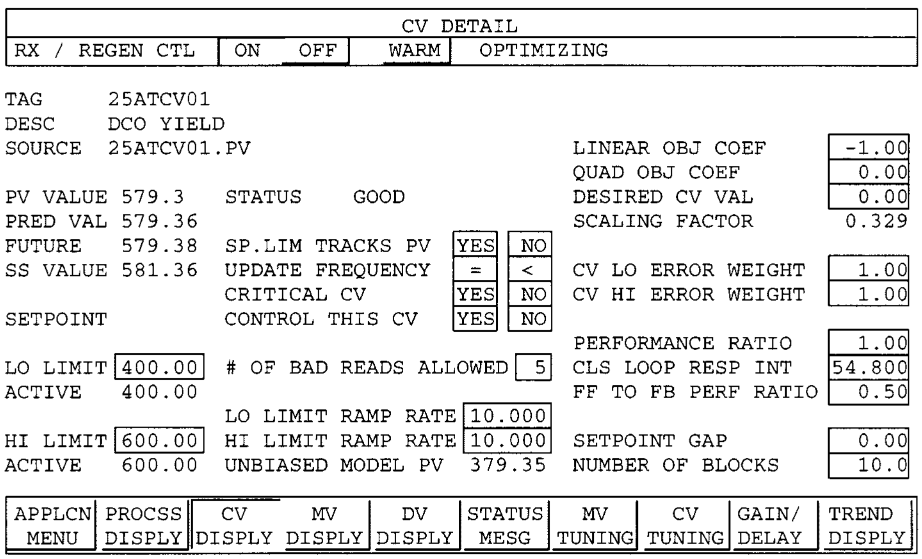


Fig. 2. Example CV detail display.

traditional regulatory displays to alert them to potential problems with the controller.

2) Diagnosis: The difficulty of gathering and assimilating information also has an impact on diagnostic activities. In the course of their monitoring activities, operators will sometimes notice that the controller is behaving in an unusual manner. This is often due to the controller becoming constrained. A constrained controller is one that has exhausted its available degrees of freedom.[1] If MPC becomes constrained, it may take what seem like drastic measures, such as cutting overall production, in order to keep all of the variables in the controller within constraints. If the operator can diagnose which variable is presenting the problem, it is often a simple solution to change the limit range on that variable, take that variable temporarily out of control, or make changes to other parts of the process to relieve that constraint.

Engineers often diagnose the root cause of constraint problems off-line by examining the model algorithm. They do this by using the gain/delay matrix that defines how the model parameters interact. Some board operators will mimic this diagnostic process at their workstation, by using the gain/delay matrix screen on their displays (see Fig. 3). However, conducting this kind of analysis with the current user interface requires navigating through several pages to gather information, hold it in memory, and then make inferences from the collected information. This is because the gain/delay page does not show the current status of each of the variables, so an operator must continuously move back and forth between the gain/delay page that

[1]Available degrees of freedom are calculated as follows: Sum the MVs that are not at constraints. Subtract the sum of the CVs that are either at constraints or constrained to setpoint. If the resulting value is greater than zero, then the controller can maintain control. If the value falls below zero then the controller will shut down. Prior to shutting down, however, the controller will act to retain degrees of freedom. The resulting behavior can be very confusing to an operator.

ONLINE GAIN AND DELAY CHANGE

RX / REGEN CTL | ON OFF | WARM | OPTIMIZING

	CV DESCRIPTION	MV01	MV02	MV03	MV04	MV05	MV06	MV07	MV08	MV09	MV10	DV01
1	REACTOR BED TEMP	-1.0	2.0	-3.5	4.2		6.1	-0.5	0.25			
2	REGEN BED TEMP	4.0				5.9						
3	REGEN EXCESS O2	0.3		-1.0	2.0	-3.5	4.2		6.1	-0.5	0.25	
4	RX/REGEN DELTA P	.12	-1.0	2.0	-3.5	4.2		6.1	-0.5	0.25		
5	REGEN CAT SLV DP	10.0	-3.0	1.0	-2.5	4.2		6.1	-0.7	0.70		
6	SPENT CAT SLV DP	-0.4		7.2		9.0						
7	STRIPPER LEVEL	12.0					-8.0		-2.0		6.9	
8	BLOWER AMP's	-.60		3.0	5.2	-2.5	9.0			1.5		3.6
9	WET GAS RPM's	1.2						-3.5				
10	FEED HDR-PRESS	3.0			-5.5			.02	6.2		-8.3	2.1
11	FRAC BTMS TEMP	2.2		-7.3			4.5					
12	FRAC DELTA PRESS	.04										
13	BLOWER VLV OP	5.1		4.4		2.6			-9.0		-.06	5.5
14	WET GAS VLV OP	3.2	6.3		4.0			6.2		-.25		
15	RX PRED OCTANE	-0.4					4.3		7.0	-8.2		

Gain Multiplier 1.000 Deadtime Bias 0.000
Gain 3.750 Deadtime 0.000 Max Deadtime 2.00

APPLCN MENU	PROCSS DISPLY	CV DISPLY	MV DISPLY	DV DISPLY	STATUS MESG	MV TUNING	CV TUNING	GAIN/ DELAY	TREND DISPLY

Fig. 3. Example gain/delay display.

shows the model information and the relevant MV and CV pages that show the current status of those variables. Remembering the relevant information while navigating across displays adds to the difficulty of this reasoning task.

3) Control: The primary operator interaction with MPCs is changing the high and low limit for any variable in the controller. This is accomplished by entering text values in the HILIM and LOLIM fields of the detail displays. The user interface offers little assistance in letting the operator know what is an acceptable limit change. The display does not show a history of previous limit changes, nor why those were made. Further, the trend graphs of a particular variable are not shown in relationship to the limits that were in effect, so it is not possible to see if a variable has been operating within, beyond, or close to limits. This type of information must be assembled from data on various display pages.

Operators are also given little information to assess how the health of the controller will be affected by changes to limits. Sometimes the limit change will have little immediate effect but will cause the controller to become unduly constrained in the future when process conditions change. Over a period of several weeks, operators tend to "clamp" the limits (make the allowable operating region tighter) due to local operating conditions. Eventually, these latent problems will limit the controller's ability to control effectively in all situations.

D. Conclusion

Our cognitive task analysis provides insight into the challenges experienced by operators interacting with MPCs. In general, these challenges are typical of other forms of human–automation interaction. Operators interacting with automated systems must know the objectives of the automation, whether the objectives are being met, how to diagnose what might be limiting the performance of the automation, and how to assist the automation. When interacting with the automation, it is necessary to know what acceptable, feasible options are available, taking into account safety constraints and operating objectives, so as to keep the overall system running in a safe and effective manner. As we have shown, the current MPC operating displays provide limited support for these generic human–automation interaction requirements. We therefore sought to design a set of interface displays that would help operators more effectively monitor, diagnose, and control MPC. Our goal was to use the representation aiding approach to make the task more perceptual for all phases of cognitive activity and to support seamless transition from one phase to another through improved workspace management. The result is the MPC Elucidator.

VI. MPC ELUCIDATOR

The MPC Elucidator user interface is shown in Fig. 4.[2] The user interface was motivated by the following design principles [18].

Design Principle 1: Use representation aiding design principles to map domain properties into corresponding graphical elements.

1.1: Use consistent color coding throughout the display.
1.2: Show variable information relative to limits.

Design Principle 2: Create a workspace that supports monitoring, diagnosis, and control.

2.1: Support periodic monitoring of the controller through the design of an overview display.
2.2: Support direct navigation from the overview display to more detailed information.
2.3: Show important context information when the user makes a control change, including past operator changes and predicted behavior.

[2]The MPC Elucidator was designed to be consistent with current display capabilities in petrochemical control rooms. The display is designed for a 21″ full color monitor at a resolution of 1280 × 1024. Such displays are standard in current practice. The screen images shown in this article are prototype drawings rendered in Visio Technical 5.0. The displays are implemented as ActiveX Controls through Visual Basic 6.0.

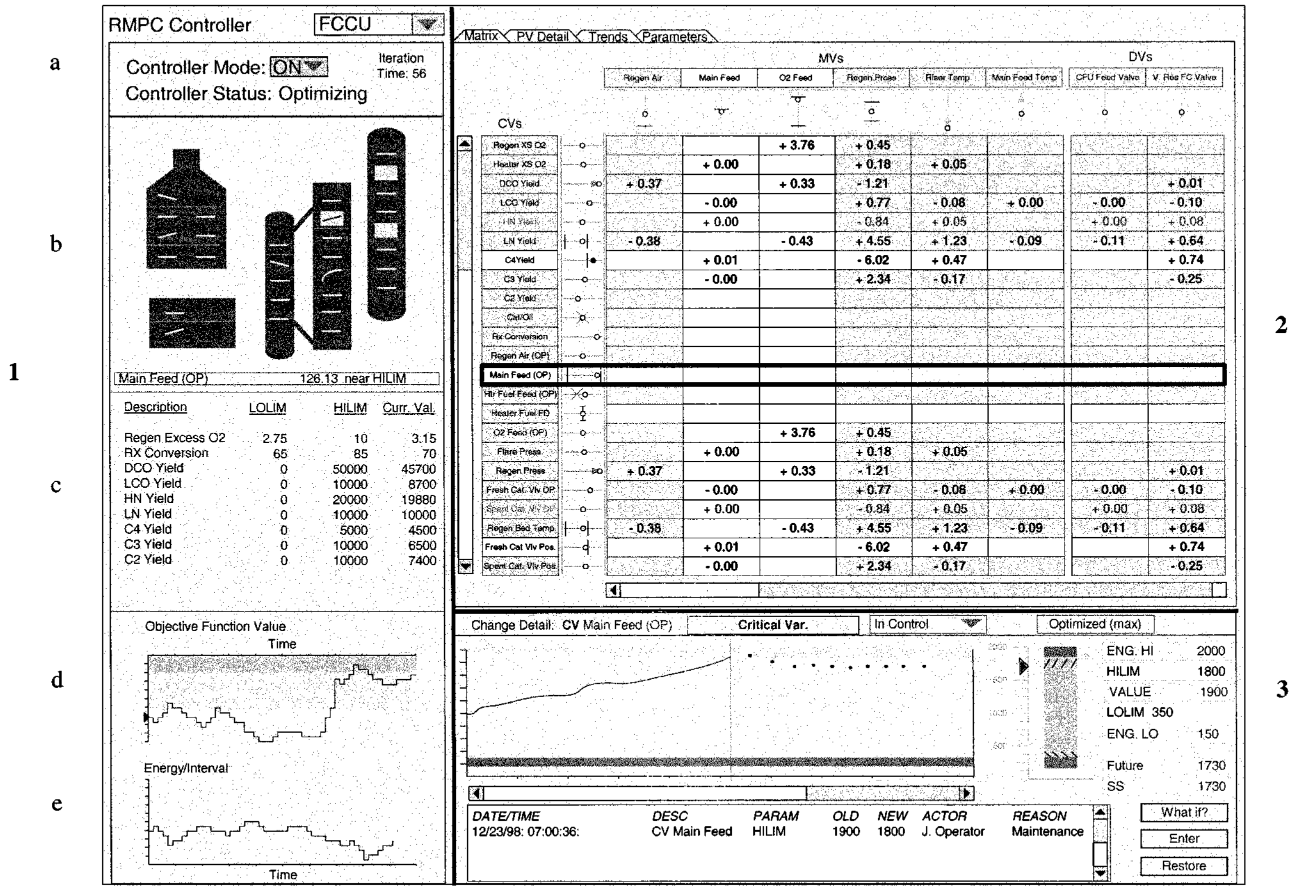


Fig. 4. Elucidator user interface.

The user interface is split into three Viewports[3] (see Fig. 4). The left third of the screen (Viewport 1) is dedicated to overview information. This area is intended to alert the operators to anomalies that may need further examination. It is also intended to support infrequent viewing of the controller displays (as task demands only allow operators to check MPC periodically) by providing relevant overview and recent history information that would indicate a potential problem that requires additional investigation. The second viewport (Viewport 2) contains a tabbed dialogue view, which takes up the top two thirds of the remaining area of the screen. This view is designed to support more detailed monitoring activities of the controller, and to assist operators in understanding the interactions between variables in the controller to support diagnosing why the controller might be constrained. The third viewport (Viewport 3) shows more specific information about a particular variable, useful when changing a variable's limits. Thus, the three viewports of the screen generally support the three major cognitive activities of operators: monitoring, diagnosis, and control.

A. Overview

The Overview pane (Viewport 1) is designed to present information that the user will want to have access to at all times (to support monitoring). It is composed of five process views presented in parallel. The PV Overview (1b in Fig. 4) and the two trend plots (1d and 1e in Fig. 4) are described in more detail below.

[3]The terminology employed in describing the interface is taken from [52].

B. The Process Variable (PV) Overview Display

The PV Overview (see Fig. 5 for a detail) is a novel display that has been adapted from the work on mass-data-displays (MDDs) [3]. MDDs rely on the human's ability to detect abnormalities in visual patterns to alert operators to changes in a process. In the PV Overview, a *signature trend plot* represents each variable in the controller. This signature trend plot relies on an algorithmic technique that maps the recent behavior of the variable into one of the seven standard first and second order trend patterns: steady state, ramping up, ramping down, increasing at an increasing rate, increasing at a decreasing rate, decreasing at an increasing rate, or decreasing at a decreasing rate. When all of the variables are at steady state, the signature trend plots form a consistent pattern of horizontal lines. As changes occur, anomalous data breaks that pattern.

In addition, if the variable is within 1% of a limit, the signature trend plot turns yellow, and if the variable is outside its limits, the signature trend plot turns red. These colors are consistent with the existing alarm color-coding scheme and are repeated several times in the Elucidator. Further, the background highlighting of the icon indicates the results of *abnormality assessment* algorithms. These algorithms are designed to identify variables that exhibit short-term behaviors that are incon-

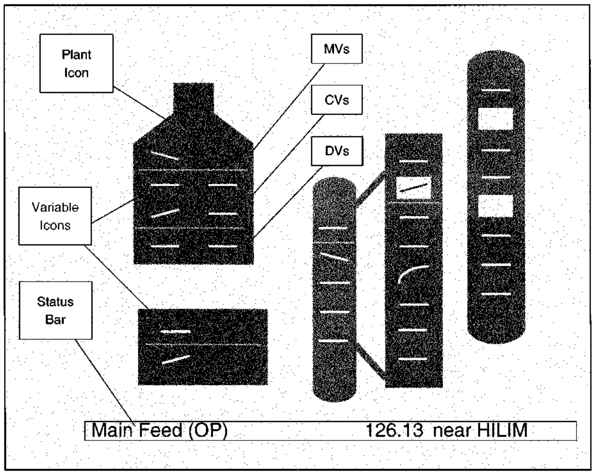


Fig. 5. PV overview display.

sistent with their long-term behaviors. For example, a variable that normally hovers near its low limit and has recently started trending toward its high limit might be flagged as abnormal. The variable need not be in violation of a control limit or in an alarm state. Rather, the algorithms are designed to raise operator awareness of dynamic behaviors that may lead to future problems (i.e., prognostic information). In summary, if all is normal, each variable in the PV overview display will have a steady state plot (i.e., a horizontal line), with no background shading or line coding. As abnormalities or changes take place, the icons represent those changes, alerting the operator to explore the situation in more detail.

The individual icons populate a static background graphic that depicts the major pieces of plant equipment (following [3]). The purpose of this arrangement is to help the operator localize a variable to a region of the unit under control. Within the background forms, the icons are arranged with MVs at the top, CVs below them, and DVs (if any) at the bottom.

The PV Overview display also serves as a stepping stone for further investigation or control. We do this in two ways: 1) by allowing the operator to "mouse over" a variable of interest, and obtain a status indicator below to identify the variable and any abnormality, if applicable, and 2) by allowing the operator to click on a variable to navigate to more detailed information about that variable in the corresponding process views on the right hand side of the screen. When a variable is selected in the PV Overview display, it will also be selected in the Matrix Display in Viewport, and the details about that variable will be displayed in the Change View in Viewpoort. This allows an operator to quickly navigate to details about a variable in corresponding views on the screen.

C. Objective Function Value and Energy Plots

Two plots are shown at the bottom of the Overview viewport. The first, the Objective Function Value Plot (1d in Fig. 4), provides insight into how well the controller is optimizing the process. Using this plot, the operator can determine if the optimization performance is slipping, initiating a targeted search for an explanation. To assist rapid monitoring, colored bands appear behind the plot to convey qualitative characterizations of the objective value performance. These bands are shades of gray when the optimizer is performing well and the value of the function is low. As the value rises, and enters one of the gray regions, the band changes color (yellow and then red) to alert users that the optimizer performance is slipping. This technique of context sensitive display augmentation is employed again in the trending function in Viewport 3.

The Energy Plot (1e in Fig. 4) provides the operator with an indication of how hard the controller is working to adjust the manipulated variables. The controller calculates a single energy value at each control interval. Through the presentation of the time history of this value, the user can detect when the controller is making larger than normal adjustments to the process. This indication has two uses, depending on the context. If the operator is expecting the controller to make a large move, a spike on this plot would confirm that the controller is doing that. In contrast, if the controller makes a sudden large move that is not anticipated by the operator, the spike on the plot helps call his or her attention to it.

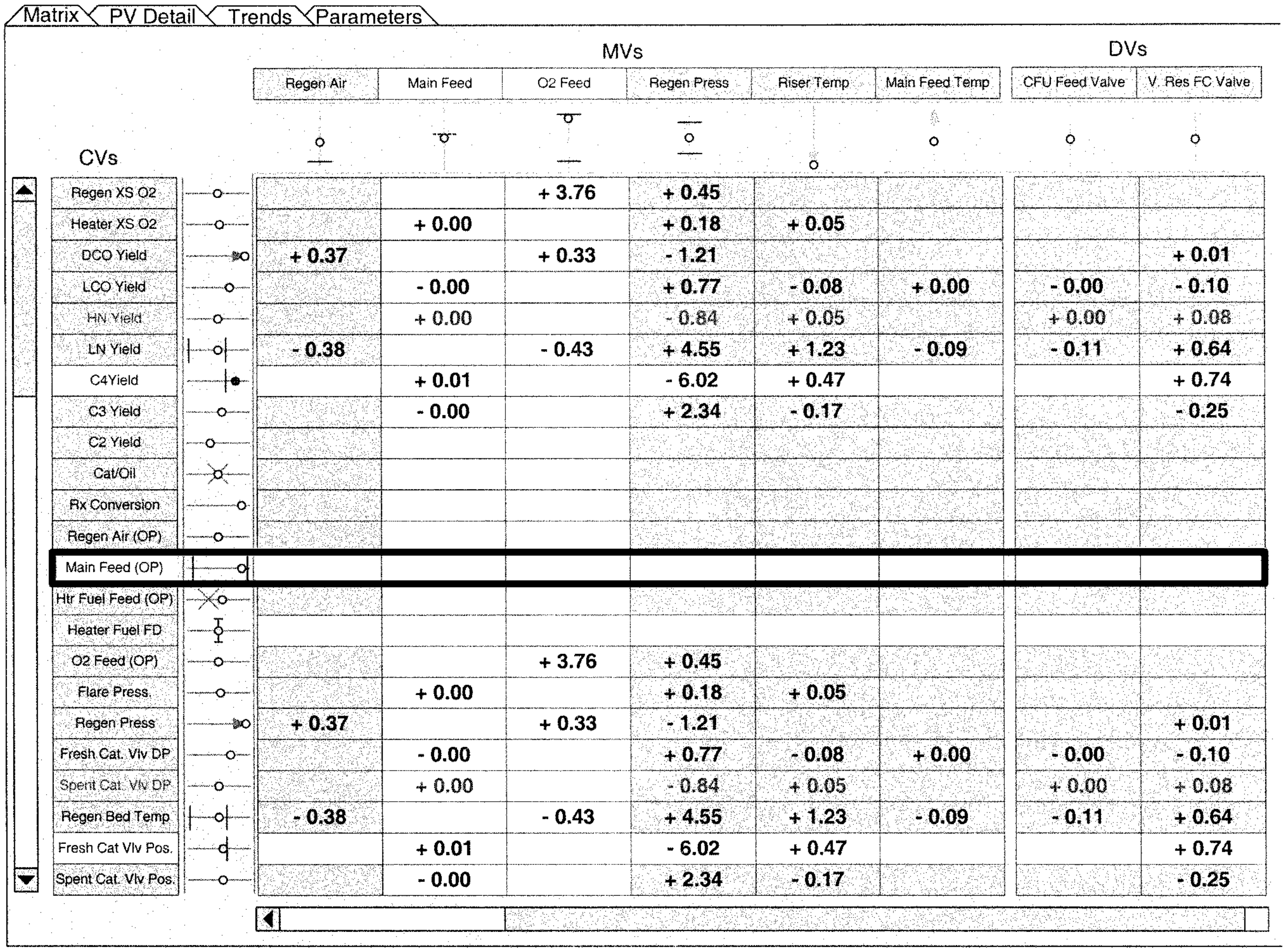
The inclusion of these two plots reveals the value of analyzing both the operator tasks (CTA) and the functionality of the automation (CWA). Both the objective function and energy information have always been components of the controller algorithm, but neither has been displayed to the operator previously. By performing both types of analysis, we were able to identify readily available information that would support an operator task that was not displayed directly with the previous interface.

D. Matrix View

The Matrix View is the primary process view that appears in Viewport 2. (Three other process views may appear in this Viewport, none of which are described here). The Matrix View is comprised of two graphical forms, the Gains Matrix and the Bubble Gauge Display (see Fig. 6 for detail). Each is described in turn.

1) Gains Matrix: The Gains Matrix is a table showing the predicted interaction between the variables in the controller. These values indicate how a one-unit increase in a manipulated or disturbance variable will affect each of the controlled variables. For example, for the controller shown in Fig. 6, a one-unit increase in regenerator air flow (Regen Air) will increase the regenerator pressure (Regen Press) by 0.37 units. This information can be used for diagnosis or predicting controller behavior. We have added a number of features to put the static model information into the context of the current status of the controller variables. This design approach minimizes the need to navigate to other displays to find this information.

Variables selected in the Gains Matrix (or in other views) are highlighted with a rectangle drawn around the entire column or row. This correspondence helps the user to locate references to common variables between views. Under normal conditions, the values in the matrix are displayed in black text on a white background. However, grayed out text in a column or row indicates that a variable has been dropped from control. A row or column whose background has been highlighted in white indicates a variable in a state that is costing the controller a degree of freedom (e.g., a CV constrained to setpoint or violating a limit).



CVs	Regen Air	Main Feed	O2 Feed	Regen Press	Riser Temp	Main Feed Temp	CFU Feed Valve	V. Res FC Valve
Regen XS O2			+ 3.76	+ 0.45				
Heater XS O2		+ 0.00		+ 0.18	+ 0.05			
DCO Yield	+ 0.37		+ 0.33	- 1.21				+ 0.01
LCO Yield		- 0.00		+ 0.77	- 0.08	+ 0.00	- 0.00	- 0.10
HN Yield		+ 0.00		- 0.84	+ 0.05		+ 0.00	+ 0.08
LN Yield	- 0.38		- 0.43	+ 4.55	+ 1.23	- 0.09	- 0.11	+ 0.64
C4Yield		+ 0.01		- 6.02	+ 0.47			+ 0.74
C3 Yield		- 0.00		+ 2.34	- 0.17			- 0.25
C2 Yield								
Cat/Oil								
Rx Conversion								
Regen Air (OP)								
Main Feed (OP)								
Htr Fuel Feed (OP)								
Heater Fuel FD								
O2 Feed (OP)			+ 3.76	+ 0.45				
Flare Press.		+ 0.00		+ 0.18	+ 0.05			
Regen Press	+ 0.37		+ 0.33	- 1.21				+ 0.01
Fresh Cat. Vlv DP		- 0.00		+ 0.77	- 0.08	+ 0.00	- 0.00	- 0.10
Spent Cat. Vlv DP		+ 0.00		- 0.84	+ 0.05		+ 0.00	+ 0.08
Regen Bed Temp	- 0.38		- 0.43	+ 4.55	+ 1.23	- 0.09	- 0.11	+ 0.64
Fresh Cat Vlv Pos.		+ 0.01		- 6.02	+ 0.47			+ 0.74
Spent Cat. Vlv Pos.		- 0.00		+ 2.34	- 0.17			- 0.25

Fig. 6. Matrix display.

2) Bubble Gauge: A Bubble Gauge[4] is shown for each variable (row and column) in the Matrix display. The gauge shows the current value of the variables in the context of both its control limits and its optimization objectives. The Bubble Gauge consists of an axis, a small hollow circle to represent the current value of the variable, black lines for both engineering and operator limits, and gray crosses and arrows to represent optimization information.

The span of the axis for each variable is normalized to the engineering limits (those limits that represent the widest allowed range for that variable as defined by the control engineer). These limits do not formally exist in the current MPC database, but the cognitive task analysis showed these limits would provide the operators with a context for knowing how the current limit values compare to the range deemed safe by a process engineer. Since each bubble gauge is normalized to this range, it is easy to scan across the bubble gauges in the matrix display to see which variables have had their limits "clamped" (tightened) by an operator.

Fig. 7 shows a representative set of potential states that a bubble gauge can assume. Examples a, b, and c show different normal states. The alarm color codes discussed in the signature trend plots of the PV Overview display are mapped onto the current value circle (examples d and e). If the operator constrains a variable to setpoint, then the variable limits are shown with wing tips (example f). A wound up control valve takes on the appearance of example g. In the existing display scheme, the operator would have to identify each of these states by comparing several digital values.

The bubble gauge shows optimization information as well. If a variable is set to be maximized or minimized (i.e., linear optimization), a gray arrow is depicted in the direction of optimization (examples h and i). Quadratic optimization is depicted by a gray cross at the target value (example j). The current MPC displays show this optimization information indirectly on a variable's detail page that operators rarely consult. On this detail page, the operator must know that a negative linear coefficient means "maximization," and a positive linear coefficient means "minimization." The bubble gauge alleviates the need to mentally encode this counter-intuitive relation.

The bubble gauge is a good example of the benefits of using a representation aiding approach. In isolation, each bubble gauge shows the variable's current value with respect to its context. Scanning across the bubble gauges in the matrix display, one can quickly see which variables are at either a high or low limit, which have been constrained to setpoint, which have an optimization parameter associated with them, which have been "clamped" by an operator, and which are out of range. This is in

[4]The bubble gauge design was inspired by the redesigned box plot of Tufte [46, p. 62].

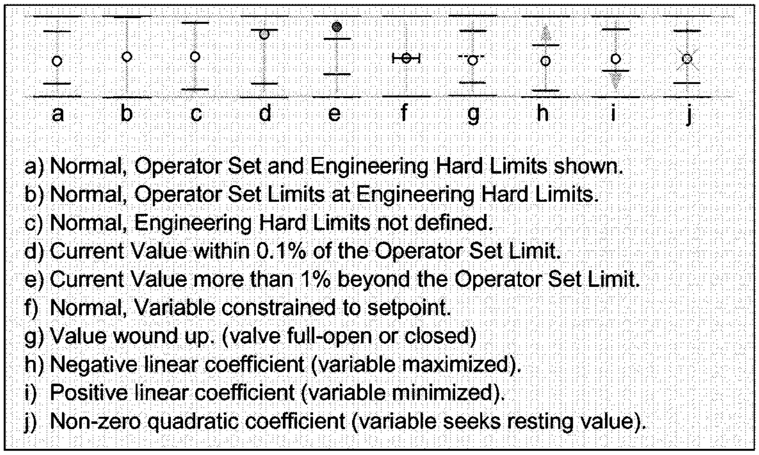


Fig. 7. Example bubble gauge states.

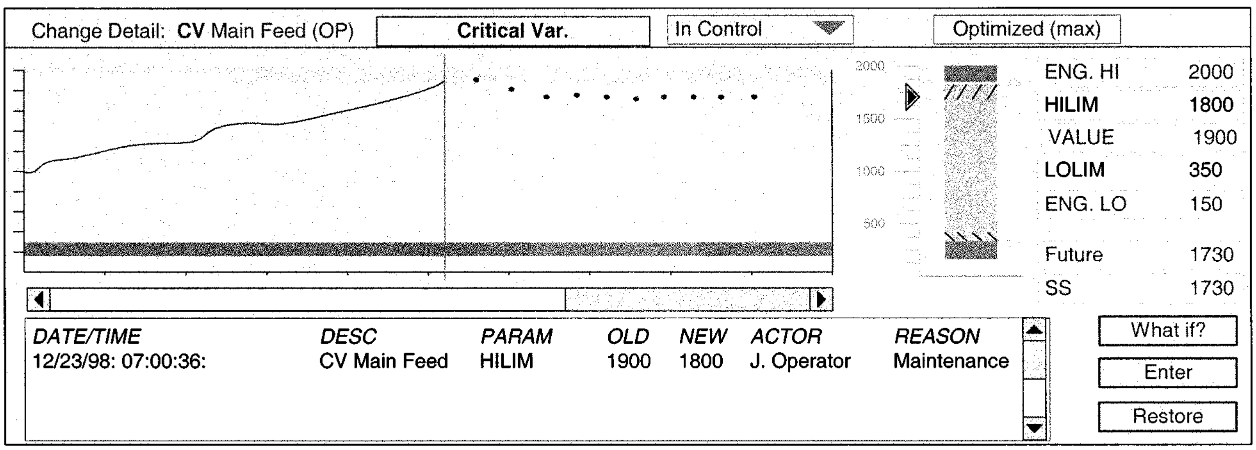


Fig. 8. Change view.

contrast to the current operating displays, which show the same elemental data in several pages of numeric text. With the bubble gauge, we have sacrificed the precision of numeric values for the advantage of showing several variables simultaneously. Given that our task analysis showed that numeric comparisons across variables were rarely necessary, we developed an analog representation that aids operators in making higher-level assessments about controller health. If exact values are needed, (such as when changing the variable's limits), then the operator can click on the variable of interest in the matrix display, and all the details about that variable are displayed in the Change View (described as follows).

Taken together with the display of the gain/delay matrix, the operator can more readily see which variables are constraining the controller, and what other variables may be influencing a particular variable's performance. We observed operators trying to do this kind of analysis with the current displays, but it is a cumbersome and difficult task. With the Elucidator, an operator can see the relevant information together on one screen, significantly easing the task difficulty.

E. Change View

The final viewport in the Elucidator interface (Viewport 3 in Fig. 4) is populated with information specific to a single process variable. This Change View (see Fig. 8 for a detail) allows the user to view and manipulate the current limits in the context of the engineering limits, delta limits, and the current value of the variable. A trio of buttons allows the user to 1) view predictions of the impact a limit change will have using a "What If" prediction algorithm, 2) instruct the controller to carry out those changes, or 3) restore the limits to the values used in the previous control interval. The Trend History/Prediction Plot provides trending of the variable *in relation to operator set limits*. This is a noteworthy improvement upon current displays that do not show these limits. A corresponding history log shows details about previous limit changes to give the current operator a historical context for changing the limits.

1) PV Gauge: The PV Gauge in the Change View displays the current, future, and steady state values in relationship to all the relevant limits on the variable. We incorporate a direct manipulation feature to allow the user to change the LOLIM and HILIM settings (see Fig. 9 for detail) by clicking and dragging on the flags that extend from the gauge. Alternatively, the operator can choose to set the limits by typing into the fields next to the gauge.

The limits, current value, and future values are shown on a single scale to create a uniform frame of reference. The dark gray bar represents the magnitude of the engineering limit

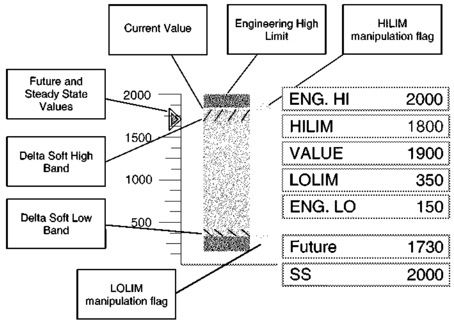


Fig. 9. The PV gauge control and its supporting fields.

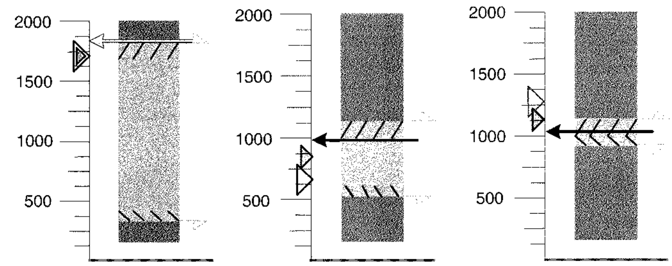


Fig. 10. Example PV gauge states.

range. A lighter gray bar is drawn inside that bar to show the range defined by the operator set limits. Thus, the dark gray bar represents room that the operator has to adjust the interior limits. Hashmarks inside the light grey region represent controller off-sets (called "delta-limits") that MPC engineers define. The controller will try to maintain the variable within the light grey range, avoiding the hashmark region as a safety cushion. A thin arrow pointing to the scale from the right denotes the current value of the variable. The predicted future state value (at the end of the control horizon) and predicted steady state value (at the end of the prediction horizon) are also shown on the scale as two concentric triangles pointing to the scale from the left. These values show where the variable is predicted to go in the nearer and longer term, respectively. Color coding of these indicators is consistent with the signature trend plot and bubble gauge. In the example shown in Fig. 10(a), the current value is shown in yellow, but the predicted and steady state values are shown in black, indicating that the controller will be bringing that variable back into a safer region. In Fig. 10(b), one can see that the variable is predicted to go down, but stay within the allowable region. In Fig. 10(c), the current value is right on target, but the variable is predicted to go above its high limit.

2) Trend History/Prediction Plot: Trending packages are commonly employed in the process industries for monitoring, diagnosis, and evaluating the effectiveness of control actions. The Trend History/Prediction Plot in the Elucidator Change View (see Fig. 11 for detail) displays the historical values of a variable, the historical trend of the limits, and a prediction of the anticipated behavior. The vertical scale of the Trend History/Prediction Plot matches the scale specified by the PV Gauge control for this variable. This equivalence makes it easier to compare the trend to the PV Gauge control.

Two bars on the top and bottom edge of the plot depict the history of the constraint relationships. The bars reflect the difference between the operator set limits and the respective engineering limits. The current difference is projected across the prediction plot as well. Note that as the distance between the engineering limits and operator set limits increases, this bar becomes thicker. It is easy to see when a user has changed a limit because of the abrupt change in the width of the limit bar. Further, by displaying the limits in conjunction with the actual value, it is easy to see when a variable is, has been, or is predicted to be at or beyond its limit.

3) Change Log: The PV Gauge and trend controls are complemented by a change log just below the trend that automatically documents critical information about limit changes and encourages users to give explanations for them. When the user enters a limit change, Elucidator creates a log entry with fields specifying the variable, parameter, old and new values, a date and time stamp, and the user. A cursor is then placed in the reason column. The intention of this feature is to document not only a limit change, but also the reason for it so that operators on later shifts can make decisions about whether that limit should be changed again. Clicking on one of these entries scrolls to the corresponding time on the trend graph above.

VII. Have We Been Successful?

Table III presents a summary of how the Elucidator provides the information required for effective human–automation interaction with MPC. Comparing Table III with Table II, one can see the significant reduction in the number of steps and data interpretations. Information that previously required scores of coordinated mental and navigation activities can now be accessed directly at the main level of the display. For example, in our previous example, determining whether each of the optimized variables are meeting their objectives would require a minimum of 75 workspace navigation activities (moving from screen to screen). This can now be performed by glancing across the bubble gauges in the matrix display to see if any of the circles are not "on top" of any targeted value (represented by a gray X or arrow).

Unfortunately, despite our arguments for rigorous user testing, the product development group was convinced that our design is "obviously better" than the existing display suite and, as such, will be implementing Elucidator in a new product release. (This is an undoubtedly a common "Catch 22" for user interface designers. On the one hand, the designers promote the design in the hope that it will be accepted by management and development, while on the other hand, they need to argue that the designs should be tested and validated by users prior to release). We took what we knew from the literature, and from our cognitive task and work analysis of MPC, and employed our best engineering knowledge to design a system that should be successful according to the research on which it was based.

The Elucidator has undergone several iterations of comments and review by the developers of the MPC technology, and has been greatly enhanced by their inputs. These engineers' in-depth knowledge of the controller algorithms enabled them to quickly identify missing portions of our design and offer suggestions for adding information to the displays. For example, our original bubble gauge design depicted minimum and

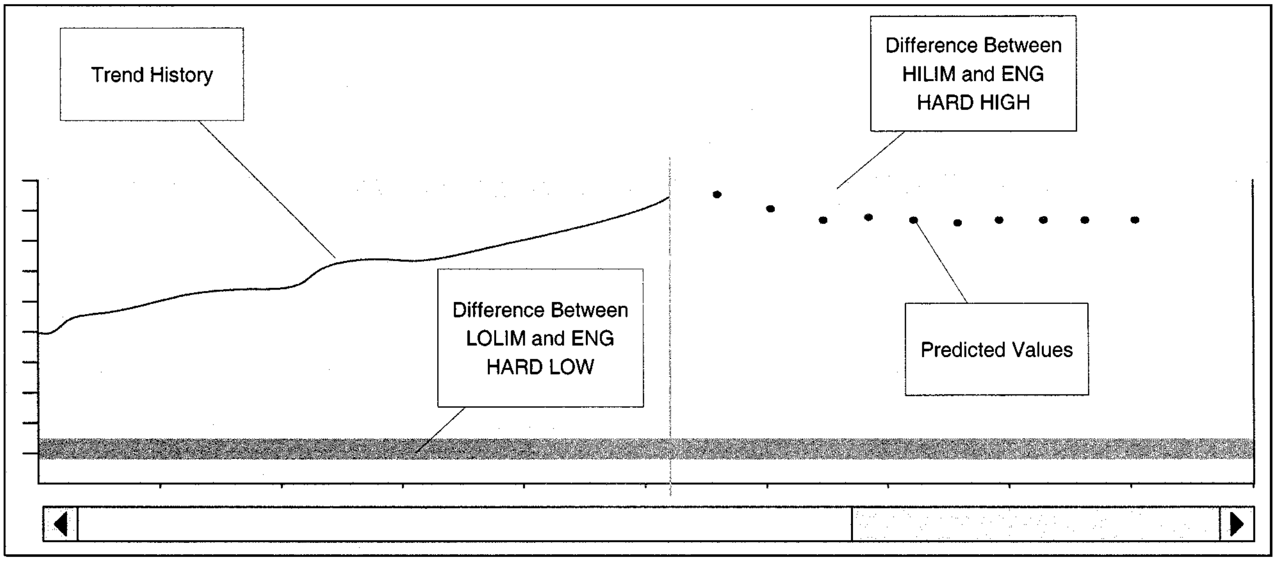


Fig. 11. Trend plot.

TABLE III
HUMAN–AUTOMATION INTERACTION WITH REDESIGNED MPC DISPLAYS (MINIMAL NAVIGATION AND DATA INTERPRETATION REQUIRED)

GENERIC HUMAN-AUTOMATION INTERACTION QUESTION	SPECIFIC INFORMATION THAT HELPS ADDRESS GENERIC QUESTION	HOW ELUCIDATOR DISPLAYS MEET NEED
Monitoring		
What are the automation's objectives?	Knowledge of which variables are being optimized (either minimized or maximized or targeted)	Look to see if a gray up arrow (maximization) or down arrow (minimization) or X (targeted value) is shown for any of the bubble gauges in Viewport 2.
How well are the automation's objectives being met?	Are optimized variables near optimum?	See if circles on bubble gauges are on top of arrows and X's.
What is the current state of the automation?	Which MVs and CVs are at their limit?	Look for yellow or red circles in the bubble gauges in Viewport 2 OR for similarly colored signature trend plots in Viewport 1.
	Is MPC currently making large moves? If so, why?	See if there are any non-horizontal lines in Mass Data Display in Viewport 1 OR look for a spike in the Energy Plot in Viewport 1.
	Are an abnormally large number of MVs at their limit?	Look for yellow or red circles in the bubble gauges in Viewport 2 OR for similarly colored signature trend plots in Viewport 1.
Diagnosis		
Why is the automation performing poorly? What factors are constraining the automation? Is it possible to relieve the automation's constraints?	What is limiting the controller? e.g., What is preventing it from increasing feed?	Use Gain/Delay Matrix and bubble gauges to see which variables are in fact at a limit (shown with a red or yellow circle) or have a wound-up variable (shown by a dashed horizontal line across Bubble Gauge).
Control		
How do I make adjustments, taking into account system constraints and objectives of previous operators?	What is the widest allowable range for this variable (as defined by plant engineers, process constraints or best practices)?	Look at range of bubble gauge in Viewport 2 OR range of PV Gauge in Viewport 3.
	What are the delta soft "cushions" set by the engineer?	Look for hashmarks on PV Gauge in Viewport 3.
	What recent limit changes have been made for this variable and why?	Look in scrolling change window in Viewport 3 OR on trend plot in Viewport 3.

maximum optimization parameters, but neglected to include quadratic optimization. A design review by the MPC developers revealed this shortcoming and prompted us to add the X marker on the bubble gauge. This type of iterative revision happened several times throughout the design and review process. The unexpected lesson in this experience is that the emerging design itself served as a good communication device between the design team and the developers of the controller algorithms. The cognitive work analysis and cognitive task analyses were actually enriched through the design of the display. Thus, the representations served as a model of our understanding of the important domain properties and relationships. When both groups agreed to a final design it was because both had come to an agreement on a) the functionality of the automation and b) the role of the operator.

The direction of knowledge sharing between the designers and the development team was not one-way. Whereas the development team was initially resistant to some of our design suggestions, we were able to demonstrate their utility and win acceptance. For example, engineering limits were previously considered almost incidental because they did not contribute to the MPC control algorithms. However, our demonstration and explanation of how they enhanced the context in which operators must make control decisions convinced the development team of their utility. This example serves to emphasize that human factors engineers have a contribution to make to the engineering design process.

VIII. Conclusion

This case study describes the development of a representation aiding system intended to help operators monitor, diagnose, and control a complex automated controller. The design was guided by cognitive task and work analyses, which helped define the information requirements of the user interface. This case study is the first of its kind that we know of that illustrates the process of developing a representation aiding decision support system for understanding and interacting with complex algorithmic automation. In addition, particular attention was paid to the design of the overall workspace, so as to support correspondence of information across displays. By reducing the need to navigate from one screen to another, operators can more smoothly transition from monitoring to diagnosis to control. Although our particular design is specific to the features of this type of model-based predictive controller, we believe that several of the individual representational aids have applicability to many process monitoring applications. Further, many of these design features may be applicable to other domains that use optimization algorithms.

Because the user interface was designed based on the cognitive task and work analyses conducted, it essentially served as our model of what was operationally relevant for the users of this automation. No other formal modeling representation was used, beyond developing a detailed list of information requirements based on our understanding of the automation's behavior and the cognitive activities and context of use by operators of the automation. The representation aiding approach was thus useful not only for designing the human–automation user interface, but also for conveying our understanding of the automation's features and properties. As these representations were developed, they became more detailed and more correct, because the domain experts could see what was missing from our designs, explain the gap, and often suggest design revisions to make them more accurate.

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Stephanie Guerlain (M'95) was born in Norwalk, CT, in 1967. She received the B.S. degree in engineering psychology from Tufts University, Medford, MA, in 1990 and the M.S. and Ph.D. degrees in cognitive systems engineering from The Ohio State University, Columbus, in 1993 and 1995, respectively.

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Greg A. Jamieson was born in Cincinnati, OH, in 1971. He received the B.S. degrees in mechanical engineering and in psychology (with distinction) from the University of Illinois at Urbana-Champaign in 1996. He received the M.A.Sc. degree in mechanical and industrial engineering in 1998 from The University of Toronto, Toronto, ON, Canada, where he is currently pursuing the Ph.D. degree.

In 1996, he was a Research Associate with the Battelle Seattle Research Center, Seattle, WA. From 1998 to 1999, he was a Research Intern at Honeywell Laboratories (formerly Honeywell Technology Center), Minneapolis, MN, and has held the position of Research Scientist since 1999.

Mr. Jamieson is a member of the Human Factors and Ergonomics Society, having held several offices at the local chapter level. In 1999, he was recognized for an Outstanding Contribution to the Human Factors and Ergonomics Society by a Student Member.

Peter Bullemer was born in Minnesota in 1960. He received his Ph.D. in cognitive psychology from the University of Minnesota, Minneapolis, in 1985.

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Dr. Bullemer received the Honeywell Lund Award for Leadership in 1998 and the Honeywell Technical Achievement Award in 1999.

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He was Principal Research Engineer at Honeywell Technology Center, Minneapolis, MN, from 1986 to 2000 and is now an independent software consultant. He has also taught in the computer science postgraduate program at the University of St. Thomas, Minnesota.

Mr. Blair received several technical merit awards while working at Honeywell.

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Interaction Design - Toolbox Talk

B. Hove

Mere informasjon:
http://www.hse.gov.uk/humanfactors/

Tomorrow's human factors standards, today

Toolbox talk
Interaction design

Berte Hove 06.04.2011

Agenda

- What is interaction design (ID)?
- Who are working with interaction designer?
- What does the ID toolbox contain –methods:
  - to understand
  - for Envisionment and design
  - for Evaluation

What is Interaction design

Designing for people using technology to undertake activities in context(Benyon, 2005).

'Interaction Design defines the structure and behaviour of interactive systems. (Interaction Design Association, IxDA)

- \- structure – what a user is required to do
- \- behavior – how can I accomplish that'

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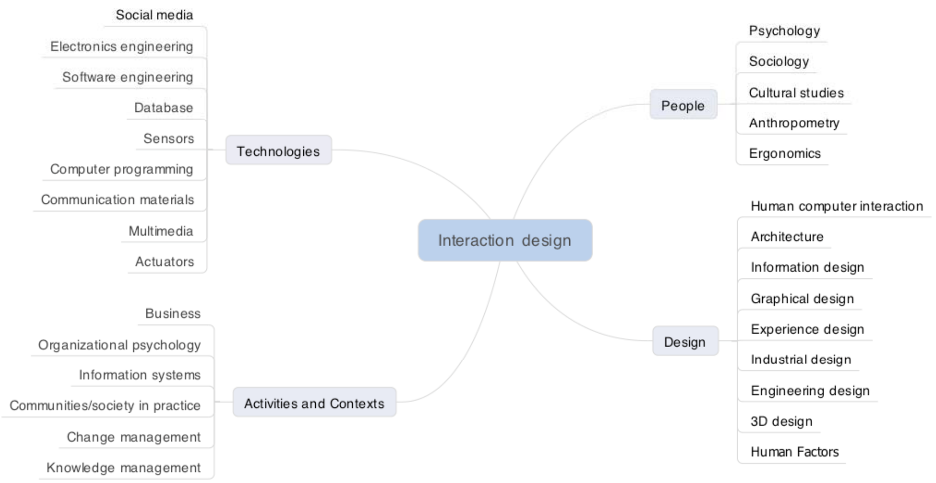
Slide 3

Who are working with interaction design x-disciplinary



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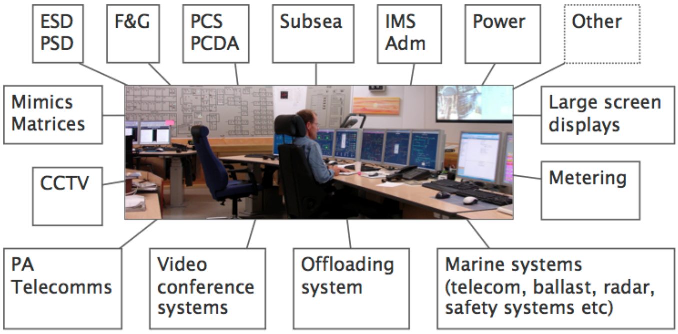
Slide 4

Some areas where ID is used - Oil and Gas Industry



- Design
- Content
- Availability
- Position/ location

What does the interaction design toolbox contain?

- Methods to understand PACT
- Methods for envisionment & design
- Methods for evaluation

Goals

Usability goals (efficient, effective, easy to learn, easy to remember, safe)

User experience goals (satisfying, motivating, helpful, entertaining etc.)

There are several ways of measuring whether goals were met,

for example by usability testing and surveys.

Slide 7

Understanding user needs – why?

- From success to flop
- Requirements for success

Slide 8

Understand - methods

- Stakeholder analysis
- Observation
- Interviews – personas/stories/use case
- Probes / participants journals
- Card sorting
- Function analysis and task analysis

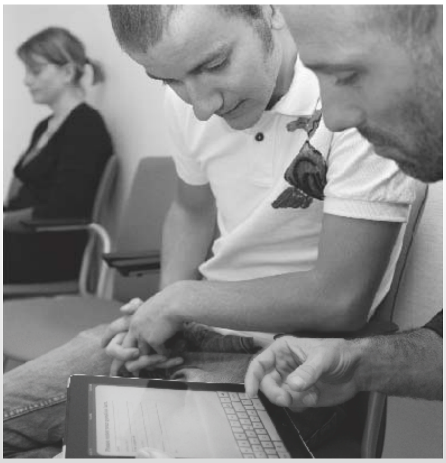
Slide 9

Stakeholder analysis

Kunde/ Interessent	(P)/ (S)	Behov/Krav /Forventninger
	P	

Slide 10

Observation



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Slide 11

Interview

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Slide 12

Personas, usecase, stories

Name: Anders Kristiansen
Age: 38 år
Family: wife and kids 1-3 år
Anders is a heavy coffee drinker. Anders kitchen is small and the coffee machine has a central location.

Because Anders works at home, the coffee machine is always on in order to keep coffee hot. His wife is also a heavy coffee drinker.

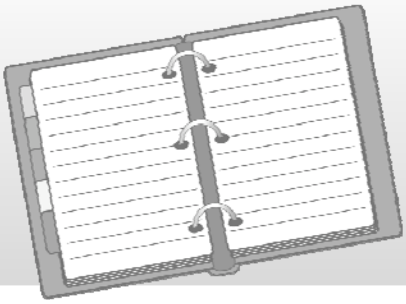
To Anders it is important that the coffee machine has a modern design.

At night Anders always forget to switch the coffee machine off.

Participants journals

How: Ask potential/existing users to keep a written and visual diary of their impressions, circumstances, and activities related to the system.

Why: The rich self-conducted notation technique is useful for prompting users to reveal points of view and pattern of behaviour.



Card sorting

How: Name exsting, possible features, functions or design attributes. Ask users to organize the cards spatially, in ways that make sense for them.

Why: This helps expose peoples mental models of the devise/system or solution. Their organisation reveals expectations and priorities about the intended functions.

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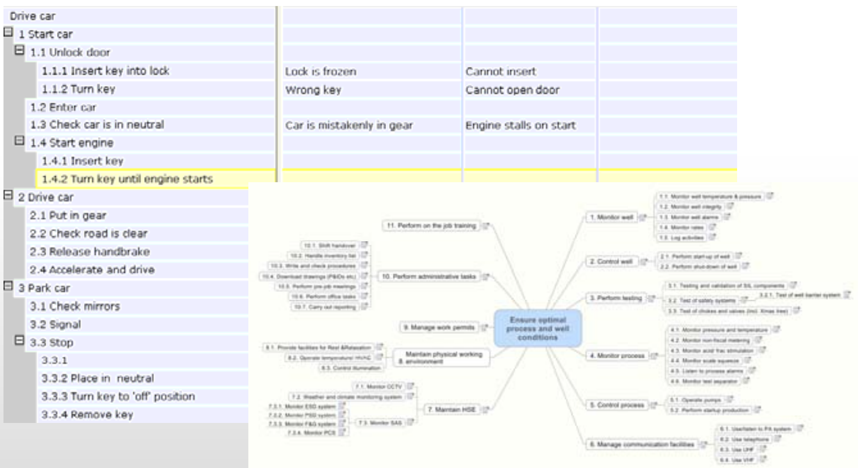
Hierarchic and tabular task analysis



Drive car			
1 Start car			
1.1 Unlock door			
1.1.1 Insert key into lock	Lock is frozen	Cannot insert	
1.1.2 Turn key	Wrong key	Cannot open door	
1.2 Enter car			
1.3 Check car is in neutral	Car is mistakenly in gear	Engine stalls on start	
1.4 Start engine			
1.4.1 Insert key			
1.4.2 Turn key until engine starts			
2 Drive car			
2.1 Put in gear			
2.2 Check road is clear			
2.3 Release handbrake			
2.4 Accelerate and drive			
3 Park car			
3.1 Check mirrors			
3.2 Signal			
3.3 Stop			
3.3.1			
3.3.2 Place in neutral			
3.3.3 Turn key to 'off' position			
3.3.4 Remove key			

Slide 16

Hierarchic and tabular task analysis

How: describe and breakdown

- Goals - desired states of the system
- Tasks - the methods adopted to attain goals
- Operations - the goal directed behaviour
- sub-tasks

Fit to the purpose:

Task, human error/consequences/mitigations

Equipment/people/communication, preconditions etc.

Slide 17

Envisionment & design – why?

- Create and innovate, to improve solutions
- Making the ideas visible – externalising thoughts, common understanding

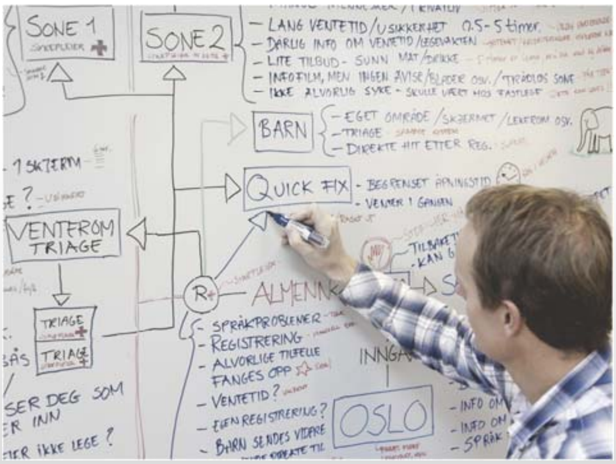
Slide 18

Envisionment & design - methods

- Brainstorming
- Navigation maps
- Scenarios
- Storyboard
- Sketches (low fidelity)
- Wireframes (high fidelity)

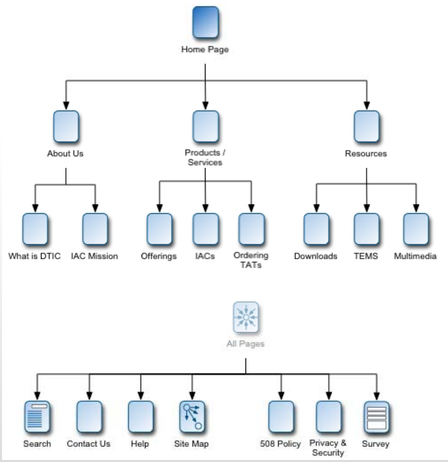
Slide 19

Brainstorm



Slide 20

Navigation maps



Slide 21

Scenarios

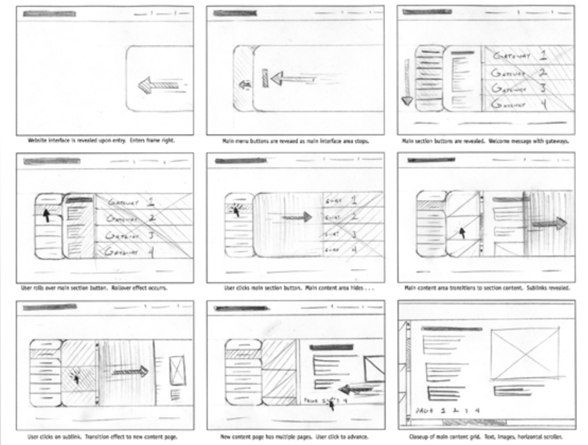
How: illustrate a character rich story describing the context of use for a system

Why: this process helps communicate and test the essens of a conept within its probable context of use.

Done in a walktrough/tabletop exercise

Slide 22

Storyboards



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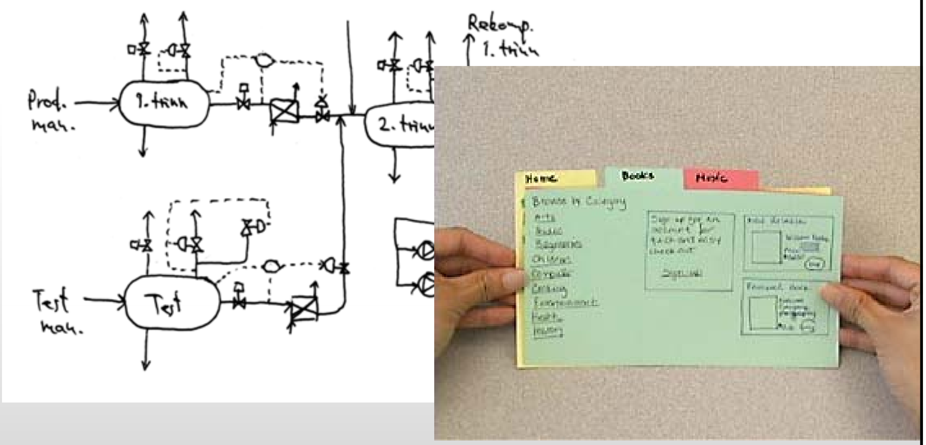
Sketches - paper prototype low fidelity



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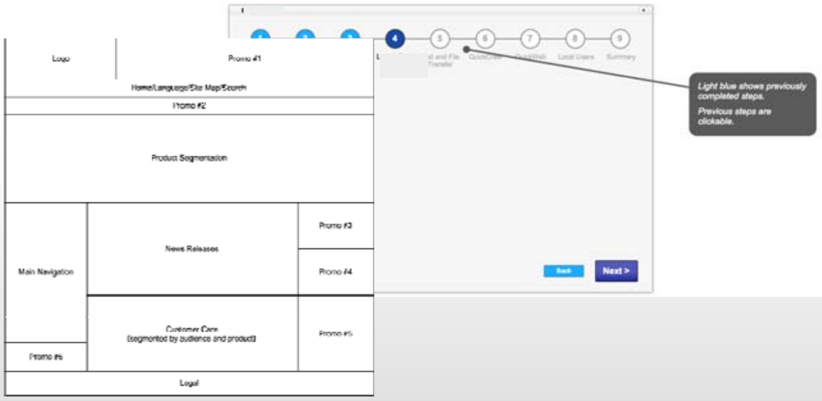
Wireframes - high fidelity



Evaluation – why

- Through evaluation reviewing, trying out, or testing design ideas, a piece of software service, to discover areas of improvement
- Meet goals
- Solution fit the mental model of the users
- Solutions are designed according to PSA regulations, standards, project requirements etc.

Evaluation - methods

- Expert evaluation
  - Heuristic evaluation
  - Checklists
- Participants-based evaluation
  - HMI reviews
  - User testing
  - CRIOP

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Slide 27

Heuristic evaluation - principles

- Suitable for the task
- Consistency
- Error handling
- Simplicity
- Self descriptiveness

……

So simple and so difficult....

3.1. General principles

No	Issue
	Does the information on the screen support the tasks that this screen is intended to support?
	Is there any information on the screen missing that should be included to support the relevant tasks?
	Is there information on the screen that does not support any of the tasks associated with the screen?
	Is the salience of the information appropriate to its level of importance or urgency?
	Is the screen information presented in a manner that minimises clutter and information overload?
	Is the information coded in an appropriate manner?

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HMI reviews

Slide 29

Usability testing

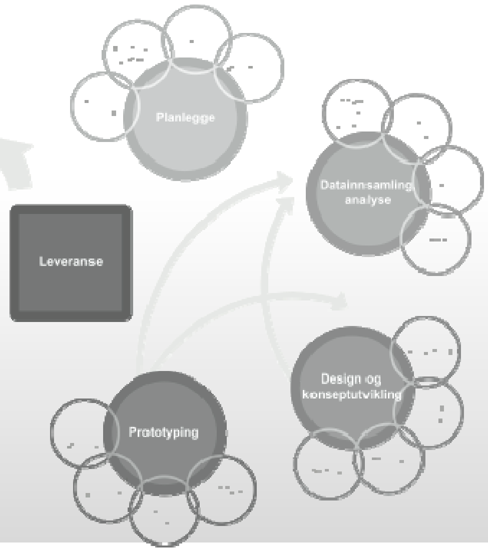
How: ask user to perform a/several tasks with new design

Why: to see if concepts/solutions meet users mental models

Can use measurement such as time, accuracy, number of errors

Slide 30

Iterations



Slide 31

User centred design

Users in all phases of the design

Slide 32

Standards

ISO 11064 Part 1 - 7: Ergonomic design of control centres, 1999 - 2009
ISO 6385: Ergonomic principles in the design of work systems, 2002
ISO 13407: Human – centred design processes for interactive systems, 1999
EN 894 Parts 1 - 4: Safety of machinery, Ergonomic requirements for the design of displays and actuators, 1997 - 2004.
EN 981: Safety of machinery – system of auditory and visual danger and information signals, 1997.
EN 614 - 1: Safety of machinery, Ergonomic design principles, Part 1: Terminology and general principles, 1995.
EN 614 - 2: Safety of machinery, Ergonomic design principles, Part 2: Interactions between the design of machinery and work tasks, 2000.
EN 60073: Basic and safety principles for man-machine interface, marking and identification, 2002.

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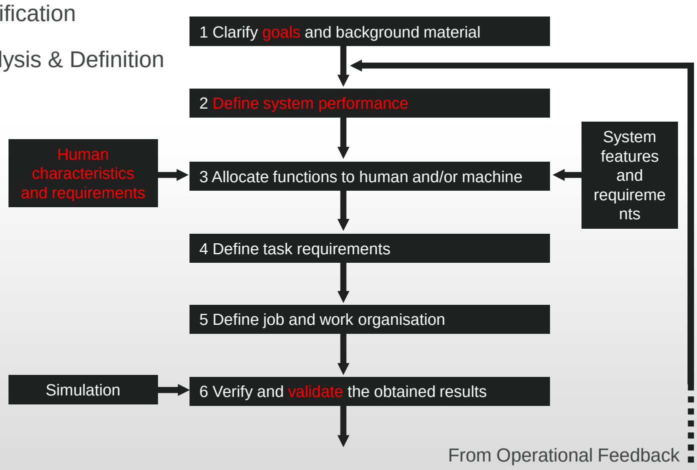
Design process: ISO 11064 (1 of 2)

- Phase A: Clarification
- Phase B: Analysis & Definition



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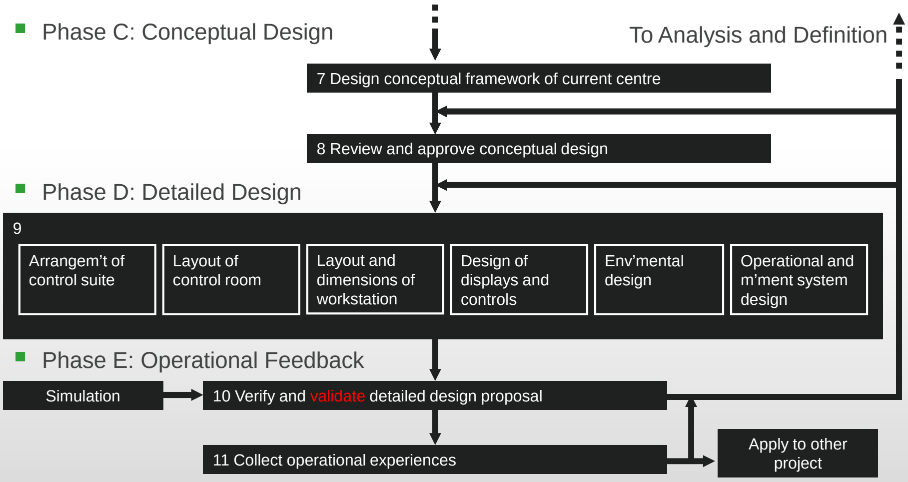
Design process: ISO 11064 (2 of 2)



Said by a colleague:

The major questions like:
"Do we really need this application?
Can we provide this information in another way, maybe by combining applications, reducing the amount of information, changing the way of working?"
are never asked.


Questions
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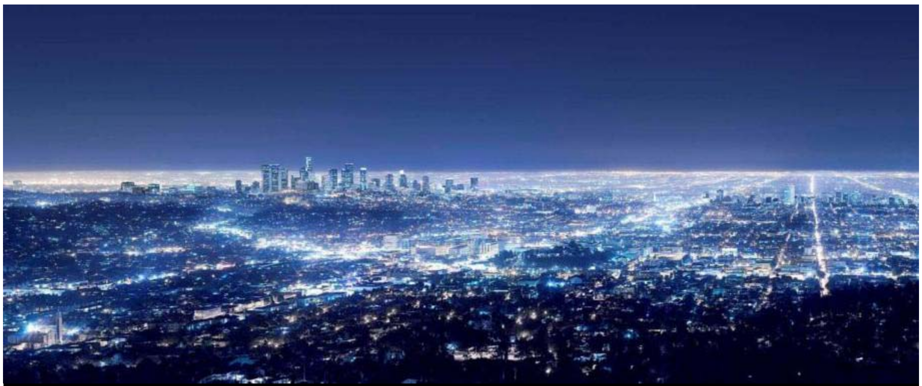
Slide 37

HFC

Beyond Best Practices - Concepts for Future Operator Interfaces

K. Husøy

Mere informasjon:
K.Husøy and T.Enkerud “HawkEye: a novel process automation interface”
C. Heyer “High-Octane Work: The oil and gas workplace”



Kristoffer Husøy, ABB Strategic R&D for Oil, Gas & Petrochemicals, 6. April 2011

ABB HawkEye
HFC-forum

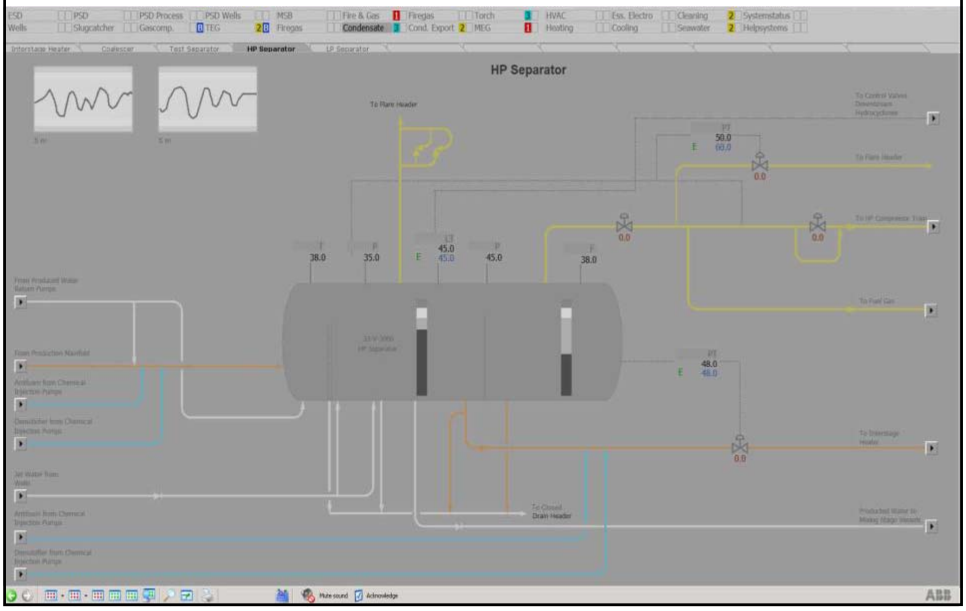
ABB Strategic R&D for Oil, Gas & Petrochemicals

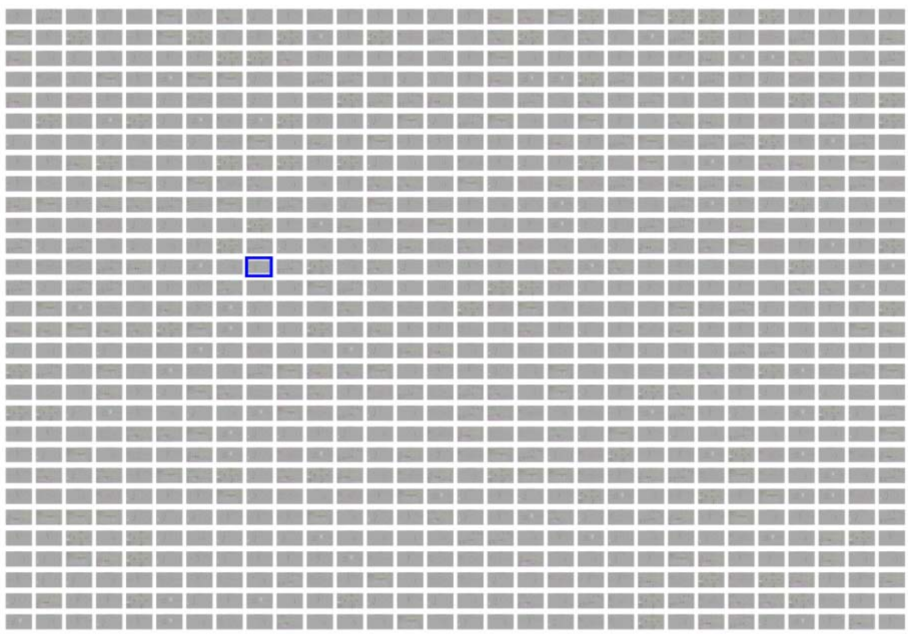
- Focus areas:
  - Human Machine Interfaces - Visualization, HF, Usability
  - Asset management
  - Robotics for Oil & Gas
  - Electrical Integration
- Responsibilities
  - Development of new technology & products (2-5 years)
  - Participation in delivery projects – develop new philosophies, specifications
  - Research together with partners and customers

Ethnographic study

- 5 oil & gas installations in Norway and India
  - Upstream & downstream
  - Offshore & onshore
  - Old & new

ABB HawkEye
Ethnographic study - Complexity





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•April 15, 2011 | Slide 8

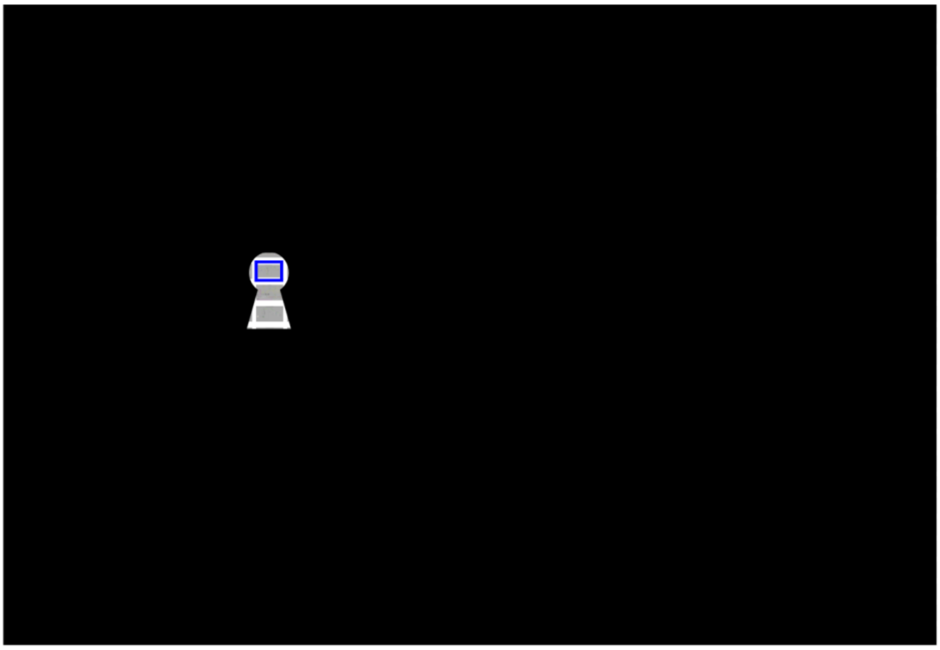


ABB HawkEye
Ethnographic study - Mapping to real world

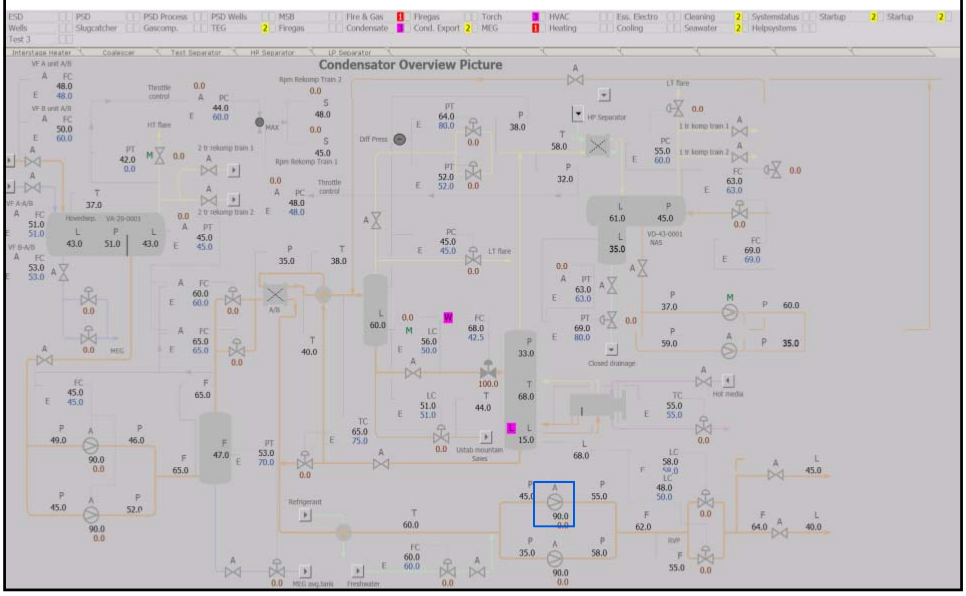
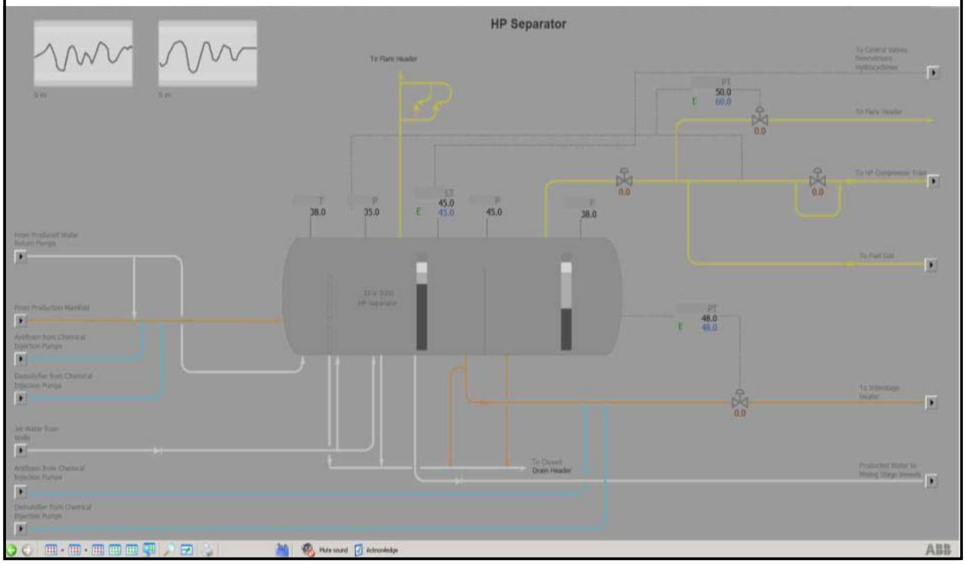
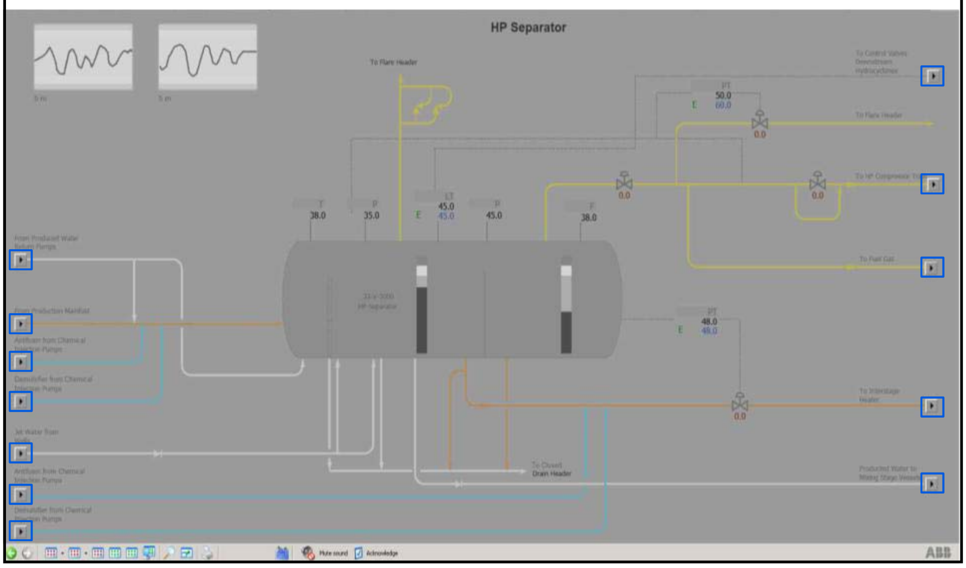
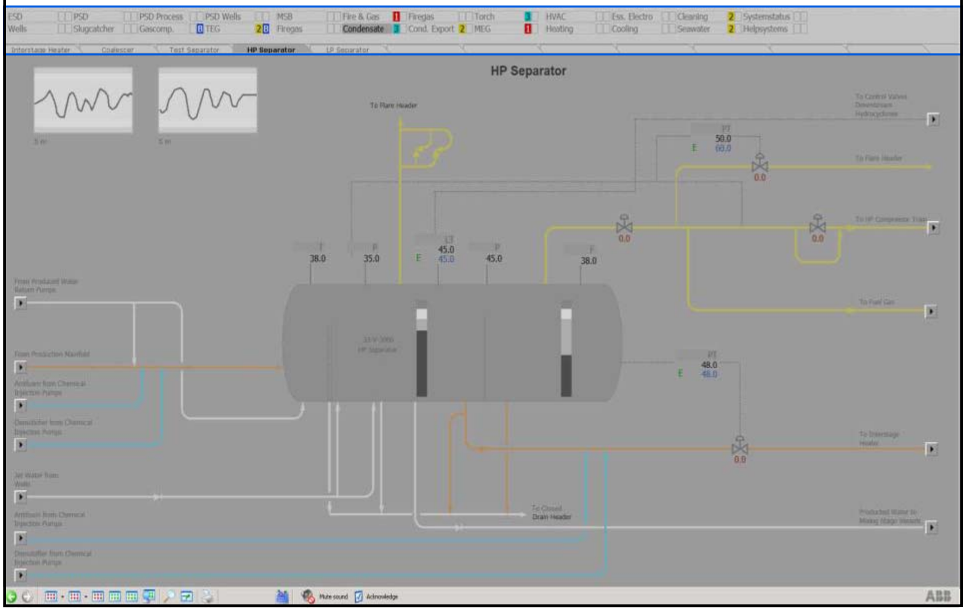


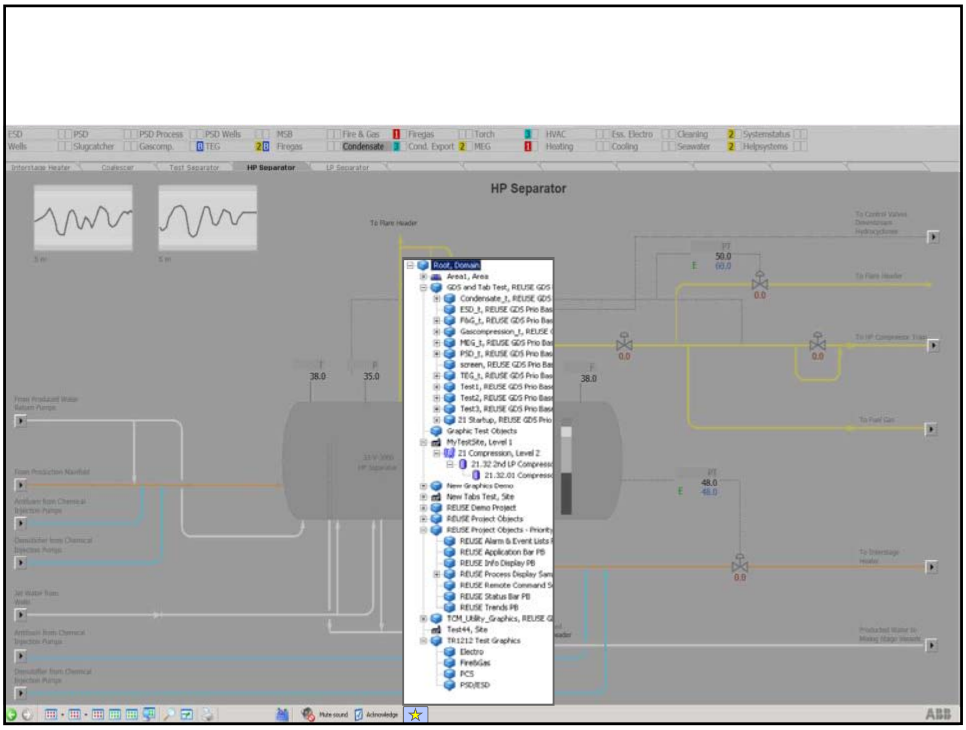
ABB HawkEye
Ethnographic study - Navigation







- Hotkeys (i.e. CTRL+121 for “Condensate overview”)
- Operator keyboards & consoles


HP Separator
Root, Domain
ABB

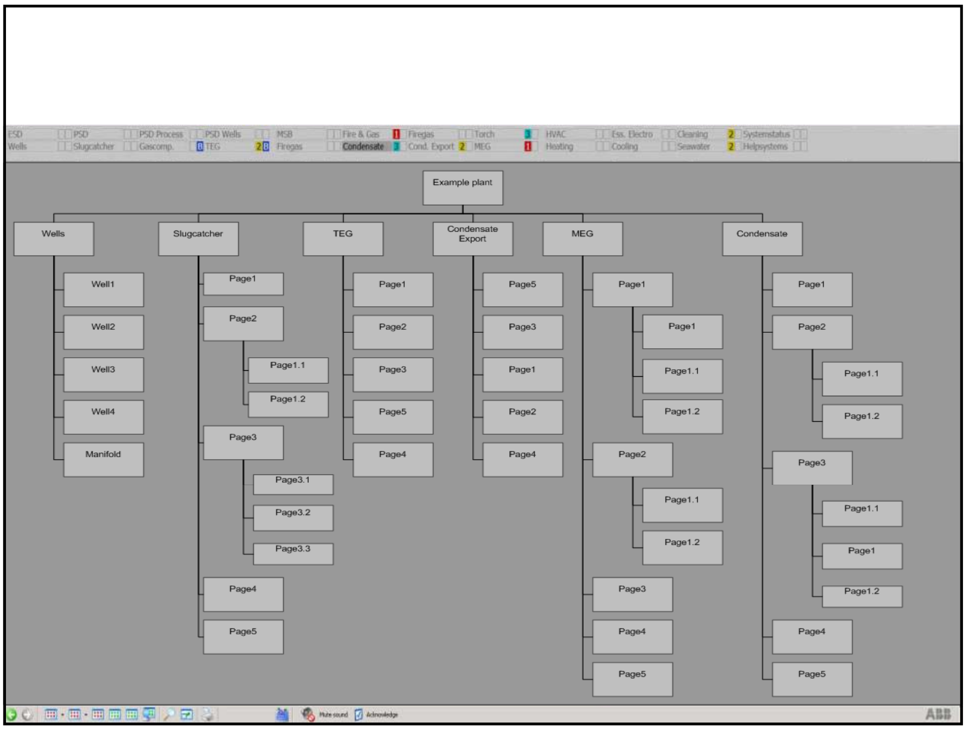

Example plant
Wells
Slugcatcher
TEG
Condensate Export
MEG
Condensate
Well1
Well2
Well3
Well4
Manifold
Page1
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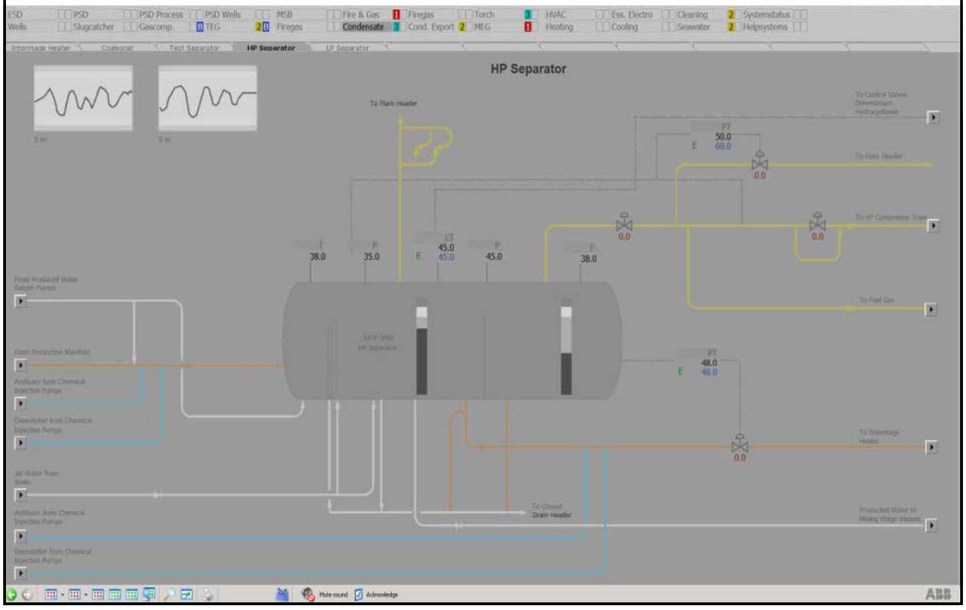
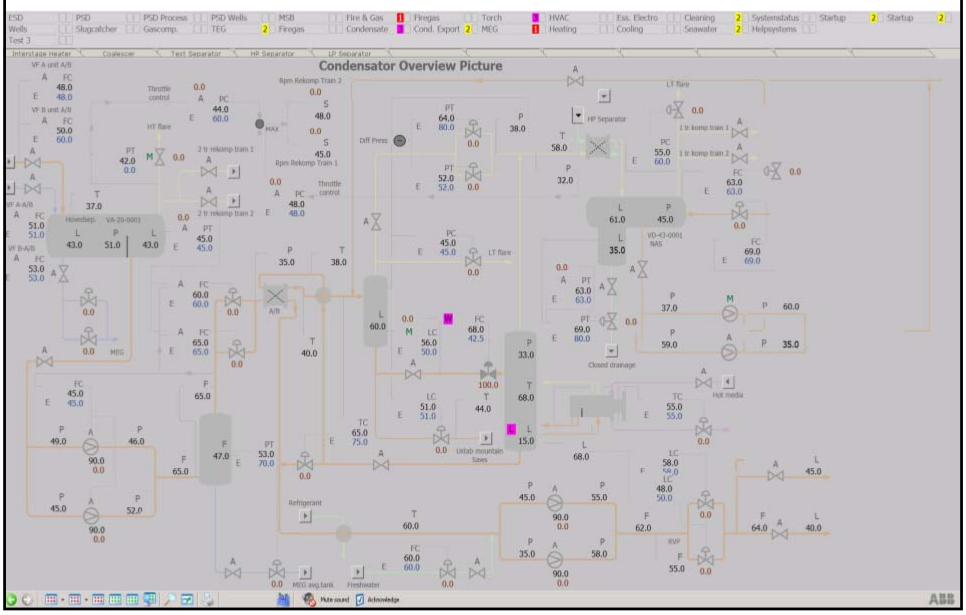
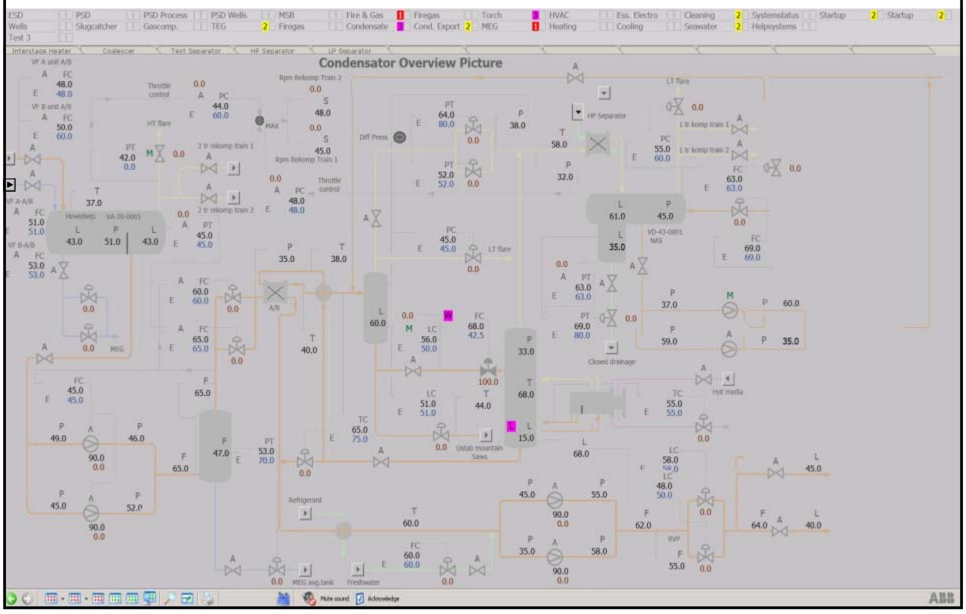
ABB

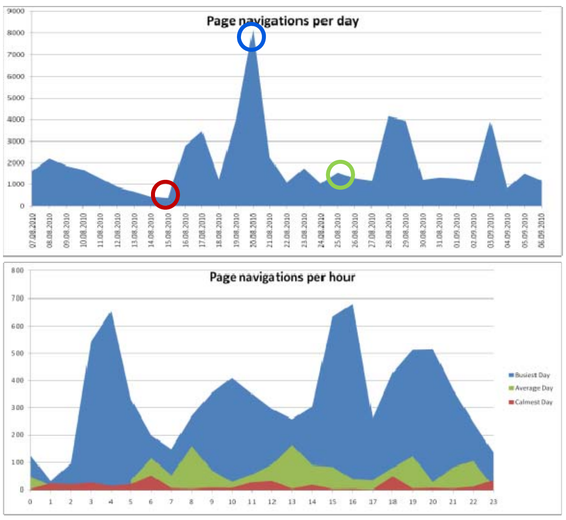
ABB HawkEye
Navigation – context switch

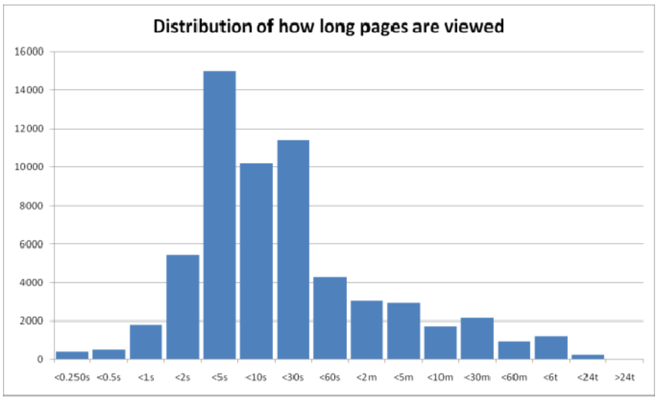






Operational user statistics





HawkEye
Key Design Goals

- **Mitigate the keyhole effect** – Reduce the gap between overview and drill-down views
- **Increase navigation efficiency** – Reduce time spent on navigating and on learning the interface
- **Support both experts and novices** – two distinct end-user groups: process expert oldtimers with poor computer skills and digital native novices with less process knowledge
- **Prevent user alienation** – safety-oriented culture leads to extreme conservatism

Power and productivity
for a better world™

High-Octane Work: The oil and gas workplace

Clint Heyer
ABB Strategic R&D for Oil, Gas and Petrochemicals
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Abstract. This paper introduces the oil and gas workplace context and describes work practices observed at a large Norwegian gas refinery. Ethnographic fieldwork was carried out over a ten day period, consisting of observational studies and informal interviews. They are a small, inter-disciplinary group who are highly mobile and work in a hazardous, critical environment where mistakes can pose risk to health, safety and the environment as well as significant financial loss. Two main shift roles, field operator and central control room operator, are discussed and related to the wider workplace. Even in this technologically-advanced workplace, non-digital informational artifacts are important, often serving as bridges to support flowing activity between communities of practice and the physical and digital. Spending time in the physical plant was seen as an important way to develop an understanding of the process and to gain insight not available through a control system. The primary contribution of this paper is the detailing and discussion of an oil and gas workplace from a CSCW perspective, a context not well established in the literature, yet one that poses an interesting range of design challenges.

Introduction

Oil and gas (O&G) workplaces present manifold challenges for design and seem a promising area of future research. O&G operators are mobile, work in inter-disciplinary teams, in and in-between harsh outdoor and benign indoor environments. They make use of spectrum of tools, from complex ERP (Enterprise Resource Planning) information systems through to rudimentary mechanical tools. Additionally, the refinery or process they attend to is spread over a large space which is both logically and physically complex. High-pressure pipes, extremely low and high temperatures and explosive materials mean the workplace is also a hazardous one, posing risks to human health and safety as well as the environment (HSE). As such, work practices, protocols and equipment are first and foremost designed to promote safety and decrease risk. This naturally impacts what kind of technology can be deployed at a site, for example a normal camera cannot be used without special precautions due to the risk of explosion. Work is of a critical nature: mistakes can cause HSE issues and/or disrupt production, both of which can have a very large financial impact.

Kvasir[1], the studied site, is a refinery situated in a remote area of Norway, supplying a large proportion of the European market and one of many onshore and offshore facilities operated by its parent company. Like most onshore facilities, it is separated into two areas, administration and plant. The three-storey administration building is where regular day shift workers have their offices and also houses the control room, meeting rooms and cafeteria. The plant is where the refining takes place, thus the location of highest HSE risk. It is located 2km from the administration building with workers transiting by vehicle or bicycle. Shift teams' priority is to ensure safe, 24-hour production, while engineers and maintenance staff focus on longer-term upgrades and repair work.

Control rooms featured in CSCW literature have frequently been transport-related, such as air (Bentley, Hughes, Randall et al., 1992), subway (Heath and Luff, 1992) and ambulance (Martin, Bowers and Wastell, 1997). We suggest that the O&G control room is different in two ways. Firstly, there is a significant amount of collaboration and interaction in the O&G control room between people of different disciplines. For example, engineers and field operators might meet in the control room to work through a fault with a control room operator. Furthermore, O&G control room operators have frequent and direct contact with the people they issue directives to (field operators) and work with them in a highly collaborative fashion remotely or co-located in the control room. Secondly, the high degree of automation in O&G facilities mean 'control work' is usually only conducted when something is amiss or when maintenance or repairs are being carried out. As such, control room operators are often idle, particularly on night shifts, yet still need to be attentive and ready to take action.

The industrial workplace - and the O&G workplace in particular - is not well documented in the CSCW literature. We have previously suggested that the O&G workplace has parallels to the (commonly-studied) hospital workplace, which may offer opportunity for re-framing existing studies (Heyer and Grønning 2008). The contribution of this paper is an introduction and discussion of the workplace and its work practices, from the perspective of the shift team who work in and across the industrial environment and the control room. In this publication we do not seek to provide 'implications for design', merely to provide a descriptive account of the context and serve as a resource for future design and research.

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1 Names have been made anonymous.

Future work will report on subsequent field studies at other facilities, and develop a set of general design recommendations and insights for the oil and gas context.

The next section of the paper outlines the methodology, followed by an examination of how work is conducted at Kvasir. A discussion section analyzes observations thematically and the concluding section highlights main findings.

Methodology

Ethnographic fieldwork (Hughes, King, Rodden and Andersen, 1994; Randall, Harper and Rouncefeld, 2007) was conducted over a period of ten days, consisting of participant observation and informal interviews. The focus of the observational study was the shift team, however regular day shift employees such as managers and engineers also participated in the study through semi-structured interviews. Observations were conducted by shadowing a particular participant for a shift, or by observing a particular work area, such as the shift leader's office or central control room. Participants would often volunteer information, describing what they were doing and why and speaking aloud information they received on the radio or computer. It was more likely though that we would ask participants questions as they went about their work to provide explanations and clarifications. Eight different shifts across all three shift periods (day, evening and night) were observed, as well as interviews with 28 people. Notes, photographs and sketches were made during observation and interviews, which were reflected upon and expanded at the end of each day. On the following day, observations were discussed with participants in order to validate their correctness or discover alternative or more detailed explanations.

Work Practices

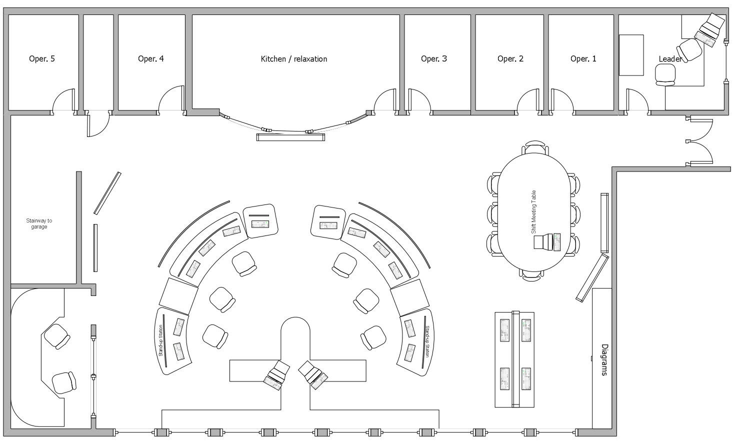

Figure 1. Central control room map. Two control stations are located in the center of the room.

The shift team of around ten people is made up of field operators, two central control room operators and a shift leader and is based in the central control room (Figure 1). Kvasir also has a "day shift" that works regular office hours that includes engineers, administrators and other personnel. The shift leader is a senior member of the shift who manages the team and acts as a mediator between them and the wider organization.

Field operators

Field operators have particular core competencies (such as mechanic or electrician) and are also assigned to particular plant areas. Operators usually work solo as they roam around the plant but frequently liaise with other operators, contractors and engineers. Much of the upgrade and repair work is carried out by contractors, whom the operators oversee, managing work orders and permits as well as ensuring the safety and quality of the work. During a shift, operators also perform maintenance duties, such as draining fluids and cleaning motors.

Field operators have offices adjoining the central control room where they have computing resources and can attend to paperwork. On a usual day shift, operators spend half their time in the plant (Figure 2), half in the administration building. A stairwell from the control room leads straight into a ready room where operators pick up their safety gear and "check in" to the plant with a proximity card. Operators always wear their radio, safety boots and high-visibility, flame-retardant clothes, so they are ready to go to the plant at a moment's notice. When in the plant, field operators have little in the way of advanced technology except for a radio or frequently, a portable gas detector.

Figure 2. A typical oil and gas plant environment.

Central control room operators

Kvasir has two central control room operator roles (CCROs), each responsible for one of two main process areas. From the control system, CCROs can physically manipulate the process, such as remotely controlling valves and pumps. CCROs report that there is usually little need for such manipulations, except in the case of major maintenance or during a shutdown or startup procedure. One operator reported performing manipulations in order to better understand the process, “to see what would happen”.

In their role as a hub and mediator of information and control, CCROs exhibit a high degree of multitasking. For example, we observed an operator who was on a personal mobile phone call also juggle multiple landline calls, radio communication with field operators, radio communication with a moored ship and also making process manipulations – all within a two minute period. Each operator sits at a control station (Figure 3) which has a large projected composite display positioned above and behind four individual screens, all of which predominately show process graphics. Process graphics are a visual depiction of some part of the logical process, overlaid with live process values such as pressures, temperatures and flow. The large display’s abstracted, simplified view and physical size makes it easy to see important information at-a-glance. During emergencies or shut-downs the screens are a useful way of keeping a number of people informed about critical parameters without interfering with the CCROs.

Figure 3. A control station.

Smaller displays are set to show areas of current interest and used to perform process manipulations. Surrounding each process graphic screen is an interface to browse or go directly to particular areas of the plant. In some configurations, panels also appear in the display, for example a list of alarms or video camera feeds. Temporary, overlaid dialog boxes can also be shown, most often for detailed trend line views or ‘faceplates’. Faceplates are used to view detailed information and make adjustments to particular pieces of equipment, with each major class of equipment having its own specialized interface. Three separate computers provide the graphics for the control station's five screens, each with its own keyboard and mouse. This can cause some confusion when moving between the boundaries. Attention can switch quickly to a new screen simply by glancing, while a higher level of cognition is required to release and reacquire input devices. CCROs deal with by attempting to keep the three sets of input devices in spatial relation to their respective displays, to mixed success.

Training, learning and understanding

Field and control room operators both undergo extensive training before being able to work on their own. The training process is a combination of theory learning and apprenticing, with skills being honed and maintained by way of examinations and running through simulated scenarios.

Field operators report that it takes about one year to gain an understanding of a single plant area, perhaps four to five years for the whole plant. Control room operators have a two-year training period before being able to operate a control station solo, and they report that it takes an additional two years to get a good sense of the more complex of the two control areas. Learning periods are dependent on how stable the plant is: an unstable plant is a better teacher than a stable plant. During learning, operators develop an internal model of how the plant works and how the individual components function and fit together to form the process. Both operator roles will have memorized a large number of tags (an identifier assigned to each component of the plant, such as pipes, valves and compressors and used as a uniform referencing system). For a tag number, such as '0300GTFC1AK', an experienced operator knows what it is, where it is located, its history, expected behavior and other properties.

While training provides theory and practical skills, it can still take time for operators to get an understanding, or 'feeling' for the process, a sense of knowing appropriate process values, sounds, smells, vibrations and when things are out of place. Novice CCROs tend to browse process graphics more, as they are not sure which areas to focus on and don't want to miss anything, while expert CCROs tend to jump directly between a small set of graphics. Maintaining an understanding of the process and its operation requires time in the simulator as well as also running the process. For this reason, it is not possible to keep a large number of people 'current' as a CCRO. After returning from the shift's break period (once every six weeks), control room operators run through scenarios in the simulator for around four hours before resuming active duties. Some also read through a log of events to get a sense of what has happened in the plant while they were away. On the first shift back in control, operators report feeling somewhat overwhelmed by the amount of data and alarms, although using the simulator reduces the period of this sensation.

Inspections

Both operator roles conduct regular observation rounds per shift, using their understanding of the plant's norms to detect irregularities. Control room operators conduct their round by traversing the process graphics with their mouse, looking for anything out of the ordinary. By setting their multiple screens - sometimes up to 13 discrete displays - to show particular areas of the plant, the CCRO can be peripherally aware of activity around the plant. Field operators conduct their round by walking through their part of the process, checking oil levels, looking for leakages and so on. This takes an experienced operator around 15 minutes and is conducted thrice per shift.

The 'pull' mode of fault detection is complimented by a 'push' mechanism. For control room operators, this takes the form of control system alarms (Cauvin, Cordier, Dousson et al. 1998) forcing the operator to examine a particular part of the process for sign of fault. For field operators, the 'push' usually comes via radio, for example a control room operator or contractor making a request. For both, these events occur unexpectedly and can interfere with existing work at hand as they usually require immediate attention.

Ritual and routine

Work is ritualized for safety and quality reasons. As an illustration, consider the scenario when a pump needs to be disconnected so it can be cleaned. One operator (with electrical competence) picks up the isolation form from the shift leader's office and travels to the pump's location at the plant. Once there, she verifies the tag number on the paperwork matches the pump in front of her. She depresses the manual stop button and pins a white copy of the isolation form to the pump. At the appropriate electrical substation, she finds the switch panel for the pump as well as a padlock for the panel. The handle is switched into the off position and the padlock inserted to prevent it being turned on inadvertently. It is critical that the right switch panel is isolated and that it does not get reconnected while someone is working on it. A red duplicate of the form is attached to the panel and the key is put back in the cabinet, or given to the person working on the isolated equipment if they request it. After the inspection is completed, the operator is called down again to reverse the process, step-by-step. Each step is ritualized and formalized so all parties can be sure the process is carried out correctly and safely. The paper copies of the isolation form pinned on the equipment and switch panel serve as visual notifications of the alteration and that protocol is being followed.

Situated action

There is usually some amount of pre-determined structure and activity to operator's work, such as routine inspection or maintenance, depending on the prevailing plant conditions. However, we suggest that most of field and control room operators' work is reactive, based on emergent conditions and activity of others. For example, a field operator might be performing an inspection round, and then be radioed by a contractor to approve that the work site is safe to commence work. The operator interrupts his current task, travels to the contractor and signs one part of the work permit. He then resumes his work, but will be likely interrupted again when the contractor radios again for the final signature when the work is complete. Field operators are also frequently issued commands and requests from the control room, such as to perform isolations, check valves and so on. Because requests are ad-hoc and not centrally triaged, it can result in inefficiencies. For example, we often observed an operator driving down to the plant and start work, but after receiving a radioed request need to travel back to the administration building to pick up a form, and then drive back to the plant.

Collaboration and communication

Kvasir is a small organization of approximately 130 employees with a relaxed, informal atmosphere. The flat organizational structure results in short lines of communication and it is typically easy to directly communicate with the required people, regardless of their organizational division.

Technologies

A patchwork of different technologies are employed for collaboration and communication. Computer-based systems include the ERP system, web-based document management systems, email and instant messaging. Radios are mostly used to communicate between shift members and to on-site third parties such as contractors and ships. Wide-area broadcasting is accomplished using the public address system, installed in the administration building and the plant, however considered ineffective in the plant where loud noise and hearing protection occludes the speakers.

Mobile telephones are pervasive, however because they introduce an explosion risk, are only permitted in the administration building. Some employees carry three mobile phones: one personal, one company-issued work phone and another company-issued emergency phone. Those with an emergency phone are expected to have it with them at all times, even after hours, so they are reachable in case a problem arises. Although most people are reachable through a phone connection (be it fixed or mobile), it is seldom used between people at Kvasir, as face-to-face communication is preferred.

Radios are the predominate medium for mediated communication between shift members. Under normal circumstances, around 20 people are tuned to the main channel used by the shift. In the plant, operators wear helmets with integrated ear protection and headphones, by connecting the helmet to their radio they can reduce background noise and hear the radio clearly. A microphone and button is integrated into the cable so the operator can speak while leaving the radio clipped to her belt. There can be issues with radio congestion, especially during periods of intense activity such as during a shutdown, although operators report that normally it is not a problem. Radios provide a shared awareness for the entire shift, as everyone can hear the broadcast utterances which reflect location, activity and progress of each member. Shift leaders note that a sophisticated presence or location awareness system is not needed because simply listening to radio chatter tells them much of what they need to know.

Cross-talk, static and high background noise can impede hearing of radio communication. Instructions and numbers (such as new set points or tag numbers) are repeated back to ensure correctness. Operators will also physically move away from particularly noisy areas in order to better hear the radio, although normal conversation volume is usually sufficient when speaking. The volume of the radio is continually manually managed, for example in the administration building, operators keep the volume low, selectively turning it up when they hear something that might be important. In the field, a higher volume is used which can surprise operators when returning to the administration building with their headphones disconnected. Likewise, operators sometimes forget they've turned their radio down, with the whisper-volume of the next transmission acting as a prompt to turn it up again. When talking with people face-to-face in the field, operators constantly alter the volume to zone in and out of the radio chatter and balance hearing the person next to them with hearing the radio, another form of boundary management.

Many informants reported not using instant messaging "as much as they should", acknowledging the benefits of instant messaging (asynchronous, quick communication), but preferring a short face-to-face chat. Instant messaging is often used as a support for face-to-face conversation, for example sending hyperlinks and tag numbers through instant messaging prior to visiting someone. It was also used for quick, simple inquiries, such as a control room operator asking the shift leader for a clarification about a work order. Most IM communication took place between employees who had a reasonable amount of personal familiarity. For unknown persons within the wider company, participants reported they were more likely to use email or telephone.

Email was used when a digital artifact was needed to support the communication, such as an attached document, or when a higher degree of formality is required. Email is also preferred when a single communication needs to be distributed to multiple recipients or when an audit trail is desired.

Face-to-face

As a result of a small, informal workplace, a significant amount of communication takes place face-to-face. One informant reports that he prefers to pick up a coffee and meet someone for a chat rather than arrange a formal meeting or communicate via a technology-mediated method. Impromptu "drop-ins" aren't successful when people are out of the office, however. To deal with this, people check others' instant message status to see if they appear to be in their office or send a message asking if they have time to chat. Several informants reported being annoyed at not knowing people's availability well enough: time can be wasted if a person goes to visit a colleague, but she is not there. On the other hand, one informant reported quite enjoying the excuse to get out of his chair and go for a walk, and didn't see these missed connections as a problem.

Kvasir has an open-door policy, which encourages communication but also disruption. Informants report different experiences with this policy. For some, this open door policy can be more disruptive than it is helpful, as their work is constantly interrupted by a stream of people at their door. Others find it very helpful to be able to directly visit and ask someone a question quickly without having to make formal arrangements. Clearly a balance between these experiences is desired and even those informants who were often interrupted thought it was a worthwhile policy overall. Hallway-facing walls of offices have large glass panes which facilitate awareness of office activity and presence.

Intra-shift

Shift meetings are held at the beginning of each shift at a desk in the control room. The shift leader chairs the meeting and operates the meeting computer, the display of which is also visible on a large screen behind him. Using the ERP system, the shift leader runs through the digital shift log, a list of current issues with the plant. Issues which are new to the shift or have undergone change are focused on, with long-running outstanding issues largely ignored.

Because of the consistent shift composition, shift members recognize each other's voices on the radio which aids communication. Members know who is responsible for which area for a given shift period, so people are normally summoned by name ("Anders?") rather than by role or responsibility ("Control room?"). Interaction can also take place wordlessly, in one situation we observed a field operator walk in to the control room and sit next to a CCRO. Without a word, the CCRO, aware that the operator was just working on a pump, switches graphics on a screen to show the pump in question.

Intra-day shift

Formal meetings between day shift workers takes place in dedicated meeting rooms, or rooms with added meeting-support technology. An example of the latter is the maintenance office, which has a large wall-mounted display that the maintenance leader uses to send a clone of his desktop to so that others can follow along as he navigates through defect notices. Meetings usually take place around computer-based output, be it an on-screen application or slide deck, with the ERP system widely used as a way of navigating and presenting data. There are difficulties with this approach as the program was not designed for presentation, especially not on a large screen.

In a recent change, some Kvasir management personnel now report to management located in distant cities. Collaboration takes place over instant messaging, email, phone calls, and increasingly, video conferencing. Naturally, these types of communication and collaboration are not well suited to the informal style of interaction that is commonplace at Kvasir. Informants noted that it was thus harder to maintain personal ties and feel connected to those located remotely. Travel to either of these locations is also difficult due to Kvasir's remote location and requires a significant amount of time.

Central control room operators

Although the two central control room operators sit in close physical proximity there appears to be little collaboration between them. Partly, this is because when the plant is running as it should, there is little to work together on: they share a role, but rarely share tasks. The alarm list which appears on both operator's large screen (and often duplicated on a small screen too) is shared. As alarms occur, an audible tone is produced and a new entry appears at the top of the alarm list. Operators use the mouse to mark an alarm as acknowledged; collaboration can thus take place around this shared alarm list. Operators do not manage alarms which are unrelated to their part of the plant, however they serve as a useful peripheral awareness as to their colleague's activity and status. Alarms might not be directly related to their part of the plant, but because of the interconnected nature of the process, may have an impact if the situation is not managed. Thus, if an operator notices her colleague's unacknowledged alarm list growing she might ask him how he is going, or simply look over to his desk to gauge his activity. There are different styles of alarm management which can cause some mild tension between operators, for example, some acknowledge alarms as they occur while others prefer to process alarms in batches.

Engineers and the shift

Engineers draw up work orders which are carried out by operators or contractors. A work order might be simple, such as modifying a pipeline's pressure, re-routing flows or more complicated upgrades and repairs. The central coordination artifact for such operations exists in digital form in the ERP system but is regularly printed throughout the workflow. Engineers will occasionally visit the person responsible for carrying out the task with the printed work order, sketches and annotated diagrams in hand, to talk through the plan. Operators have a rich practical understanding of the process which complements the engineer's theoretical perspective. Engineers noted that operators will often suggest an alternative plan which achieved the same result but was easier to implement. It is important for the engineer to ensure that the operator understands the work plan or shift instruction and some engineers suggested that this was easier to accomplish face-to-face.

Engineers and operators also occasionally work around the stand-up stations, or at the main control stations. For example, an operator might pull up the process graphics for a particular system and use that as a basis for conversation with the engineer, highlighting particular process values using trend lines. The stand-up stations, more so than the control stations, encourage collaboration around the data, and there were a number of occasions observed when operators or operators and engineers worked together around the screens.

Many engineers make a point of regularly visiting the control room to maintain a good relationship with the shift and to pick up on issues unreported through official channels. It also provides an opportunity for the shift, which is largely bound to the control room and plant areas, to informally and directly interact with the engineers. Sometimes these visits might amount to little more than drinking a coffee while hovering near the control station, or perusing process graphics at the stand-up station. More often than not however, conversation would be initiated and news and updates exchanged. One engineer also reported it being useful to talk face to face as some things are not well expressed in written communication. Engineers also note that the frequent contact is useful for building up two-way trust and better understanding of each other's competencies.

Remote communication between operators and engineers is usually via email, partly due work period mismatches. It is also because communication often includes hyperlinks, documents and precise numbers which need to be expressed clearly and in an auditable manner. For urgent issues, operators will send a text message if they don't expect the engineer will check their email soon. Shift leaders also maintain close ties to engineers and will often call them down to the control room for consultation.

Information and systems

In the plant, various informational artifacts are used to situate temporal information to a particular location and piece of equipment. For example, when a valve is manually changed from its normal operating state, a large plastic sign is attached. It has a "blinding" number written on it in temporary marker that cross-references a printed list kept in the shift leader's office as well as in the ERP system. The tag number, date and who made the change is also written on the sign. During maintenance rounds, paper tags are used by operators to keep track of which equipment they have inspected, usually with only their initials or a date written on them. Once the round is complete (perhaps over several weeks), the tags are taken down. Operational transactions such as isolating an electrical circuit can also result in temporary notices being pinned to different equipment.

The ERP system is the primary common information system (Bannon and Bødker, 1997), integral to most aspects of work at the refinery. For example, if an operator notices a defect at the plant, this is entered as a 'notification', which is then reviewed and annotated by the maintenance network, and possibly goes on to form the basis for a work order and work permits. Information is extensively cross-linked, for example when reviewing a work order, it is possible to see if required parts are in stock, retrieve product specification information or diagram the fault in the context of the logical process. New informational artifacts or exchanges are often composed from disparate sources, such as collating diagrams, specifications, notes, instructions and annotations in a work order. Like Fitzpatrick's (2004) observation of hospital patient records, these composite, multimedia, locally-contextualized artifacts are "living documents" which frame and support work activities rather than being a passive information repository.

Piping and instrumentation diagrams (P&IDs) are perhaps the most important reference document in the oil and gas workplace, or as one operator called them, "our bible". In the diagrams, a logical view of the process is shown similarly to the on-screen process graphics but in greater detail. They are often referred to when there is a need to isolate a section or to trace through the process. Operators with different competencies read the diagrams differently. For example, some read the diagram for valve details, while others read it for the properties of pipes (such as the type of steel and pressure class).

P&IDs are drafted and maintained on a computer but the canonical version of a P&ID is the printed master copy kept in the control room. They are updated over time to reflect alterations in the plant – these too are living documents. Diagrams are frequently printed, which enables them to be physically attached to a work order, carried to the plant or around the building, or used to support discussions. Reading diagrams online in PDF form is common and considered a useful and viable alternative to paper-based diagrams. Diagrams are usually sparsely laid out and thus do not demand the high resolution that paper affords. They are hyperlinked so that the user can navigate the process or retrieve further detail by clicking hotspots. This is considered one of the more useful aspects of electronic viewing – the ability to explore the process with minimal effort. When using printed diagrams, the user would need to know what part of the plant to print and at what detail, and there is a time penalty of finding and printing or retrieving the diagram if another view is required.

Vignette: Dealing with pressure

To illustrate the collaborative work and use of informational artifacts by the shift, we describe the following event which took place during an evening shift:

> Suddenly the irregular audible warnings sounded continuously. Soon afterwards, the pitch becomes higher, indicating the warnings are now alerts. The alarm list on the control station blinks frantically as new alarms are rapidly appended. Across the operator's smaller screens, various displays blink urgently. Two field operators come in from their offices, standing behind the control room operator whose area is being affected. The CCRO had not seen this type of alarm before and was a little worried. He also knew from experience that problems in this process area can shut down a boiler which would be a significant problem. On the control system, he quickly opens trend line displays relating to the boiler, scaling them back in time to look for sudden changes. On seeing that the boiler was not being affected, he relaxes somewhat. One operator returns to his office, the other stays and helps the CCRO as the event unfolds. While the boiler did not appear to be affected, pressure was being built up in the distillation column, which would need releasing urgently. P&IDs are brought up in PDF form on the workstation, and quickly printed out. The operator fetches the printed document and he and the CCRO talk around it, trying to establish what is going wrong and how to reduce the pressure. The CCRO's first thought was to relieve pressure via the flare, but after examining the P&IDs and current process values, it would seem as though several valves are in the wrong positions and that the flow could be routed back into the process normally. They then go to the shift leader, an expert in the distillation area, who agrees with their course of action. A field operator is radioed to make changes to the valves and shortly afterwards, everything returns to normal. The entire activity took no longer than 25 minutes, 10 minutes of which was highly tense whilst the alerts sounded continuously.

As a result of flow re-routing during repair work, parts of the plant that have lain dormant for nearly 10 years were used and an error in the original valve diagram was discovered. After addressing the immediate problem, the CCRO composed an email to the responsible process engineer. He attached a screenshot from the erroneous P&ID with mouse-drawn annotations and included hyperlinks from the ERP and web-based documentation system.

Discussion

Non-digital informational artifacts

As described earlier, temporary in-situ notices are used in order to link status information to the physical plant, for example that a valve has been changed from its normal state, or a circuit has been disconnected. Notices are almost always explicitly linked to a particular piece of equipment by a tag number, the universal referencing system in a plant. Notices serve two main purposes: to make visible that which is invisible and to link the physical with the digital. For example, that a valve is in a changed position is not externally observable without prior knowledge of its proper state. Hanging a sign on it makes it clear to everyone that it is currently in an altered state. Because of the enhanced visibility, the valve will also be easier to find when it comes time to changing it back. Moreover, notices express *purposeful* action. If a pump was found to be switched off, the presence of a sign hanging on it will indicate that it was intentionally put into that state.

Digital-based information, such as work orders and reported faults are linked to the physical artifacts by way of the signs. Each notice has an identifier in addition to the tag number which allows people to trace why an action was carried out and other particulars. Brief information is also included on the notice itself.

Sticky notes were only occasionally used for inter-shift communication, such as the night-shift leaving a message asking if a pipe should be running at its current pressure. During a shift, paper was used differently depending on plant activity and operator's experience level. Some maintained pads of paper to keep track of process values and reminders, while others remembered everything: for some entire shifts control room operators would not use any informational artifacts beyond the on-screen process graphics.

Most field operators use a pocket notebook of some type - usually rather tattered - in which they keep notes, tag numbers, part numbers, test results, sketches and so on. Notes range from being highly temporal, written down but meaningless after an hour, to notes which were referred back to years later. Notebooks are often used as an intermediary to the control system, an aid for discussion (such as drawing a picture) or memory.

Plant piping and instrumentation diagrams are useful to locate tags and understand the process. A single plant is represented by hundreds or thousands of P&IDs, available digitally but frequently printed out on an on-demand basis. The A4- or A3-sized pages can then be studied and marked up with highlighters and pens, and is often used as the basis of interaction between colleagues. The diagram is eminently portable and does not introduce a safety hazard in the plant where it is used to identify physical assets or as a navigation or memory aid. For example, whilst in the administration building with full documentation available to him, an operator might highlight on a P&ID valves that need altered and then use this annotated diagram as a spatial workflow to carry out the tasks when at the plant. Engineers also use P&IDs extensively. Marking streams, valves, flows and values on the printed diagram is a way of building an understanding of the process and a useful part of the diagnosis process for engineers, whether working alone or with others.

Perhaps the most prominent use of paper is that of work permits. Work permits have a short lifespan – typically no longer than a day – and are linked to a single unit of work being carried out in the plant. They are an important part of the audit trail, to not only ensure that work is carried out properly, but that it is done in a safe and verifiable manner. Usually a contractor carrying out the work will produce the permit, which is first signed by the shift leader. Some types of work (those with a higher risk category) might require additional signatures before work can commence, such as from the operator responsible for the area. When work is complete, the contractor signs and then the operator responsible for the area signs, taking the permit back to the shift leader's office for archiving.

Signing pen-on-paper is quick and accessible with the only requirement being that the parties and the paper are co-located. Typically, contractors achieve this by radioing for operators when they require a signature, however this can cause delays if the operator is some distance away. Because operators usually need to verify some aspect of the physical scene before signing, the co-location requirement of pen and paper is not necessarily an inconvenience. Co-location can also be achieved somewhat creatively, for example signing forms through open car windows, as one car heads up to the administration building and one heads down to the plant.

Bridging boundaries and flowing activity

Boundaries between systems, people, knowledge, perspectives, practice, groups and locations are bridged in a number of ways. For example, field operators often act as a bridge to the physical process for engineers who do not visit the plant as often. Shift leaders act as bridges between shifts, exchanging information about what has happened during the outgoing shift so the new shift is up-to-date. Artifacts can also act as bridges, in a similar manner to "boundary objects" (Star, 1989; Lee, 2007). Indeed, the sole value of some artifacts appears to be their bridging quality.

Sticky notes are a common example of a bridging artifact in the workplace. Short snippets of information are jotted down and then either pinned up, to inform later shifts, or handed over, for example to exchange a tag number. Their value is often highly temporal, serving a purpose as a bridge in an interaction and then no longer being useful. During maintenance network meetings, work order numbers are often passed to the network leader via instant messaging as the meeting progresses, an even more temporal form of sticky note.

P&IDs serve an important role in bridging the communities of practice (Lave and Wenger, 1991) of engineers and operators, as one engineer reported, "[we] mainly talk with diagrams". The diagram serves as a common foundation upon which new understandings can be built. All parties know how to read a P&ID, and it is through the P&ID that a meaningful discussion can take place, grounded in the common understanding. The diagram also facilitates talking about a process which is physically and logically large and complex through a standardized, simplified proxy.

A common quality of the aforementioned artifacts is their ability to bear free-form expression and direct interaction style. A sticky note and P&ID can have anything written or sketched on top and an instant message can hold free-form text. They are also direct in that they require minimal preparation to use and there is little interactional work required beyond that to express the desired message. These qualities are not found in Kvasir's web- or ERP-based systems, which typically involve extraneous navigation and form-filling work.

The O&G context brings boundaries to the fore partly because of the rich, multifaceted ecology in which activity takes place. Consider for example, how field operators transition between perusing interlinked information systems in an office environment, discussing a procedure over a printed P&ID through to opening a valve in a noisy, hazardous plant. In addition to organizational and technical boundaries, there are also explicit policy boundaries which partition and restrict access to physical spaces and infrastructure such as electrical and computer network grids. Practitioners flow their activities across the multitude of boundaries and diverse resources in order to accomplish their work. To some degree the work environment (computer-supported or otherwise) supports them in this task, however we suggest that flowing is largely accomplished through assembling and tailoring appropriate resources by workers themselves.

The plant

Shift members have a strong phenomenological connection with the plant, which has also been observed in the nuclear power plant shift members (Vicente and Burns, 1996). They speak of the freedom of walking around in the fresh air, the sound of the plant, the smells: feeling and knowing. Frequent contact with the plant over a long period of time allows them to learn what is expected and what is not, what equipment is prone to failure and so on. Shift members' deep understanding of the physical plant is unmatched in the organization and a useful resource for diagnosis and maintenance.

During inspection rounds, rather than simply examining dials and gauges, operators engage with the plant in a rich, experiential manner. For example, an operator will take his glove off and hold his hand to a motor to feel for heat and vibration. Operators listen to equipment's noise, observe steam quantity, color of flames and smell for gas leakages or burning oil. Because of their experience and knowledge of the plant, operators can in effect sense when something is wrong: for example, there might not be enough steam being produced, a motor might be too hot, or a pump might be rattling. These environmental, ambient cues are an important aspect of the operator's diagnostic and observational role. Manual observations are used to look for faults which are not revealed by instrumentation and thus invisible to control room operators in their control system. For example, it is simple to monitor gradual wax build-up on a valve through visual inspection, however it is only when a valve has seized up that the build-up is apparent via integrated sensors, at which point the issue could be critical.

Field operators visit the plant more frequently than other employees. On a regular day shift, an operator will usually spend about half their time in the plant.

As such they are subject to the variable - and very often harsh - environmental conditions, with frequent rain, high winds and temperatures as low as -15°C. Operators liked the variety of being inside and outside, likening it to having two different jobs. Inside, they enjoy the sociality of control room, outside, they enjoy the freedom of movement and contact with plant. Informants enjoy the physical aspect of the work, being able to hear and smell the plant and "get your hands dirty". Most control room operators periodically rotate as field operators, and while they enjoy the chance to visit the plant, they dislike the loss of ownership and mastery when they are "only" field operators.

Engineers also note a strong connection with their work and the physical plant. Because engineers do not visit the plant as frequently as for example, field operators, they have a lower level of awareness about their plant area and can easily overlook small-scale faults. As such, they often rely on operators to bring issues to their attention, especially when they visit the plant together. One engineer reports that there is "something special" about being in the plant itself and that doing diagnostics over a video link would not suffice. He notes that a report or account might miss something important and there is not the "personal impression" you get with a firsthand visit. For example, if a leak is reported, he likes to see it to get a sense of its scale, what it looks like and where it is coming from – properties that could be represented in a fault notification, but are unlikely to give the same sense as to actually observe it directly.

Conclusions

The oil and gas workplace presents a rich, multifaceted ecology of action, spaces, information and artifacts in which activity is carried out. While the facility is technologically advanced, various non-digital informational artifacts are used as critical parts of work. In the plant, situated signs are used to express purposeful action, make visible that which is invisible and to serve as a link between the physical and virtual. Pocket notebooks are used extensively to record both fugacious and enduring information. Most safety and quality protocols require paper forms and written signatures, such as work permits.

Boundaries between systems, communities of practice and the physical and digital are bridged a number of ways. Piping and instrumentation diagrams are frequently used as a resource in communication, permitting a higher-level understanding to be reached from the common understanding of the diagram. Pocket notebooks are used to jot down tag numbers or values in the field, which later serve as input when accessing online information at a workstation. Discussions often take place around a particular tag, with sticky notes or instant messages commonly used a way of exchanging these identifiers. Such mundane technologies are well suited to these bridging tasks due to their ability to bear free-form expression simply and directly. As is often the conclusion in CSCW, designers need to give special attention to the mediation of boundaries in order to support smooth flowing of work across diverse physical and digital resources.

Participants cited a strong phenomenological connection to the physical plant. They note the importance of smell, sound, vibration and sights for understanding the plant as well as detecting and diagnosing faults. More generally speaking, the importance of physical presence emerged as a theme, such as engineers spending time in the control room to build relations with CCROs, or field operators spending time in the plant to learn more about its operation and develop a sense of its norms and quirks. This may suggest limits to tele-operation of facilities, or having operators service multiple plants.

The results reported here hint at some danger in implementing 'obvious' solutions. For example, a system to provide digital P&IDs to the mobile field operator would have limited value over paper P&IDs if it does not support annotations, shared interaction, is explosion-proof and usable whilst wearing gloves outside. In another example, the work permit signing process could potentially be made quicker by using mobile devices which communicate directly with the ERP system and do not require pen, paper or radio communication. This, however, would reduce the shift's shared peripheral awareness of each others' activities since there is no usage of the shared radio channel. Shift leaders and control room operators in particular benefit from the awareness the radio channel provides, even though congestion can be an issue during periods of intense work. An apparatus designed to reduce radio congestion and offer alternative mobile communication to the radio would also need to consider how operators today continually manage volume as they pass between different spaces and selectively place the shared channel at their focus or periphery. For example, if text messaging was to be used to support communication, how would the operator know when a message was important enough to focus on without actually diverting attention and reading the message? How would operators exert fine-grained focus-control?

This paper presented the results of ethnographic fieldwork at a gas refinery focusing on the shift team, which consists of field operators, control room operators and a shift leader. The paper's contribution is an initial description and discussion of the work practices in the oil and gas workplace, a context not well explored in the literature, yet one that poses interesting challenges to the CSCW community.

Acknowledgements

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HawkEye: a novel process automation interface

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ABSTRACT
Operators in the automation industries today have difficulties in maintaining their situation awareness and understanding the impact of events. Massive amounts of data must be perceived and made sense of in a short amount of time, and maintaining overview is difficult while digging deep into the details when solving problems. The HawkEye prototype described here seeks to overcome these problems by providing a zoomable interface with animated movement and information aggregation. The intentions are that the information layout with zooming can provide a better sense of context, the animated movement can support continuous learning and the information aggregation can help operators make sense of the events and their implications as they occur.

Author Keywords
Interaction techniques, zooming, information navigation, sensemaking, situation awareness, process automation, DCS

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

THE PROCESS AUTOMATION DOMAIN

Industrial processes such as oil production and refining are difficult to control and require the operators to monitor and control tens of thousands of process measurements. These process measurements (temperatures, pressures, levels, flow rates, etc) are in modern process control systems presented to the operators on computer screens, where the measurements are visualized on a set of schematic graphics of the plant, known as process graphics. A typical plant can have between 50 and 5000 of these process graphics, depending on size and complexity of the process.

Naturally, the operators cannot see all of these graphics simultaneously and must focus on one or a few at a time. This is within the industry known as the keyhole effect, and points to the trade-off between digging deep into one area of the system to solve an issue while at the same time maintaining overview of current state within the rest of the system.

Navigating between these process graphics is today cumbersome and tedious. Normally, the operators can either use dedicated navigation displays that depict the graphics in a hierarchy or flow-based schematic, or they can use link buttons in each graphic that follow the process flows. As all graphics cannot be linked to directly from each other graphic, the operators must navigate via several intermediate steps. This resembles the navigation between pages on an internet site, where one navigates to the main area first, e.g. men's shoes, then to sneakers and maybe to separate pages for each brand, and even several pages for each brand, thus involving 5-6 navigations before arriving at the desired page.

In critical situations efficient navigation can be vital to avoid a plant upset. An unplanned plant shutdown can incur costs in the millions and it often takes days to get the plant back to normal steady-state production. When combining this level of criticality with the timing constraints in plant upsets and the immense complexity of the system, it should be clear that achieving good navigation and operation scheme is of great benefit to the operators.

HAWKEYE - THE PROPOSED SOLUTION

The HawkEye process control interface seeks to remedy these issues by improving the interaction methods, navigation scheme and information layout. The keyhole effect is thus mitigated by providing better sense of context, quick access to overview information and more effective navigation methods.

In HawkEye, the process graphics are spread out on an infinitely large zoomable virtual surface. The process graphics layout can mimic the overall functional structure of the plant, making the placement of each graphic easy to remember for the operator. This matches the operators' mental models of the plant segregated into functional modules such as import stages, initial separation, second stage separation and then export. Furthermore, by animating all movement in the interface, operators are continuously and unobtrusively reminded where the different parts are in relation to each other, without having to navigate out to the overview level. The animated

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ACM 978-1-60558-934-3/10/10

navigation is important to help operators learn the relationship between process equipment and location in the process graphics quickly.

Figure 1. HawkEye: continuous, animated zooming between all levels, with aggregated state presentation in overview levels

Contextual & aggregated information

One of the main advantages with this solution is that it provides a powerful method for presenting all information in context. As the whole plant can be seen at the top level, zooming in and out shows clearly where the issues are arising and how it relates to surrounding equipment. By aggregating information in the higher zoom levels, e.g. combining individual alarms, the operator can clearly see where he should focus his attention and also how – on an overview level – an emerging incident affects the plant areas.

The ability to show correlations between objects in different process graphics is especially valid for the lowest level of graphics, often referred to as the detail graphics or level 4 graphics. These can show the intricate details within a subsystem, e.g. an export compressor, and was in earlier systems shown as a separate page. As HawkEye is infinitely zoomable, the details of the export compressor become visible as the operator zooms in on the export compressor, as the additional information is faded in while the zooming occurs. This facilitates the process of understanding how an event within the export compressor influences the surrounding equipment, as the alarms and process deviations are represented directly in context.

The HawkEye interface thereby builds on the existing concepts for contextual information presentation in process graphics as they are today. But HawkEye extends the design pattern to also include the context between process graphics, to see how a process object is connected to objects in the surrounding graphics.

Interaction techniques

To support operators in effectively navigating the interface, the de-facto standards for user interactions that are emerging within mapping and photo editing software have been applied and adapted: Zooming by mouse wheel scroll, radar view to continuously maintain overview and quickly move around, double-click to zoom in to the next level, single key access to zoom out to full overview, panning by click-n-drag with momentum and acceleration, etc.

Operators can view a single process graphic, or zoom slightly out to see how it relates to the surrounding process objects, thereby overcoming some of the issues related to the keyhole effect. To further take advantage of how all information is presented in context and in relation to the plant as a whole, the embedded incremental search function highlights all hits in the graphics and can automatically zoom to include all hits while it is being typed. This presents the search results in context rather than (or alongside) in a list, helping the operator to quickly determine the correct item.

To maintain backward compatibility with existing systems and to let the migration to new navigation methods happen gradually and smoothly, the existing direct link buttons within each graphic have been kept. The only addition is to include the navigation animation also here, to add to the learning effect of where objects are placed.

CONCLUSION

The HawkEye prototype is an exploration into a new paradigm for operator interaction within the process automation industry. The preliminary user tests and concept evaluations indicate that the fluid, seamless interface and its effective, zooming navigation scheme can reduce the negative impacts of the keyhole effect. Further user testing and field piloting must be performed to verify the potential and provide deeper insight into the benefits and challenges of the prototype.

HFC

Design of visual facilities within collaborative decision environments

A.Clark

Mere informasjon:
A.Clark “Design of Visual Facilities Within Collaborative Decision Environments” 2008 SPE Intelligent Energy Conference.

Design of Visual Facilities Within Collaborative Decision Environments

SPE Ref: 112040

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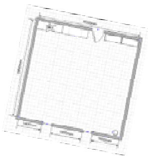
How it all began…

www.epsis.no

What to consider...

- Physical space available and how it is arranged

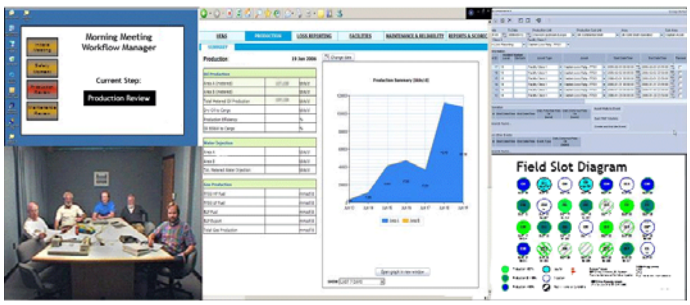


- Number of people required to work in the CDE & where they are located

- Amount and type of data that needs to be displayed at any one time

The Use Cases

- Who is there
  - Example: 10 folks offshore & similar in onshore facility
- Mock-up each step of each use case for the facility
  - Example:



Resolution vs. Distance

Resolution:

 £ ££ 

Size:

 $ $$ 

Size & Resolution:

 € €€€€€€€€€ 

Perceived Pixel Size (Craggy Island Version)

*"Father Ted," Season 2, Episode 7, "Hell," by Graham Linehan and Arthur Mathews, first aired Friday, 8 March 1996.

Perceived Pixel Size (Science Version)

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"Visual acuity (VA) is acuteness or clearness of vision, especially form vision, which is dependent on the sharpness of the retinal focus within the eye, the sensitivity of the nervous elements, and the interpretative faculty of the brain."

- 20/20 is the visual acuity needed to discriminate two points separated by 1 arc minute.

* "Visual Acuity," from Wikipedia, the free encyclopaedia, extracted 8 November 2007, http://en.wikipedia.org/wiki/Visual_acuity.

Perceived Pixel Size (Science Version) continued...

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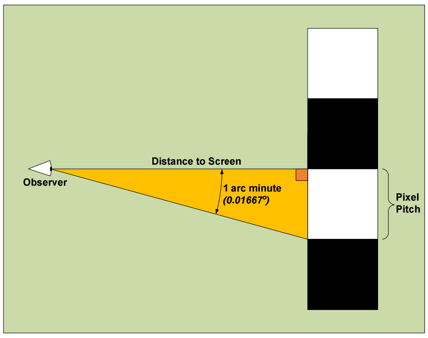

Boring maths bit:

Using "old school" trigonometry:
Tan θ = Opposite/Adjacent
Using Figure for reference:
Opposite = Pixel Pitch
Adjacent = Distance to Screen
Θ = 1 arc minute = 1/60th of a degree = 0.01667º
Therefore, the following holds true:
Tan (1/60) = Pixel Pitch/Distance to Screen

Rearranging this equation and resolving the maths gives us:
Distance to Screen = 0.000291/Pixel Pitch
or
Distance to Screen = 3438 × Pixel Pitch

In English this equates to the following:

An ideal viewing distance for people with 20/20 vision should be 3,438 times the size of a single pixel.

Very impressive you remember trig from school, but what the hell did that mean...

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- It means we can construct a table like this showing us the viewing distances for common sizes of high definition (1920 pixel x 1080 pixel) LCD Panels:

Screen Size (16:9)	H Size (in.)	H Size (mm)	H Resolution	Pixel Density (mm)	Opt View (mm)
42 in.	36.72	932.7	1920	0.48579235	1669
47 in.	41.09	1043.8	1920	0.543624772	1868
55 in.	48.09	1221.4	1920	0.636156648	2186
65 in.	56.83	1443.5	1920	0.751821494	2584

Factors for the range...

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Take into consideration 3 factors:

- Most people have better than 20/20 vision
- Most data viewed on the screen will not use the "finest detail" available (e.g., fonts and diagrams).
- Much of the data will not require the user to resolve every pixel (e.g., video and graphic images).

Arial @ 6pt

Arial @ 8pt

Arial @ 10pt

Arial @ 12pt

Arial @ 14pt

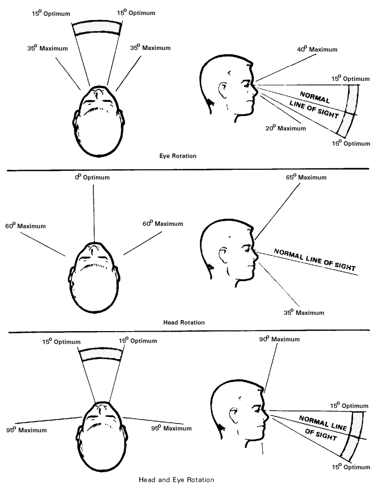
Arial @ 16pt

The range...

- 60-140% either side of the "Optimal diatance" giving us...

Screen Size	Opt View (mm)	Max View (mm)	Min View (mm)
42 in.	1669	2782	1002
47 in.	1868	3114	1121
55 in.	2186	3644	1312
65 in.	2584	4306	1550

The ergonomic aspect..



*Sourced from the Human Factors Research and Engineering Group for the Federal Aviation Administration

Want to keep a single sub-screen of information within comfortable eye movement (50% of max)

= 30 degree arc

Want to keep whole screen within head movement (50% of max)

= 90 degree arc

Combining all we have learnt...

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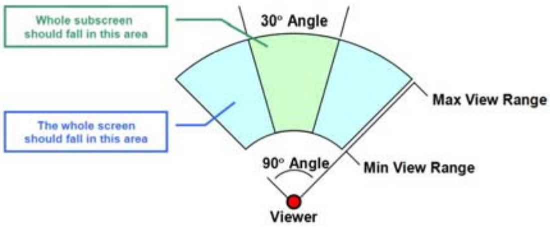
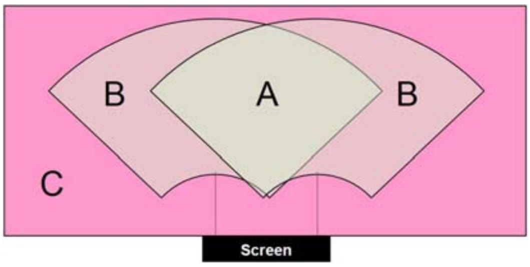


A – sweet spot

B – borderline

C – "no view" zone



Our worked Scenario: Setting the ground rules

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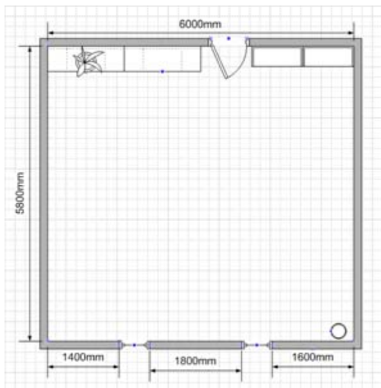
Notes:

- Located offshore
- Room & existing furnishings fixed
- Up to 10 participants
- Videoconferencing required
- 3-4 million pixels of screen resolution to fulfil use case scenarios



Our worked Scenario: Adding the screens

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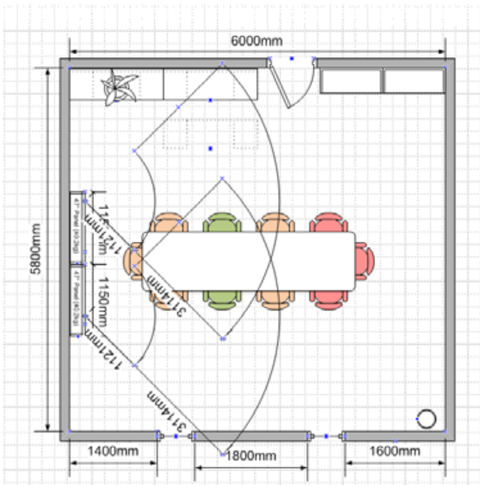
Try out the
47” screens



Our worked Scenario: Adding the screens

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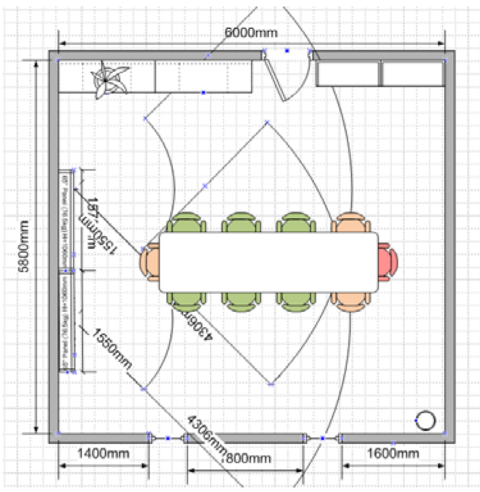
Try out the
65” screens



Our worked Scenario:
Fix the table

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Try out the
new table

Our worked Scenario:
Finishing Touches

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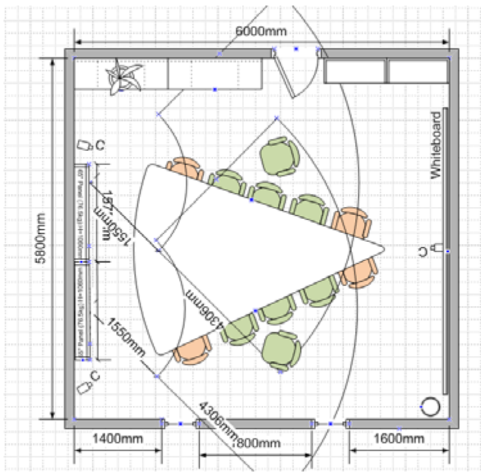
Add the:

- Whiteboard
- Video cameras for videoconferencing



Our Worked Scenario: Screen Design

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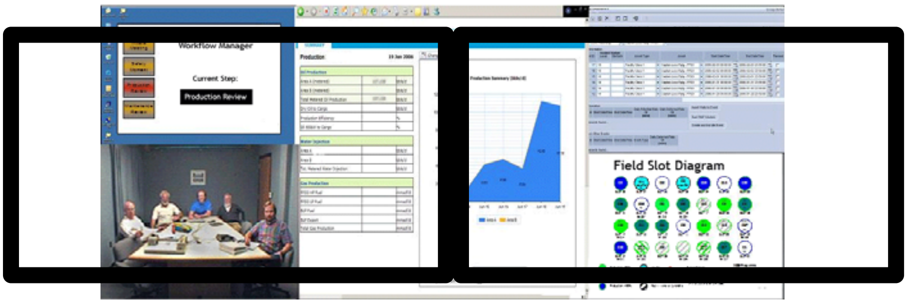

Our Worked Scenario: Screen Design

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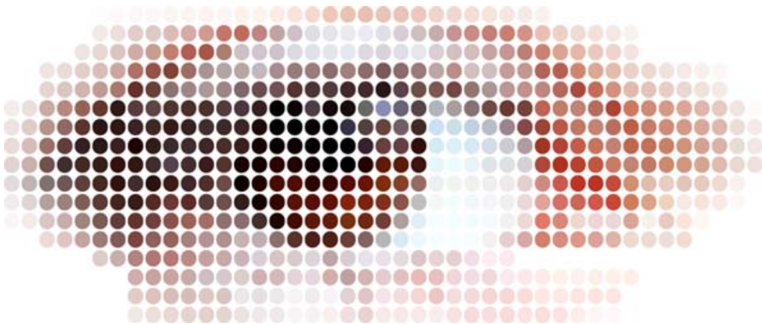
Conclusion

- Use these simple tools that take into consideration
  - Visual acuity of the participants
  - User ergonomics
- Create use-cases for room usage and create mock-ups for each stage in the workflow
- Combine to provide:
  - Most cost effective solution to satisfy your needs
  - Clear guidelines to help turn mock-ups into usable screens

How it ended…

Any Questions?



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Novel Interaction with Computers

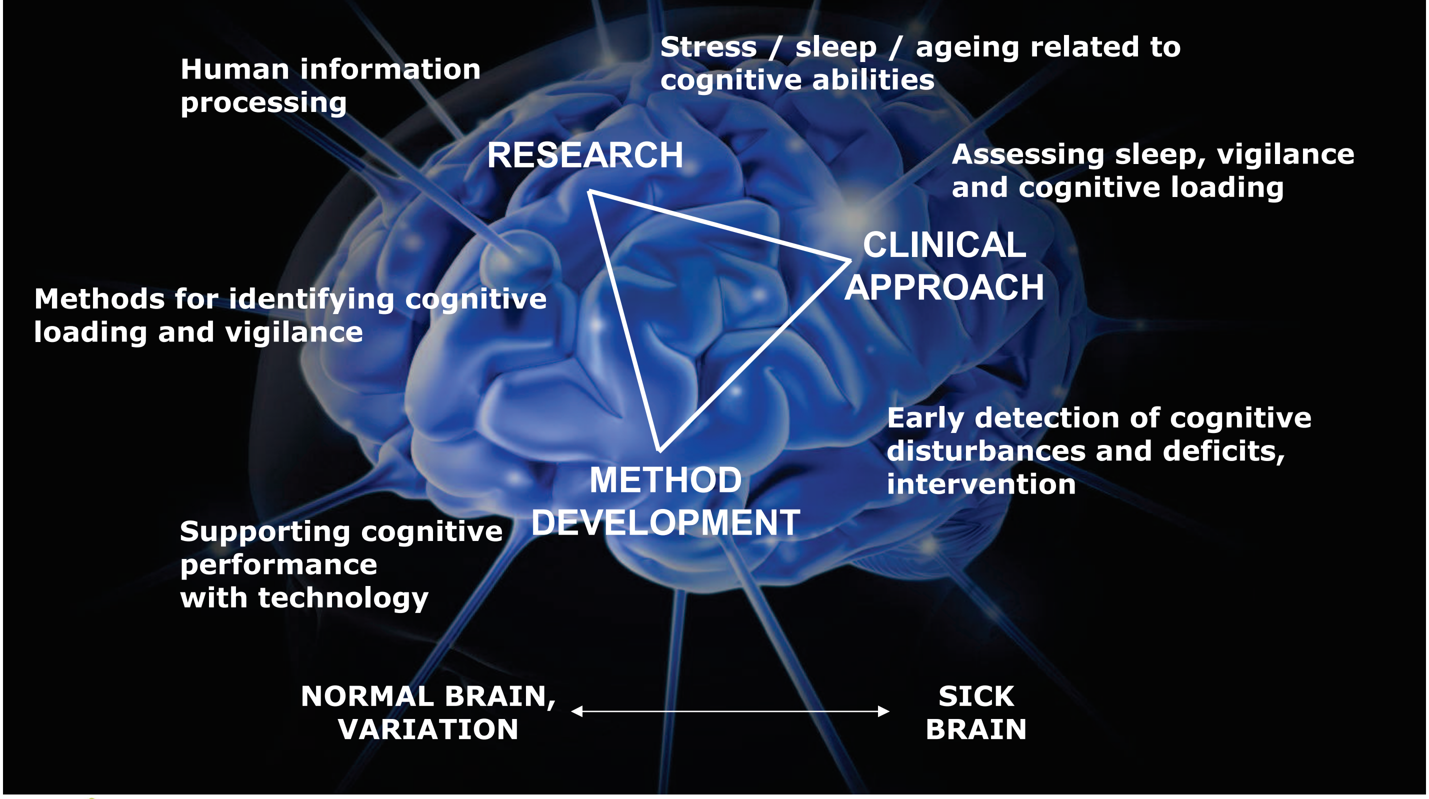
K. Lukander

Mere informasjon:
http://www.ttl.fi/en
Holm, A., Lukander, K., Korpela, J., Sallinen, M., and Müller, K.M.I. (2009) Estimating brain load from the EEG. - TheScientificWorldJOURNAL 9, 639–651. DOI 10.1100/tsw.2009.83

Novel Human-Computer Interaction

HFC Møte
06.04.2011
Kristian Lukander
Brain Work Research Centre
Finnish Institute of Occupational Health

The Brain Work Research Centre FIOH



Cognitive ergonomics

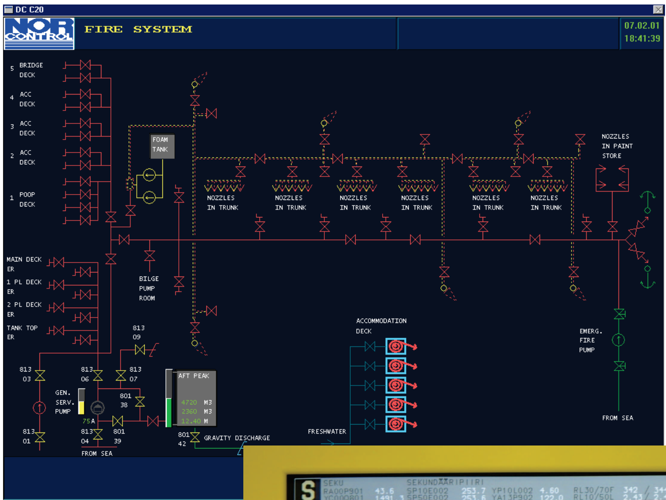
The design of information artefacts and work spaces

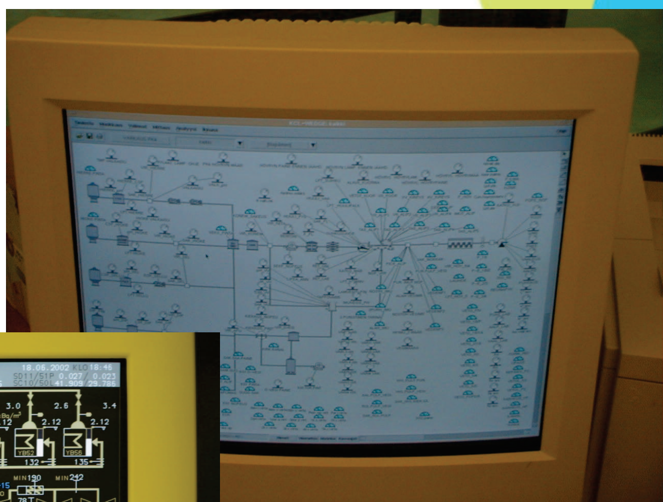
based on knowledge on human cognition

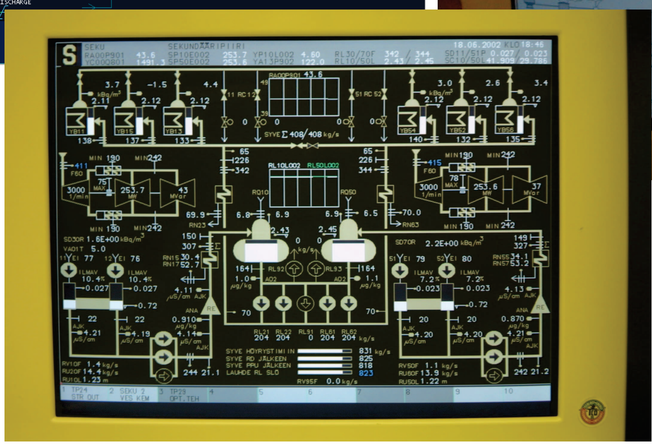
in order to optimize

human well-being

system performance







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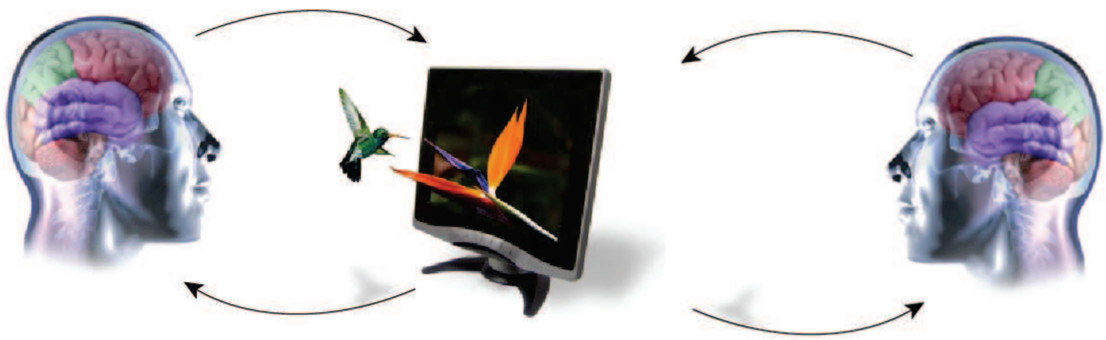
HCI

…is basically
man-to-machine-to-man
communication

INPUT



OUTPUT

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More effective communication

34 *The Mathematical Theory of Communication*

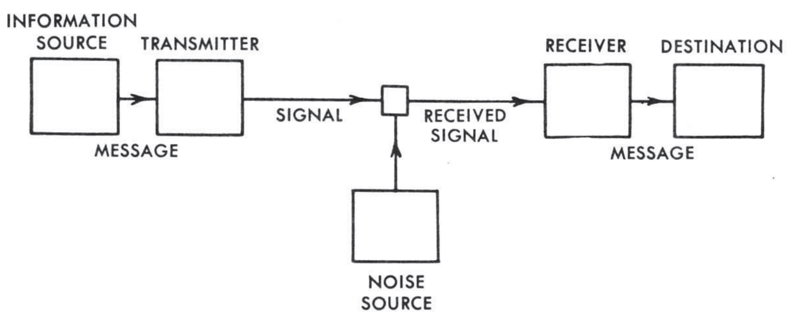

Fig. 1. — Schematic diagram of a general communication system.

- Less noise, more information (throughput)
- Less cognitively loading
- Better understanding
- Results in better decision making!

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AI is developing

- Area-specific "intelligence" is already very impressive
- "Generic intelligence" under rapid development

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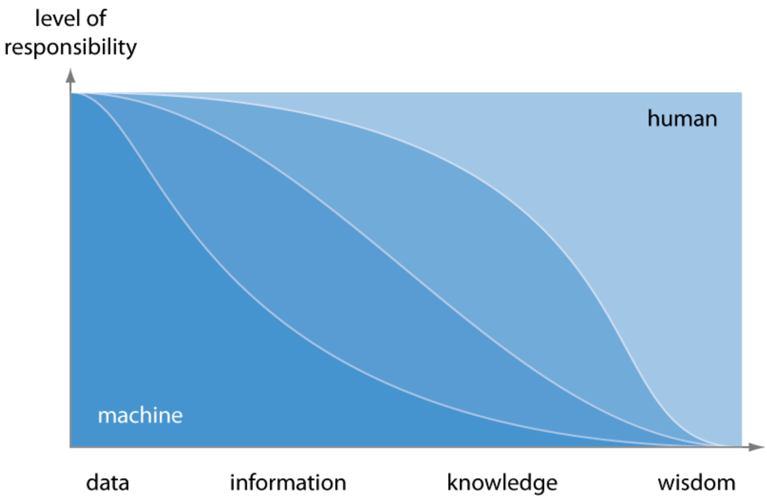
The human's place in the information continuum is changing



- Machines (try to) make smarter decisions
- Human operators (try to) supervise

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Making good decisions requires

- A correct Mental Model
- Up-to-date information
- Valid, relevant data
- Good control over the system

→ situational awareness

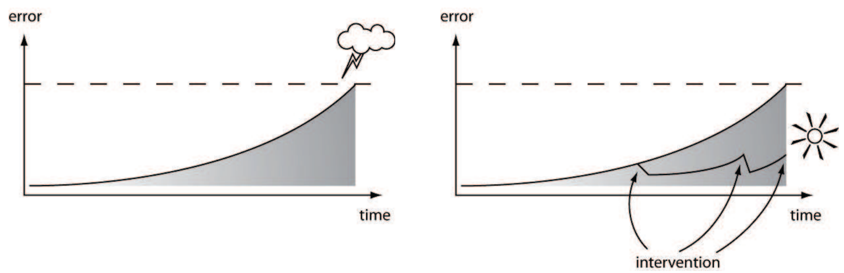
MODEL ⚡ TRUTH

ENTROPY

"Essentially, all models are wrong, but some are useful."
-- George Box, statistician

Future: Co-operation between smart people and smart machines

- How sensible is it to build systems where the smartest component only supervises the operation?
  -- Hannu Nieminen / Honeywell Measurex
- Even smart machines make (cumulative) errors



- To correctly evaluate machine decisions, the human operator needs the right information at the right time

Stating the obvious

The amount of available data grows exponentially, and
Models become more complicated

↓

We need better UI's!

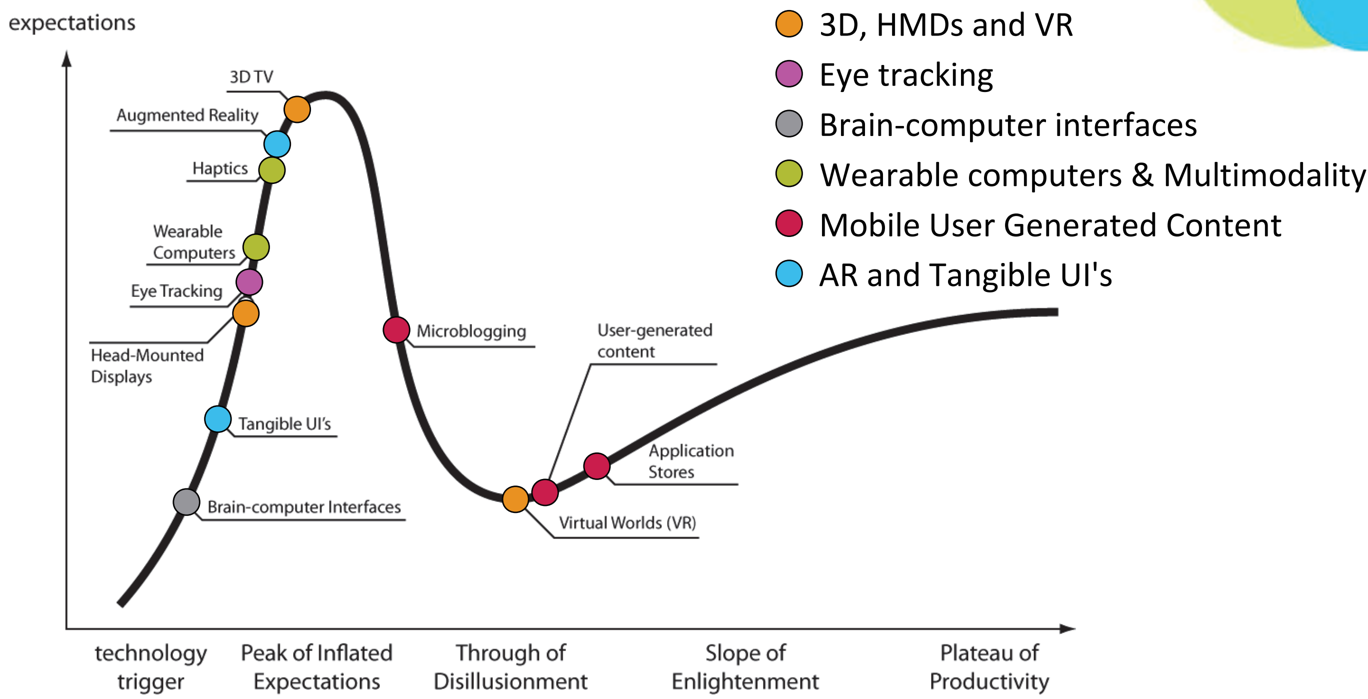
↓

that allow better communication

How do we optimize for HCI?

- **Teach good models to avoid entropy**
- **Make use of human capabilities**
  - **Pattern recognition**
  - **Multimodal communication**
- **Avoid human deficiencies**
  - **Use good contrast, avoid noise, use sufficient lighting…**
- **Design for human capacity**
  - **do not overload working memory**
  - **support with cues**
- **Take human variance into account**
  - **Vigilance, sleep deprivation, blood sugar level…**

"Novel" UI's...?



3D + HMD's + VR

- "3D" not really 3D
  - accomodation vs. vergence => strain, flicker, problems
  - technology might develop?
- HMD's
  - blocking
  - the competition is bad for the human visual system
  - focus either on display or in the environment, not both
  - might work on very special use cases
- VR
  - good for game-like practice environments
  - still suffers from issues with lag etc

Eye Tracking & Gaze interaction

- good (expensive) solution to some problems
  - quicker pointing
  - automatic selection
- creates new interaction dilemmas (midas touch)
- gaze is primarily for collecting information, not pointing
- needs better integration

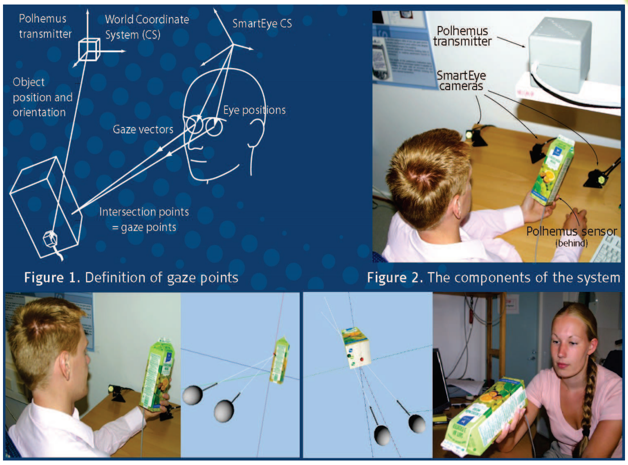
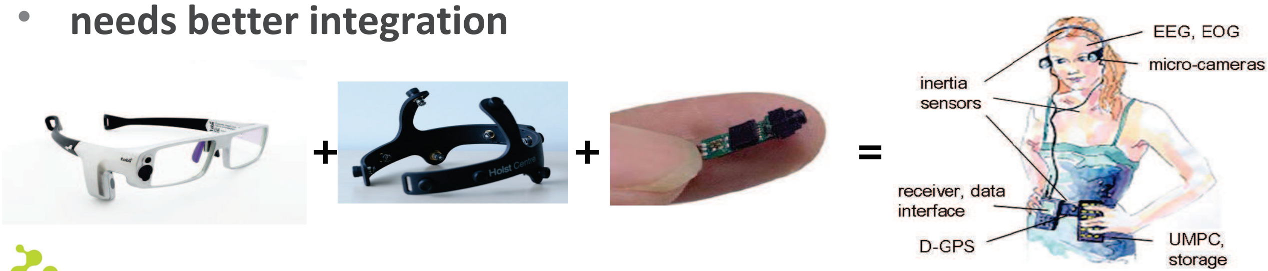


Figure 1. Definition of gaze points

Figure 2. The components of the system



Wearable & Multimodal

- In order to integrate wearable computers to operation on-the-go, we need to use other sensory channels than vision
  - What is the optimal sensory channel?
- Wearable computers are operated in very different environments
  - Changing lighting conditions, noise, movement…
- Multimodal communication might be a good idea?

Using multimodal cues to direct attention and action in a field setup

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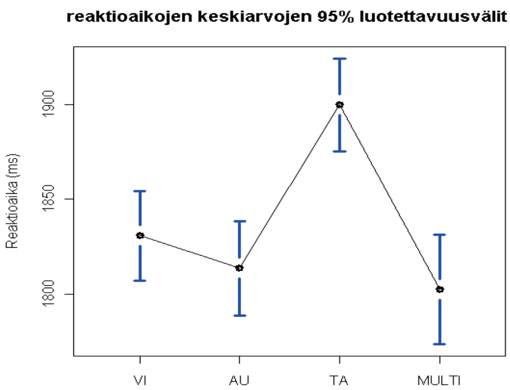
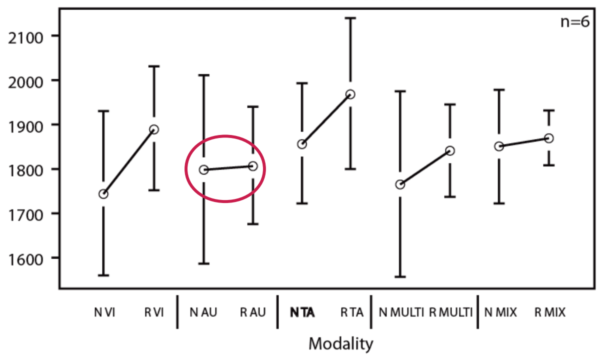
Results in a nutshell

- exogenous cuing (directional) more effective than endogenous (symbols)
- tactile stimulation slightly slower, multimodal the fastest
- auditory stimulus more robust under heavy physiological stress
- cue preference varied between shooters
- shooter performance did not correlate with cue preference
- environmental and task related issues should be emphasized when designing multimodal systems



95% Confidence limits for Mean reaction time



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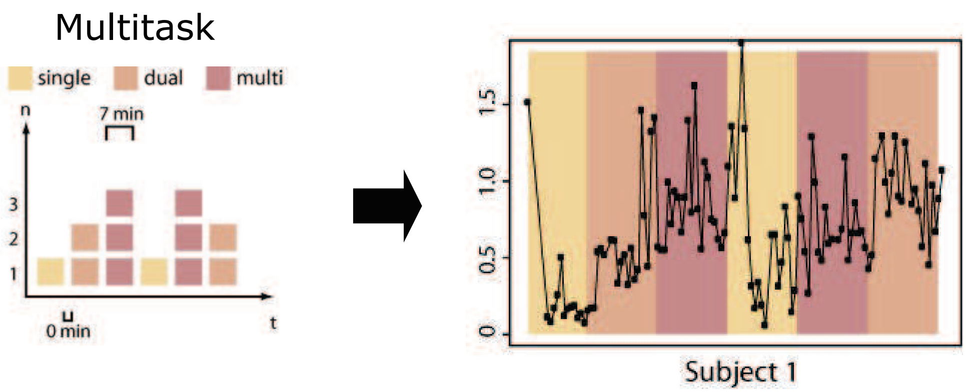
Brain-computer Interfaces

- Thought control?
- Passive human-state monitoring

Brainbeat, an EEG index for measuring overall brainload online



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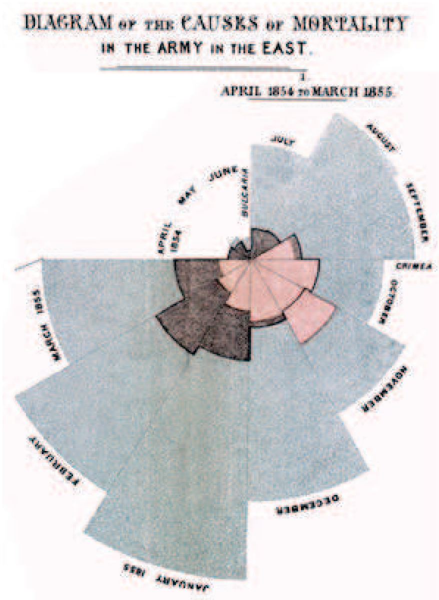
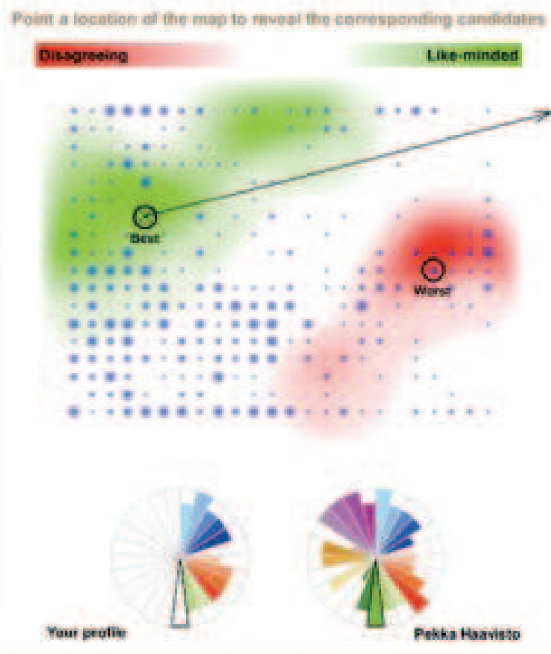
Mobile user generated micro-blogging (intro)





FLUID INTERACTION

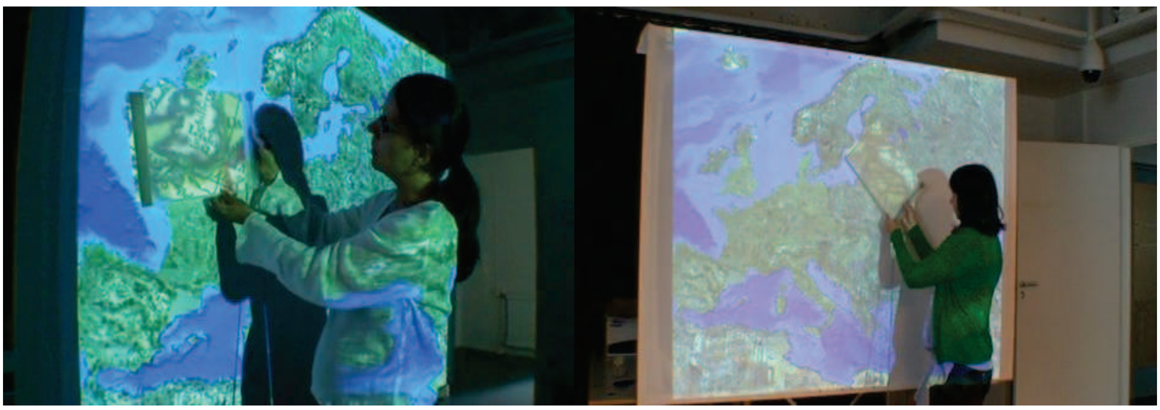
Mobile user generated micro-blogging

- Massive amounts of rich on-line data
- Often on small mobile screens
- Completely new take compared to lists
  - Focus on content
  - Provide visualizations of metadata
  - Direct interaction with the infographics

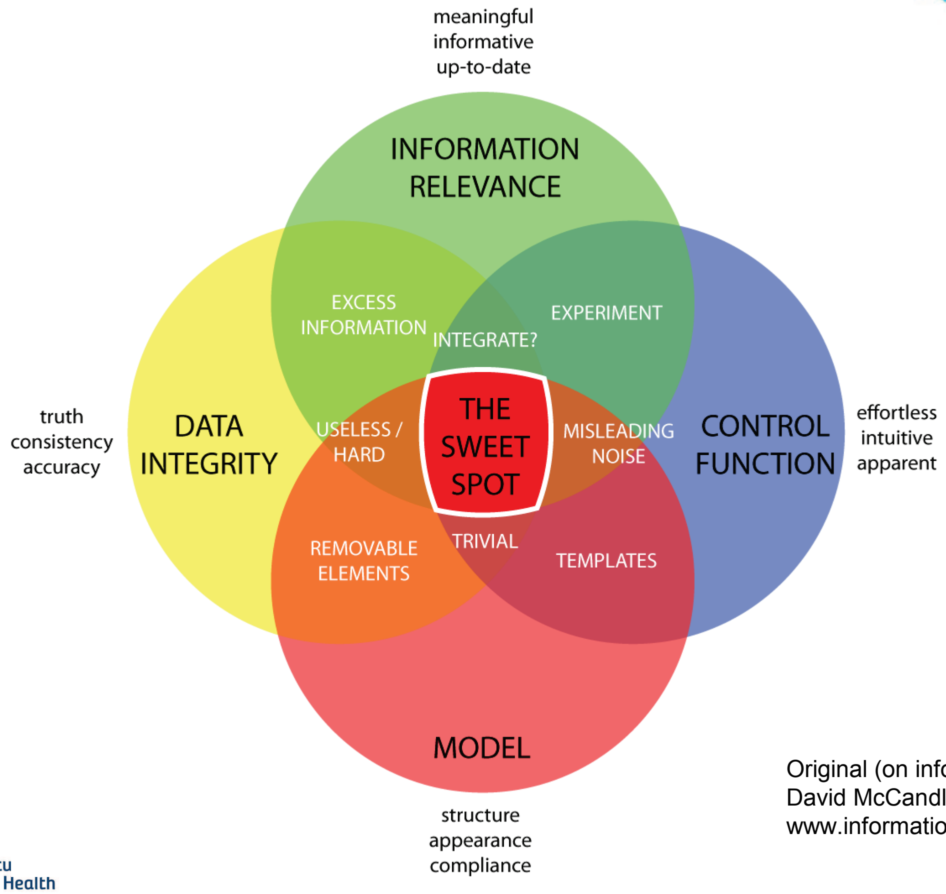
http://www.differenttack.com

AR and Tangible Interaction

- Tangible interfaces integrate the real with the virtual
- Natural manipulation



How to develop good UI's for the future?



Original (on information visualisation):
David McCandless
www.informationisbeautiful.com

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Estimating Brain Load from the EEG

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Modern work requires cognitively demanding multitasking and the need for sustained vigilance, which may result in work-related stress and may increase the possibility of human error. Objective methods for estimating cognitive overload and mental fatigue of the brain on-line, during work performance, are needed. We present a two-channel electroencephalography (EEG)–based index, theta Fz/alpha Pz ratio, potentially implementable into a compact wearable device. The index reacts to both acute external and cumulative internal load. The index increased with the number of tasks to be performed concurrently (p = 0.004) and with increased time awake, both after normal sleep (p = 0.002) and sleep restriction (p = 0.004). Moreover, the increase of the index was more pronounced in the afternoon after sleep restriction (p = 0.006). As a measure of brain state and its dynamics, the index can be considered equivalent to the heartbeat, an indicator of the cardiovascular state, thus inspiring the name "brainbeat".

KEYWORDS: EEG, cognitive, workload, work load, brain, assessment of workload

INTRODUCTION

Modern working environments are often information intensive and work performance requires acting on multiple tasks simultaneously, i.e., multitasking. This is also true for everyday activities. For example, while driving a car, the driver can simultaneously navigate with the GPS and talk on the phone.

In a 24/7 society, shift work has increased in most professions[1], raising the risk of sleep deprivation. Multitasking requires contributions from prefrontal cortical regions that control attention functions. These prefrontal regions are also susceptible to sleep restriction[2,3,4]. The lack of sleep results in a nonoptimal physiological state for performing challenging tasks.

In many cases, these components of load, increased external task demands, and decreased internal physiological resources are present at the same time. Subjects suffering from even modest sleep loss have shown decreased performance in tasks that require neural control by prefrontal areas[5,6]. Warm et al.[7] and Young and Stanton[8] also raised the issue of mental underload and decreased vigilance, which can be as detrimental to performance as mental overload.

Predicting these performance decreases is difficult from performance data alone, since humans are able to maintain acceptable performance levels even with increasing task demands or under growing sleep pressure, to a certain point. Humans are also poor in self-identification of decreased vigilance and

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cognitive overload[5,6], which increases the risk of human error at work. If the state of increased workload could be detected, it would offer the possibility to either warn or assist subjects with automated systems before unfavorable performance failures occur.

Despite the fact that sustained high cognitive effort may have detrimental health effects and raises the risk of human error, studies on performance have typically focused on the efficacy of behavior, i.e., how well task demands are achieved. The physiological "costs" for maintaining the required performance level in demanding task conditions has been studied to a lesser degree. Maintaining acceptable performance levels under increased sleepiness or cognitive demands requires the mobilization of further brain resources, which is revealed as increased activation of physiological systems and can be detected by observing brain oscillations.

Brain oscillations are the biophysical result of complex interactions of neuronal networks, taking place both in the idling, as well as in the performing, human brain[9,10]. Oscillations of different frequencies have been linked to different functions of the brain. In electroencephalography (EEG) studies, growing task demands, as well as time-on-task demands, increase frontal theta activity and decrease parietal alpha activity[11,12,13,14,15,16]. Additionally, tasks that place extensive demands on executive functions affect frontoparietal EEG coherence in the alpha and theta bands[15,17]. The need for sleep (sleep pressure) can also be detected from the EEG spectrum. In awake subjects that are suffering from sleep deprivation, low-frequency EEG activity is increased in frontal areas with time awake, with only little circadian modulation[3,4]. A similar effect can also be seen during non-REM sleep[3].

Another EEG measure, the event-related potentials (ERPs), are neural responses to specific sensory and cognitive events. Especially, the P300 component of ERPs has been shown to be sensitive to the available processing capacity[18] and is thus widely used in cognitive workload assessment[19,20,21,22]. Despite the fact that ERPs provide a millisecond resolution for observing the subjects' cognitive processing, the methodology is not usable outside of the laboratory, as recording ERPs requires external stimuli, time locked to the measurement system, making the setup unrealistic for use during everyday activities.

EEG has the potential to identify changes in cognitive load in tasks that require continuous and intensive allocation of attention. Modern, compact measurement technologies enable measuring EEG even wirelessly during typical daily activities[23]. EEG measurements have adequate time resolution, conveying information nearly on-line. EEG thus provides a promising tool for assessing cognitive workload, comparable in simplicity to measuring the physical workload with heart rate monitors or pedometers.

We investigated how information derived from the EEG spectrum, especially frontal theta and parietal alpha activity, could be used as an indicator of overall brain load. This was done by combining EEG recordings with cognitive task performance, and manipulating external and internal factors affecting the person being tested.

MATERIAL AND METHODS

Subjects

Twenty nonsmoking healthy men (19–22 years of age) participated in the changed task demands (CTD) condition and 16 participated in the time awake (TA) condition. The protocol was accepted by the local ethics committee. Informed consent was obtained from the subjects. Prior to the experiment, their health status was examined by a physician. The use of alcohol, tobacco, or caffeine was forbidden as of 24 h prior to the experiment. Each participant visited the laboratory three times: first they trained in the tasks until a constant performance level was reached with an individual task difficulty level[6]. On the second and third visits, the subjects performed the CTD and TA conditions.

On the first visit to the laboratory, each participant was given a sleep diary and was instructed to record information about their sleep for the 2 days prior to the forthcoming laboratory visits. The mean sleep length of the night immediately before the first visit was 408 ± 83 min (S.D.) and 505 ± 112 min (S.D.) the previous night. The corresponding values prior to the second visit were 425 ± 81 min (S.D.) and 488 ± 115 min (S.D.).

Task

We used a modification of our computerized multitask[6], which is composed of four selectable subtasks (Fig. 1). The auditory attention task consists of two tones (target and nontarget standard, 20 and 80% of tones, respectively, interstimulus interval 1.5 sec) delivered through loudspeakers. The subject presses a separate response pad when a target tone occurs. In the arithmetic task, subjects add numbers and input the answers with a mouse on a number pad presented on the monitor. In the memory task, the subjects detect whether the letter shown was among a list memorized before each trial. In the visual vigilance task, a dot appears in the center of the circle and starts to move towards the outermost border of the circle. The subject has to return the dot back to the innermost circle with a button press before the dot reaches the edge of the outermost circle. Subjects scored points with correct responses, and lost points with wrong or missed responses.

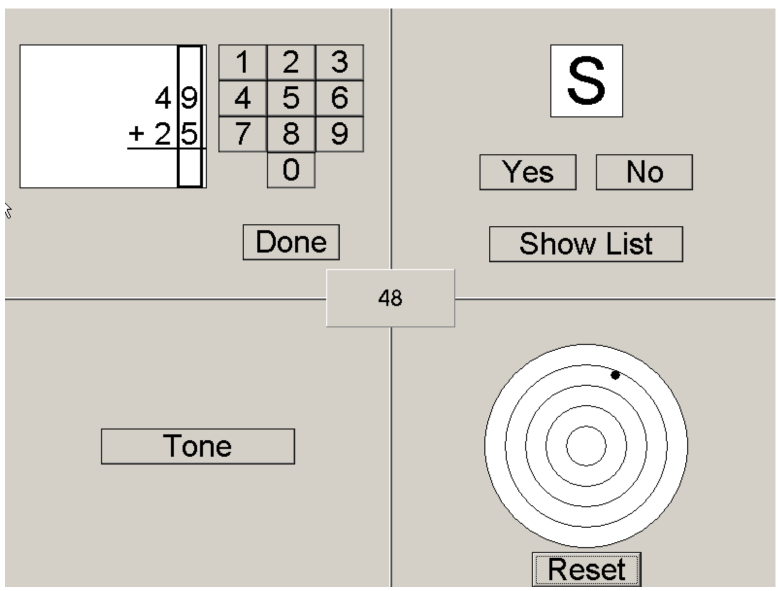

FIGURE 1. Example of the user interface of the computerized multitask. Top left, the arithmetic subtask; top right, the memory task; bottom left, the auditory attention task; bottom right, the visual vigilance task.

In the CTD condition, we varied the number of tasks the subjects performed simultaneously between single (auditory attention task), dual (auditory attention and arithmetic tasks), and multi (all four tasks simultaneously) conditions starting at 15:30. Each condition was done twice in counterbalanced order to reduce the time-on-task effect.

In the TA condition, we studied whether the EEG content could also be used to identify changes in internal load. We kept the multi condition demands constant and used time awake and sleep restriction as internal loading factors inducing sleep pressure. The subjects were instructed to perform all the subtasks equally well and as well as possible. In the normal sleep protocol, the subjects slept an 8-h night (23:00–07:00) in the laboratory. The following day, they performed four multi sessions, each lasting 70 min, with simultaneous EEG recording. Test sessions started at 8:30, 11:00, 13:30, and 15:45 (Fig. 2B). In the sleep

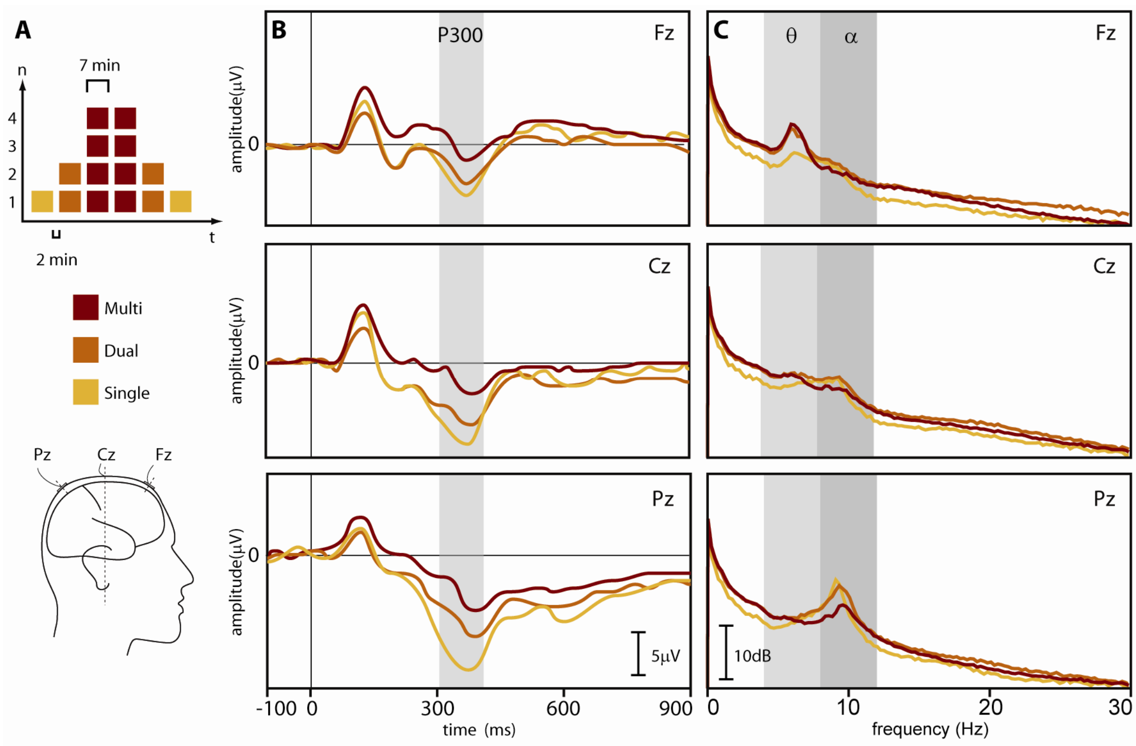

FIGURE 2. EEG spectrum is modulated by external demands. (A) Task setup. In the single condition, subjects performed an auditory attention task; in the dual condition, the auditory task together with an arithmetic task; and in the multi condition, four tasks (auditory, arithmetic, memory, and visual) concurrently. (B) Auditory ERPs in different task conditions. Increasing task demands decreased the P300 amplitude in the parietal area Pz ($F[1.5, 23.4] = 28.2$, $p = 0.001$, $n = 20$). Negative plotted upwards. (C) EEG spectra. Increasing task demands increase frontal theta (Fz) and decrease parietal alpha (Pz). Only the change in alpha range is statistically significant.

restriction protocol, the subjects slept 2 h between 05:00–07:00 in the laboratory and performed four multitask sessions similar to the normal sleep protocol.

EEG Measurements

EEG was measured continuously with silver electrodes, referenced to the right and grounded to the left mastoid (impedance <5 kΩ), pass-band filtered (0.5–50 Hz), and digitized at 500 Hz using a SynAmps amplifier. With Scan Edit 4.3.3 utility, we transformed the data measured to 4-sec epochs, corrected for eye movement artefacts with the ocular artefact reduction (OAR) utility, excluded epochs containing other artefacts (±70 μV), and computed spectrograms for the 10–20 system derivations Fz, Cz, and Pz using a Fast Fourier transformation. The sweeps were smoothed using a 2048-sample Hanning window, and absolute spectral power values for theta (4–8 Hz) and alpha (8–12 Hz) were calculated.

ERP Measurements

For P300 analysis, EEG was transformed to epochs of –100 to 900 msec relative to the onset of the target tones in the auditory attention task. Eye movements were corrected and artefacts removed as in the EEG analysis. The response for auditory target tones was computed for the 10–20 system derivations Fz, Cz, and Pz. The average waveforms were low-pass filtered at 20 Hz, and P300 component detected as a maximum positive peak within 250–550 msec. The amplitude of P300 was measured relative to the 100-msec prestimulus baseline.

Statistical Analyses

Statistical analyses were performed using repeated measures of ANOVA in SPSS 12 for Windows. When studying the power spectrum values, the data were log transformed to achieve normal distribution. Greenhouse-Geisser degrees of freedom were used to correct the violations of the spherical assumption when appropriate. To explore and compare metrics that correlated with the changes of brain loads quantitatively, the Receiver Operating Characteristic (ROC) curve analysis was carried out. For this purpose, the difference between each parameter and the baseline value (auditory oddball condition) was calculated and used in the ROC analysis. To study the effect of the sleep deprivation on performance and EEG content, corresponding values in the sleep restriction protocol and the normal sleep protocol were subtracted from each other. The significance of the sleep restriction effect was studied with Wilcoxon's signed rank test.

RESULTS

EEG Spectrum and External Factors

To determine the effects of external load on the EEG spectrum, we varied the number of tasks the subjects performed simultaneously between single (one task), dual (two tasks), and multi (four tasks) conditions (Fig. 2A). To verify that the increase in the number of tasks to be performed concurrently actually increased the cognitive workload of the subjects' brain, we measured ERPs to the auditory attention task simultaneously with other EEG measures. In accordance with a previous report[18], the P300 amplitude of ERP decreased with increasing task demands (Fig. 2B), showing that our loading manipulation was successful.

The absolute EEG power spectrums for the different task conditions are shown in Fig. 2C. A growth in task demands increased the amount of theta activity in the frontal site (Fz) and decreased alpha activity in the parietal site (Pz), as was also reported in previous studies[11,12,13,14,16]. However, only the change in the alpha range was statistically significant.

Even though the P300 amplitude decrease shows that the cognitive workload increases, the absolute power of the EEG spectrum ranges themselves were not sensitive enough to detect this change. However, the visual inspection of the data in Fig. 2C revealed that theta increases and alpha decreases with increasing task difficulty. The trends seen inspired us to test whether we could improve the estimation of brain load by calculating the ratio of the absolute power of frontal theta activity to the absolute power of parietal alpha activity (theta Fz/alpha Pz). We discovered that the value of this index increased with increasing cognitive task demands ($F[1.3, 25.0] = 8.6$, $p = 0.004$, $n = 20$; single vs. dual, $p = 0.002$; dual vs. multi, $p = 0.014$) (Fig. 3A). The index value was already higher in the dual condition in 15/20 and almost in all cases in the multi condition (19/20) when compared to the index value in the single condition.

The comparison of the brain load metrics with ROC curves revealed that the ratio performed well in brain load estimation when compared to the P300 amplitude or the power measures (Fig. 4 and Table 1).

We also tested whether different combinations of the theta and alpha power (i.e., theta Fz * alpha Pz, log [theta Fz]/log [alpha Pz], or theta Fz + alpha Pz) could differentiate brain load levels. The ROC analysis showed that these combinations performed at the level of the parietal alpha power, but did not reach the level of the theta Fz/alpha Pz ratio (Table 1).

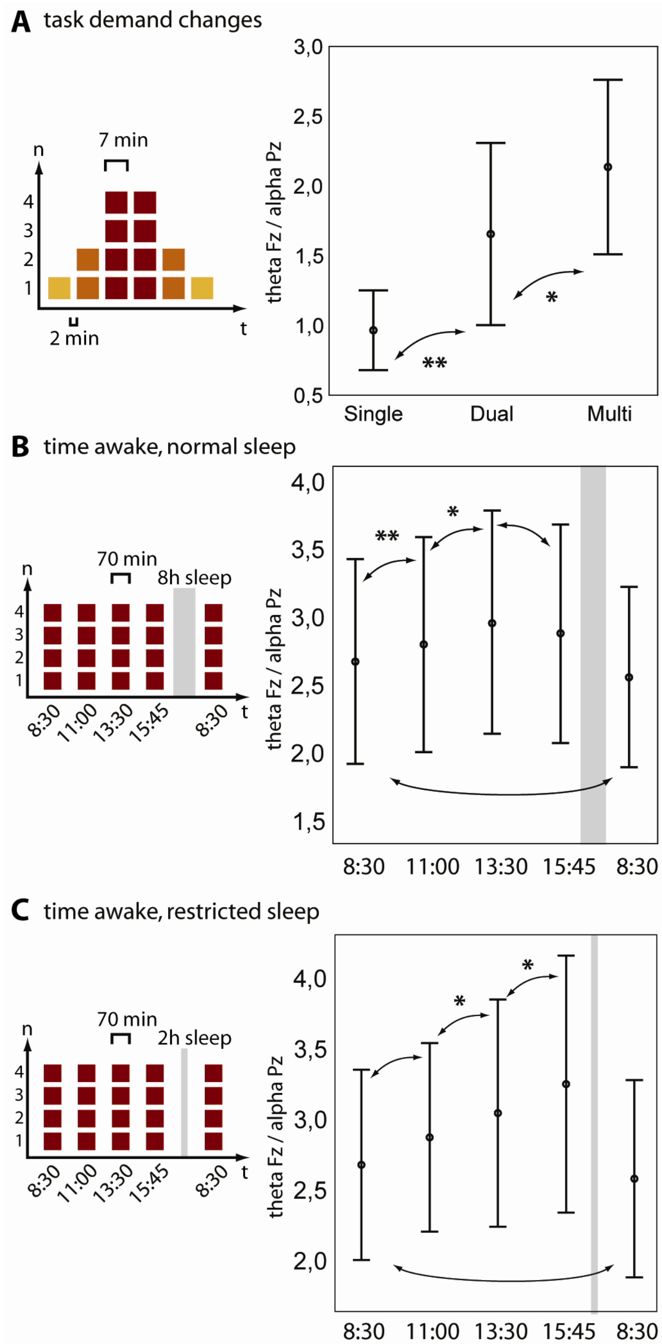

FIGURE 3. Theta Fz/alpha Pz correlates with external and internal factors. (A) The theta Fz/alpha Pz ratio increased systematically with increasing task demands (F[1.3, 25.0] = 8.6, p = 0.004, n = 20; single vs. dual, p = 0.002; dual vs. multi, p = 0.014). (B) Normal sleep protocol. The theta Fz/alpha Pz ratio increased with time awake (F[2.4, 35.6] = 7.1, p = 0.002, n = 16; 8:30 vs. 11:30, p = 0.009; 11:30 vs. 13:30, p = 0.029; 13:30 vs. 15:45, p = 0.168). After a well-slept night, the ratio returned to the baseline value, p = 0.139, even though the performance was improved. (C) Sleep restriction protocol. The theta Fz/alpha Pz ratio increased with time awake (F[2.3, 34.0] = 6.2, p = 0.004, n = 16; 8:30 vs. 11:00, p = 0.096; 11:00 vs. 13:30, p = 0.027; 13:30 vs. 15:45, p = 0.017). After a well-slept night, the ratio returned to the baseline value, p = 0.477. Error bars indicate S.E.M.

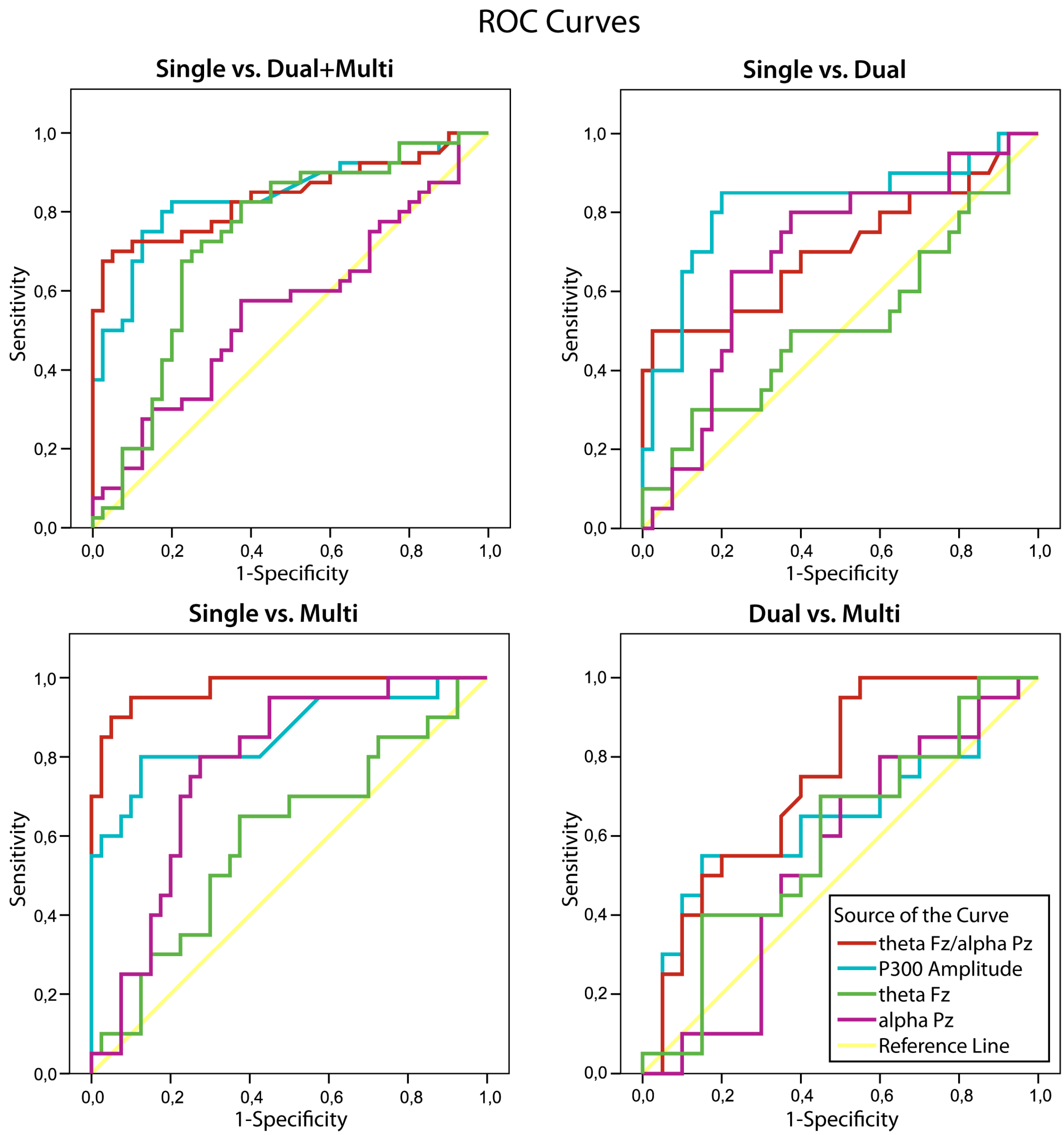

FIGURE 4. ROC curve comparisons of different brain metrics parameters**.** Area under a ROC curve is plotted for single vs. dual (upper left), single vs. multi (upper right), dual vs. multi (lower left), and single vs. dual + multi (lower right) situations. The P300 amplitude and theta Fz/alpha Pz ratio perform equally well in discriminating task demands. The alpha power also performs reasonably well, where as the theta power does not.

TABLE 1
The Comparison of Different Brain Load Metrics*

Parameter	Area Under Curve			
	Single vs. Dual + Multi	Single vs. Dual	Single vs. Multi	Dual vs. Multi
P300 amplitude	0.84 ($p < 0.001$)	0.82 ($p < 0.001$)	0.86 ($p < 0.001$)	0.64 ($p = 0.123$)
Theta Fz/alpha Pz	0.84 ($p < 0.001$)	0.71 ($p = 0.008$)	0.97 ($p < 0.001$)	0.75 ($p = 0.008$)
Theta	0.56 ($p = 0.376$)	0.52 ($p = 0.802$)	0.59 ($p = 0.233$)	0.54 ($p = 0.646$)
Alpha	0.73 ($p < 0.001$)	0.69 ($p = 0.016$)	0.77 ($p = 0.001$)	0.60 ($p = 0.317$)
Theta Fz + alpha Pz	0.74 ($p < 0.001$)	0.69 ($p = 0.017$)	0.79 ($p < 0.001$)	0.59 ($p = 0.358$)
Theta Fz * alpha Pz	0.64 ($p = 0.031$)	0.60 ($p = 0.198$)	0.68 ($p = 0.026$)	0.54 ($p = 0.665$)
lg(Theta Fz)/lg (alpha Pz)	0.72 ($p = 0.001$)	0.67 ($p = 0.037$)	0.77 ($p = 0.001$)	0.62 ($p = 0.194$)

* ROC curve was used to compare the classification performance of brain load metrics P300 amplitude, theta Fz/alpha Pz ratio, theta and alpha power, theta power + alpha power, theta power * alpha power, and lg(theta Fz)/lg (alpha Pz) ratio. Area under ROC curve is shown with *p* value.

Internal Load Affects EEG Spectrum

Normal Sleep

After normal sleep, time awake had a statistically significant effect on both the frontal theta and the parietal alpha, F(1.382, 20.724) = 6.082, $p = 0.015$ and F(1.999, 29.978) = 4.365, $p = 0.022$, respectively. The power of frontal theta activity increased with increasing time awake (8.30 vs. 11.15, $p = 0.004$; 11.15 vs. 13.30, $p = 0.051$; 13.30 vs. 15.45, $p = 0.071$). The power of parietal alpha activity also increased somewhat with increased time awake (8.30 vs. 11.15, $p = 0.056$; 11.15 vs. 13.30, $p = 0.036$; 13.30 vs. 15.45, $p = 0.252$). The recovery night restored the absolute power of both theta and alpha activity to the baseline levels, $p = 0.211$ and $p = 0.372$, respectively.

Performance in the multitask was stable across all four sessions (F[1.87, 28.06] = 2.276, $p = 0.124$), while the theta Fz/alpha Pz ratio increased with time awake (F[2.4, 35.6] = 7.1, $p = 0.002$, n = 16; 8:30 vs. 11:30, $p = 0.009$; 11:30 vs. 13:30, $p = 0.029$; 13:30 vs. 15:45, $p = 0.168$), (Fig. 3B). Additionally, to test the effect of a well-slept night (8 h) on theta Fz/alpha Pz ratio, a fifth test session was carried out at 8.30 a.m. the next morning (Fig. 3B). The performance after the second night was better than during the sessions on the previous day ($p < 0.05$ in all comparisons) and the theta Fz/alpha Pz ratio recovered to the value of the previous morning.

Sleep Restriction

When the subjects were sleep deprived, performance in the multitask deteriorated across the four sessions (F[2.34, 23.26] = 6.68, $p = 0.004$; 8:30 vs. 11:00, $p = 0.234$; 11:00 vs. 13:30, $p = 0.051$; 13:30 vs. 15:45, $p = 0.032$). The theta Fz/alpha Pz ratio increased with time awake (F[2.3, 34.0] = 6.2, $p = 0.004$, n = 16; 8:30 vs. 11:00, $p = 0.096$; 11:00 vs. 13:30, $p = 0.027$; 13:30 vs. 15:45, $p = 0.017$) (Fig. 3C).

The performance after the second night (8-h sleep) was better than during the session at the same time on the previous morning after 2-h sleep ($p < 0.001$). The theta Fz/alpha Pz ratio recovered to the value of previous morning, $p = 0.477$.

Difference between Normal Sleep and Sleep Restriction

The performance in the multitask was significantly decreased after sleep deprivation when compared to the performance in the normal sleep protocol at the same time of day. The performance difference between sleep deprivation and normal sleep state was statistically significant in all four comparisons: at 8:30, $p = 0.002$; at 11:00, $p = 0.004$; at 13:30, $p = 0.008$; at 15:45, $p = 0.001$. The theta Fz/alpha Pz ratio was larger after sleep restriction than after normal sleep: at 15:45, $p = 0.006$. After the 8-h recovery night, the theta Fz/alpha Pz ratio did not differ from the normal sleep protocol: at 8:30, $p = 0.393$. On the contrary, performance after the 2- and 8-h nights was lower than after two 8-h nights in the normal sleep protocol ($p = 0.036$), and was comparable to the performance level after one 8-h night after the normal sleep protocol ($p = 0.681$).

Estimating Workload On-Line with EEG

Thus far, we have shown that the theta Fz/alpha Pz ratio indicates changes in the internal and external load on group level. For the ratio to function as a continuous monitor of brain load in everyday use, the index should be reactive enough to reflect temporary changes in cognitive task demands. To test this, we introduced task demand changes to a few subjects continuously, without pauses between sessions. The preliminary data for three single subjects presented in Fig. 5 show that the changes in task demands result in rapid changes in the values, especially when comparing the switch from, cognitively, the least demanding single to either the dual or multi conditions.

DISCUSSION

Here we have reported the effects of internal and external load on EEG content. We manipulated external load by changing the number of tasks to be performed simultaneously. Internal load was manipulated with time spent awake and sleep restriction. We have shown that the frontal theta/parietal alpha ratio is sensitive to these manipulations and increases both with growing task demands and time spent awake. This study extends the previous findings on EEG content in awake, task-performing subjects, by taking into account the interactions of frontal and parietal areas during challenging task performance, and providing a tool for overall brain load assessment.

We have shown that the theta Fz/alpha Pz ratio was more sensitive in detecting increased task demands than the absolute power values of frontal theta and parietal alpha, which have been shown to be reactive to task demand manipulations[11,12,13,14,15,16]. However, absolute power values have not been sensitive enough to be used in continuous monitoring of brain load in everyday use. Therefore, their sensitivity has been improved with advanced analysis methods[14,24,25] and combined analysis of other physiological measures[26]. We suggest that the simple theta Fz/alpha Pz ratio described in our paper is, as such, sensitive enough to detect workload changes.

The increase in the theta Fz/alpha Pz ratio with time awake, both after normal 8-h sleep and restricted 2-h sleep, and an enhancement of the time awake effect by sleep restriction are in good accordance with previous findings that have shown that frontal theta increases with time awake, with minor circadian and major homeostatic modulation, whereas parietal alpha activity exhibited circadian variation and no increase with time spent awake[3,4]. In addition, high sleep pressure increased frontal theta and low sleep pressure increased parietal alpha in comparison to the baseline. Even though subjects in these previous studies were performing simpler tasks than our multitask, the results support the idea that the ratio represents the level of sleep pressure caused by time spent awake instead of pure circadian modulation.

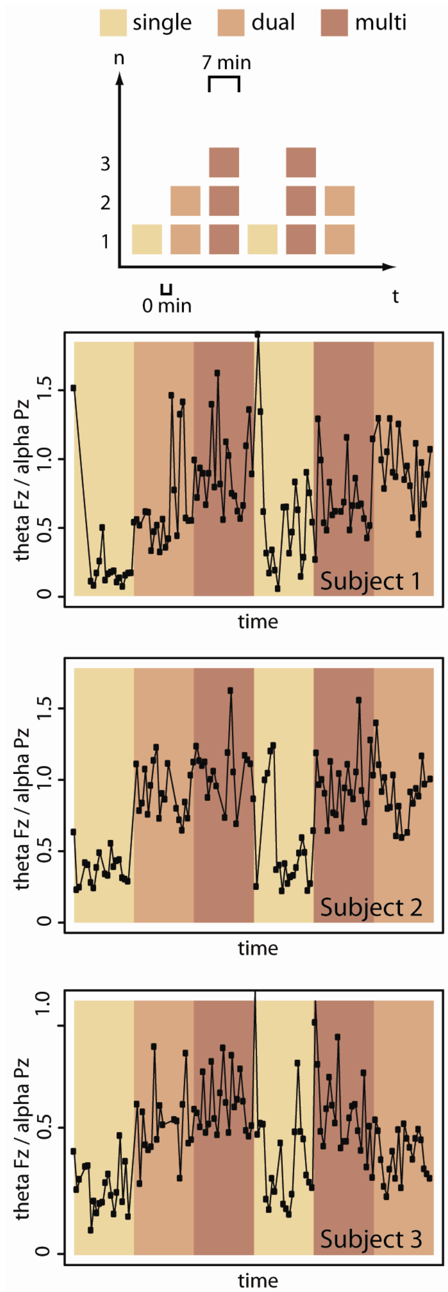

FIGURE 5. Examples of reactivity of the theta Fz/alpha Pz ratio to continuous changes in task demands. Task setting: the subjects performed the single, dual, and multi conditions continuously, 7 min per condition, for a total time of 42 min. The value is averaged over 20 sec. The change between single compared to dual and multi was clear, but between dual and multi at the individual level varied somewhat more (clear in subjects 2 and 3, but not in 1). The fluctuating attention and/or effort of the subject may affect the ratio.

We have also shown that while subjects' performance in the multitask was stable across four sessions performed during a single day in the laboratory, the theta Fz/alpha Pz ratio increased with increased time awake and sleep restriction enhanced the effect. This indicates that subjects had to put in more effort to sustain the performance level, which affected brain physiology. This is in accordance with the cognitive-energetical model described by Hockey[27], which states that performance may be protected under stress by the requirement of further resources, but only at the expense of increased subjective effort, and behavioral and psychological costs.

Our study showed that after two well-slept nights, performance was better than after one well-slept night, and the theta Fz/alpha Pz ratio recovered to the level of one well-slept night. On the contrary, after sleep restriction, the theta Fz/alpha Pz ratio recovered, whereas the performance did not show learning, but stayed at the same level as with one 8-h sleep. Sleep is considered essential for brain plasticity, restoration of energy resources, as well as consolidation of memory traces and learning[28,29]. Additionally, both increased sleep pressure and task demands have been shown to affect energy metabolism of the brain[27,30,31]. We suggest that consumption and restoration of energy resources are reflected in the theta Fz/alpha Pz ratio.

A somewhat similar approach, but in resting subjects, has been used in neurofeedback studies[32]. In these studies, theta/alpha ratio is measured using only a parietal electrode Pz, and feedback of the alpha and theta signal is given by auditory tones. In neurofeedback applications, this ratio has been used to produce a hypnagogic state, similar to a meditative or hypnotic state of relaxation, in an eyes-closed condition over a 30- or 40-min feedback session. Repeated sessions where subjects have drifted down to alpha-theta state have resulted in long-term abstinence and changes in personality testing results. In our study, we also tested whether workload and increasing sleep pressure could be detected on alert subjects, who simultaneously perform a challenging task, using only the parietal theta Pz/alpha Pz ratio. We discovered that while the ratio somewhat reacts to workload manipulations, it was not as sensitive as an index where frontoparietal information is used, i.e., when the ratio is calculated as theta Fz/alpha Pz (sensitivity for dual vs. single condition, 0.6 for theta Pz/alpha Pz and 0.75 for theta Fz/alpha Pz; for multi vs. single, 0.8 for theta Pz/alpha Pz and 0.95 for theta Fz/alpha Pz).

In addition to neurofeedback studies, the use of the frontal theta/parietal alpha ratio in a task load estimation has been suggested in Postma et al.[33]. Contrary to their findings, we also found that the internal state of the subject has a strong effect on the ratio. Time awake significantly increased the theta Fz/alpha Pz ratio. Moreover, we found that sleep restriction enhanced this increase.

Lower frequency oscillations (delta, theta, and alpha) have been suggested to form the basis for longer-range communication between brain areas[9,34]. Especially, increased synchronization in lower frequencies between posterior and frontal regions during cognitive task performance has been shown with EEG studies[15,35]. In addition to task demand changes, frontal low frequency activity has been connected to sleep pressure level in the awake subject[4]. We suggest that the theta Fz/alpha Pz ratio measures the overall brain load (a sum of internal and external factors affecting the brain) at a given time. Our study showed that the frontal theta increased and the parietal alpha decreased as the task load increased, whereas both variables increased as time awake increased. These two loading factors seem to have partly different neural origin, as has also been reported in a functional magnetic resonance imaging study by Drummond et al.[36]. However, both increased external and internal load increase the theta Fz/alpha Pz ratio, suggesting that it may be used in overall brain load estimation. Because the index reacts to loading changes of the brain, we named it "brainbeat".

Quantitative comparison of the P300 amplitude, theta Fz/alpha Pz ratio, theta and alpha power parameters with ROC curves showed that the ratio performed well in differentiating task demand levels. The ratio was comparable with the P300 amplitude, making it possible to estimate the task demand levels without an additional oddball task required by the P300 measure.

Our study also showed that the alpha power could differentiate task demand levels from each other. However, alpha power is not an optimal method for estimating overall brain load, since it increases both when an alert subject is working at easy task demand level, as well as when a subject is engaged with complex multitask and sleep pressure increases.

The effects of internal and external factors cannot be distinguished from one another solely on the basis of the brainbeat value. On the contrary, we hypothesize that the same level of brain load can be caused by different loading factors. Thus, for example, a high external load, such as demanding work, causes a temporary loading effect that is comparable to what would be accumulated by the gradual increase of the internal load as a result of time spent awake. It is also possible that when the internal state of the subject is not optimal, cognitive overload situations may develop faster in high workload conditions in relation to low workload conditions. This creates restrictions to the usability of the brainbeat in brain computer interaction applications, where internal and external load need to be differentiated. However, in many other applications, (e.g., in traffic safety issues), detecting overload situations regardless of their origin is essential in order to avoid detrimental errors.

Assessment of the brainbeat is based on information obtained with two EEG electrodes and can be implemented into a compact, wearable device for on-line monitoring of brain state in both field and clinical settings. It can be used as a first-stage diagnostic tool and follow-up measure of the overall functional state of the brain. This enables the study of the effects of various stressors on brain physiology in both daily life and at work. Such information could be used to ensure that operational environments at work and in everyday life are humane by, for example, optimizing cognitive demands and work shifts, and thus protecting the health of a "working brain". Oscillatory phenomena of the neural networks can be seen as a metric for the functional state of the brain equivalent to the heartbeat as a metric of the physiological state of the cardiovascular system. As the brainbeat reacts to both acute external and cumulative internal load, we suggest that it could be used as a measure of the overall brain load.

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Cross- and multimodal spatial cueing on wearable user interfaces in a field setup

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INTRODUCTION

Novel wearable user interfaces (UIs) may improve situational awareness in highly demanding professions such as crisis management or fire and rescue services.

The human ability to attend to simultaneous events is restricted, as the speed and number of concurrent mental tasks is limited (Eysenck & Keane, 2005). In order to enhance attentional capture, stimulus cues may be used to direct attention to relevant events in UIs or the environment. Directing attention with cues can utilize any modality regardless of the target as the shift of attention in one modality to a certain direction leads to directing attention of other modalities as well, and may ensure and speed up processing of target stimuli (Spence & Gallace, 2007; Ferris & Sarter, 2008).

This study investigated, in field conditions, how to support performance in a spatial task with different modality cues, and how physical strain affected the results. Three modality cues (visual, auditory and tactile), and their multimodal combinations were studied with and without pre-task physical exercise.

METHODS

Fig.1. The field setup

Fig.2. The wearable UI: a head-mounted display, LED glasses, tactors, and the ECG device

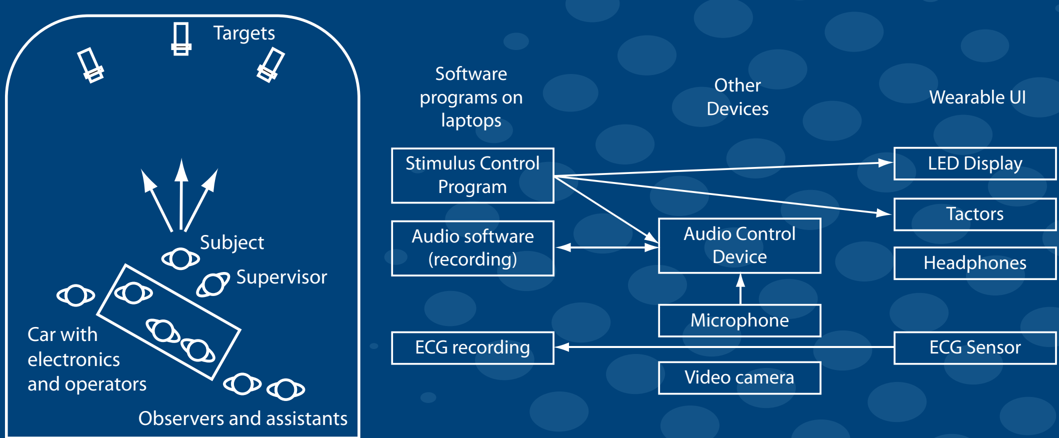

Fig.3. Experimental and system design

An applied real-world setting was selected. The task was a shooting task performed at a military firing range. Shooting creates a demanding field test situation, used here to simulate a crisis management task. The focus is on presenting time-critical information in a way that results in reliable detection, but without disturbing the task.

Six professional soldiers participated in the task, shooting at three targets (Left, Center, And Right), and the stimuli were used to direct fire per each shot: e.g. "shoot the left target".

SAWUI

RESULTS

Different modality cues were judged according to performance (reaction time, shooting accuracy, and analysis of speed-accuracy trade-off) and subjective measurements (questionnaires and structured interviews). ECG was used for controlling the level of physical exercise and the NASA-TLX (Task Load indeX) for estimating subjective workload.

Differences between modalities:

- reaction time differences close to significant (+)
- multimodal cues faster but less accurate than tactile cues
- possible speed-accuracy trade-off
- questionnaire results were mixed, and did not distinguish between better and worse modalities
- the subjects had very different experiences over the cues and devices

Effects of physical exercise:

- reaction time differences not significant
- all modalities scored worse for cue clarity in the questionnaire after physical exercise
- subjective experiences of effects of physical exercise did not correlate between subjects
- although a slight trend for performance degradation with physical exercise was detected, no significant difference was found in NASA-TLX ratings for subjective workload

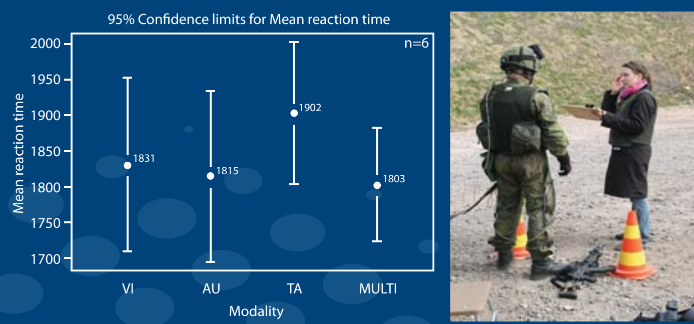

Fig.4. Differences between modalities; Interview

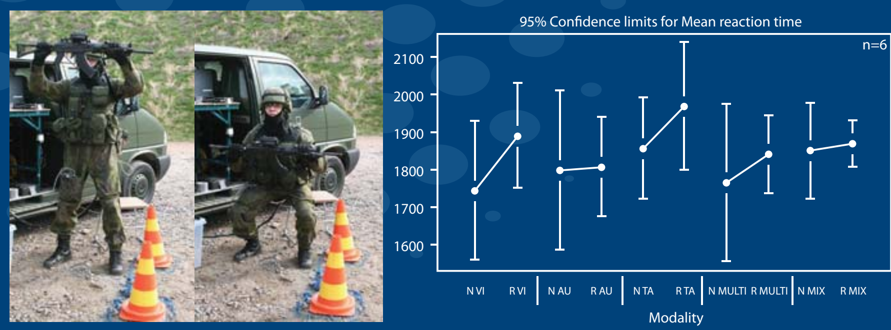

Fig.5. The effects of physical exercise

DISCUSSION

The results of this study do not allow ranking modality variations, neither by performance nor by subjective measures. The subjects had preferences among the modalities but these were mixed between subjects.

The stimuli evaluated on the actual experiment performed equally well in the task, and all of them could be used for supporting situational awareness. None of them had negative mean ratings in the questionnaire. Delivery of visual stimuli through a HMD in the pilot experiment was found unsuitable for a time-critical shooting task because the subject had to focus his gaze and attention away from the environment to detect the cues.

The speed benefits related to cross-modal cuing only represent a small proportion of reaction times in a complex motor task like shooting, even with well-trained subjects. Thus such effects, although validated in laboratory settings, may prove less interesting for applied real-world environments. It would appear more appropriate to support reliable detection and focus on cue saliency and detectability under various environmental conditions (changing environmental luminance, noisy environments, vibration) and task requirements (body position, move-

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The robotized field operator

Greater safety and productivity by design

Charlotte Skourup, John Pretlove

The aim, in almost all industries, is to have a high level of automation to increase productivity and efficiency. Industrial robots, which have been one important technology enabler in achieving this aim, are designed to perform repetitive, heavy, dirty and dangerous tasks. Within the oil and gas industry, robots have been used in very specific niche applications where the main driver has been safety, but this trend is now changing. Oil and gas companies have started to explore broader applications where robots may also have a positive impact on productivity and efficiency. One such application is the remote operation of oil and gas fields, particularly those in hazardous environments. ABB is a leading manufacturer of robots and is committed to developing "robotized field operators" for the oil and gas industry.

An orange robot moves around the process site and performs a combination of routine inspections and replaces a safety valve. This robot works along side two others. All three are supervised by a human operator located hundreds of miles away in the process control center. The human supervisor has defined and initiated the maintenance tasks in response to a condition-based monitoring (CBM) report generated by the automation system. With overall responsibility for safety, the operator instructs the automation system to reschedule the subtasks. Using the 3-D camera mounted on one of the robots, the operator inspects the machinery and identifies further components that require removal and replacement.

Frequently, robots are used to carry out repetitive routine tasks, which may be heavy, dirty, remote, dangerous or otherwise better suited to a robot than a human.

Although this scene is set sometime in the future, it is not far from reality. Some aspects of it are already happening in space and deep beneath the oceans, where tasks cannot easily be performed by humans. The scenario shows how robotics technology could be taken a step further and moved into oil and gas facilities to improve health, safety and the environment (HSE) and to increase productivity.

Trends in oil and gas

The oil and gas industries are facing a number of challenges that require novel technical solutions and business models. The world's energy consumption is growing and although alternative energy sources are currently expanding, there remains a high demand for oil and gas. However, recovering oil and gas from existing reservoirs and new fields has become more challenging with reduced profit margins. Many of the more accessible oil and gas fields have already been exploited, leaving the more remote and technically challenging reserves for future exploration. Furthermore, experienced crew are fast approaching retirement age, which means that fewer experienced workers will be available to extract these reserves. Based on the expectation of continuous market growth, the trend will be for stronger cuts in costs and increased energy efficiency. These trends suggest there will be increased investments in new solutions and business models to build on the existing infrastructure and also to develop new oil and gas fields. To successfully meet these goals, the oil and gas industry is prepared to change working practices and adapt their infrastructure.

Collaboration is recognized by the industry as an essential element to achieve the efficient and safe operation of their industrial processes. In many cases, the collaboration takes place over a distance, for example, between the control room and a remotely located expert or field operator 1. Integrated Operations[1] (IO) (also known as eField, iField, SmartField, etc) is a broad philosophy that aims to tackle the overriding challenges faced by the industry. The IO idea attempts to achieve goals through a combination of new methods focusing on the latest developments in technology and work processes.

Robotics business and markets

The use of robotics technology has made a large impact in many industries, particularly in the manufacturing area. Efficiency and productivity remain the main incentives for industries to use robots to automate their manufacturing processes. Most often, particularly in manufacturing plants, robots are used to carry out repetitive routine tasks, which may be heavy, dirty, remote, dangerous or otherwise better suited to a robot than a human. Also, these tasks typically require very high reliability and accuracy for which industrial robots are designed.

The automotive industry has had a major influence on the development of industrial robots. The principal goals of the car manufacturing industry are to increase productivity, flexibility, reliability and product quality at a lower cost. These business aims have pushed manpower away from

1 ABB-Shell collaboration room – an example of an integrated operations center

Footnote

[1] Integrated Operations (IO): StatoilHydro defines IO as "collaboration across disciplines, companies, organizational and geographical boundaries, made possible by real-time data and new work processes, in order to reach safer and better decisions – faster." To help identify the methods, technologies and work processes necessary to integrate its operations, StatoilHydro appointed an R&D consortium consisting of ABB, IBM, SKF and Aker Solutions. One of the seven sub-projects concentrates on robotics technology to supplement and extend human inspection and intervention capabilities at topside and onshore facilities. The objective is to develop solutions that combine tele-robotics and advanced visualization to enable remotely operated inspection and maintenance operations, as well as to identify and close technology gaps.

the production lines in favor of robots. Robotic production facilities are largely fully automated and run 24 hours a day seven days a week (24/7). Robots handle everything from sheet metal cutting, assembly and welding to painting, coating and general material handling 2. Robot manipulators are typically developed to handle one specific task and have even, in some cases, been developed particularly for a certain application such as to open and close car doors.

When automating a manufacturing plant with robotics technology, the greatest impact can be made when the entire process from start to finish is redesigned, rather than when only individual processes are automated.

A higher degree of automation naturally implies changes in technology, peoples' work patterns and organization. Although robotic systems can carry out repetitive, heavy and dirty jobs, they can rarely operate entirely without human intervention. Operators are required to monitor and control their operations and hence, they become an integrated part of the control loop and the receivers of the robot's output. Naturally an increased degree of automation results in job description changes so that personnel with different competences, such as planning, programming and maintenance, are required to maintain productivity. A critical component to successfully implement automated processes within a manufacturing plant is to be prepared and plan for such organizational changes by updating job descriptions, roles and responsibilities to suit the reorganization.

A higher degree of automation requires changes in technology, peoples' work patterns and organization.

Robotics for oil and gas

The use of robots in the oil and gas industry has been limited. The industry has generally only automated processes that are either difficult or impossible for people to perform, or that would dramatically improve HSE issues. Examples of such applications are found in subsea facilities and pipeline inspections, in the automation of drilling operations, well tractors and in special inspection applications. Very often, the industry has experienced a negative impact on productivity with automation, running counter to the general goal of automation. This trend, however, is now changing. Today, the oil and gas business sees robotic technology as an enabler to increase efficiency, productivity and to improve HSE issues. The oil and gas extraction processes are generally dangerous and risky. Offshore facilities operate in rough seas and all kinds of weather conditions. In addition, hazardous environments are encountered, for example those with high concentrations of dangerous gases, such as hydrogen sulphide (H_2S). The use of robots in such environments has the potential to reduce human exposure to hazards. They are designed and manufactured to operate reliably 24/7 and can be designed to cope flexibly with a range of operations. With greater demands for energy and the increasing difficulty experienced by the industry to extract oil and gas economically, it is clear that the oil and gas industry will have to change its strategy and think afresh, especially if it is to successfully extract tail-end production from existing sites and exploit the smaller more marginal oil and gas fields of the future.

There are two broad areas in which robots can be used for oil and gas: those applications that demand completely new robot designs and those in which existing industrial robots can be applied. The further development of subsea oil and gas production relies heavily on remotely operated vehicles (ROVs). These are used for exploration, inspection and interaction with the process structures. Such applications are unique to the oil and

2 ABB robot spray painting in an automotive production facility

3 ABB robot at work performing routine inspection of process equipment

gas industry and require completely new robot designs.

Robots in the oil and gas industry would be expected to perform inspection and operational tasks to maintain the process infrastructure.

Other applications show clear similarities to manufacturing processes, where robots have already been deployed to carry out repetitive tasks and where this increased automation has already produced benefits. However, the characteristics of the tasks in the oil and gas industry differ from conventional manufacturing processes. Robots in the oil and gas industry would be expected to perform inspection and operational tasks to maintain the process infrastructure 3. This means that the robot would have more than one task and not all tasks could be predicted. Furthermore, offshore topside[2] facilities would have to be redesigned, since space is restricted, so that robots could move around and access the process equipment. The design of such automated topside facilities focuses on existing industrial robots, with minor modification, so that applications for the oil and gas industry can be performed successfully in harsh environments. This application is recognized as a "game changer" for the oil and gas segment.

Challenges for oil and gas robotics

Robotizing oil and gas facilities present many different challenges. These challenges are not only technical, but also have an impact on the whole organization, including the workforce. Although robotics technology has already been proven in other industries, it must be applied and adapted to the specific applications of the oil and gas industry. These applications are typically carried out in extreme environments and are often located far away requiring remote operation 4. There are also system integration issues with a prerequisite for full data access and availability.

The roles of the robot will, therefore, change from the more conventional single repetitive, yet continuous task, often encountered on a production line, to the execution of a number of different tasks, each requiring flawless performance on demand. The robot will have to operate at various levels of automation, from fully automatic, requiring no human intervention at one extreme, to completely manual operation at the other extreme. In between there will be various tasks with semi-automatic features, which will require varying degrees of human interaction. This represents a departure from the more traditional industrial robotics applications, in that human decision makers must be integrated within the control loop to collaborate with the robots and the control system. The successful automation of the oil and gas industry will, like all human-machine systems (HMS), rely on the seamless integration of man, technology and organization (MTO).

Oil and gas installations impose different demands on the design and requirements of the robot. The robot will have to be explosion-proof approved, in addition to being resistant to harsh weather conditions. Offshore robots will have to tolerate extreme temperatures, extreme winds, exposure to salt water and even exposure to snow and ice. Onshore robots will have to tolerate sand storms, direct sunlight, rain and humidity, extreme temperatures and exposure to different poisonous gases such as H_2S. Such specifications are not usually required for reliable robot operations in conventional manufacturing process plants.

To a large extent, the success of an automation project is influenced by the design of the facility in which the task is to be carried out. It is much more difficult to automate tasks in an existing facility than it is in new purpose-built facilities. The layout of existing facilities is not designed for standard industrial robots, particularly offshore topside installations, which

4 The offshore StatoilHydro Troll A gas platform located in the North Sea

Footnote

[2] Topside means offshore oil and gas installation (or the body of a boat or ship) above the water level.

are generally compact, presenting difficulties even to human workers when executing tasks. Modifying existing installations is rather limited and represents major costs. It is generally more effective to design new facilities, or to perform a major redesign of existing facilities, with the automated process in mind, so that many tasks can be carried out in a single facility and design features can be made to accommodate further additions should the process require scaling up. Such flexible facility design will allow greater process flexibility, increased productivity and reduced cost.

Telepresence keeps the human operators in the control loop, allowing them to use their high levels of skill to control the robot's operations.

While a robotized task, application or facility provides many safety and productivity advantages, it also presents additional challenges with regard to their maintenance and operation. Industrial robots are designed in general to replace human operators in the field; however, these robots are tools, which must be supervised and controlled. The robots themselves and how they perform a task should be of no concern to the human decision makers. The human supervisor's role is to control the robot's operations through the automation system based on the need to monitor, inspect and maintain the oil and gas process equipment. Data concerning the state of the process equipment must be collected either automatically or on demand. Such data cannot replicate the human senses and hence, cannot provide a similar representation of the process as it is carried out today. However, the robots can use other sensors that human operators are unable to use, such as x-ray and computer chromatography. This so-called telepresence provides an advanced representation of the current process infrastructure so that human operators are kept in the control loop, allowing them to use their high levels of skill to complement the power of remote manipulators. Robots as extended operator tools make up a natural part of the IO concept. The robots represent assets that are fully integrated in the automation system. The various IO teams will base their understanding of the process and decisions on such representations.

The automation system receives and processes data collected by the robot before the system stores them for later use in other applications, or presents them directly to the operator, eg, in the form of a report. The operational team use this information to make decisions. Team members can also actively search and ask for information. Their ultimate goal is to use all the information to monitor the current process and make decisions that will optimize the operation of the facility.

5 The ABB robot test laboratory in Oslo, Norway

A major challenge for tele-operation within the oil and gas industry is, in particular, the remote nature of offshore installations. These can be located hundreds of miles away from land, conducting complex and dynamic operations in harsh environments. Operation failures in such installations may result in major consequences for the environment and process equipment. Safe and efficient tele-operation is critical for such unmanned facilities, securing added value and optimal productivity at remote locations.

The ultimate goal of the operational team is to use all the information to monitor the current process and make decisions that will optimize the operation of the facility.

There is a clear incentive for oil and gas companies to automate their oil and gas facilities, starting with isolated operations, such as pipe handling and assembly for drilling and tasks related to pig operations[3)]. These examples represent high-risk operations for humans and therefore provide opportunities to improve HSE. A major step in the future will be to fully automate larger parts of the facility or even the entire facility. Such an approach has the potential to make a large impact on the flexibility and productivity of a facility.

ABB oil and gas robot test facilities

Currently, three ABB robots communicate daily to perform inspection tasks on a "working" process module in an ABB facility in Oslo 5. Either the control system or the operator initiates tasks for the robots. The (remotely-located) expert uses a 3-D process model to interface with the robots, defining and initiating tasks, and receiving feedback. The robots act as the operator's extended "eyes, ears and hands" in the process to maintain presence and awareness of the status of the process infrastructure. The focus has been to build and configure a highly advanced working facility for remote inspection. The robotics system is further configured to handle maintenance tasks, such as to open and close a valve, replace wireless sensors, or exchange components and handle material.

ABB, together with StatoilHydro, is addressing both the technical and personnel-related challenges in an ambitious cooperative research project to automate the oil and gas industry.

This lab provides a unique robot test facility to explore, demonstrate and test concepts for future robotized oil and gas applications. The lab is a part of a larger research project conducted in collaboration with StatoilHydro to integrate remote automated operations. The main lab comprises three robots and a "working" process module. Typically, one robot is used for inspection and the other two for co-operative maintenance. The inspection robot is mounted on a flexible gantry crane, while the two maintenance robots are mounted on rails 6. In addition, a waterproof ABB robot is located outdoors at the StatoilHydro site in Kårstø (on the West coast of Norway). For a six-month test period the robot will be analyzed in severe weather conditions as a first step toward the creation of a robot able to withstand extremely harsh environments.

6 An ABB robot equipped for visual inspection mounted on flexible gantry crane

These two ABB robotics test labs provide excellent facilities in which to demonstrate and pilot a variety of automated tasks for the oil and gas business.

Robotized operators for the future

Oil and gas facilities have huge potential to increase productivity, a significant part of which will result from the use of robotics-based automation. In addition to productivity and efficiency gains, robots used for high-risk tasks will also lead to improvements in HSE. Such tasks are not necessarily always predictable and represent unusual robot activities. The robot will therefore require features that extend the "eyes, ears and hands" of the human decision makers as they carry out inspections and maintenance operations on the process infrastructure. The new role of the oil and gas facility operator will be to supervise and instruct the robots and to make operational decisions. The robotized facilities will allow marginal, remotely located fields to be cost effective for oil and gas production.

The greatest gains will come when the robotics systems are fully integrated with the automation system, providing a tool for the human decision makers that is aligned with the IO concept. The goal of IO is to make real-time data available to the decision makers in (virtual) teams so that they can make better and faster decisions. The robotized field operator is one of many means by which data can be collected and tested to achieve a complete IO environment. A major advantage of robots is that such data collection tasks can be performed in environments impossible for human operators, such as those rich in H_2S, or can be collected using methods hazardous to human health, such as x-rays.

Two ABB robotics test labs provide excellent facilities in which to demonstrate and pilot a variety of automated tasks for the oil and gas business.

The degree to which the oil and gas industry benefits from robotics technology depends on how willing the industry is to change its organization and work processes in order to fully integrate the technology and overcome the technical challenges of IO.

ABB, together with StatoilHydro, is addressing both the technical and personnel-related challenges in an ambitious cooperative research project to automate the oil and gas industry. Access to operative sites, together with unique competence in robotics, oil and gas, and systems integration, means that ABB is well placed to develop integrated robots and automation systems specifically adapted for the harsh and demanding oil and gas industry applications.

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Footnote

[3] These are operations that are performed within the pipeline, without stopping the flow, and include inspection and cleaning. Pigs get their name from the squealing sound they make while traveling through a pipeline.

HFC

Human Factors Integrated System Validation

P. Ø. Braarud, presentert av A.Bye

Mere informasjon:
Braarud, P.Ø and Skraaning, G. "Insights from a Benchmark Integrated System Validation of a Modernized NPP Control Room: Performance Measurement and the Comparison to the Benchmark System".

Human Factors Integrated System Validation

Per Øivind Braarud
and Andreas Bye,
Industrial Psychology Division
OECD Halden Reactor Project /
Institutt for energiteknikk, IFE

Overview of presentation

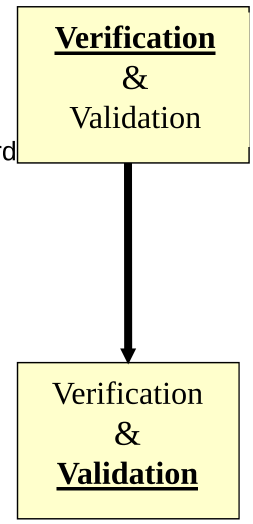
- What is Human Factors Integrated System Validation (ISV)?
  - Performance based validation of control centres
- Experiences and Research issues
- Nuclear domain, Process Control Centre
- Discussion: application to other domains given other conditions

Integrated System Validation (ISV)

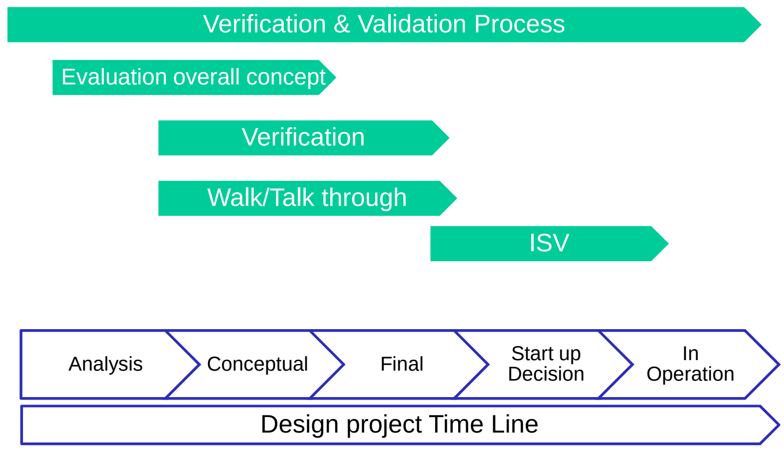
- "... evaluation using performance-based tests to determine whether an integrated system design (i.e., hardware, software, and personnel elements) meets performance requirements and acceptably supports safe operation of the plant." (Human factors Engineering Program Review Model", NUREG 0711, p. 55, US Nuclear regulatory Commission review guidance)
- An activity of the design process of modernisation or new builds
- Confirmation / Acceptance focus

HF V&V plan

- *"Simple" V&V activities for separate sub-systems* as early as possible
  - Verification using philosophy, guidelines, standard
  - Validation using scenarios of operator tasks
- *V&V activities for integrated sub-systems*
  - Small-scale validation using preliminary simulator, VR, prototypes
- *V&V in the fully integrated, "finished" control room*
  - Using a full-scope simulator



Example of V&V activities incl. ISV



Verification vs. Validation

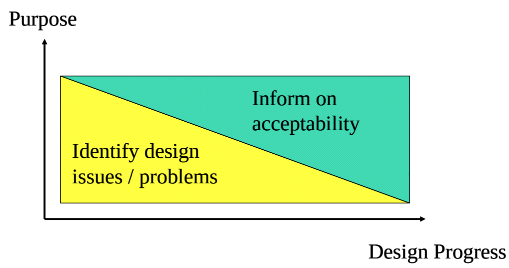
- Verification
  - Can be performed for individual system elements
  - System elements can be compared for consistency
- Validation
  - An element needs to be tested within the integrated system

ISV, I

- System:
  - HSIs (Overview/LSD, Alarm system, Process formats...)
  - Operating (Emergency) Procedures
  - Operator Expertise
  - Work Organisation & Work Practices
  - Technical Control Agents
  - Physical plant process
- Integrated
  - How system elements perform together and in interaction
- Validation
  - Can **Human Performance** be validated according to safety goals and efficiency?

ISV, II

- ISV focuses on Confirmation / Acceptance
- V&V earlier in the design focus on identification of design issues, evaluation of alternatives, and more on the acceptability of individual system elements



- Acceptability of integrated performance, but also how the system elements support performance

ISV, III

- Realism – Simulators
  - Walk through/Talk through often underestimate the complexity and problems that can occur in a realistic setting
- Actual Users
- Final test before implementation
- Evaluation of “final” design results
- Indirect evaluation of the design process & previous V&V by evaluating the outcome / product of design

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Example Modernisation Projects

- Large scale plant modernisation projects
  - To improve safety in accordance with new standards, new and modernised plant systems
    - Redundancy, Diversification, and Separation of Safety systems
  - To increase production (power uprate)
    - Exchange Turbine systems, modernisation of production systems
  - New I&C systems
- Control Centre Modernisation
  - New Interfaces
  - Adjusted interfaces
  - Hybrid solutions of new and old interfaces
  - New and adjusted operating procedures

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Control Centre Design Goals

- Provide Situation Awareness and Understanding
- Able to control plant and safety status
- Support safe operation (safe way of working)

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ISV Methodology Issues

- Performance Dimensions – Measures / Observations
- How to define and specify criteria for acceptability?
- Scenarios (Test Situations)

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Two Main Approaches to Validation

Benchmark

1. Human Performance assessment in **existing** CR
2. Human Performance assessment in **new** CR
3. Comparing existing and new control room
   - Existing CR serves as Baseline/reference for acceptable performance

NUREG/CR-6393

Criterion-referenced

- No Baseline for comparison

1. Specify acceptance criteria (analytically derived)
2. Human Performance assessment (in new CR)
3. Compare test results to the predefined acceptance criteria

- Need for development and evaluation of criterion-referenced approaches

Performance Dimensions

	Measurement	*Actual measure used in validation*
Outcome	Plant and process status	Crew Plant Performance Observer assessment of crew plant performance
	Task performance – primary task activities	Task activities Observer asessment of performance Task performance time
Process	Cognitive factors	Situation awareness Workload
	Work Method/Practices	Observer assessment of teamwork Qualitative analyses
Support	Support and influence of System elements for performance	Operator Questionnaires Observer assessment Interviews

Interpretation of Results - Prioritization of performance dimensions

- Issue: Prioritisation of Human Performance dimensions for deciding acceptability
  - Guide recommends and research points to a number of dimensions, no prioritisation
- Outcome Measures
  - Plant performance and Task performance have by their content a more “direct” interpretation in terms of outcome
- The process measures
  - Potentially important performance issues not covered by outcome measures?
  - Process measures and outcome measures need to be interpreted together?

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Process measures

- Measures like workload and situation awareness
  - Sometimes difficult to link results of these measures to outcome and to control room elements
- Experts/Observers and operators assessment and judgement very useful
  - Often covers the “situated” elements of performance, the teams’ expertise
  - Not clearly covered by NUREG/CR-6393
  - Techniques for ISV purpose could be further developed

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Support from control room elements?

- Control room elements such as Overview information, Alarm system, Procedures,...
- Improved process measures should inform on causes for observed outcome
- Not covered by NUREG 0711, NUREG/CR-6393
- Techniques for ISV purpose could be further developed

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Research issue: Model of Performance dimensions and their relationship, specification of "acceptance" criteria

Type 1	Status of safety functions and barriers Requirements in given situation Maintain margins	Relate to Defence in depth
Type 2A	Work Method/Process Characteristics Represent "Margins" for Type 1	
Type 2B	Support from Control room "elements" (HSIs, procedures, training) Represent "Margins" for Type 1	

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Performance Model / Dimensions

- Improved safety indication of “human performance” measures
- The human contributions to “margins”, “defence in depth” and how this can be observed in sharp end operation needs to be further developed
  - Beyond outcome in given scenarios
- Global and general measures need to be complemented by more task specific, safety specific measures

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Scenarios

- Alternative 1: sampling and broad covering
  - Large number of criteria for broad covering, “sampling”.
  - Cover the modernisation
- Alternative 2: Strategic development of scenarios challenging the control room
  - Type of challenges expected to be predictive for target performance
  - Could include testing assumed vulnerabilities identified during the design process
  - Complex scenario versions covering a number of less complex versions of prototypical scenarios

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Scenarios

- Stress test, worst cases, need difficult scenarios
  - Unexpected, un-modelled, unfamiliar
- What defines complex scenarios for the control room team and is at the same time sufficiently probable and realistic?

Summary, Research Issues ISV

- Guidelines and standards need to be updated and developed
  - Current technical basis has many gaps and unsolved issues
  - Research and development needed
- Performance Model, humans as providing margins/defence in depth, relationship between dimensions, how to interpret multi-dimensional human performance results
- Test scenarios, minimum set, level and type of complexity, relationship with the performance model
- Criterion referenced approaches

General issues, ISV

- “Final” test “somewhat” independent from evaluation during the design process
  - DIfferent scenarios (or scenario versions) for evaluation than scenarios used for creating design basis
- ISV team for planning and analysis should have some independence from design team
  - But, personnel with good knowledge of the actual design must participate in the ISV planning
- When is a full ISV needed?
  - How big change/upgrade of existing system?

Generic Issues for Evaluation (V&V)

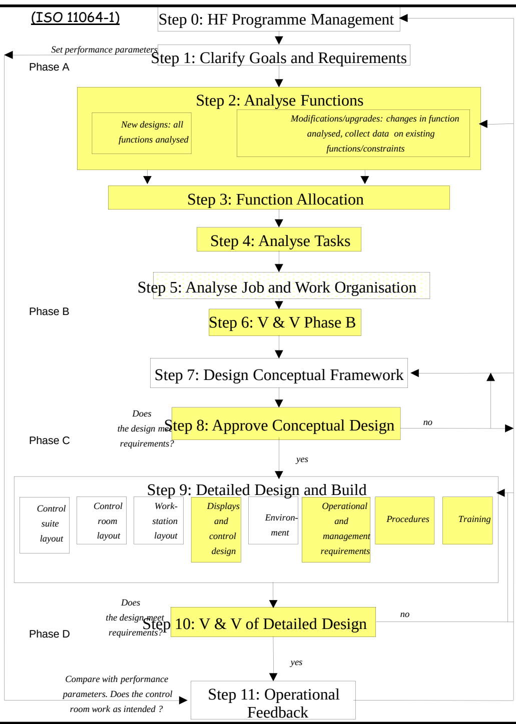
- During the design process gradually increase focus of evaluation on acceptance / confirmation
- A “final” evaluation / acceptance test focusing on performance requirements and support for performing these requirements
  - Focus on overall goals of the design, Safety and /or efficiency
  - In Realistic operation, Integrated
  - How elements support realistic performance
- Collect issues from the design process, analyse the resulting design and its principles as input to final evaluation
  - Test issues (scenarios) – Robustness, Adaption

Evaluation in general, I

- What is possible, what methodology exists today?
  - Which method for which step in the design
  - Verification of design documentation/concepts
  - Usability
- How valid & efficient is what type of evaluation?
  - Measures: subjective vs objective
  - Usability vs. Performance
- Is it possible to do ISV-like validation without a simulator?
  - Other scenario-based methods

Evaluation in general, II

- Final «product-focused» validation vs. «process oriented» QA
  - Balance, enough to fulfil the steps in ISO-11064-1?



Conclusions

- Different methods needed for different stages in the design
- Complementary methods and measures needed
- HF ISV is necessary when high requirements on safety in a complex system

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Insights from a Benchmark Integrated System Validation of a Modernized NPP Control Room: Performance Measurement and the Comparison to the Benchmark System

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Abstract – *The technical basis for performing Integrated System Validation (ISV) of new or modernized NPP control rooms needs further development. Most of the basis for conducting benchmark testing can be found in the review guideline NUREG/CR-6393. The experiences from a benchmark ISV of a modernized control room led to the identification of several unsolved practical and methodological issues. This paper discusses two such issues, i.e. the construction of usable performance measurement batteries, and how one should identify noteworthy performance differences between the modernized system and the benchmark system.*

I. INTRODUCTION

The purpose of Integrated System Validation (ISV) is to test if the integrated design supports plant personnel to successfully perform their tasks to achieve plant safety and to achieve the operational goals. ISV concentrates on the human performance of the whole control room function opposed to verification and validation of individual sub-systems. Integrated Validation refers to the integration of personnel, human-machine interfaces, procedures, and other work tools. ISV means using realistic scenarios in a high fidelity simulator focusing on the human performance of the integrated control room. ISV constitutes an essential step in the licensing process for new or substantially modernized NPP control rooms.

This paper was motivated by the experiences from a modernization project utilizing the Benchmark approach to ISV [1]. The Benchmark approach uses the performance of an existing system as the acceptance criterion for the new system. The paper looks at the insights regarding the battery of performance measure, and how to decide what is a noteworthy difference between the modernized system and the benchmark system.

The plant that serves as a case in this paper was a Boiling Water Reactor that had been in operation for about 30 years previous to the modernization. The modernization included the installation of additional safety systems, physical separation of safety systems, digital instrumentation and control systems, and a new power production turbine. The modernization project renewed the major part of the control room's human-machine interfaces, replacing conventional instrumentation and control panels with computer work stations. The modernization included changes to the emergency operation procedures and the organization of the work in the control room. The design project developed a human factors verification and validation plan consisting of activities that followed the design phases towards the final design. The ISV utilized the full-scope control room simulator developed for the operator training on the modernized plant and control room. The project chose to use the human performance of the old control room as the acceptance criterion for the human performance of the modernized control room; a benchmark approach. The existing control room had been in operation for nearly 30 years without human performance problems, and the plant had conducted regular simulator trainings for the crews that included a broad set of accident scenarios. The motivation for the modernization was the improvement of safety based on physical and technical changes to the plant. Thus, human performance issues were not the motivation for the modernization project. It was judged that the existing control room represented acceptable human performance for operating the existing plant, and that the performance level of the existing control room could be used as an acceptance criterion for the human performance of the modernized control room. The ISV plan included a test before the startup of the modernized plant and a test after operating the modernized plant for some time, in addition to collecting the benchmark data in the old control room simulator.

For the planning of the benchmark ISV, the project looked into the general human factors test and evaluation literature, simulator experiments on human performance, and review guidance for ISV. The most relevant basis for the overall planning of the Benchmark ISV was the review guides the NUREG-0711 [2] and the NUREG/CR-6393 [1], the latter one focusing solely on ISV. We complemented the review guides at a detailed level with methodology and measures from simulator experiments on human performance. The project's human performance measures included the task performance measures

Operator Performance Assessment System (OPAS) [3], The NASA TLX workload assessment [4], the Situation Awareness Control Room Inventory (SACRI) [5], observer rating of task performance and teamwork, and the operators' self-rating of process overview and teamwork. OPAS is based on a scenario analysis identifying crew activities needed for handling the scenario events. The crew activities were weighted according to their importance for reaching the event goal. During the run of the scenario, a Subject Matter Expert observed which of the predefined activities the crews performed. A score was calculated from the proportion of performed activities. The NASA TLX is an index resulting from the operator's self rating of six workload items. SACRI is based on the operator's assessment of process parameter development compared to the actual development of the process parameter logged by the simulator. The observer's assessments and the operators' self assessment utilized different types of rating scales.

II. HUMAN PERFORMANCE TEST BATTERY

The guides recommend applying a battery of human performance measures for integrated system validation based on the assumption that operator performance is multidimensional. The guide suggests several measures for the performance categories: Plant Performance, Personnel Task, Cognitive factors, and Anthropometric and Physiological Factors. During the work with the Benchmark case, questions arose about: (a) the selection of performance measures for the test battery (b) how to prioritize and how to interpret the results of the different performance categories, as well as the results of measures within a given performance category.

II.A. Plant Performance Measure

Firstly, the experience from our ISV case was that plant performance was difficult to measure for the purpose of benchmarking. In general, plant performance measures that give clear indications of human performance are difficult to define. Candidate elements of a plant performance measure are the development of important plant parameters and the status of plant systems and plant components. The project selected for each scenario, plant parameters that were judged to be important and clearly influenced by the crew's operation. The changes to the modernized plant process from the old plant process resulted in a different parameter development for some of the parameters independent of the effect of crew operation. These differences would have been difficult and resource demanding to identify before the modernization. Further, and more important, the modernization required the development of a new process simulator due to the upgrading of the plant process and the I & C. The realism of the new simulator was not fully at the same level as the old simulator for the first test of the modernized control room. This can be expected also for other modernization projects, since it will typically take some time of actual use of a new NPP process simulator to gain the experiences needed to fine tune the process simulation. In addition to these technical difficulties, an important question about a plant performance measure is what additional or complementary information a plant measure gives to the other performance categories? The plant performance measure can inform about the outcome of human intervening actions or the consequence of missing human intervention. But, the intervening actions with the plant process should be captured by the personnel task performance measures. One argument against the plant performance measures is that the measure in isolation do not inform about human performance. One exception is the case where there is a one-to-one correspondence between a human activity and a plant consequence, such as manually stopping a process object or manually controlling a system. But, this kind of activities can easily be captured by the task performance measures. The experience from the case ISV was that the plant performance measure was difficult to develop, and that the measure did not give additional information to the other human performance measures. This does not mean that plant outcome of human performance was considered less important, but rather that the outcome of human performance was incorporated into the other measures. Future ISV projects should consider the need for a plant performance measure, for example what additional information compared to the other performance measures is gained. This view challenges the recommendations given by current ISV guidelines.

II.B. Performance Categories

The NUREG/CR-6393 describes a hierarchical causal model where cognitive factors such as situation awareness and workload drive task performance. This model is rather strongly cognitive oriented and can be interpreted as a model were the operators are collecting and processing information, and performing actions based on the processed information. The work in the control room is typically highly standardized by the use of well trained work methods and a comprehensive set of operating procedures. This is the case for accident operation especially. Based on the experiences from the operation of the plant and the experience with the human-machine interfaces 'work methods' emerge. The work method can be an important factor for human performance, and this factor is only covered indirectly by the current ISV guidelines.

Work method was not a focus in the planning of our ISV case. The case included self-rating scales for the operators (in addition to the NASA TLX workload scales). These were self-rating of task performance, teamwork and situation overview. The measures showed a relatively small decrease in the first measure of the modernized control room and a level similar to the old control room in the second test of the modernized control room. This was similar to the pattern of several of the other measures. The subjective measures could be interpreted as a "correlation" of the objective measures or as a causal measure for the task performance measures in a similar way as the cognitive factors in the NUREG/CR-6393. Or, the subjective measures could represent an element not captured by the other measures. There were low and non-significant bivariate correlation between the self-ratings and the observer rating of performance (r ranging from .01 to .12), and low bivariate correlation between operators' self-ratings and objective task performance (OPAS) (r ranging from .04 to .15). After the administration of all scenarios, the operators completed a usability assessment of the modernized control room and participated in a short interview. In the first test of the modernized control room the operators' comments written during the usability evaluation and during the interview were about the need for more training and practical experiences with the control room, such as methods for using the new human-machine interface, methods for keeping overview of each others work at the computerized work stations, cross training on the various positions in the control room and the division and organization of the work in the control room. For example, in the first test of the modernized control room, 45% of all written comments during the usability test were related to the need for more training on how to operate using the new human-machine interfaces, while in the second test of the modernized control room there were 0 % comments about the need for more training. A statistically significant moderate negative correlation between the operators self-rating and NASA TLX (r ranging from -.32 to -.56) suggested that the self-rating captured some meaningful aspects for human performance. The low correlations between the operators' self-rating and task performance measures can be interpreted in several ways, but the results may suggest that the self-rating capture something not captured by the task performance measures. The usability comments indicate that the operators put more weight on how confident they felt in using the new control room and how confident they felt in operating the modernized plant. In other words, the operators' evaluation could represent the status of the work methods in the control room. These experiences can be a reason for including the work method as an element in future ISV projects. One commonly focused area with respect to the work method is teamwork, i.e. how work is coordinated, and how information is communicated. Other areas include the goals and intentions of the control room crew based on their understanding of the goals and constraints of the plant operation [6].

For ISV measurement purposes one can argue that cognitive factors and task measures are sufficient since work method is reflected in the tasks and cognitive factor measures. But, important measures for generalization and long term prediction of performance may then be left out. Similar arguments are used to include human performance measures and not use only plant performance measures for ISV. So, in principle there are "endless" layers of potential causal and influencing factors. For ISV purposes the goal must be to define a model that represents the important elements for deciding on the acceptability of human performance in the new system. At a certain level, the limits of the model must be specified, and our impression was that work methods should be included in a performance model for ISV, or at least further investigated.

To illustrate the performance categories and their relationship, a simplified model from the NUREG/CR-6393 guideline with the addition of work methods as an element is depicted in Figure 1 below.

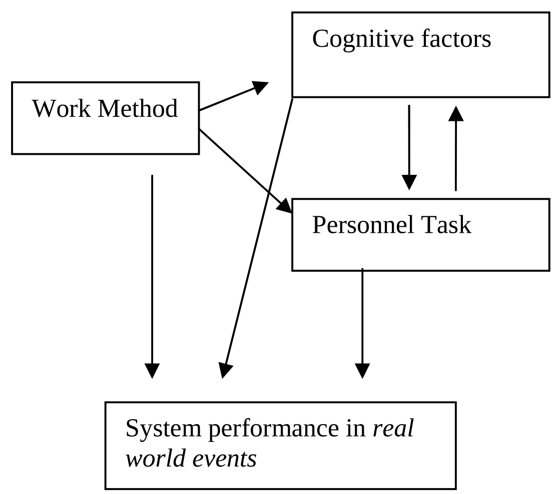

Fig. 1. Performance Categories

For ISV purposes it is important to distinguish between causal relationships between the elements of test results, and the relationship between test results and the real world human performance of the human-machine system one aims to predict. The ultimate purpose of an ISV model is not to model human operation in the real world as realistic as possible. The purpose is rather to measure elements of human performance in a test situation that is predictive for human performance in real events that can occur during the life-cycle of the system under validation. In principle, cognitive factors in the test situation could be as predictive for real world human performance as the task performance measures, therefore Figure 1 above includes connections directly between the cognitive factors and real world system performance and between work methods and real world performance.

II.C. Prioritization of Categories and Measures

Another issue revealed during the ISV case project was the interpretation of the results from the multi-dimensional battery of measures. Several types of human performance indicators collected in several events, give the potential for effects in different directions for the individual measures. One criterion for the interpretation of the measures can be the degree of convergent validity between performance measures. The criteria for performance measures of a given performance category, if the measures are aimed at capturing the same phenomena, should be convergent validity. For example different measures for overall workload should be correlated. When it comes to the whole set of measures, the picture becomes more intricate. We can expect a modernized control room to have effect only on some of the performance measures or in some cases to have different effect on different performance dimensions. Further, the effect on a given measure may need to be interpreted together with the effect on other measures.

For the ISV case, we decided that some measures could individually indicate acceptability, while other measures needed to be interpreted together with other performance measures to indicate acceptability. Based on the experiences from the project, this has been elaborated a little further to support the interpretation of measures from Benchmark ISV in general. The following performance categories presented below are suggested. Some of these categories are sub-categories to the categories in Figure 1 above.

- Task Performance
- Event Process overview
- Global Process overview
- Work Method
- Workload
- Diagnostic Measures

The term ‘Event’ implies that the test scenarios need to contain process events that require the operators to respond.

The Task Performance is defined as the human actions intervening with the plant process to handle the event of the scenarios. For many scenarios the procedures give the basis for defining the content of the measure, while for some scenarios an additional analysis by subject matter experts is needed. Process overview is divided into two parts. One part is the overview of a given event and the other part is the overview of the whole plant. The division of process overview into two parts is based on that the crew’s task is to handle the scenario’s events and simultaneously keeping an overview of the whole plant. For example, in some test scenarios this can mean to have the overview of that there is more than one event in the scenario and how many parts of the plant needs deliberate attention. The work method focuses on how the given events are handled and how the crew keeps overview of the plant at a more overall level. For example, how the crew manage their resources in scenarios with more than one event, how the crew verifies that their intervening actions result in the goals they want to achieve, and how communication is performed.

Workload is thought of as a capturing the total effort the operator needs to invest to handle the scenario demands. Workload is not only event-oriented but also a result of the work method. The workload measure is expected to be a global measures on the total efforts invested in all types of activities that the scenarios elicit.

The Diagnostic category is not necessarily a measure as such, but can be represented by for example the type and amount of relevant training, or the quality of the human-machine interface. In addition, to the scenarios for the human performance tests, usability rating of the elements of the human-machine interface can be obtained and interviews can be conducted to have an assessment on the status of skills and knowledge of the modernized plant systems, I&C, and interfaces. This will help to diagnose eventual performance problems and will help to interpret the results from the human performance measures.

For the case ISV we prioritized the measures based on consideration of the measures validity for safety assessment of the system and the measures reliability. We defined that Event Personnel task performance and Event process overview could directly indicated acceptability of the modernized control room. The content of these measures were easy to interpret due to the direct impact on the process or due to the direct link to the process development. The measures were based on observable human actions that in many cases could be confirmed by process component status, or based on the explicit communication within the crew. During scenarios runs, the measures’ human activities were recorded by a SME having on-line access to the simulator logs and the human machine interface.

The validity of cognitive measures for deciding on acceptability of human performance of the control room is more difficult to establish than for observable task performance activities. This does not imply that the performance measured by these measures is less important. E.g., it is technically more difficult to measure operators’ process overview than to measure operators’ observable task activity. Process overview need to be inferred from operator activities or from operator responses to inquires or by other elicitation techniques. The validity of the cognitive measures’ for assessing acceptability of human-machine systems need to be established through empirical studies. While several studies have looked at the validity of individual measures for human performance assessment of elements of the control room, few studies have looked at the validity of cognitive measures that assess the integrated performance of complex human machine systems. Based on the current technical status of cognitive measures, it was decided in our ISV case project that the results from these measures had to be interpreted together with the results of the other measures. For example, a change in workload seen in isolation could not be used to determine whether the control room's human performance was acceptable. In the case ISV there was an instance of increased workload and increased situation awareness for the reactor operator position. The increased workload could then be interpreted as higher load and/or higher effort leading to a "safer" operation.

III. COMPARING PERFORMANCE OF THE NEW SYSTEM TO THE BENCHMARK

Comparing the human performance of the new or modernized system to the benchmark system raises the question of what is a noteworthy performance difference between the two systems. Regardless of the approach chosen for performance measurement and regardless of the method for comparing the modernized system to the benchmark system, this question is relevant. The NUREG/CR-6393 gave limited guidance on this issue.

The Benchmark approach assumes that human performance in the benchmark system is defined as representing an acceptable performance level. How far away from unacceptable the benchmark system is and how the performance level is for the different operational conditions is an interesting question. For the operational conditions where no related deficits to the control room is known, and the crews have a substantial number of years of relevant training and experience, the criteria from the benchmark system can be seen as high. An ISV includes testing before the system is taken into real operation and the conditions for the test of the new or modernized control room, at this point in time, can be lacking in quality compared to the benchmark system. The peak level of expertise on the control room and the operation of the plant may take years to develop. Therefore, it is likely that theoretical education and the simulator training performed ahead of the implementation of the modernized control room cannot develop an expertise that fully matches the level of the benchmark system. On the other hand, for some operational conditions the benchmark control room may have deficits that lead to a low level benchmark criteria.

This question was actualized for our ISV case project where the mean performance for some operational conditions were lower for the first test of the modernized control room compared to the benchmark performance. Our ISV project used statistical inference as the approach to test hypotheses about differences between the modernized system and the benchmark system with respect to performance. For the statistical tests, this difference between two populations has been referred to as *the practical significance* [7]. By the term *statistical significance* [7] we talk about the probability of getting data that suggest a difference between the old and the new control room given that we hypothesize no difference between the new and the old control room. In other words statistical significance informs about if the observed difference between the new and old control room is due to chance or sampling variability. The higher statistical significance of the results, the more support we have for rejecting that the new control room performance is the same as the old control room performance.

A key to this test is what we mean by "no difference". Practical significance indicates whether the effect of the control room configuration, i.e., if the difference between new and the old control room is large enough to have practical implications. The case ISV project used the variation between the crews in the old system to support the definition of a practically different significance between the old and the new system. The figure below illustrates the variation observed in the benchmark control room.

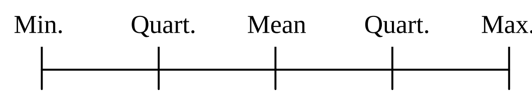

Fig. 2. Illustration of variation

The various indications of crew variation were used to define practical significance. For example, the crew with the minimum score and the crew with the maximum score were used to define a range of high practical significance. If the mean score in the modernized control room approached either the minimum score or the maximum scores obtained in the old control room, this would be interpreted as large and a rather dramatic change in performance. The quartile range was used to define a medium practical significance. Thus, the variation was used as a guide to define practical significance, together with a judgment of the practical significance implied by the scores. The approach for establishing and using variance from a benchmark or other type of reference system could be developed further.

IV. SUMMARY

The most relevant basis for conducting a Benchmark ISV of a NPP control room was found in the review guide

NUREG/CR-6393. The experience from an ISV case project was that the guide can be developed further and/or complemented on several issues. This paper discussed the battery of performance measures and considered if the plant performance measure was really needed, expansion of the performance categories to include work method, and the prioritization of performance measures. Further, the paper discussed using the crew variance from the benchmark system to support the definition of noteworthy differences between the modernized and the benchmark system.

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HFC

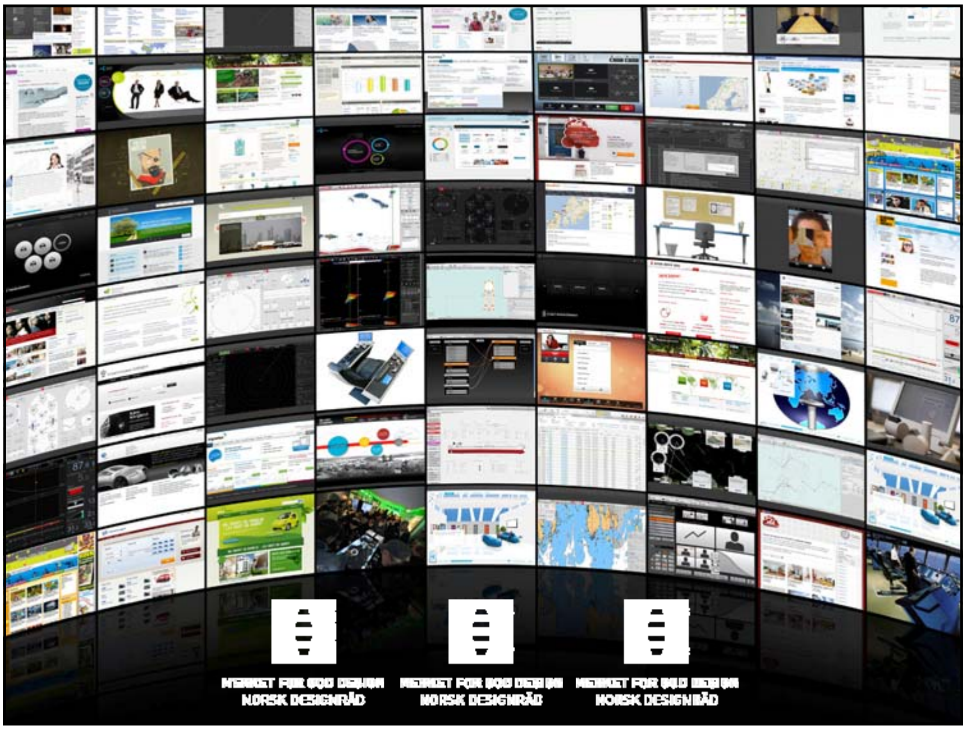
User Centric Design for Professional Applications

P. Holter

Mere informasjon:
Hvordan designe vellykkede touch-grensesnitt

Paal Holter

1976 | 98-03 | 03-05 | 05-11 | 4 & 7


MERKET FOR GOD DESIGN
NORSK DESIGNRÅD
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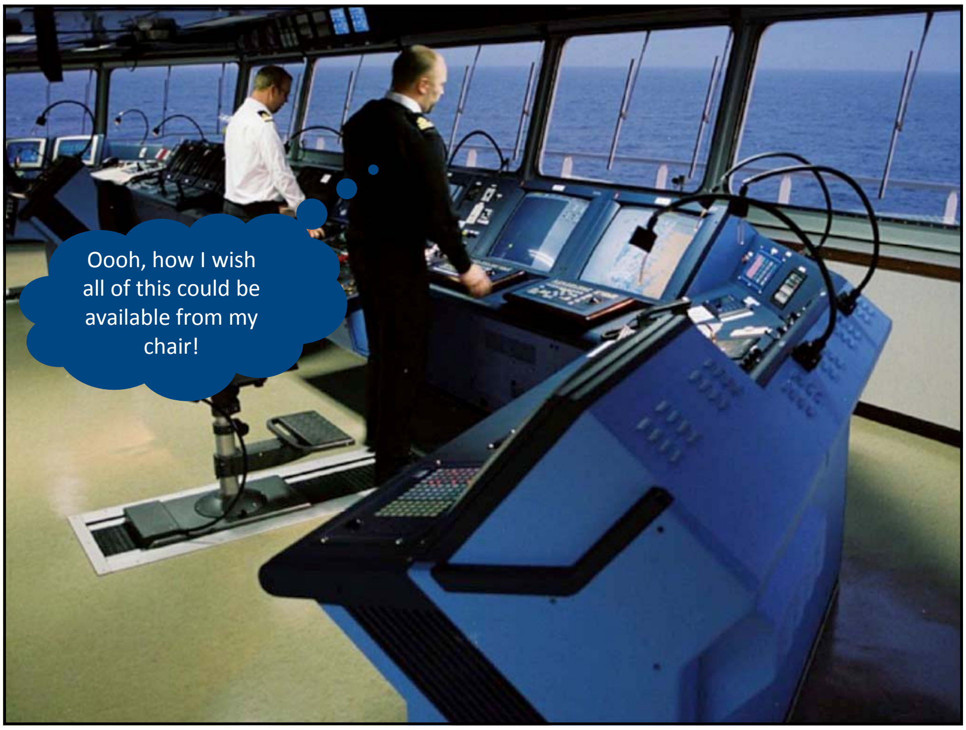
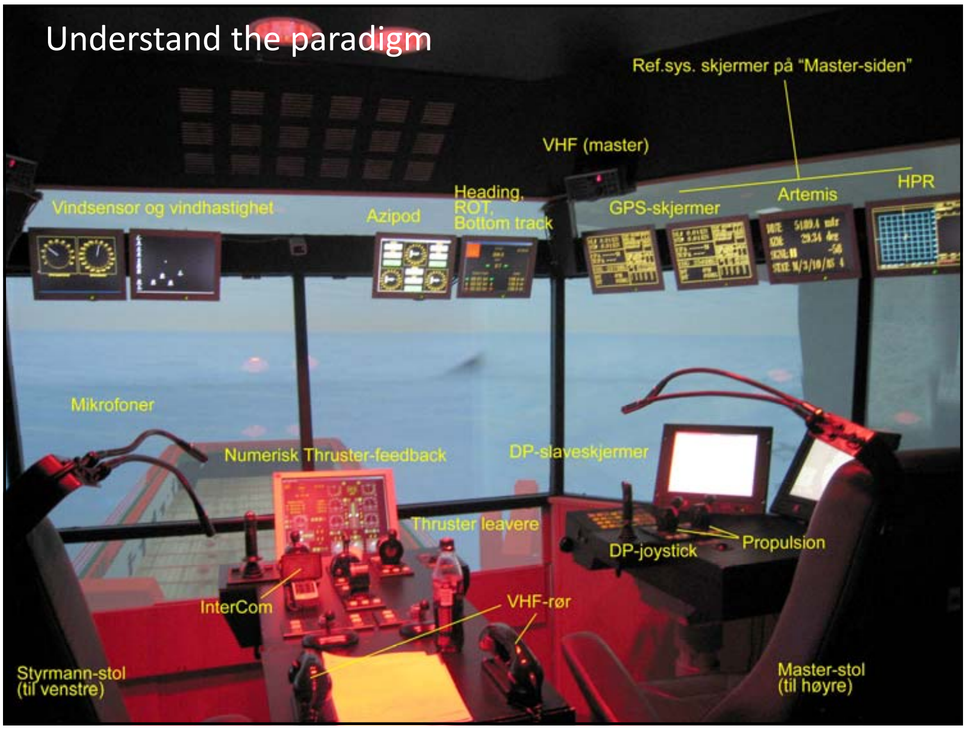
KONGSBERG

Kongsberg Maritime

Complete workstation for rear bridge




Understand the paradigm
Ref.sys. skjermer på "Master-siden"
VHF (master)
HPR
Artemis
GPS-skjermer
Heading,
ROT,
Bottom track
Azipod
Vindsensor og vindhastighet
Mikrofoner
Numerisk Thruster-feedback
DP-slaveskjermer
Thruster leavere
DP-joystick
Propulsion
InterCom
VHF-rør
Styrmann-stol
(til venstre)
Master-stol
(til høyre)

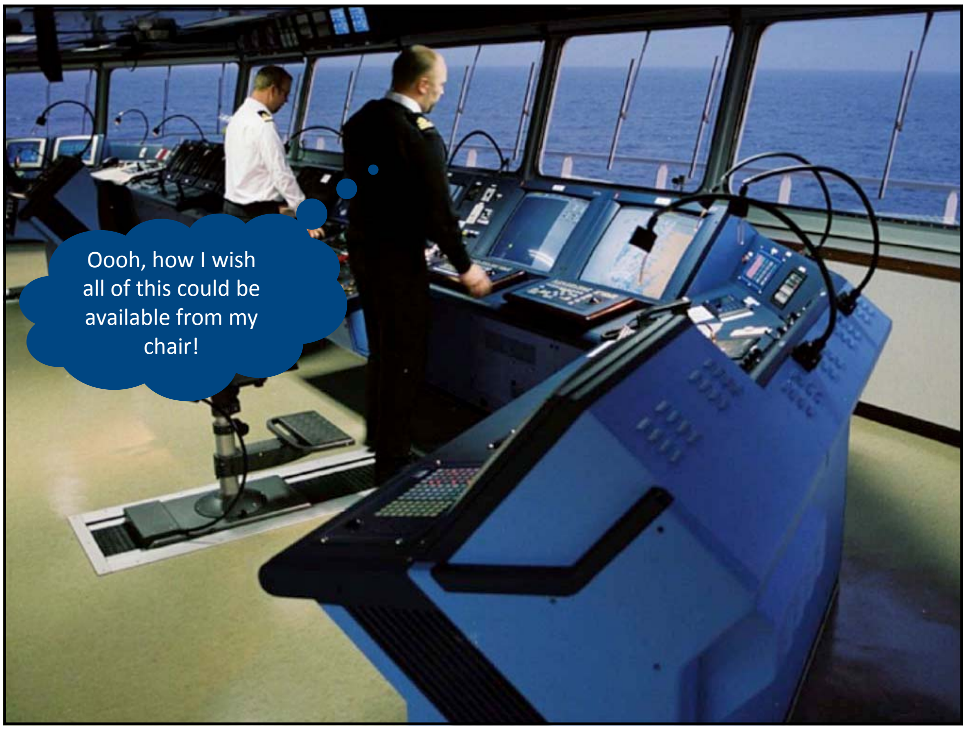

Understand the users' mental model

The core

Priority

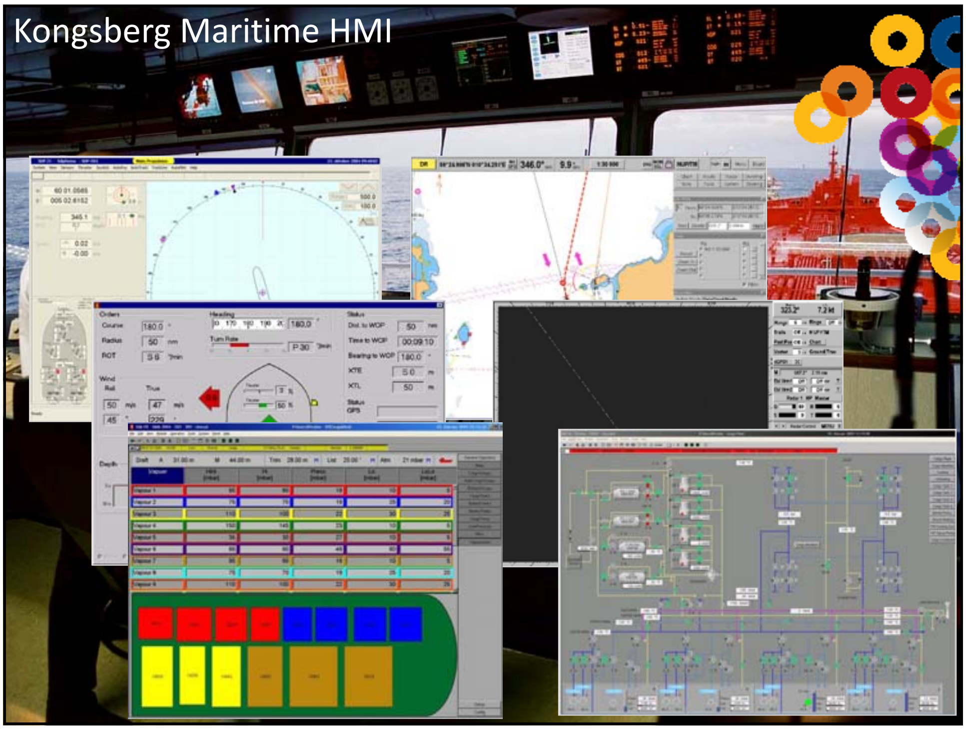
Flow

Awareness



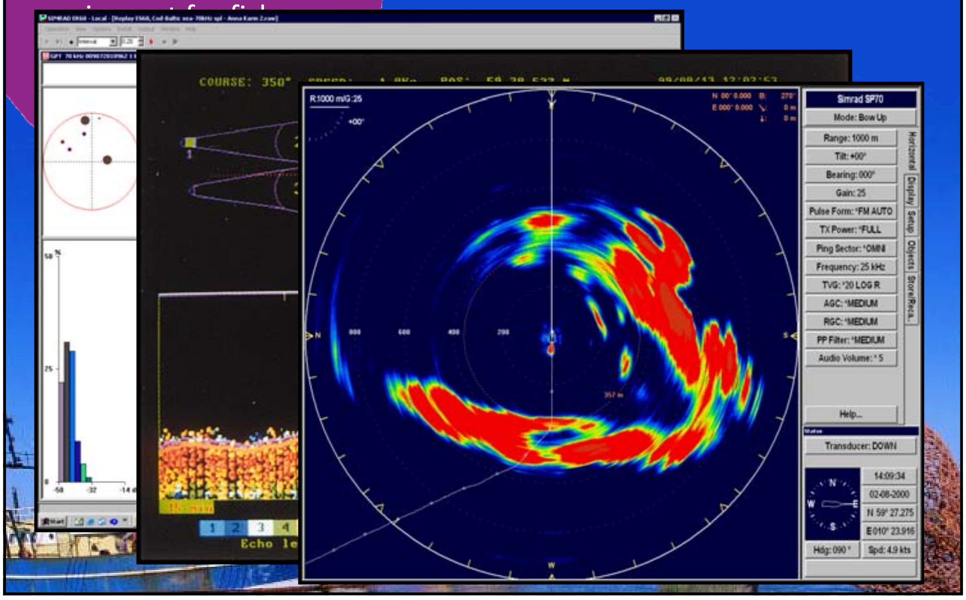
Tadaaa…

Kongsberg Maritime HMI

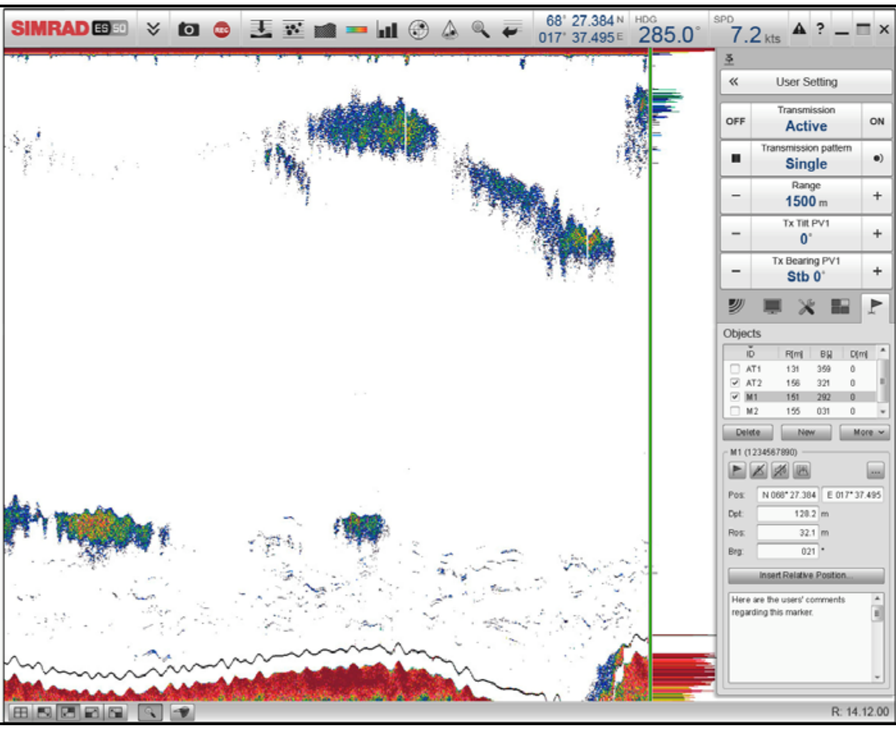


The new KM product family

Simrad delivers advanced, high-end

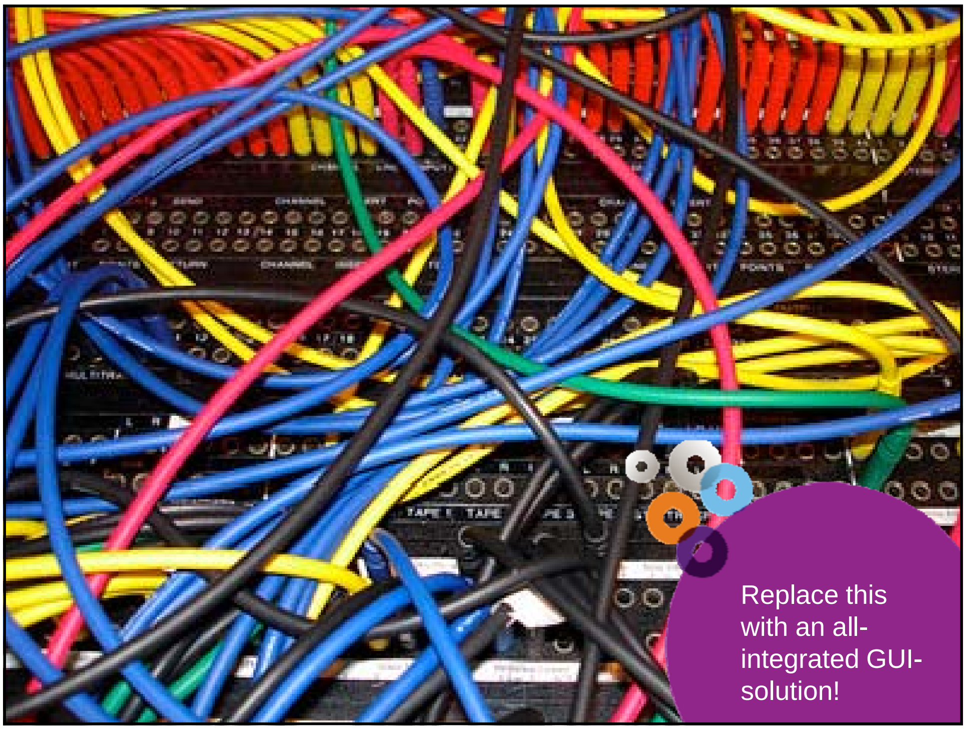


Card sorting and user survey



CISCO

TANDBERG

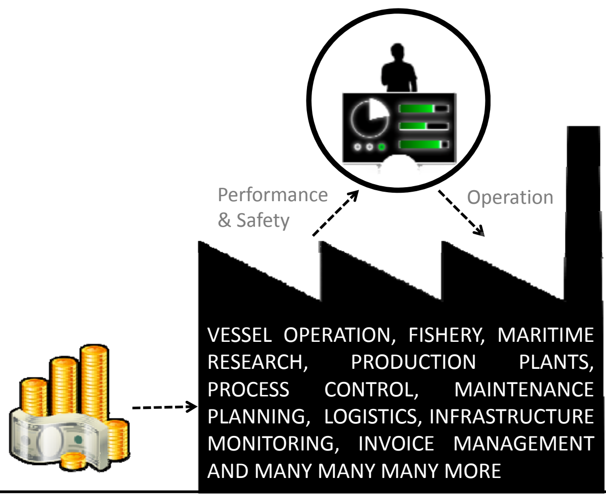


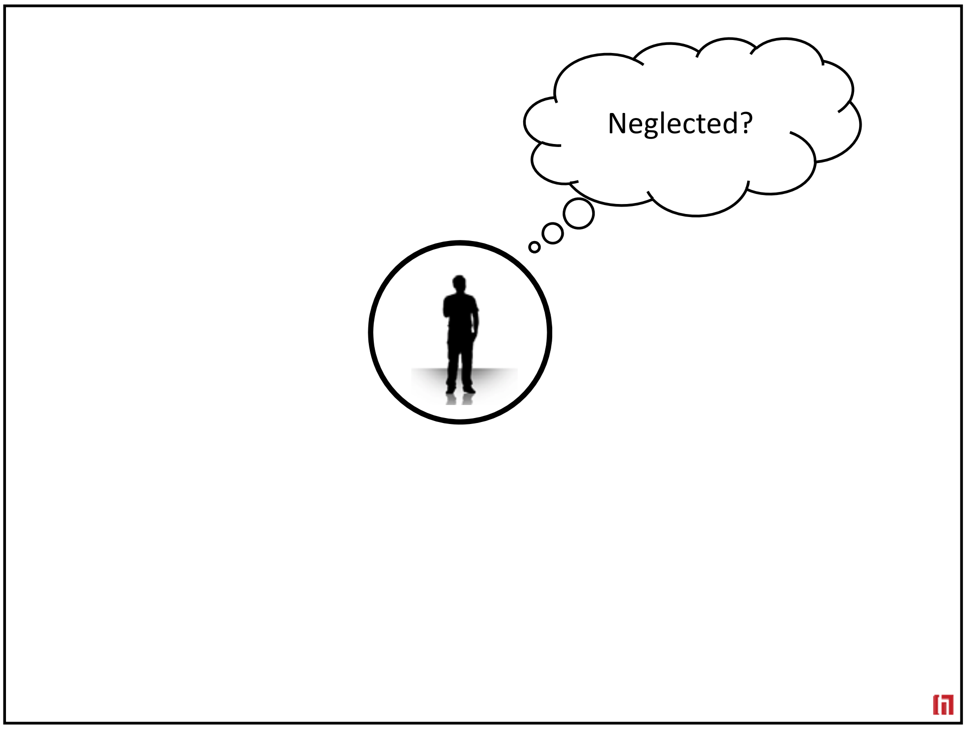

Full flexibility
Full overview of all input and output channels
Negin Niknejad
Easy to set up and connect input and output groups
I want a really cool equalizer
Oh… and I don't really understand computers.


TANDBERG Audio Console
Profile
Codec
Equalizer
Help
C90 default profile
New Input
Inactive
No inactive connectors.
Microphone
Settings
Microphone 1
Edit gain
Loudspeaker
Settings
HDMI 1
New Output
Inactive
No inactive connectors.
HDMI 4

The way I understand the universe of professional interfaces…

USER CENTERED DESIGN
PROFESSIONAL APPLICATIONS

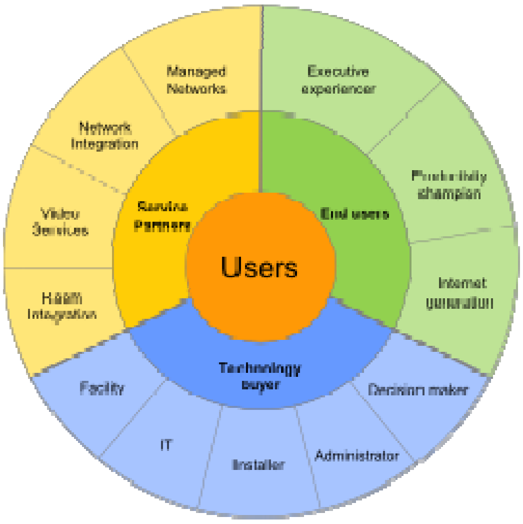



Neglected?

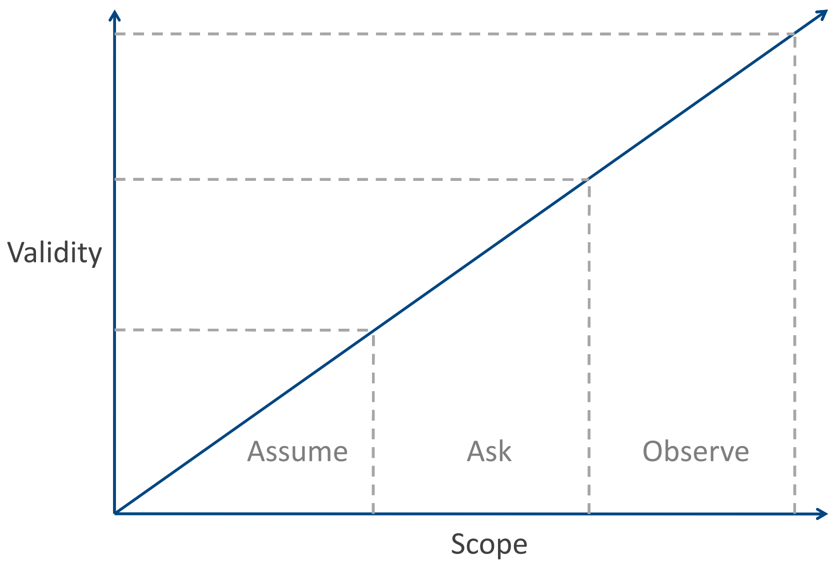

My client buys technology, not design
Design is gay
Change is risky
I know best

So we agree on involving the users, but how?

Consider the user segments - prioritize



Consider available methods and availability of users

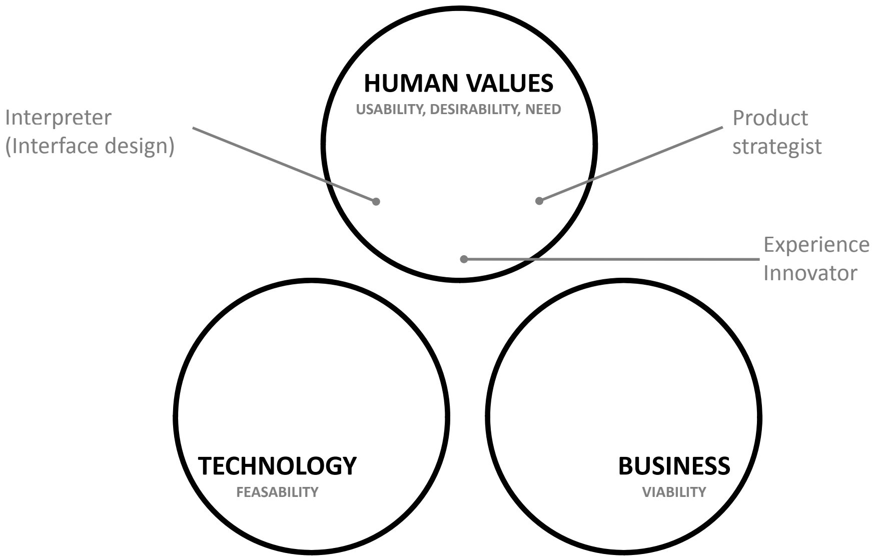



r timing (early input can save time and money!)
Assume and ask
Structure and priorities
• Objectives
• Requirements
Understand
Concep
Build
• Product
• Marketing
• Sales
Rapid prototyping
Observations
Validate
User tests


And what is really the designer's role in all of this?

The role of the designer

The role of the designer



Ambitions for the user interface

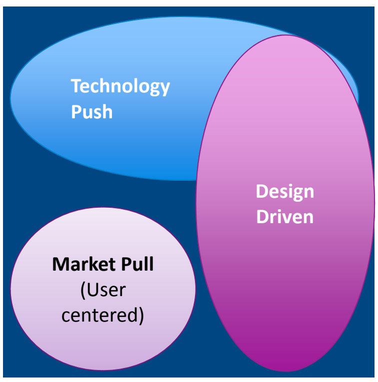
Meet requirements	Facilitate & interprate
Make a good user interface	Understand users' real needs
Strengthen the brand	Understand design values
Explore opportunities and innovate	Understand business

Innovation is not user driven

Technology

Radical Improvement

Incremental Improvement



Incremental Change

Radical Change

Meaning

Illustration: Roberto Vergantini

What happened to the design values?

A brand is build by design values

Design values are deeply rooted in both **communication** (marketing) and **user experience**

Convinced users may build a stronger brand and boost **reliability**

User appeal does not necessarily disrupt efficient communication

High performance HMI

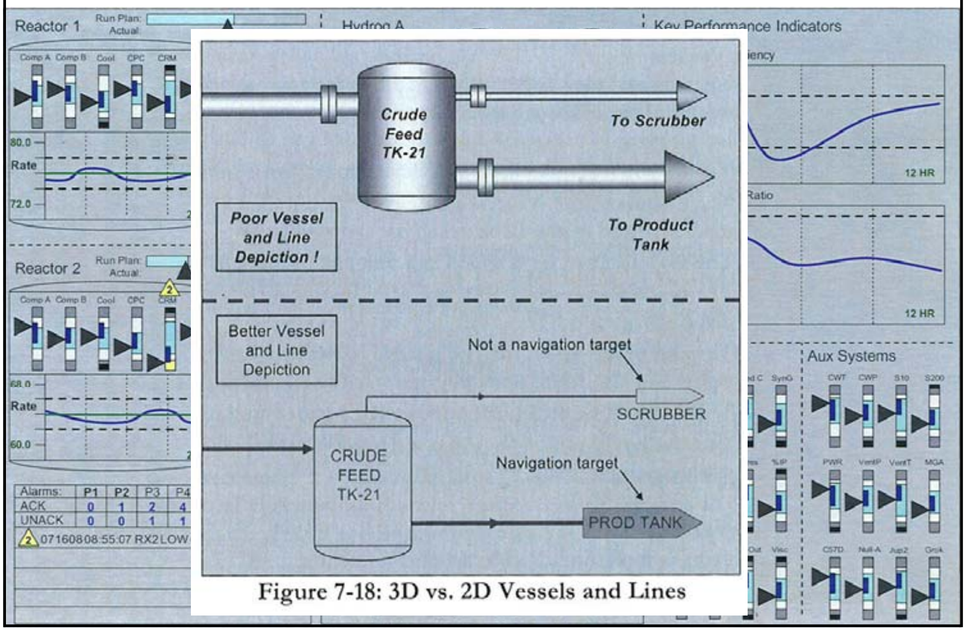
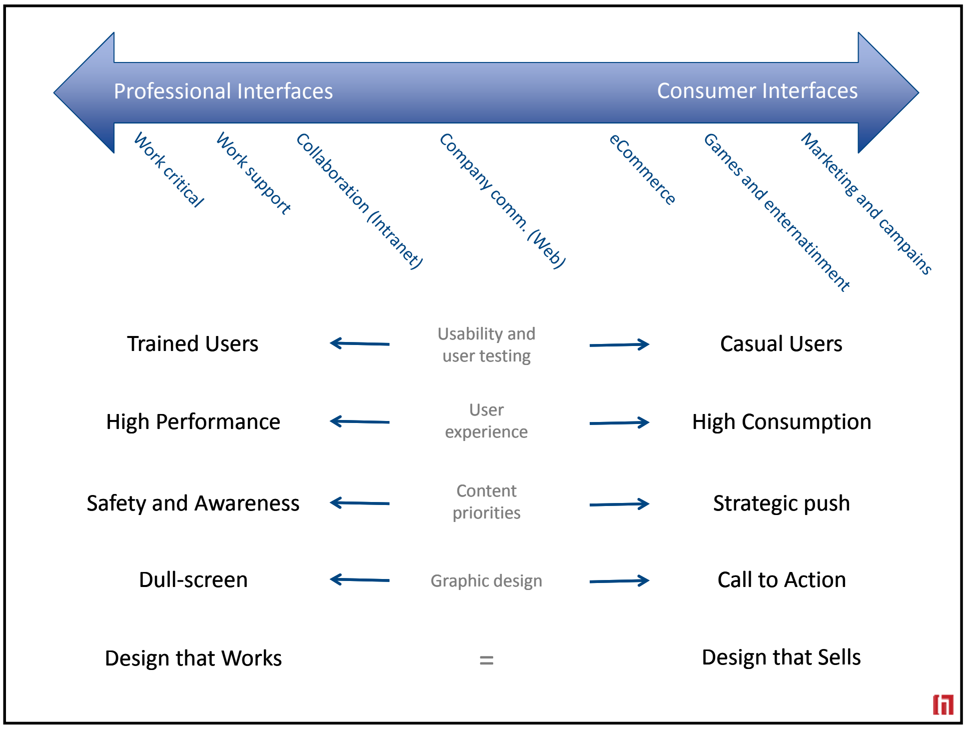
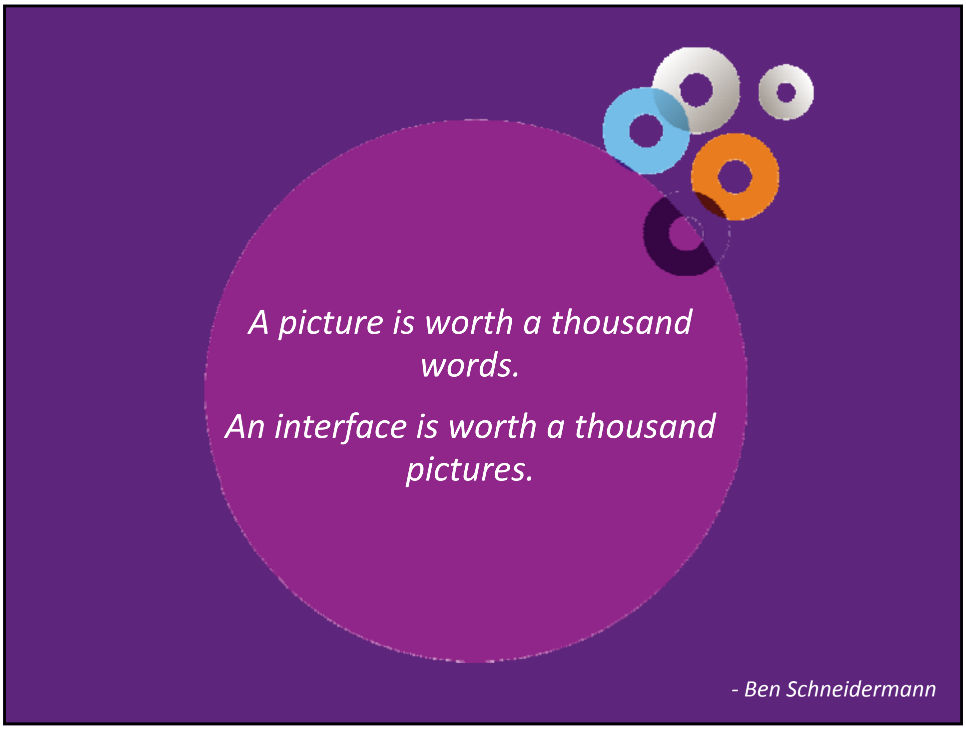


Figure 7-18: 3D vs. 2D Vessels and Lines



Professional Interfaces
Consumer Interfaces
Work critical
Work support
Collaboration (Intranet)
Company comm. (Web)
eCommerce
Games and enternatinment
Marketing and campains
Trained Users
Usability and user testing
Casual Users
High Performance
User experience
High Consumption
Safety and Awareness
Content priorities
Strategic push
Dull-screen
Graphic design
Call to Action
Design that Works
=
Design that Sells



A picture is worth a thousand words.
An interface is worth a thousand pictures.
- Ben Schneidermann


HALOGEN
Paal Holter
Lead Designer
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linkedin.com/paalholter
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Designing successful touch interfaces

Paal Holter – www.halogen.no - August 18th 2009

After years of experience with interaction design, I have become well acquainted with usability principles that apply to traditional desktop applications and web interfaces. However, the majority of these principles and design patterns are prepared for cursor interaction, using an indirect pointing device such as a mouse or touchpad.

When the user operates directly on the interface with the fingers, new opportunities, limitations, and principles apply. In this article, I will discuss the additional usability aspects that I have gained practical experience with throughout my most recent work with touch screen interfaces.

A little history

Touch screens have already been used for decades, as they were invented as early as 1971. However, for a long time their applications have been mainly limited to information kiosks, point-of-sale systems, and ATMs. Neither of these succeeded in promoting the real benefits and potential of the technology, and they failed to provide the reliability needed to achieve over-all user satisfaction.

Even though the PDAs with its stylus-based touch gained some popularity during the 90s, it is not until recently we have seen more sophisticated high-scale use of the technology. Commercialization of multi-touch technology is one of several factors that have changed the role of the touch interfaces.

One must inevitably mention Apple's iPhone when discussing the availability of touch screen interfaces and the market maturity. The technology was perhaps not revolutionary for its time, but Apple made a gigantic leap when converting the opportunities into one of the most successful electronic consumer products in history. This product alone has created a change in general users' expectations and faith in the technology.

Simultaneously, touch interfaces have gained popularity in professional industries where keyboard and mouse systems are not satisfactory.

Going for touch

The touch screen has two main attributes as an input device: First, it enables the user to interact with what is displayed directly on the screen, where it is displayed. Secondly, it lets one do so without requiring any intermediate device, such as a mouse or touchpad.

Obviously, this has many benefits. Primarily, it is a mental simplification to the user, as the attention to input and output may be focused to one device only. Touch displays is also a space saving solution that facilitates cleaner surfaces and a more flexible form of interaction close to the action.

Touch technology has come to represent a modern and high-tech form of interaction. Some products include this quality for the sole purpose of being up-to-date with market expectations. If the users' needs are neglected for the sake of sales attractiveness, we have what is called "The wow-trap". There are some characteristics that should be considered before making the final decision of using touch screen as the only input device:

1. Interaction intensity

   If high interaction activity over a certain period of time is required, touch screens are normally not appropriate. The main reasons are the amount of ergonomic restraints and the lack of input efficiency. This especially applies for applications that require heavy input of text and numbers. Hand-held devices are possible exceptions here, because of the special ergonomic availability of the interface.
2. Accuracy

   Reconsider using a touch screen if high input accuracy is required. This is both because of the size of the finger, and the lack of fine-motor skills when holding up our hand. Again, there might be exceptions, especially if a stylus may be used.
3. Blind operation

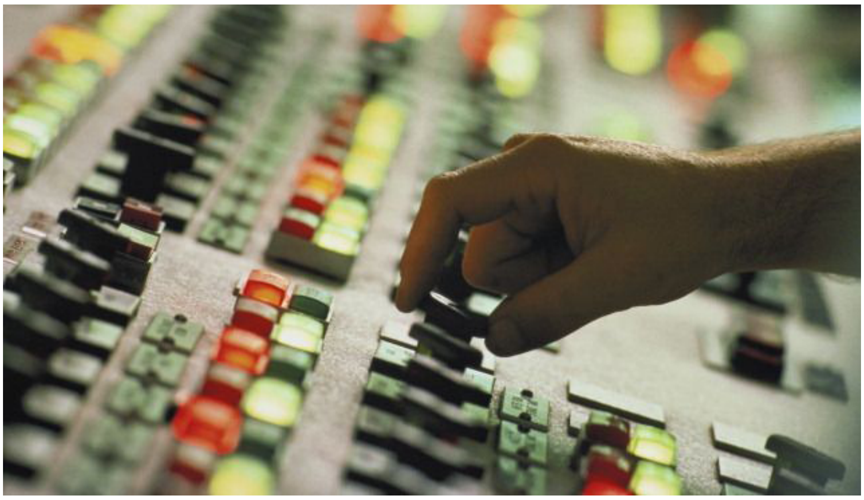
   If the user needs to operate partly or fully without looking at the interface, the tactility of physical buttons and switches is highly preferable. Because a touch interface always has multiple points of interaction within one smooth surface, it requires frequent eye contact.
4. One-handed operation

   Hand-held units that require one-handed operation, such as cellular phones and remote controls, are poor candidates for the touch interface. Notice that the popular iPhone is rarely operated with one hand only.

Most of the usability principles we are familiar with from conventional interfaces still apply for touch interfaces. However, since the mouse, buttons, and keyboards are not available, it is crucial to adapt the interface to a set of new restraints. The next sections include tips for designing successful touch interfaces.

Tips for compensating the lack of haptic response

Physical buttons and switches are available to explore with your fingers without activating. Also, most instruments are equipped with clear feedback for activation, such as press and release of a button. This provides the user with a safe and intuitive understanding of the presence of and response from the points of interaction.



Buttons have the advantage of physical presence

One of the greatest downsides of touch interfaces is the lack of haptic response. There are some ways to compensate for this, mainly by applying other means of feedback. However, be aware that many users still might find the touch screen too volatile to trust.

1. Clear visual communication
Graphic effects should be applied to provide predictability and feedback. Be clear in all stages of each interaction event:

a) **Before:** Clickable elements should look clickable. Remember good labeling to increase predictability. Icons should be limited to the most obvious, since tool-tip is not available without a cursor.
b) **On click:** Communicate *clearly* which button is being pressed. Use graphical effects, such as border, color, size and shape.
c) **Avoiding click:** If possible, allow the user to avoid the click by sliding finger away from the button before release.
d) **On release:** It is still standard to execute actions on release rather than on click
e) **After release:** Provide the user with feedback on what is executed. If no other visual reaction occurs (such as opening a new page, or flap), consider applying temporary flash or alternative graphics on the clicked element.
f) **Processing:** If the function takes more than a couple of seconds to execute, communicate the ongoing process.
g) **General state:** Compared to physical buttons, touch buttons have a rich opportunity to communicate its states, such as on, off, value, or error. However, avoid too many abstract symbols, as this will only confuse the user.

2. Consider audio feedback
To enhance the feedback, consider applying audio effects. It is more common to apply sound on click rather than on release.

Also, sound can be used for numerous other feedback scenarios, such as error or completed sequence.

Be aware that sound effects may be annoying to the user or people nearby. For personalized interfaces, it would be a good idea to provide audio settings.

Using the right kind of sound for the varying kind of feedback is an entire field of study. This might seem as a small thing, but can have a significant effect on the total user experience.

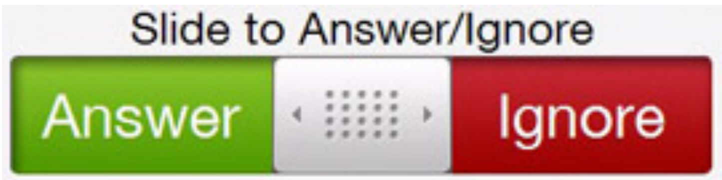
3. Consider mechanical feedback
Today, mechanical feedback is most relevant for handheld units, in form of vibration. This is particularly useful when audio is out of the question, and when it is important to catch the user's attention.

4. Prevent unintended activation
Unintended clicks are more common with touch screens than with physical buttons, since there is no mechanical resistance to the touch. There are two major approaches to avoid unintended activation:

a) **Avoid single-click access to crucial or un-undoable commands:** If a command is crucial or un-undoable, consider replacing single-click access with other forms of alternatives, such as combination clicks, click-and-hold or slide-functions
b) **Use confirmation dialogs:** If a command is crucial or un-undoable, consider introducing a confirmation dialog giving the user a chance to regret.

5. Consider alternatives to multi-click
The standard double click does not translate terribly well to touch screens. This is because the feedback from the interface is less obvious than from physical buttons.

Again, you can consider replacing this by combination clicks, click-and-hold or slide-functions.



Slide button from HTC Touch Diamond

Tips to survive without a cursor

Many usability conventions are linked to the presence of the cursor on the screen–which brings me to the first tip: Please remember to turn the cursor off.

The user should focus on the screen, rather than the cursor, which merely represents the position of the last interaction.

No cursor please

Eliminating the cursor, however, has several consequences for the user.

1. Communicate touch
Users should recognize that the interface is touch-sensitive by the appearance. Typically, tactile 3d-effects are used to simulate physical controls.

2. Indicate points of interaction
Cursors may occasionally change to other symbols to indicate available interaction related to the context. For example, it changes to a finger to indicate a clickable link, or a side-to-side arrow to indicate resizing opportunities.

In a touch interface, all forms of interaction should be clearly indicated with ever-present graphics, since any similar cursor related feature is inapplicable.

3. Labels must talk without tool-tip
The little tool-tip and info-tip most users are familiar with are not available, since they are related to the cursor position. Consequently, icons and abbreviated labels should be limited to the most obvious.

However, tool-tip or info-tip can still be applied for touches on non-operational items. This can for example be useful on disabled buttons. Remember then to place the tool tip container above the touch position, rather than the conventional position at the lower right corner that most probably will be covered by the hand.

4. Mouse-move events may be too complex
Depending on touch technology, certain mouse-move events might not be applicable, such as drag-and-drop, resizing, and multiple selections.

Depending on the level of training one can expect from the users, you could consider using multi-touch features to perform similar actions with touch. However, in some cases it might be better to walk around the challenge with simple point-and-click interaction.

5. Indication of processing state
The cursor is occasionally used to indicate that a task is being processed or that the system is busy. There are three approaches to replace this feature:

a) If there is a button representing the on-going process, indicate the processing state with a symbol or effect directly on this button.
b) Display a status area on the screen that may indicate an on-going process (along with other things).
c) Use a message box to communicate that a task is being processed. However, since dialog boxes interrupt the user, this is best applied when the processing task is modal (no other tasks can be performed while waiting).

Tips to prepare for the sausage finger

"Sausage finger" is a term used to illustrate the phenomenon where a bulky finger meets a hard surface to make a pinpoint selection. Unless you are designing for a niche market with highly specialized users, you have to consider the users with the most rugged finger anatomy. Normally, you should avoid hit-areas smaller than 2x2cm. Obviously, this greatly affects the design of your interface, compared to the world of the more accurate cursor.

1. Design big buttons

The bigger the buttons, the better. 2x2cm (3/4") is generally considered the minimum size for comfortable operation. However, this depends on the several factors, such as size of screen, calibration accuracy, ergonomic working-position, and the skills and finger anatomy of the user.

If the space is critical, consider decreasing the size of the buttons where a mis-hit has the least consequence.

Also, you can consider decreasing the size of the buttons along the screen edge. There, the user probably has the best ergonomic support for interaction (depending on the surrounding hardware).

2. Illustrate the hit areas

When considering the required precision, it is not really the graphical size of the buttons that matters, but rather the defined hit-areas. Theoretically, a button could look small graphically, but still be defined to be activated within a bigger area one the screen.

However, to increase the predictability of the interface, the graphics should coincide rather precisely with the hit areas. This is especially important when the points of interaction are relatively close to each other.

Radio buttons and check buttons are examples of interactive elements that one might be tempted to display conventionally, compensating the accuracy challenge by increasing the hit area. As suggested though, these should rather be drawn as part of a button or with clearly marked frames to illustrate the hit areas.

3. Include space
In a space critical interface, it might be necessary to stack some buttons closely. However, it is recommended to include a minimum space of 3mm (1/8") between the buttons – both graphically and in the defined hit areas. This visual and actual gap decreases the chances of mistakes.

4. Avoid high-precision interaction
Small hit-areas and high-precision movements are demanding. If you cannot avoid it, you should consider magnifying parts of the display according to context.

Tips for overcoming visual hand obstructions

Another challenge with touch screens is that your finger and hand will cover an area of the screen when interacting. This can feel disruptive to the user, and even lead to mistakes.

1. Design increased or displaced feedback area
When a button is clicked, the finger will necessarily cover this button. One approach is to temporarily increase the size of the button, or displace it so that it appears over or next to the finger. This will provide the user with a clear and visual feedback of the selected element. (See illustration below.)

2. Place labels on top of or over the buttons
If the label is placed in the center of the button, or even below the button, the hand will most probably cover it during interaction. Chances are greater that the label stays visible, if it is on top of or over the button. This is particularly relevant if the buttons are big enough to avoid the increased or displaced feedback area.

3. Use time-delay on feedback
If neither of the above is applicable, consider using a time-delay on the button feedback. Then at least, after retrieving the hand, the user will have their operation confirmed.

4. Place buttons along the screen edge
A benefit of interacting along the screen edge is to obstruct as little area as possible. This is most effective along the bottom edge and right edge of the screen for right-handed users.

The iPhone uses a displaced feedback area to overcome obstruction by finger

Keeping the user on the right track

The touch display is a wonderfully flexible interface. In fact, since context adaptations and variations are so available, one might easily get carried away as a designer. Here are a few pitfalls to be aware of.

1. Don't get too creative

Point and click is the simplest form of interaction available for a touch screen. As a starting point, use that unless there is a good reason to do anything else.

Remember that even though slide-functions, multi-finger action, twists and so forth might seem fancy from the designer's, implementer's and salesman's point of view, the user might not be quite so convinced.

Limit the number of non-intuitive gestures and interactions to a minimum, and use them as effective shorthand interactions rather than the only way to perform an operation

2. Limit the number of choices

Hick's law should be familiar to most people working with interaction usability. It indicates how user efficiency drops with the number of available choices. However, since also space is critical for most touch interfaces, this now has a double purpose.

If possible, present the most probable options or defaults on the interface, and hide everything else behind a "more"-button or something similar.

3. Be consistent

As touch interfaces still is a new technology for mass-market products, conventions are in the forming phase. This makes it even more critical to be consistent in the use of interactions and gestures to make the system intuitive and perform predictable functions.

4. Handle the keyhole-effect
Considering the big size of the controls, you might easily end up in a situation where the users can see only a small part of the interface at a time. If the content structure is very wide or deep, you risk losing the user along the way.

Here are some tips to provide users with a sense of overview:

a) Keep some kind of top-level menu or access point universally present, at least an escape or home function.
b) Use tabs to provide multiple surfaces with universally present entry points. This is a well-tested concept that most users easily relate to.
c) Keep navigation buttons (such as back-button, home-button or flaps) visually distinct from task buttons. This will guide the user and increase predictability
d) Avoid scrolling of the full interface
e) Avoid multiple windows. The interface will probably be too crowded, and windows may easily be hidden behind each other.

5. Input of text and numbers
A full alphanumerical keypad would occupy much space on a touch interface. When text or number input is only occasionally required, it is natural to hide the keypad.

a) Consider providing the users with default choices, incremental increase/decrease buttons, or value slide-bars to limit the need for a keypad
b) Automatically show the keypad only when the user is in an input context
c) Make the keypad available with a universal access point

Remember that if the system requires frequent input of text or numbers, the touch interface might not be the best solution altogether.

6. Mixing operation with display
If the touch interface is used in combination with other output displays, be aware that the user will have to shift attention between different displays.

In that scenario, the user might want to relate to the touch interface as a pure input control panel. If feedback information is available at two or more locations, the mental model of the system will be more complex to the user.

7. Left handed users
With the flexibility of touch interfaces, you may accommodate for left-handed users. If relevant, be aware that mirroring the screen contents entirely might not be the best approach. Consider relocating blocks of functionality.

Tips for fighting the gorilla arm

Humans are not built to making small and precise motions while holding their arms up. A side effect of vertically oriented touch screens is that, after a while, it will cause fatigue. This phenomenon is called "Gorilla arm", and has received most of the blame for stopping the technology from becoming mainstream, despite a promising start in the 1980's. This was not a problem for specialist short-term-use devices, such as ATMs, since they only involve brief interactions, which are not long enough to cause gorilla arm.

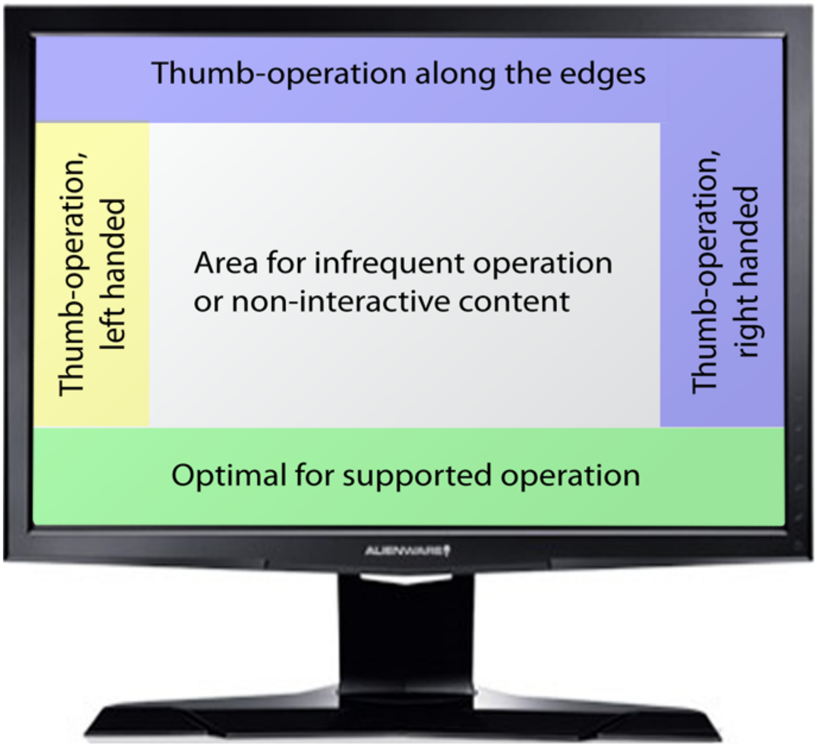
Today, we see new optimism for touch screens, partly because of the technological advances. With the resistive technology of the 80's, the user had to press with a certain force to get response from the screen, but today the response is greatly improved. However, it is still important to consider the challenges of the gorilla arm, and design to prevent it.

1. Accommodate support for arm and wrist
If possible, accommodate a physical support for the arm and wrist to rest during interaction. This is easiest to achieve for interaction along the bottom edge of the screen.

2. Be aware of the screen edges
The screen edges may be used as a natural hand support when interacting. By holding on to the edge, with four fingers, the user can use the thumb to operate (see illustrated layout approach below). This is off course less relevant, if the screen is integrated in a surrounding construction, leaving the edge unavailable.

3. Think about where you place frequently used functions
The most frequently used functions should be placed where the user has available ergonomic support. This also applies for functions that require precision.

4. Accommodate sequential functions
If the use pattern is partly or fully predictable, the functions that are operated in sequence should be placed close to each other. This is to minimize the need for movement during interaction. Off course, this applies to all interfaces, but becomes increasingly important for touch screen.



A suggested layout approach to accommodate comfortable and efficient operation, and avoid gorilla arm

Tips for fighting fingerprints and dirt

Touching a TV screen with your finger is a quick way to lose popularity. Unless using gloves or a stylus, it is inevitable to leave fingerprints, dirt or even scratches on a touch screen. Depending on the type of screen and graphics, this might create severe visual disturbance. Fortunately, there are some methods to fight this problem.

Fingerprints, dust and scratches are easily visible on dark backgrounds

1. Can you affect the choice of hardware?

The fingerprint problem can be mitigated by the use of materials with optical coatings designed to reduce the visible effects of fingerprint oils.

2. Be aware of the background graphics
Fingerprints are generally far more visible on dark backgrounds than bright backgrounds. Black is the color that is most sensitive to both fingerprints and dirt – especially in environments with strong light reflections from windows or lamps.

All visual interruptions are also more visible on clear backgrounds, compared with patterned backgrounds. However, patterned backgrounds may increase the general feeling of complexity.

3. Separate interactive elements from displayed information
The fingerprints will naturally be clustered around the points of interaction. If the interactive screen elements are placed within a fixed area of the screen, you might at least avoid prints and dirt on the area reserved for information and non-interactive content

4. Accommodate screen cleaning
Offer a "screen lock" to freeze all interaction during cleaning. This will provide the user an opportunity to clean the screen occasionally, without causing unintended operation.

Unlocking must be very available to avoid obstruction of operation.

Stay in touch

From the designer's point of view, the technology itself is not really interesting – it is *what you can do with it* that matters. There are about ten available technologies that are used to recognize a user's touch on the screen, of which the three most popular systems are; (1) Resistive, (2) Capacitive and (3) Surface acoustic wave. This is an overview of the most user-relevant qualities of these technologies:

	(1) Resistive	(2) Capacitive	(3) Surface acoustic wave
Price	Cheapest.	More expensive, but will be cost-competitive within 2-3 years.	Most expensive.
Durability	Easily damaged by sharp objects. May be worn out. Not easy to clean.	Harder to wear out, but prohibited on large scale when moisture is present.	Condensations may cause false touches and obstructions on the screen. Inappropriate for use outdoors.
Stimuli	Reacts to everything.	Requires conductive	React to almost

		input (finger).	everything (except hard, small object, such as pen tip).
Points of touch	Single-touch only.	Allows multi-touch.	Allows multi-touch.
Calibration	Requires calibration.	Self-calibrating.	
Clarity of picture	Transmits 75% of the light.	Transmits 90% of the light.	Transmits 100% of the light.
Example of use	PDA, Point-of-sale, ATM (predicted to be less used in the future).	iPhone, kitchen appliances (predicted to be most popular in the future).	Predicted to take over for resistive where gloves or stylus might be used, such as information kiosks and hospital environments.

Also, force-based touch panels have been developed, enabling the system to measure how hard the user is pressing against the interface. If pressure-sensitivity is more developed in the coming years, it may have a big effect on the user experience of touch interfaces, as it will add another input dimension and also partly compensate for the lack of haptic response.

In addition to this, we can expect to see a number of other technological advances that will have an impact on the use of touch screens in the decades to come. This includes response speed, screen reflection qualities, multi-user surfaces and biometric readers (such as recognition of finger print on the display).

With the steeply developing technology, several new interaction conventions are in the process of being established. There are well tested concepts such as the two-finger zoom and rotate. And there are interesting but not-so-well tested concepts such as rubbing, tapping, multi-finger wipes for zooming, scrolling, and short cut accessing. Undoubtedly, there will be even more exciting gestures to play with as other technical advances become more available.

Interactive table-top from Microsoft Surface

Certainly, the future of touch interfaces looks more promising than ever. Small and big touch surfaces will become ubiquitous as they starting popping up all around us – a natural part of our surroundings. It is inspiring to think about the influential and exciting role of the interaction designers while approaching this future. However, this also requires a certain level of responsibility.

To design a successful interface, remember that even small design features can be the party killers: The Devil is in the details!

Fortunately however, God is in the details too. Make sure that all levels of the interface is prepared to make life easier for the users, and you will hopefully achieve the happy and loyal customers we all are craving for.

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HFC

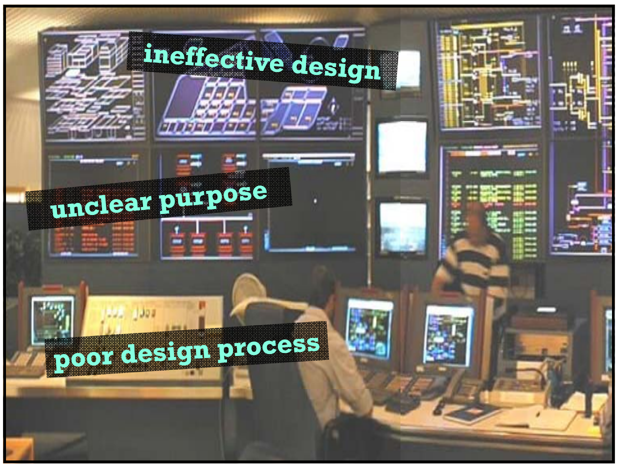
Workshop - Fordeler og ulemper med storskjerm

Innleder Ø.Veland/A.Bye

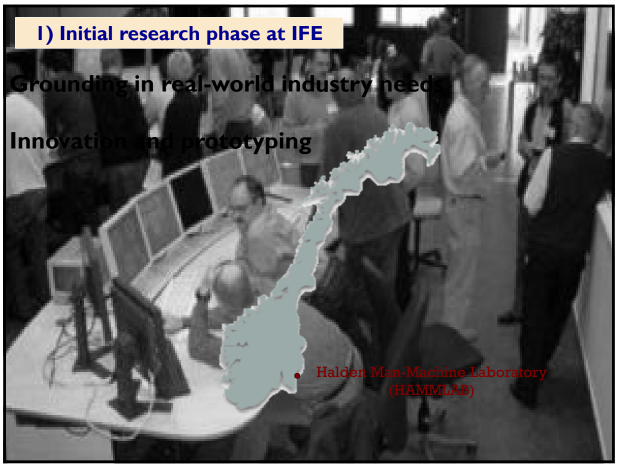
Large screen displays

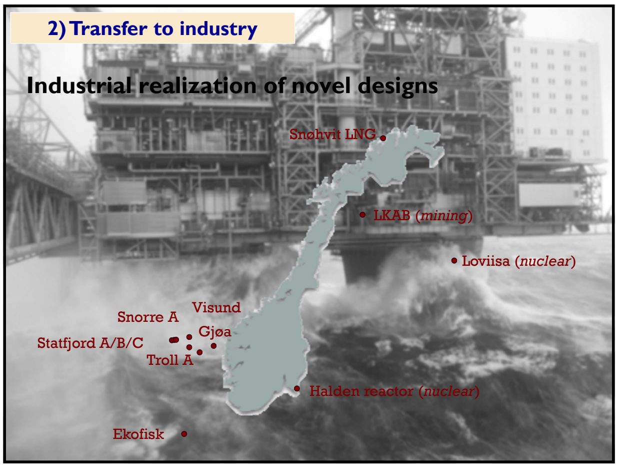
Øystein Veland

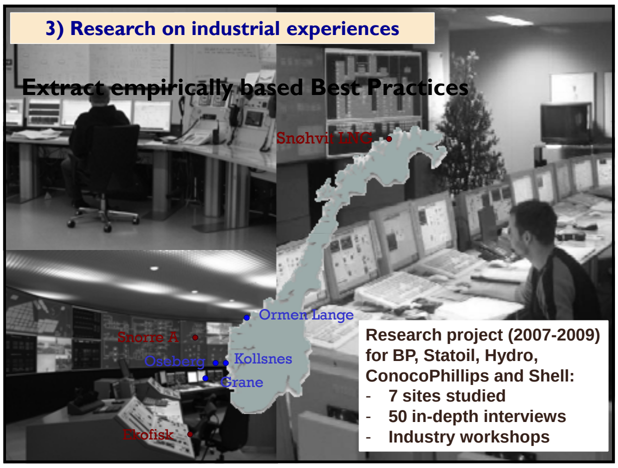
Presenter: Andreas Bye
Institute for Energy Technology (IFE)
Halden/Bergen, Norway



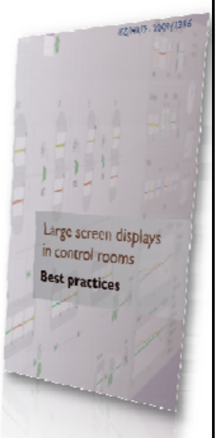
1) Initial research phase at IFE







55 design patterns for large screens in control rooms



Empirical grounding:

- Detailed operational experiences
- Design reflection

Best practice as 55 Design Patterns

Example: Design pattern 39

39 Signal layer

Context

Use this to implement *Dull screen colours (35)* and effective presentation of *Integrated alarms (53)*.

Problem

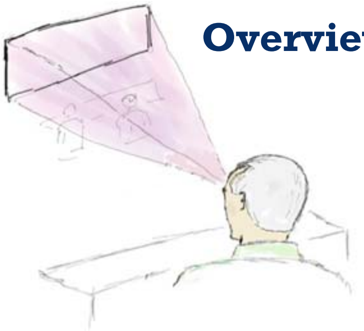
Alarms and other abnormal states may easily be missed or overlooked among all the information that competes for the operator's attention in a complex overview display.

It may be tempting to use strong contrast and saturated colours on many objects to make everything appear as bright and clear as possible. However, it is the really important and urgent objects like alarm that should be easiest to spot. Using alarm-like colours for all other purposes seriously undermines the ability of alarms to grab the viewer's attention.

Solution strategy

Use powerful signal effects only to indicate alarms and other abnormal states

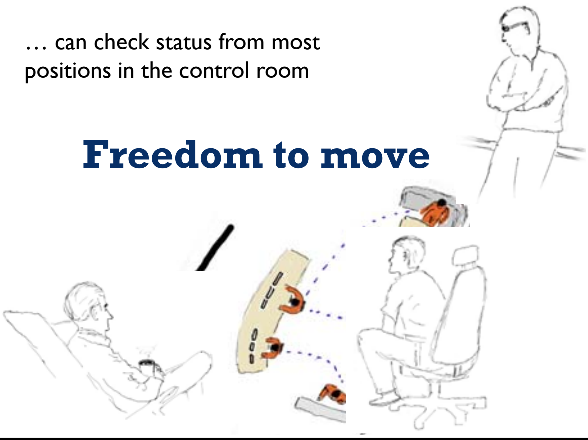
Overview on entry

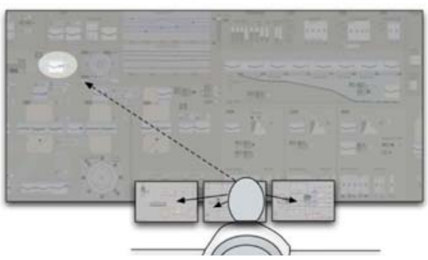


- entering personnel can quickly see current status

… can check status from most positions in the control room

Freedom to move

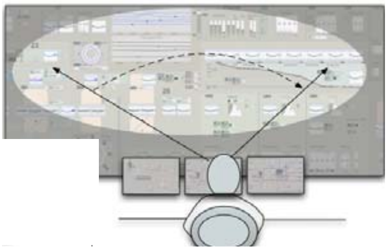




Details at-a-glance

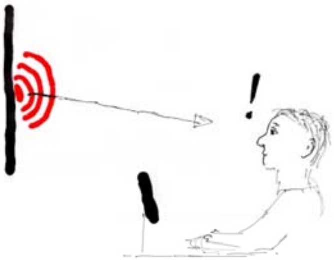
… data may be inspected instantly in parallel with other tasks

Overview at-a-glance



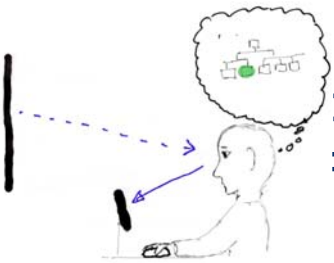
Picking up a comprehensive status in a brief sweep

Attract attention



… to important events and deviations

Point to next action

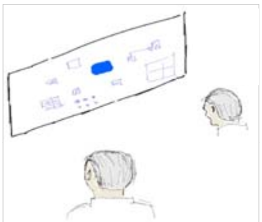


… by providing sufficient detail
to differentiate responses

Serve external requests

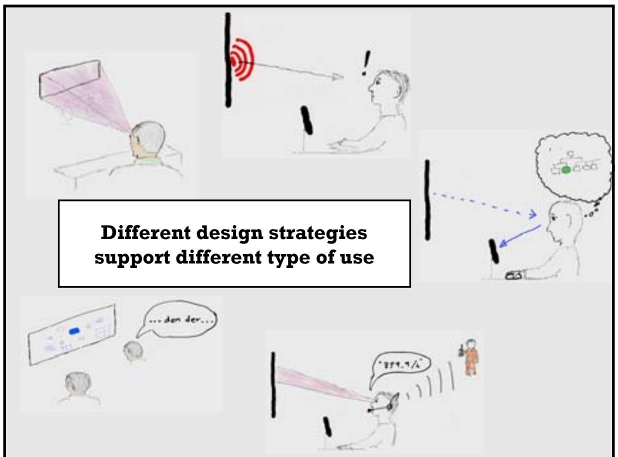
... without disturbing
ongoing tasks too much

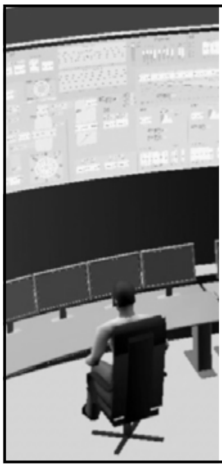
Support collaboration



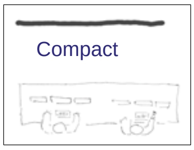
"Silent collaboration"

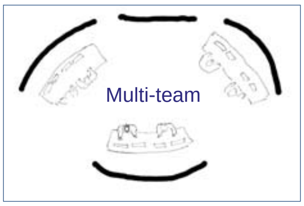
Initiate and facilitate discussi



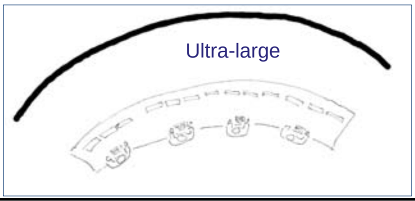


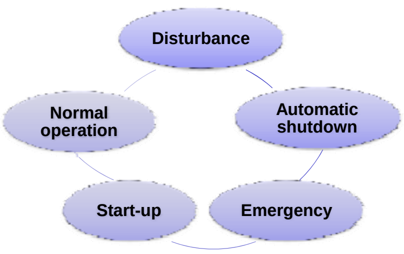
An effective large screen requires a fixed layout and carefully selected and designed information





Configurations in different control rooms

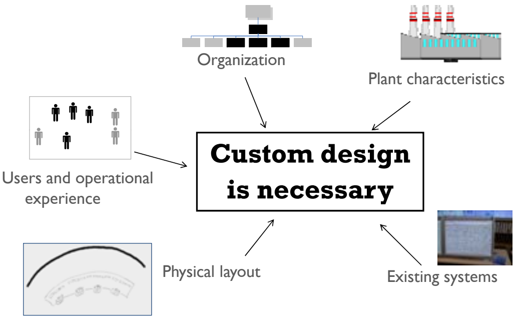




Each operational mode has different information and presentation needs

- Two very different solutions can both be "right"

Every control room presents unique constraints to a large screen solution

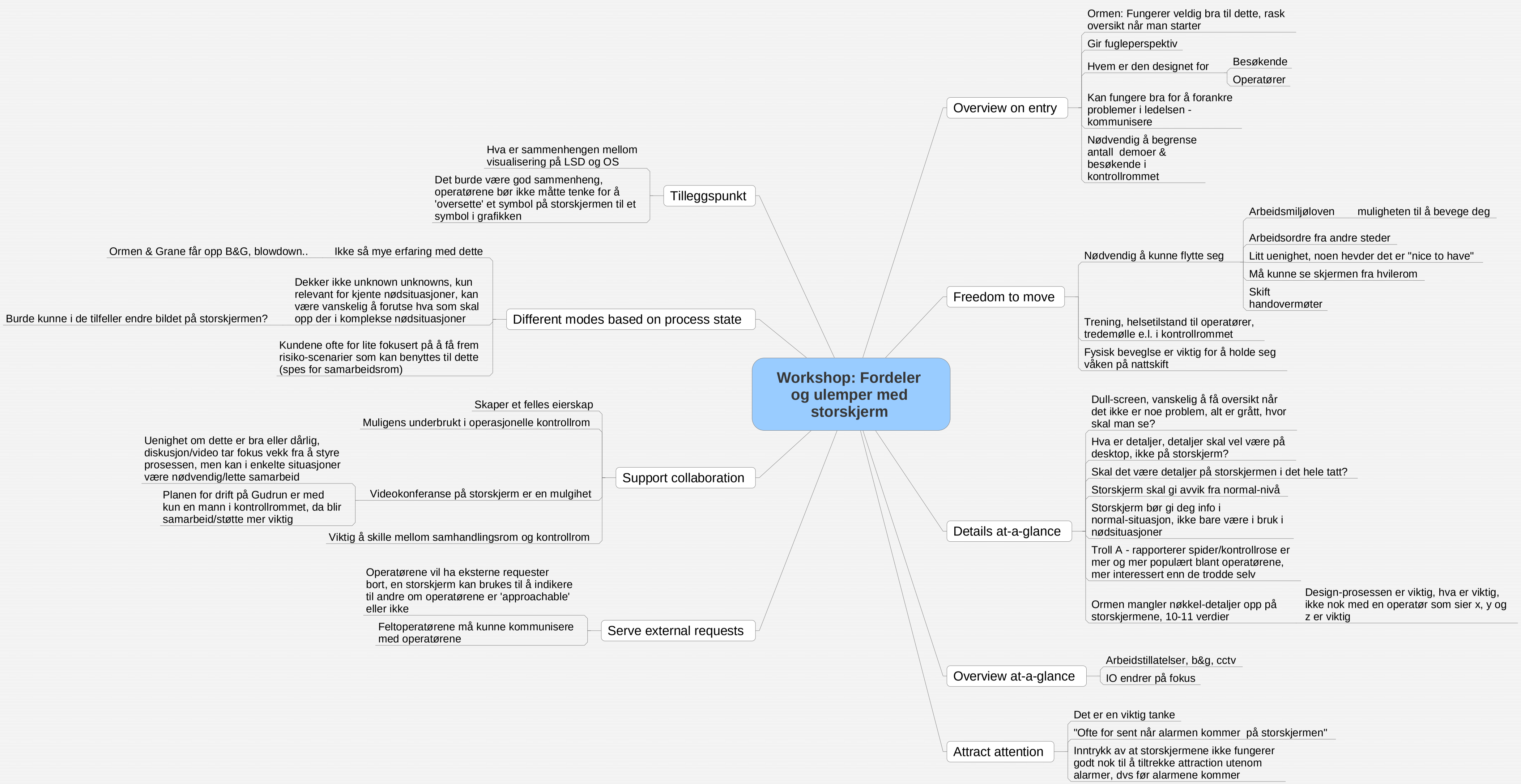


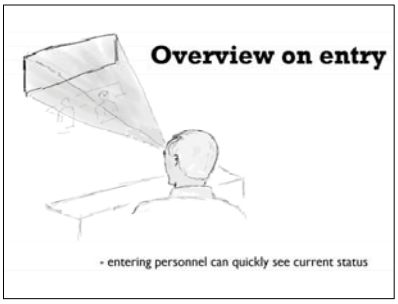
Thoughts on future development in this area

Alternative 1: Standardized *solutions?*
- *Meaningless since there are no "standard problems"*

Alternative 1: Standardized *methods?*
- *No empirical basis for this*

Alternative 3: Competent local design processes
- Large screens requires custom design
- Using specialized, flexible product and process competence


Workshop: Fordeler og ulemper med storskjerm
Overview on entry
Ormen: Fungerer veldig bra til dette, rask oversikt når man starter
Gir fugleperspektiv
Hvem er den designet for
Besøkende
Operatører
Kan fungere bra for å forankre problemer i ledelsen - kommunisere
Nødvendig å begrense antall demoer & besøkende i kontrollrommet
Freedom to move
Nødvendig å kunne flytte seg
Arbeidsmiljøloven
muligheten til å bevege deg
Arbeidsordre fra andre steder
Litt uenighet, noen hevder det er "nice to have"
Må kunne se skjermen fra hvilerom
Skift handovermøter
Trening, helsetilstand til operatører, tredemølle e.l. i kontrollrommet
Fysisk bevegelse er viktig for å holde seg våken på nattskift
Details at-a-glance
Dull-screen, vanskelig å få oversikt når det ikke er noe problem, alt er grått, hvor skal man se?
Hva er detaljer, detaljer skal vel være på desktop, ikke på storskjerm?
Skal det være detaljer på storskjermen i det hele tatt?
Storskjerm skal gi avvik fra normal-nivå
Storskjerm bør gi deg info i normal-situasjon, ikke bare være i bruk i nødsituasjoner
Troll A - rapporterer spider/kontrollrose er mer og mer populært blant operatørene, mer interessert enn de trodde selv
Ormen mangler nøkkel-detaljer opp på storskjermene, 10-11 verdier
Design-prosessen er viktig, hva er viktig, ikke nok med en operatør som sier x, y og z er viktig
Overview at-a-glance
Arbeidstillatelser, b&g, cctv
IO endrer på fokus
Attract attention
Det er en viktig tanke
"Ofte for sent når alarmen kommer på storskjermen"
Inntrykk av at storskjermene ikke fungerer godt nok til å tiltrekke attraction utenom alarmer, dvs før alarmene kommer
Tilleggspunkt
Hva er sammenhengen mellom visualisering på LSD og OS
Det burde være god sammenheng, operatørene bør ikke måtte tenke for å 'oversette' et symbol på storskjermen til et symbol i grafikken
Different modes based on process state
Ikke så mye erfaring med dette
Ormen & Grane får opp B&G, blowdown..
Dekker ikke unknown unknowns, kun relevant for kjente nødsituasjoner, kan være vanskelig å forutse hva som skal opp der i komplekse nødsituasjoner
Burde kunne i de tilfeller endre bildet på storskjermen?
Kundene ofte for lite fokusert på å få frem risiko-scenarier som kan benyttes til dette (spes for samarbeidsrom)
Support collaboration
Skaper et felles eierskap
Muligens underbrukt i operasjonelle kontrollrom
Videokonferanse på storskjerm er en mulgihet
Uenighet om dette er bra eller dårlig, diskusjon/video tar fokus vekk fra å styre prosessen, men kan i enkelte situasjoner være nødvendig/lette samarbeid
Planen for drift på Gudrun er med kun en mann i kontrollrommet, da blir samarbeid/støtte mer viktig
Viktig å skille mellom samhandlingsrom og kontrollrom
Serve external requests
Operatørene vil ha eksterne requester bort, en storskjerm kan brukes til å indikere til andre om operatørene er 'approachable' eller ikke
Feltoperatørene må kunne kommunisere med operatørene



Hvorfor trenger vi storskjerm (?) ble et viktig diskusjonstema i gruppen. Problemstillingen ble diskutert ut fra PLASSERING, BRUKERE og FUNKSJONELLE BEHOV.

PLASSERING: Storskjerm er ikke bare i kontrollrommet, men kan også være andre steder.

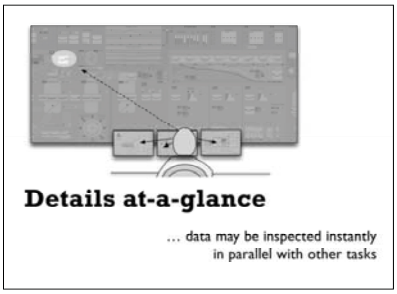
BRUKERE: Hvem er brukerne – det er ikke bare kontrollromsoperatørene, andre brukergrupper kan også være aktuelle, f.eks uteoperatører.

FUNKSJONELLE BEHOV: ”Common situational awareness” er det viktige bidraget fra en storskjerm. Kan være å gi oversikt over ansvarsforhold, ”status ” når en kommer inn i rommet.

Dessuten kan storskjerm brukes ifbm uønskede hendelser for å forbedre sikkerheten.

En del spørsmål fra gruppen var: Blir storskjermen reelt brukt – og om den blir brukt – hva brukes den til da? -Brukes storskjerm for å imponere? – Er bruk av storskjerm teknologidrevet eller er storskjerm drevet frem av ”Context” og brukerbehov? Hva er ”designbasis” / ”designprinsipper” for storskjerm?

Storskjermene må støtte arbeidsprosessen – designprosessen er derfor viktig for å få frem behovene og løsningene.



Ved utforming av storskjerm må man tenke på ”forenkling” vs ”ikke forenkling”. Både ”Details at a glance” og ”overview at a glance” bør kunne støttes.

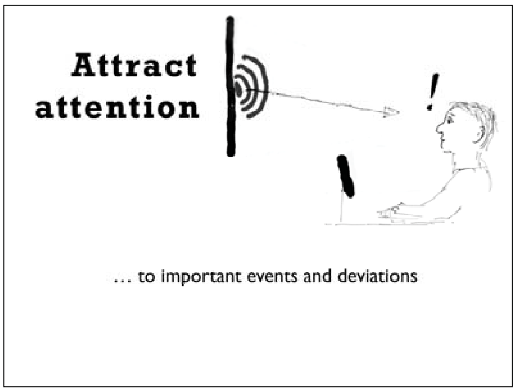
Visuell gruppering av data kan forbedre situasjonsforståelsen.

Hos JBV er det en storskjerm som viser hele banenettet – operatørene kan da identifisere ”sin” del og grensesnitt ut fra storskjermen.

Mange svaner ”mimikken” som kan gi en oversikt over prosess-sammenhengene.

Skal storskjerm bidra til å gi oversikt eller detaljer eller begge deler?

Navigasjonsproblemer kan avløses via storskjerm – dvs storskjerm kan fortelle hvor ting skjer. (ABB har et konsept med interaktiv storskjerm som kan være nyttig å utforske)..



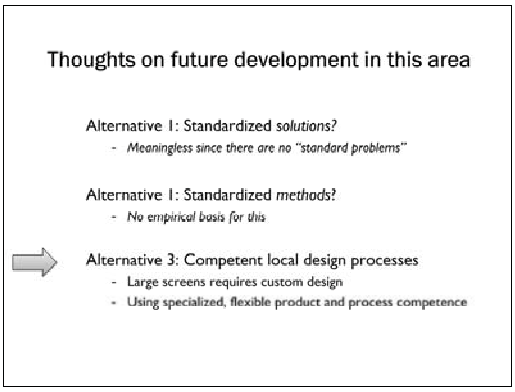
Hvordan skal storskjermen tiltrekke seg oppmerksomhet? Er det med støtte av alarmer, med bruk av farger, med bruk av symboler?

Brukes alarmer på forskjellige nivåer - for å gi informasjon eller for å gi status - hvilke retningslinjer benyttes?

Dersom symboler benyttes – hvilke sett av symboler benyttes?

Dersom farger brukes, hva er designstandarder for fargebruk? (Er det for eksempel konsistent bruk av rød vs grønn fargebruk på ventiler?) Farger brukes for å kunne påvirke brukerne – og hvordan gjøres det på beste måte?

Storskjerm kan bidra til at du retter inn oppmerksomheten mot ”nøkkelområder”. ”point to next action”# kan da være et viktig prinsipp.



Punktet ”Freedom to move” kan være viktig mht ergonomi og støtte muligheten for bevegelse for å unngå for mye stillesittende arbeide.

Punktet ”Serve external requests” er avhengig av funksjonelle behov og arbeidsbelastning.

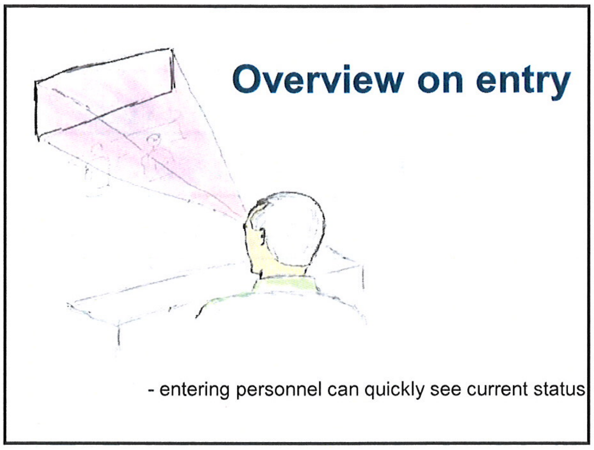
Punktet ”Support collaboration” – var ogå et viktig punkt, men da er det viktig å kartlegge brukergrupper og funksjonelle behov – for eksempel hvilke arbeidsprosesser deler man på og hva skal man samarbeide om og hvordan skal/kan storskjerm støtte et evt. samarbeide.

Det er åpenbart at ”different design strategies supports different types of uses”, det er behov for forskjellige konfigurasjoner i forskjellige kontrollrom, og forskjellige operasjonelle tilstander har behov for forskjellige støttebehov.

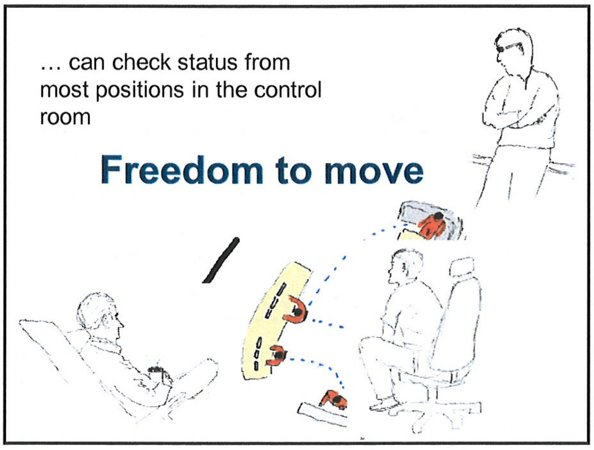
Bredden i innspill kan lede til at en bør gjennomføre en designprosess basert på prinsipp 3 – ”Competent local design process” .

WHY?
WHO?
WHAT?

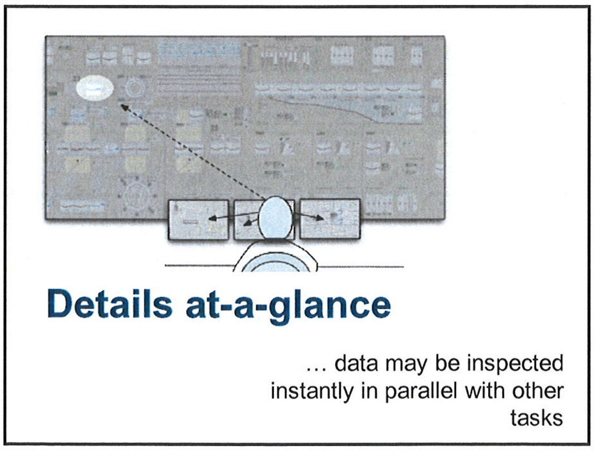
CONTENT
COLLABORATION
SITUATION AWARENESS -
FOR WHO?
INFORMATION OVERLOAD?
- CONSIDER OS/CAP, ETC.



SHIFT HANDOVER
EMERGENCY - SHARE E.P. TEAM
VISUAL ACCESS FROM
E.P. /COLLABORATION ROOM?

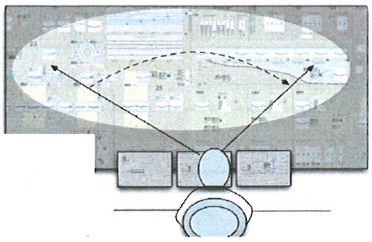


YES!
ALONE IN CCR. NEEDS TO
MOVE. NEEDS TO COLLABORATE
WITH OTHERS IN CCR -
THEREFORE MOVE.
N.B. AVOID LAZINESS -
INAPPROPRIATE BEHAVIOUR -
INFO. IN COFFEE SHOP.



NO. DETAILS ON OS!!
HIGH LIGHT CHANGES.
POSSIBILITY TO PUT UP
OWN INFO ON SCREEN.
ONE WAY OR TWO WAY?

Overview at-a-glance



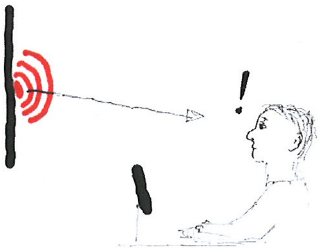
Picking up a comprehensive status in a brief sweep

YES. BUT DOES IT HELP?
IS IT USED IN PRACTICE?
REF. HFS REPORT ON
USE OF LSD IN PRACTICE.

GOOD FOR COMMON GROUND

ESCALATION PATH

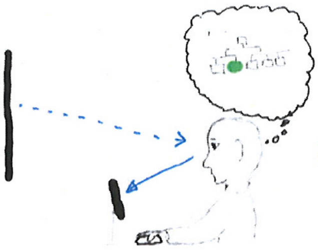
Attract attention



… to important events and deviations

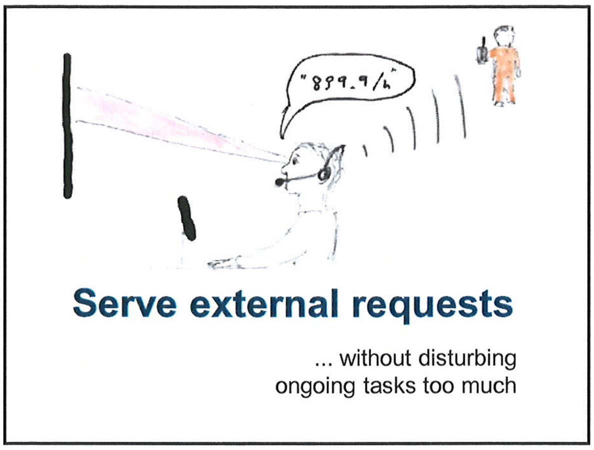
YES + NO. OTHER EQUIPMENT
DOES THIS. COMPETES FOR
ATTENTION – A DANGER ??
LSD CAN GIVE "OTHER"
PEOPLE INFO / ATTRACT
ATTENTION. WHO ARE THESE
"OTHERS"? WRONG USE OF LSD.

Point to next action

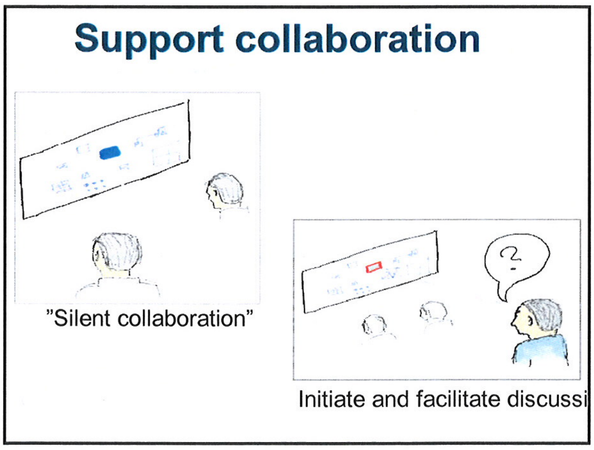


… by providing sufficient detail to differentiate responses

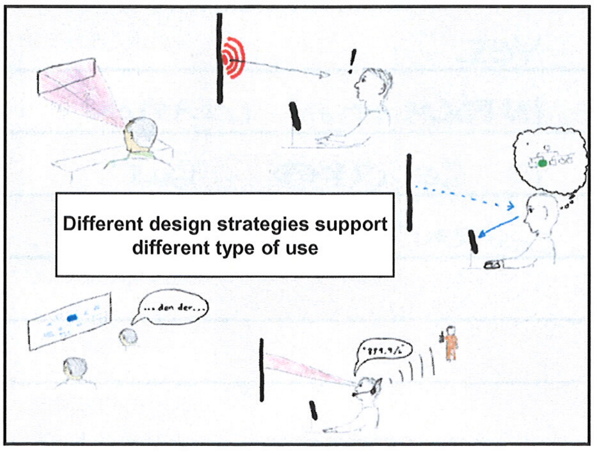
YES + NO
COVERED BY PROCEDURES,
WORK FLOWS, TRAINING.
YES – HELP VISUALISE +
GET INFO. IN FRONT OF
OPERATORS.



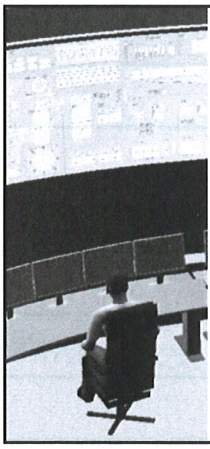
NO. SHARE INFO VIA COMPUTER.
YES. INFO - SELECTED PARTS → E. R. ROOM.
YES. MIRROR INFO CONTENT TO SHORE.



YES. AS ABOVE.
MIRROR INFO TO SHORE.
PART OF 2 WAY COMMUNICATION

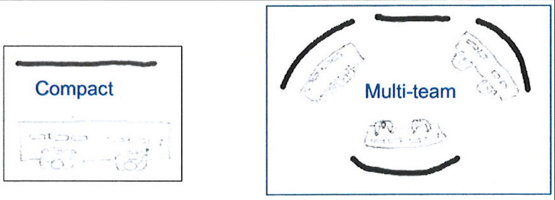


YES.
DIFFERENT MODES
NEED DIFFERENT
INFORMATION.

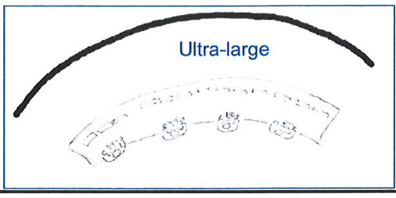


An effective large screen requires a fixed layout and carefully selected and designed information

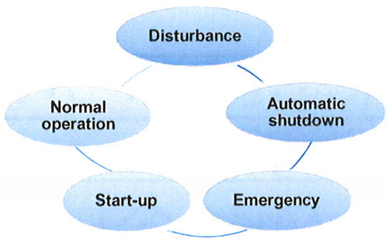
LAYOUT FIXED
CONTENT CHANGEABLE –
REF. CHANGE IN MODES.



Configurations in different control rooms



THIS IS REALITY FOR
BROWNFIELD. MAY ALSO
BE DESIRABLE FOR
GREENFIELD.



Each operational mode has different information and presentation needs

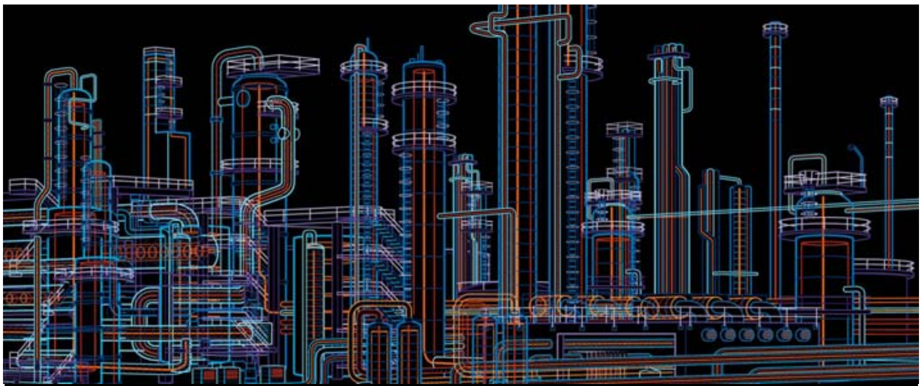
YES.
INFORMATION LOCATION
TO BE FIXED – BUT
CONTENT CAN CHANGE.

HFC

Intelligent Visualization of Alarm Information

C. Skorup

Mere informasjon:
Graven, T. G. “Intelligent Visualization of Alarm Information”



Charlotte Skourup, ABB Strategic R&D for Oil, Gas and Petrochemicals, HFC Oslo, April 2011

Intelligent Visualization of Alarm Information

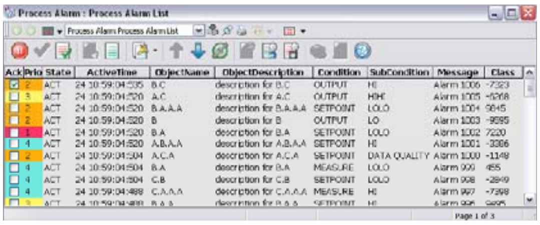
Visualization of Alarm Information
Motivation

- Focus on energy efficiency and optimalization
  - Highly coupled processes
  - High level of automation
- Increased use of smart instrumentation and wireless communication
- Demographic changes; lack of experienced personnel

⇒ *Complexity and Information Overload*

Visualization of Alarm Information
Today's Solution: Alarm Lists

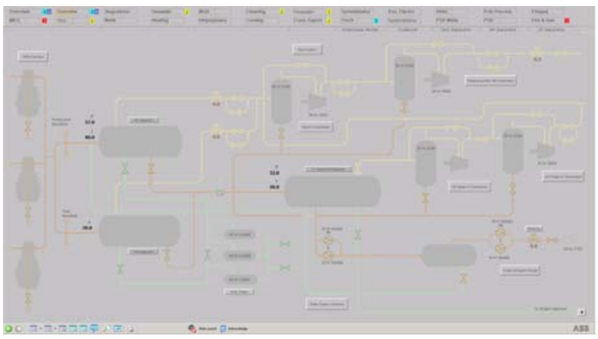
- Presentation is de-coupled from the process' logical and physical layout
- Does not present how the alarms are related or how a disturbance propagates through the plant



ABB

Visualization of Alarm Information
Today's Solution: Operator Graphics

- Represents a small window of the process
- Does not present changes that evolve over time



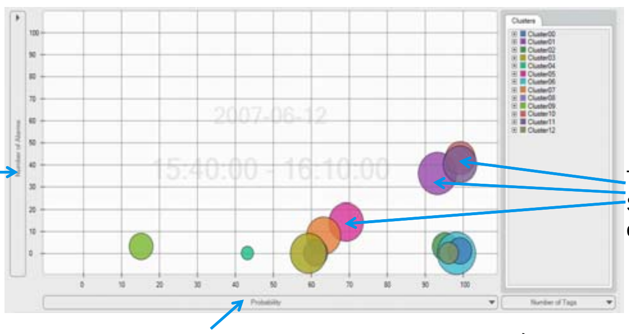
ABB

AlarmViz Prototype
Goal

- To use data analysis to detect patterns and relationships in the data
- Visualization to support pattern recognition and detection of *change*
- Highly interactive and attractive solution; the user should *want* to use the solution

AlarmViz Prototype
Bubble Chart

Y-axis: Number of alarms pr. tag group



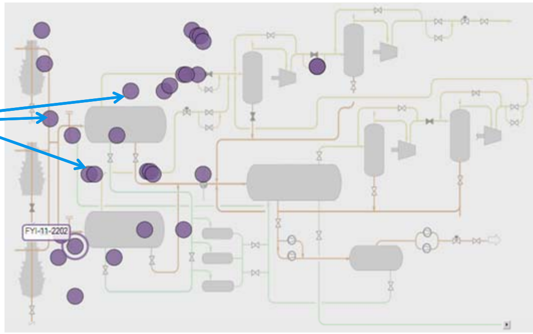
Tag groups. Size = number of tags.

X-axis: 'Abnormal' changes (early fault detection)

- Overview and presentation of abnormal changes

AlarmViz Prototype
Process Overview

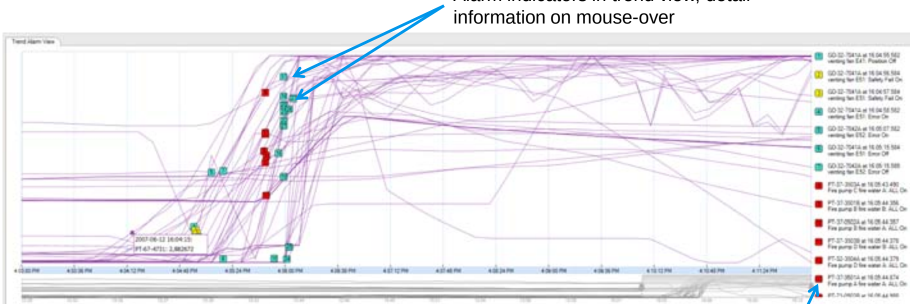
Tag in a chosen tag group. Tag names on mouse-over



- Overview of where in the plant an alarm/disturbance is localized
- Visualizes how a disturbance propagates through the plant

AlarmViz Prototype
Trend og Alarm View

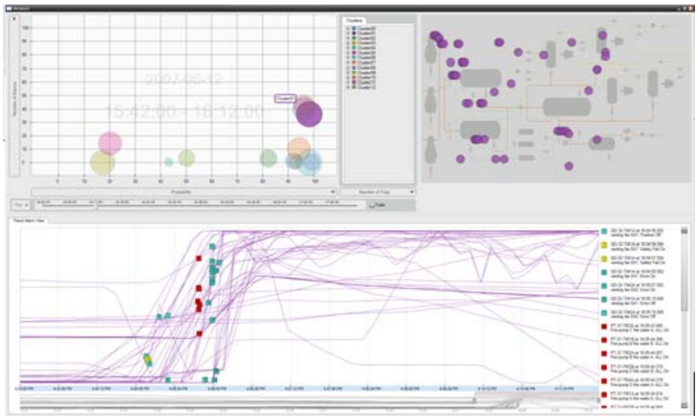
Alarm indicators in trend view, detail information on mouse-over



Alarm list for tags shown in trend display, colour on icon indicates alarm priority

- Detail information of situation
- Alarm information in context
- Colours on trend can be used to indicate causality

AlarmViz Prototype
Overview



- Overview vs. detail
- Highly interactive solution, supports active exploration of the process

ABB

AlarmViz Prototype
Testing

- Tested on three different offline data sets
- Tested online on a training simulator and evaluated by seven control room operators

- Main results:
  - Solution effectively groups ’similar’ measurements
  - Detects, and highlights, sudden changes
  - Operators find ‘Bubble Chart’ very useful for overview and early fault detection

ABB

AlarmViz Prototype
Conclusions and Next Steps

- Tests and user evaluation has verified that the solution can:
  - Provide overview of current state
  - Highlight sudden changes in the process
  - Visualize patterns and relationships in the process
- However;
  - We still need to verify that operators will use the solution, also during normal operation
  - Next step is therefore to test solution 'live'

Power and productivity
for a better world™

Intelligent Visualization of Alarm Information

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Abstract

Modern industrial facilities are continuously looking for new ways to increase profit by reducing downtime and increasing productivity. This has led to a trend towards more sophisticated automation solutions, and a larger degree of complexity in the process design itself. At the same time, the digitalization of the industry has led to an exponential growth in data availability. Unless care is taken, these factors can aggravate already known problems with relation to high degrees of automation, complexity and information overload.

To tackle this complexity and vast amount of information available, the alarm system remains an invaluable aid to the control room operators. Unfortunately, designing a good alarm system is very difficult and the way alarm information is normally presented does not aid the operator gain an overview of the complex dynamic interactions that occur during process upsets.

This paper presents a novel intelligent visualization solution to support detection and handling of abnormal situations. The solution utilizes data analysis methods for detection of patterns and trends in the data, and interactive visualization to highlight critical factors. Based on the results from testing a fully working prototype, recommendations are given for further work in this area.

Introduction

The data availability in modern industrial control rooms is higher today than ever before. This enables the operator to access important information from all parts of the plant. However, as the amount of data available greatly exceeds what can possibly be supervised at any time, the operators are also faced with a major challenge in finding the relevant information for the current operational context. The alarm system therefore remains a crucial aid for the operators to detect faults and disturbances in the process.

Unfortunately, process complexity and the vast range of possible faults that may occur make the design of an effective alarm system very challenging. It is difficult to define in advance which events will be relevant in all possible situations, and the alarm system designers must take outmost care to avoid highlighting irrelevant events, or removing events of importance. Several major accidents have been traced back to problems with the alarm system in the control room. This has led to the development of industrial guidelines and standards that provide recommendations about the how the alarm management process should be maintained at a plant. However, alarm rationalization projects demand massive efforts and not all facilities have the resources to do what it takes. And, even sites that have recently completed a large alarm rationalization project can experience alarm floods during process upsets.

Modern process plants typically have tight integration between different plant areas at the same time as the process is operated as close as possible to its physical limits. This means that a first alarm from a slowly developing disturbance may be triggered at a completely different stage of the process than where the disturbance originated. Unfortunately, the current available presentation schemes for alarm information do little to aid the operators in getting an overview of the complex interaction that occurs during disturbances.

Alarms are today most commonly presented in an ‘alarm list’, where the alarms occur in chronological order. Each alarm listed includes the tag name (a tag name is an identifier assigned to each component in the plant, such as valves, vessels or sensors) of the source of the alarm as well as a short message describing the reason for the alarm. This means that the presentation of alarm information is completely de-coupled from the process’ logical or physical layout. If the alarm is not immediately known, the operators’ first step is therefore most likely to move to the relevant process graphics to find the exact location of the fault in the process (Husøy et al., 2010). The operators are dependent on the information found in the process graphics together with their process knowledge and experience to make a quick estimate of the possible cause and consequences.

The operators do not only manage by exception, they also browse through graphics to look for changes. However, the graphics are normally designed to present the current status in the process, not to support detection of abnormal changes (Husøy et al., 2010). The shortcomings of the current presentation schemes in the control room have been thoroughly analysed within the areas of Human Factors and Cognitive Engineering (Endsley, 2001)(Christoffersen & Woods, 2003). Efforts have been made to provide better guidelines on how to design graphics that can help the operator keep an overview of the state of the process. However, focus in this area has to a large degree been on presentation of functional relationships in the process, and few examples can be found on how to highlight and present changes that evolve over time (Christoffersen & Woods, 2003).

Goals and Requirements

In control room operation, the operator needs to assemble, compare and integrate data from a variety of sources in order to make a correct judgement. This may result in a high cognitive load during high-tempo phases of operations, associated with the tasks of locating, remembering, and mentally processing all the relevant data values in order to arrive at the required assessments (Christoffersen & Woods, 2003). A good solution should be able to aid the operator in this task. The solution should present related information, such as process measurements, alarm information and information about the physical location of the measurements and alarms in the plant. Intuitive navigation is needed to help the user gain access to relevant information as a situation develops and to encourage the operators to actively explore different possibilities.

The requirements and design choices were guided by input from expert users. The expert user group consisted of experienced control room operators and process experts from two different petrochemical plants. Both plants have complex processes with much recirculation of energy and material making it difficult to get a good overview, especially during upset situations. The system experts are concerned that the solutions they have available today do not provide good help in detecting faults early. To compensate for that, both sites have a strong focus on training. During training session they use process simulators actively to teach the operators where to look and what to focus on. They will, for example, train on where in the plant variations typically show up. Through this training, the operators learn to get a good overview of the current status in the plant and therefore have a better chance to detect emerging faults or disturbances at an early point. Necessarily the training is focused on known faults.

The expert users stressed that the solution must be as valuable during normal operation as invaluable during plant upsets. This was considered important to ensure that the operators would familiarize with the tool and thus be more likely to use it in a stressful situation. The tool must therefore be easy to use with intuitive graphics and controls.

In order to deal with the large amount of data, data analysis methods must be used to detect changes and patterns in the data. For this solution, data analysis will be used to find abnormalities that evolve over time and in order to group data that have similar characteristics together. Maintaining transparency with regards to the analysis is crucial for the user to understand the information presented. While a key point in visualization research is to exploit human skills in perception and interactive manipulation, the complexity of the underlying analytic process involved in visualization solutions for complex and large data sets makes finding visualizations that are useful in practice a major challenge within the area (Tory & Möller, 2004)(Chen, 2005). It is therefore crucial that both analysis and visualization methods are carefully chosen with focus on transparency and ease of use.

The application is expected to be most useful at large and complex facilities and must therefore be able to handle a large amount of time-oriented data. This means that the tools must be able to analyse and present at least ten thousand independent process measurements.

Solution Overview

Visualization and Interaction

Coordinated views are good for visualization of different aspects of the data and can enable the user to investigate the data properties that are relevant in the current context. It also enables combined presentation of overview and detail information. North and Shneiderman (1997), observed that coordinated multiple views can improve the user performance as well as help the user discover relationships within information (North & Shneiderman, 1997). A combination display with linked, complementary views was therefore chosen for the prototype. It has a multivariate display suitable for overview and quick fault detection linked to one display providing spatial information and one display with drill-down access to time-dependent process data and alarm details.

For the main display a bubble chart display similar to the GapMinder tool (Rosling et al., 2004) was chosen. This display type allows three dimensional data to be presented, and with color coding it allows multiple data sets to be compared in one view. Each bubble represents a group of measurements which have been grouped according to their 'similarity' in behaviour over time. A measurement can be anything from typical process values such as pressure, temperature or flow to electrical measurements or mechanical vibration. Grouping the variables is useful as the root cause of a detected disturbance is likely to belong to the same group as the affected measurements. The grouping therefore also helps in providing an overview of how far a single disturbance has propagated through the plant, as the group will grow when the disturbance affects a larger part of the plant.

The temporal evolution is visualized by use of trails and animations, providing an indication of trends for each group of measurements. For each measurement group, the operators can also compare parameters such as active alarms and the number of measurements included in that group. In addition, an indication of the likelihood for an abnormality (early fault detection) being under development in that group is available. Selecting a group will display more details about it in the other two views.
Information that relates the cause of a fault or disturbance to the location in the process topology of the plant is vital in the operators' decision making process. Due to its familiarity to the operator, a topology-map based on operator graphics with indications of the locations of data sources was chosen for the purpose. The physical location of individual measurements (i.e. the sensor) corresponding to a selected group in bubble chart are indicated by transparent circles coloured as in the bubble chart. Colour shading can be used to indicate probable causal relationships. Note that even though a set of measurements belong to the same group, they can originate from many different pieces of equipment.

The last view, the trend and alarm view, presents trends with overlaid alarm information. Based on the data analysis results, colour coding can be added to visualize probable causality relationships in the data. This combination of information is intended to guide the operator in selecting the appropriate actions to deal with the situation.

More information including illustrations of the visualizations can be found in Graven and Högberg (2010).

Data Analysis

In industrial facilities, it is common to make multiple measurements around a single physical component in the process, e.g. pressure, flow and temperaute can be measured. Redundant measurements are also becoming increasingly common, in particular in relation with safety-critical equipment. Together with the tight coupling between different parts of the process, this means that the total number of measurements can become very large, but also that disturbances detected in a measurement are reflected in a high number of other measurements. Among the vast number of process measurements available, many are therefore correlated.

While the wide range of possible sources of faults and disturbances make the design of an effective alarm system challenging, these faults and disturbances are also reflected in the process measurements and can be captured by applying analytic methods on the historical process data. Oscillatory disturbances in the plant can therefore be detected by use of data-driven analytic methods and covariance calculations or spectral analysis can be used to group measurements and control loops in a plant being affected by the same disturbance.

For the present solution, cluster analysis is used to group data into groups with ‘similar’ measurements. It is difficult to know in advance how many natural clusters there are in the data set. Many popular clustering algorithms are therefore not possible to use. The X-means algorithm (Pelleg & Moore, 2000) makes it possible to perform clustering without the need to specify the number of clusters in advance.

A multivariate statistical process control (MvSPC) method using the distance measure chi-square is used to characterize the most recent states in a cluster in relation to the historical values (Ye et al., 2006). Standard univariate Statistical Process Control (SPC) methods are also used on a measurement by measurement basis. The goal with this approach is to highlight clusters with significant deviations in a multivariate sense by use of chi-squared statistics, and to be able to drill down within the cluster to find the most significant deviations in a univariate sense through SPC based indicators. The analysis results make it possible to indicate probable causal relationships in the information visualized to the operator.

Testing and Results

The prototype was first tested against three different offline data sets. The data sets contained real historical data extracted from a methanol plant, the training simulator at the same methanol plant, and a data set from an offshore oil production facility. The methanol plant was considered to be very suitable for testing the prototype as it is a complex process involving much recirculation of material and energy. Getting access to historical data from a defined upset situation can be difficult, as larger process disturbances can be far between and not always well documented. Using a data set from the training simulator therefore made it possible to test the solution for a specific known case.

The data sets contained up to 2200 independent measurements. Initial tests were done to avoid problems related to handling real-time analysis of large dynamic dataset, and in order to focus on the visualization in the first iteration of the prototype. To simulate how the visualization would behave in real-time operation, the user interface included functionality to ‘play through’ the historic data.

The initial tests allowed for tuning of the algorithms used for clustering and fault detection. The tests verified that slowly developing situations as well as sudden process upsets are captured and presented clearly. The clustering algorithm effectively grouped together measurements with similar characteristics, and if a measurement within a group (cluster) changed behaviour, the fault detection measure clearly indicated this change.

After verifying the validity of the algorithms, the next step was to test that the information presented is also truly useful for the control room operators. In the next round, the application was therefore tested online on a training simulator, and the results were evaluated by seven control room operators from the site.

From the seven operators participating, one was a former operator currently responsible for training, and four of the others also worked as simulator instructors. Most of the participants were in their twenties and had between 2-6 years of experience. The group also included one very experienced operator (10+ years of experience) and one operator trainee. None of the operators had participated in the initial expert group providing input in the requirement and design phase of the project.

The main focus for the test was to go through a series of use cases that were cherry-picked by the operators themselves. Before each use case was started on the process simulator, the expected results with respect to process behaviour, alarms, as well as presentation in the tool were discussed in the group. After a scenario had completed, the expected results could then be compared with the actual results. The operators were encouraged to interact with the tool. However, as the group was rather large and only one prototype tool was available, only two of the operators tried to use the tool in a more hands-on manner.

Some limitations were experienced during the simulator test as it turned out that some important measurements were not available as historical values. Due to limited time available, it was not possible to run 'normal operation' for a very long time before each scenario was started. This meant that the fault indications in the visualization where not as unambiguous as they otherwise could have been.

The four use cases (scenarios) tested where:

- A fault that had propagated and created problems in various parts of the process. A typical example of a situation where it would take some time before the actual cause is detected.
- A process upset situation generating many unnecessary alarms.
- A disturbance where the first alarm is generated in a much later stage in the process.
- A fault not generating any alarms at all (fault is compensated by the control system).

After the first scenario was tested the initial response from the operators was that they were somewhat overwhelmed by having so much information available in one place. This response was related to the trend/alarm view, while the initial response to the main overview (bubble chart) was very positive. The operators disagreed whether the tool should include all available data, including e.g. utility system, or only include data from the main process. Some of the more experienced operators argued that faults may very well originate from utility systems, and even though this may not develop into a serious situation, it is still a problem that is of value to detect. The operators' differences in how they expected the tool to work seemed to reflect their different main operational strategies; 'management by exception' vs. 'management by awareness'. The intention of the tool is to support both strategies; it should be able to highlight important changes as well as support active exploration of process.

The operators especially appreciated the early fault detection feature in the overview display (bubble chart). This was particularly highlighted for the two last use cases. Early fault detection based on deviation between set point and output value was pointed at as a very useful feature. As the automation system compensates for problems in the process, the output value from the control loops can be the only place where emerging problem can be detected. Another point that was highlighted was that alarms in themselves do not provide any information on how a fault is developing; slowly developing, oscillating etc. By use of this tool this type of information would be easily available to the operators.

The tests involving propagation of a fault through the plant verified that measurements affected by the initiating cause where grouped correctly. As a fault propagated through the plant, the bubble chart indicated clearly that a larger part of the plant was being affected by the same cause. The operators indicated that they would like the probable initiating cause to be highlighted more clearly in the user interface. This can be done by adjusting how this information is presented; however, it is also important that the visualization reflects that the information is based on statistical probability and not the absolute truth.

The operators responsible for simulator training appreciated that the general philosophy of the tool is to suggest and highlight information, rather than to act as a traditional expert tool that instructs the operators where the fault is and how to act on it. In general the operators were very wary towards this type of expert tools as they are afraid it will induce operator complacency. In their training they are very focused on building process knowledge and on encouraging active search for abnormalities in the process. This, they believe, is the best approach to ensure safe and efficient operation. At the same time they were conscious to avoid personnel with e.g. engineering degrees in the control room as they believe this type of personnel will be prone to over-analyse the situation and therefore be too slow to take action. In their opinion, control room operators should be 'doers' rather than 'thinkers'.

Conclusion

The goal of this project was to create a solution that would help the operators detect unexpected changes that evolve in the process providing at the same time an overview of the current situation in the plant. Analytical methods were used to find patterns and correlation in the data that may otherwise be very difficult to detect. The result of the analysis is presented in combination with alarm and event information from the plant, and novel visualization methods are used to present the information to the user.

User evaluations and testing of the solution has verified that the integration of data analysis and information visualization have high potential in helping the operator gain overview during process upsets. The solution is able to present what part of the plant is likely to be influenced by the same disturbance that caused an alarm. A disturbance that is generating few (or no) alarms but is propagating throughout a large part of the plant is highlighted to the operator. If an unrelated problem occurs during an alarm flood, this is clearly indicated to the operator. The above mentioned information is easily missed with the solutions available in the control room today. Combined, the information provided by the solution described in this paper will help the operator gain an overview of the situation, evaluate possible consequences and decide on the best corrective action to take.

However, although testing the solution on offline data and on a training simulator is very valuable; this is not enough to fully verify that the solution will be of use both during normal operation as well as during stressful situations. Further plans therefore include full-scale testing of the solution over some time on a real process.

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HFC

Collaboration Between Onshore and Offshore Supported by Video

S. Kvalheim

Forutse Forebygge Forberede

Better collaboration between offshore and onshore control rooms

Sverre A. Kvalheim

Forutse Forebygge Forberede

SAFETEC

IO: ”The great opportunity”

- Integrate competence, tools and data in realtime independent of geographic location
- Faster and better decisions
- More coordinated efforts and collaboration
- Added value potential: > 300 billion NOK

SAFETEC

Realistic potential?

Hackman (1998)

- Face to face teams don`t work

Doherty-Sneddon et al., (1997); Olson & Olson (2000); etc.

- Computer mediated teams will be even worse

Stratopoulos & Dehning (2000)

- Productivity paradox in IT

SAFETEC

Hackman (1998)

Stratopoulos & Dehning (2000)

Prerequisites for success

- Common success criteria for IT and teams
  - Organization
  - Implementation
  - Manning
  - Competence (Training/experience)

SAFETEC

Research questions

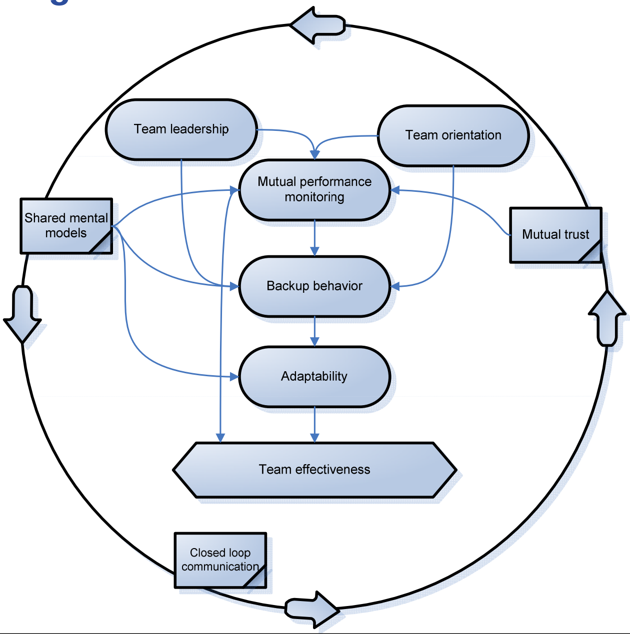
- Which factors are important in Team work?
- Sufficient media richness to support the coordination needed?
- User experiences of new systems influence on quality of the collaboration and decision making process in every day use?
- Which factors contribute to better collaboration between offshore and onshore control rooms?

Big five in teams

Which factors are important in team work?

Is there a "big five" in teams?

Salas, Sims & Burke, 2005

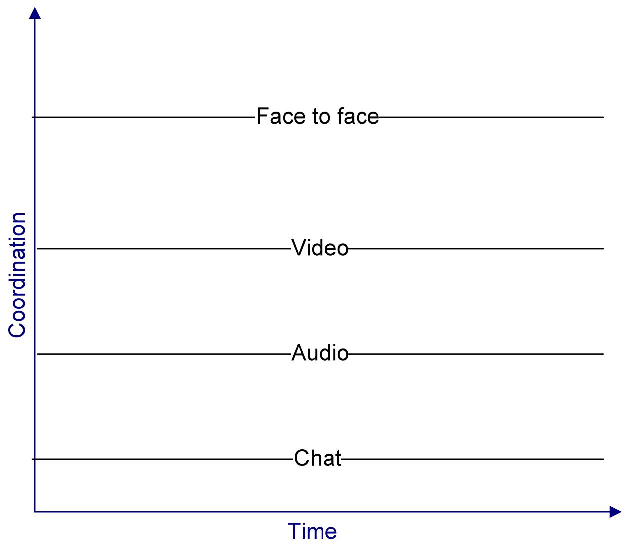


Media richness theory

Sufficient media richness to support the coordination needed?

Media richness theory (Daft & Lengel, 1984/86:

The quality of the coordination is dependent on the richness of the media.



SAFETEC

Sufficient media richness to support the coordination needed?

Social information processing (Walther, 1992)/channel expansion theory (Carlson & Zmud, 1999):

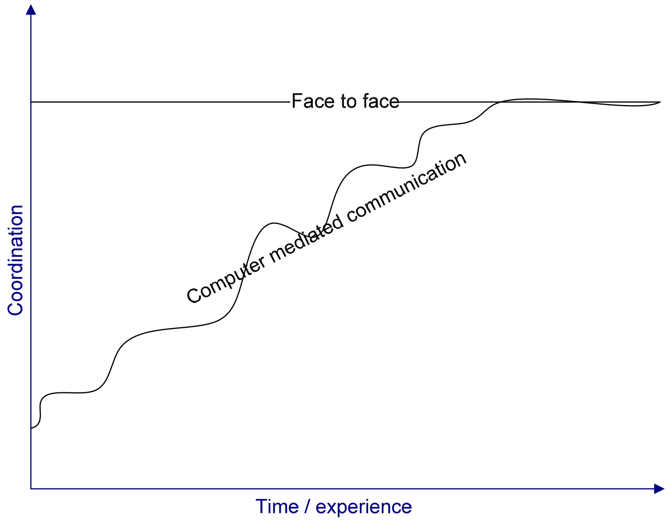
The quality of the coordination is dependent on:

The quality of the media,

The teams experience with interpersonal interactions whithin the team

Experience with the media

Social information processing / Channel expansion theory



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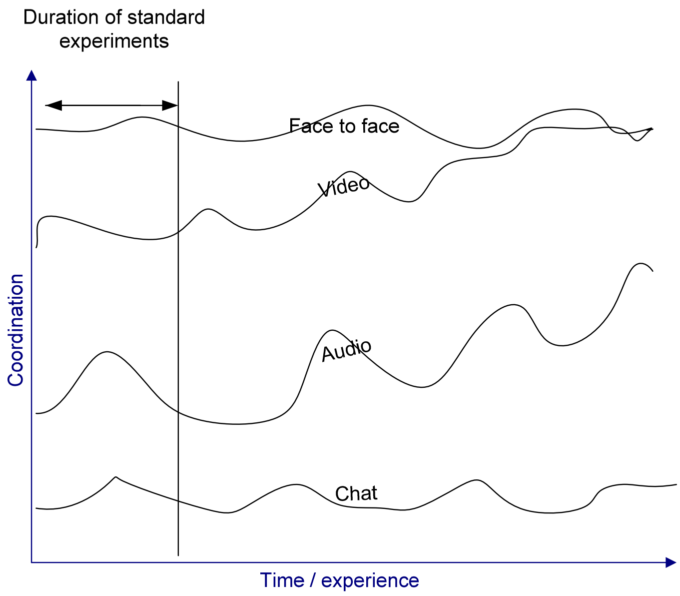
Sufficient media richness to support the coordination needed?

Most experiments end before users adapt to new media? (Alge, et al., (2003) Hobman et al, (2002); Bos, et al., (2001)

Second language: Video helps negotiate common ground (Veinott et al., 1999)

Collocation of empirical data



SAFETEC

User experiences of new systems influence on quality of the collaboration and decision making process in every day use?

Quotes from Informants

The experience of social presence in CMC settings account for approx 60 % of the variance in user satisfaction measures (Gunawardena & Zittle, 1997)

User experiences

"We used to have telephone meetings, and the people didn`t say anything… Now, in the high resolution video conference, they express themselves; look down into the table, smile… Even if they are not talking, you get a signal"

"Before (with low res), it was hard to tell who was talking. This caused misunderstandings, and a more strained atmosphere…"

"… You remember their faces, and when I meet people from meetings when I`m offshore, I spontanously say hi, even though I`ve never met them face to face before"

"The meetings are looser,with the new systems. You can see in the other peoples faces when you are stepping over the line… and then you can moderate yourself or stop…"

SAFETEC

User experiences of new systems influence on quality of the collaboration and decision making process in every day use?

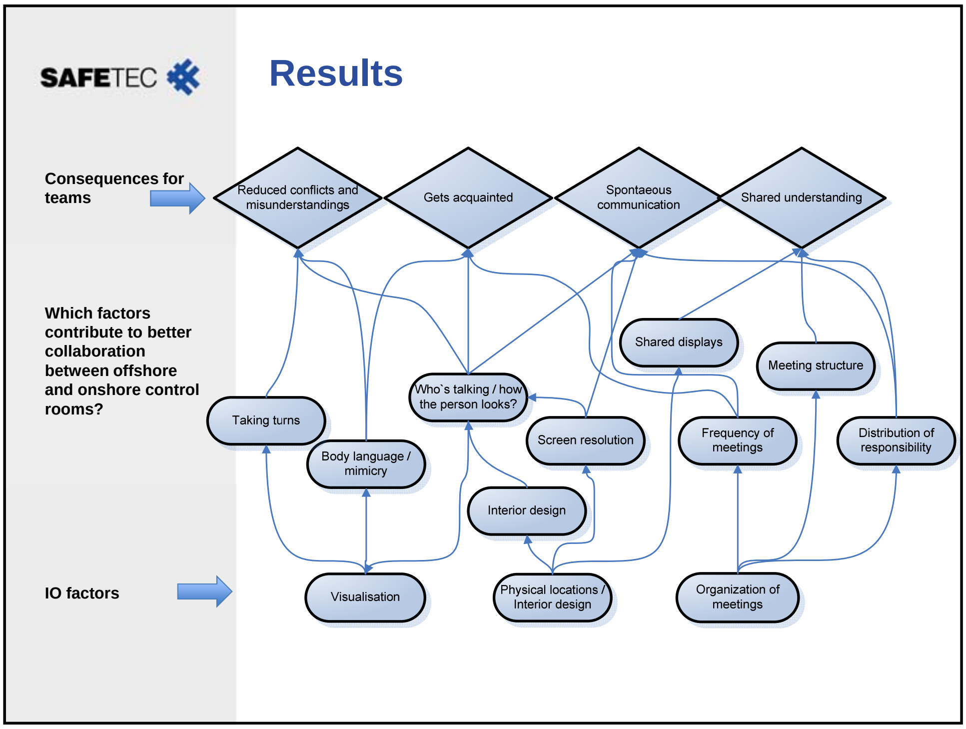
Quotes from informants

User experiences II

"In the beginning of the project, the idea was to increase communication to include more people. But the big screens, … many of them, along with dampened lighting and a control room profile… The aim was to collaborate, not control, so we adapted the rooms to support the intentions outlined in the new work processes"

"We`ve not had any team training. The only thing we have focused on, is that the meetings should hva a clear agenda, with a leader, defined input and output…"

"It`s much easier to know who you can contact between the meetings to get what you need to do the job. And now you know them, because you`ve met on video. The threshold to take spontanous contact is much lower"


SAFETEC
Results
Consequences for teams
Which factors contribute to better collaboration between offshore and onshore control rooms?
IO factors
Reduced conflicts and misunderstandings
Gets acquainted
Spontaneous communication
Shared understanding
Shared displays
Meeting structure
Who`s talking / how the person looks?
Taking turns
Screen resolution
Frequency of meetings
Distribution of responsibility
Body language / mimicry
Interior design
Visualisation
Physical locations / Interior design
Organization of meetings

INVITASJON

Human Factors in Control

6.-7. april 2011

Visualisering og grensesnitt

4.februar

Kjære deltaker!
Vi vil med dette invitere til møte i HFC-forum (Human Factors in Control).

Møtet holdes onsdag 6. og torsdag 7. april 2011 i ABB's lokaler i Ole Deviks vei 10, Etterstad, Oslo. (Fra sentrum, ta T-bane til Helsfyr, linje 1,2,3 eller 4 mot øst, deretter buss 66 til ABB, 4 minutter til stasjon Bryn skole.). Vi starter registreringen kl 11:00. Det blir lunsj fra 11:00 til 12:00. Vi har innlegg fra CEL, Chalmers, HFS, ABB, EPSIS, FIOH, IFE, Halogen og Safetec.

Vi har reservert rom på Thon Hotel Terminus, Stenersgt. 10, Oslo, ta direkte kontakt via tlf: 22 05 60 00, referanse 3801 840 eller via SINTEF. SINTEF kan bestille rom for dere – kryss av på siste side. Vi håper du har anledning til å delta, og ønsker at du fyller ut og returnerer det vedlagte registreringsskjemaet, senest 31.mars. Vi ser frem til din deltakelse.

Program (NB: Endringer kan forekomme)
Tema for møtet vil være "visualisering og grensesnitt" og vi har mange spennende innlegg, diskusjoner og workshop. Foredrag holdes bl.a. av Prof. Greg Jamieson fra Cognitive Engineering Laboratory (CEL) ved Universitetet i Toronto, se cel.mie.utoronto.ca/people/gaj/bio.htm, og av Prof. Anna-Lisa Osvalder fra Chalmers Tekniske Høyskole, fra området design og human factors, se: www.chalmers.se/ppd/SV/kontakter/personal/forskare-larare/osvalder-anna-lisa.

Det blir besøk hos ABB, hvor vi vil få presentert bl.a. Remote Monitoring and Operations Room (ARMOR™). Dette rommet brukes av ABBs spesialister til å gjøre fjernaksess på anlegg i drift, til oppgaver som f.eks. prosessoptimalisering og overvåkning av systemet. I tillegg blir det besøk på ABB R&Ds innovasjonsrom, hvor det vil være demonstratorer av dagens, så vel som fremtidens, løsninger innen visualisering og brukergrensesnitt for olje og gass produksjon.

Visjon og hovedoppgave for HFC forumet
HFC visjon: "Kompetanseforum for bruk av HF innen samhandling, styring og overvåkning i olje og gass virksomheten." HFC hovedoppgave: "Å være et forum for erfaringsoverføring som bidrar til å videreutvikle HF metoder til bruk ved design og vurdering av driftskonsepter." (Om HFC, se: www.hfc.sintef.no)
Vil minne om konferansen i regi av Human Factors and Ergonomics Society Europe, 19-21/10 - 2011 i Leeds – tema "Human Factors of Systems and Technology". Se http://www.hfes-europe.org/. Vi vil også benytte anledningen til å minne om kurset "MTO-Human factors" ved UiS som går høsten 2011, og NTNU kurset "Introduksjon til HF og integrerte operasjoner" - høsten 2011, se videre.ntnu.no/link/nv12296

Vennlig hilsen
Arne Jarl Ringstad /Statoil, Atoosa P-J Thunem/IFE, M. Green/HCD, Håkon Fartum/DNV, Stig Ole Johnsen/SINTEF.

Vær vennlig og returner registreringen innen 31.mars 2011 til:
rigmor.skjetne@sintef.no

HFC Møte

AGENDA

6. til 7. april 2011

Visualisering og grensesnitt

ABB, Forskningssenteret for olje, gass og petrokjemi, Ole Deviks vei 10, Etterstad, Oslo.

Dag 1	Innlegg med spørsmål etter	Ansvar/Beskrivelse
11:00-11:30	Registrering	HFC
11:00-12:00	Lunsj	ABB
12:00-12:30	Velkommen og presentasjonsrunde blandt deltakerne	HFC
12:30-13:15	Coping With Automation with Future Human-System Interfaces	G.A. Jamieson/CEL
13:15-13:45	Diskusjon/Pause – Kaffe og noe å bite i	ABB
13:45-14:15	Interaction Design - Toolbox Talk	B. Hove/HFS
14:15-14:30	Pause – Kaffe og noe å bite i	ABB
14:30-15:00	Beyond Best Practices - Concepts for Future Operator Interfaces	K. Husøy/ABB
15:00-15:30	Pause – Kaffe og noe å bite i	ABB
15:30-16:00	Design of visual facilities within collaborative decision environments	A.Clark/EPSIS
16:00-16:15	Pause – Kaffe og noe å bite i	ABB
16:15-16:45	Novel Interaction with Computers	K. Lukander/FIOH
17:00-18:30	ABB – Bedriftsbesøk	ABB
20:00	Middag	HFC

Dag 2	Innlegg med spørsmål etter	
08:30-09:00	Kaffe og noe å bite i	ABB
09:00-09:30	Overview of and Experiences from Human Factors Integrated System Validation	P. Ø. Braarud/IFE
09:30-10:00	User Centric Design for Professional Applications	P. Holter/Halogen
10:00-10:15	Pause – Kaffe og noe å bite i	ABB
10:15-11:30	Introduksjon til workshop Workshop - Fordeler og ulemper med storskjerm	Ø. Veland/IFE
11:30-11:45	Pause – Kaffe og noe å bite	ABB
11:45-12:15	Human Factors Engineering in Control Room Environments - Ongoing Research at Chalmers	A. L. Osvalder/Chalmers
12:15-12:45	Collaboration Between Onshore and Offshore Supported by Video Conferencing Solutions	S. Kvalheim/Safetec
12:45-13:00	Avslutning og oppsummering	HFC
13:00-14:00	Lunsj	ABB

REGISTRERING

Human Factors in Control

6. til 7. april
2 0 1 1

ABB, forskningssenteret for olje, gass og petrokjemi,
Ole Deviks vei 10, 0603 Etterstad, Oslo.

Visualisering og grensesnitt

Ja, jeg vil gjerne delta:

Navn: __ ________________________________

Tittel / stilling: ____ ______________________________

Organisasjon: ___ _______________________________

Adresse: __ ________________________________

Kryss av for:
__ Lunsj 6/4, __ Middag 6/4, __ Bestiller hotell 6/4 __ Lunsj 7/4

Tlf. : __________ Fax: ___________

E-post: _______________

Hvem faktureres (PO-Nr/Bestillingsnr/Referansenr:)___________________

For å være med må man betale inn medlemsavgift eller møteavgift. Medlemsavgiften er pr år:

- 25.000 for bedrifter med mer enn 15 ansatte (dekker 3 deltakere)
- 12.500 for bedrifter med mindre enn 15 ansatte (dekker 2 deltakere)
- 6.500 kr pr møte for ikke medlemmer (og overskytende deltakere)

Medlemsavtale, informasjon og publikasjoner om HFC kan finnes på WEB-siden:
http://www.hfc.sintef.no

Vær vennlig og returner registreringen innen 31.mars 2011 til:
rigmor.skjetne@sintef.no