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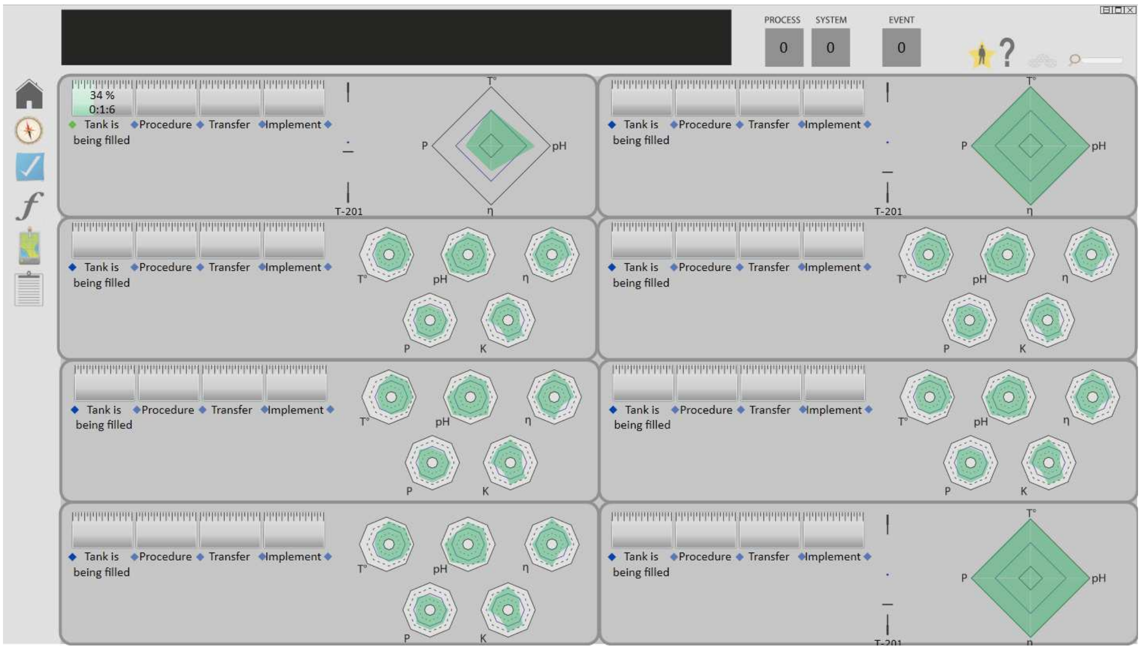

Conceptual solution for workflow visualisation on control screens

A task-based perspective

Master of Science Thesis in Product Development

Kasper Nolkrantz
Grégoire Piroux

Department of Product and Production Development
Division of Design and Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover:
Overview screen for operator's multitasking of the conceptual interface

Printed in Sweden by Chalmers Reproservice.

Göteborg, Sweden. June 2012.

Preface

This thesis work develops a new conceptual solution for workflow visualisation on control screens from a task-based perspective.

This report is the conclusion of the research and development carried out during the thesis work. It was performed with the Division Design & Human Factors at the Department of Product and Production Department at Chalmers University of Technology in collaboration with ABB Technology & Innovation (Oslo, Norway) as part of the Master of Science program entitled Product Development. It ran during the spring semester of 2012. The report presents the main development steps that lead to the conceptual solution of an interface for improved operator decision-making.

Keywords: Cognitive Ergonomics, Human-Machine Interaction, Interaction Design, Product Development.

Acknowledgements

The project team wishes to thank all individuals who contributed to the completion of this thesis work from its early phases to the final presentation of the concept.

First of all, the authors would like to express their gratitude to all the operators that helped us with this thesis by putting a human face on the user:
At the operator at Chalmers Heat Plant, we would like to thank them for opening their doors to us and showing us what was really a control room, this is where the “real world” began;
At the two operators at Göteborg Vatten, for their time, their patience for sharing their knowledge and experience with us, for presenting the main phases of cleaning the water for Göteborg;
At the operator of Swedish Match, for sharing her problem and giving us insight from a beginner’s perspective;
At the operators in Södra Cell, for taking care of us for an entire day, for showing us part of the process to understand how big is the process they control, for their detailed information about the ABB System;
At the KSU instructors in Ringhals, for the study visits in the control room from “another time” with analog indicators that showed us how hard the work can be for the operators;
And at all the operators from Statoil in Kalundborg who have taken the patience to explain us the different tasks of their work;
To all of them, thank you for making the effort to speak English (with your hands if needed and even sometimes a bit French) to explain your work instead of using your native language.

Moreover, we appreciate the external view on the report and the thesis work given by Meisam Pourghareman, the opponent, that gave us the opportunity to adapt our writing style for the report and the way of presenting our work for the presentation.

We would like to express our gratitude to the “ABB Team” in Norway, Tone Graven, Kristoffer Husøy, Torgeir Enkerud that have assisted us during the thesis work. They gave us valuable feedback on the work from their experience. We would like to thank them for entrusting us with the freedom to model the thesis topic depending on our ideas. We are also thankful for the opportunity to be in Oslo for two days for the Human Factors Conference and the fruitful discussion about the thesis work that came after.

We appreciate also the comments and the guidance from Ana-Lisa Osvalder, our examiner. The meetings and feedback with her were very helpful during the course of the thesis.

And last but not least, we would like to thank Jonas Andersson, our supervisor. Without his guidance and his support throughout the thesis, the results would have not been the same. We hope our thesis work feeds well in to his phD. We were probably one of the first human factors engineers to use his Human Automation Interaction Model (which is called the Jonas’ Model within the team) and it was very helpful for developing our concepts. We will not forget your invaluable assistance and the fruitful and long discussions we had with you.

Kasper Nolkrantz, Grégoire Piroux.

Abstract

Most of the tasks performed in control rooms in the Oil and Gas Industry have long duration and require many steps over several shifts by different operators. The procedures are not computer-based which lead the operators to interpret the workflow visualization in different ways. Moreover, the operator can encounter difficulties when it comes to monitoring of different parameters because they are not presented in context with the task.
It is therefore relevant to look for an efficient way to visualise critical process parameters, their association and their state in the workflow time (past, present and future).

This thesis work focuses on the workflow and information visualization. It takes into consideration different phases of a product development from literature review and study visits to software implementation of a conceptual solution and ends with user feedback. The end-result is a concept implemented in blend with a task-based focus.

List of Abbreviations

AH	Abstraction-Hierarchy
CV	Controlled Variable
Demo	Demonstration
DV	Disturbance Variable
EID	Ecological Interface Design
H-AIM	Human Automation Interaction Model
HTA	Hierarchical Task Analysis
KBL	Knowledge-based Level
KJ	Kawakita Jiro
KSU	Kärnkraftsäkerhet och Utbildning AB
LoA	Level of Automation
MV	Manipulated Variable
RBL	Rule-based Level
SA	Situation Awareness
SBL	Skill-based Level
SRK	Skill Rule Knowledge Model
ZID	Zigzag Interaction Design

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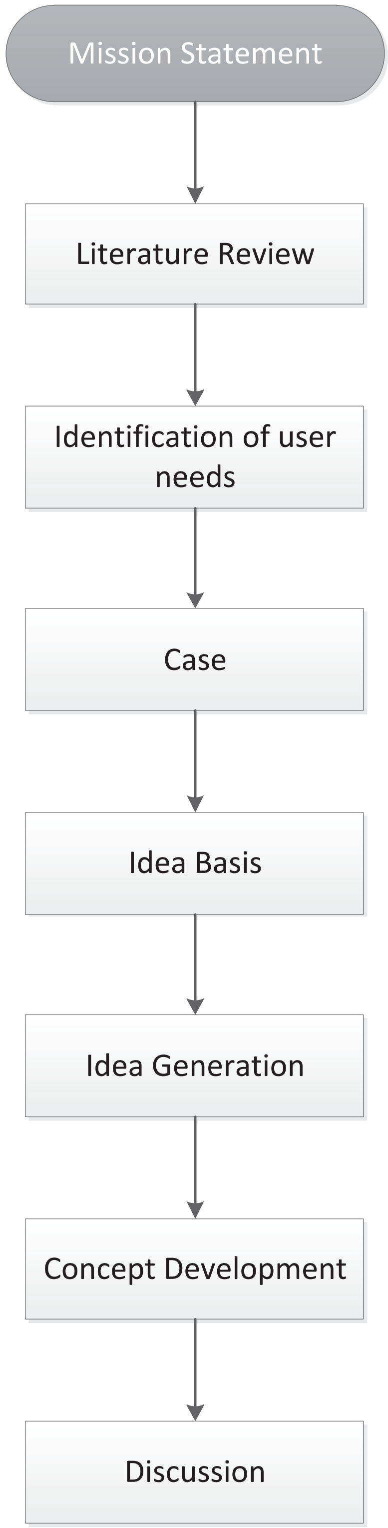


CHAPTER 1
INTRODUCTION

This chapter introduces the mission statement of the thesis with its background, purpose and aim, but also its scope and delimitations.

1.1 The Company ABB

ABB Group

ABB, Asea Brown Bouverie, is a Swedish-Swiss Company (cf. Company logo figure 1.1). It is a leading company in power and automation technology. ABB has offices and manufacturing plants all over the world and has a presence in 100 countries, with around 120 000 employees created a global revenue more than $30 billion for 2010 (Wikipedia - ABB Group, 2012). The company's core values are responsibilities, respect and determination. (ABB.com, 2012).

Figure 1.1. ABB Logo

ABB is a an old company, from the end of the 19th century. It is the result of a merge in 1988 between the Swedish Company, Allmänna Svenska Elektriska Aktiebolaget (ASEA) founded in 1883 and a Swiss company, Brown, Boveri & Cie (BBC) founded in 1891 (Wikipedia - ABB Group, 2012).

A business division of ABB is Process Automation. It designs integrated solutions to control and optimise plants for the process industries. (ABB.fr, 2012). A picture of the control room environment developed by ABB in collaboration with CGM in Borås (Sweden) can be seen on the figure 1.2.

ABB Oslo

ABB Technology & Innovation, based in Oslo (Norway) is part of the Scandinavian Research Centre (Norway & Sweden). The research group focuses its work on the Oil and Gas Industry. They work in collaboration with different customers on different domains such as control rooms for onshore and offshore platforms (ABB Norway, 2012).

1.2 Thesis Background

Control rooms are found in very different domains and the process are controlled 24/7 by operators. A lot of tasks performed in control rooms have long duration and requires many different steps during different shifts by different operators. The job efficiency can be affected depending on if the operator relies on handwritten and printed documents or on screen information for taking decisions (Ivergård and Hunt, 2009). Most procedures are not computer-based thus the operators can interpret the workflow visualization in different ways. According to Young & Stanton (2002), the lack of feedback could lead the operator to misinterpret the different states of the machine. This could lead the operator to experience difficulty when monitoring different parameters because they are not presented in a close area. An analysis by Braseth et al. (2009) shows that around 60% of the operators prefer computer-based procedures over paper-based procedures thus there is probably a need for visualising predefined tasks directly in the automation system (Task-based Displays). A large screen and desktop systems, used in control room, poses challenges and opportunities regarding layout and interaction in the control room. The multiple displays need to facilitate side-by-side comparisons of variables and parameters, and allows the operator to focus on relevant information by switching between windows (Schneiderman and Plaisant 2010) such as with the 800xA system (cf. Figure 1.2). It is then relevant to look for an efficient way to present trends of different critical parameters, their association, and their situation in the workflow time (past, present and future).

Figure 1.2. System 800xA EOW-2 (ABB)

1.3 Scope

Three different areas/types of knowledge should be produced from this thesis:

- Research knowledge about information visualization. How the design could show the operator the workflow sequence and support his decision-making.
- Product Development: Development of a concept to support the motivation points from the literature review and the study visits that should be tested before the end of the thesis.
- Test-Feedback-Test: The concept should be developed and tested. The conceptual design should be improved according to the feedback given by the users that could be either students or control room operators.

1.4 Purpose & Research Questions

The purpose of this master thesis is to investigate theories and to develop and evaluate concepts of workflow visualization to support the operator's decision-making capabilities when performing tasks by improving the information presentation layout.

This leads to the following research questions:

1. What should be and should not be simplified in information presentation compared to existing solutions in the market;
2. Investigate how improved information visualization design can be used to exploit the different screens to give the operators better support;
3. How the operators' workflow with the control screen can be improved.

1.5 Aim

The aim was defined from meetings between the authors, Chalmers' supervisors and ABB Norway.

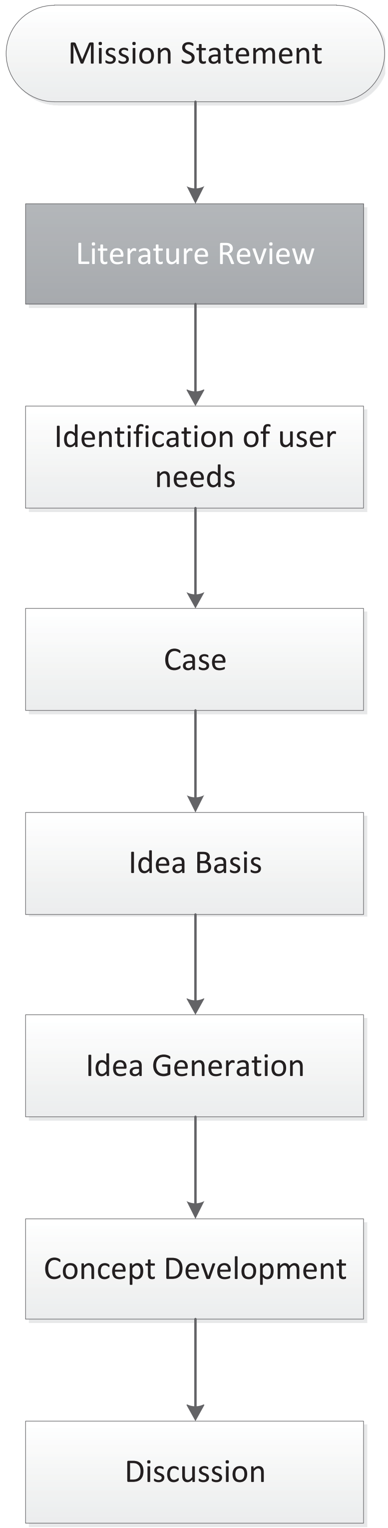
The end-results that should be provided are:

- Create around seven concept ideas described as text, drawings, sketches and pictures in any format.
- The final concept should be visualized in the form of an interactive media format (eg. video, demo) showing the main functions of the concept.

1.6 Delimitations

The thesis was initiated with almost no restrictions. However, the authors are limited in time (5 months' work of two students) and resources so the following delimitations have been decided for the work:

- The thesis work will focus on the cognitive aspects of the human-machine interaction.
- The prototype will not be a full control room implementation.
- The prototype will visualize only the process of one or two scenarios.
- The concepts will focus on the Oil & Gas Industry, even if some study visits are done in different process industries.
- There will be no major change to how process graphics are presented in existing solutions.



CHAPTER 2
THEORY

This chapter presents the main theories used in the thesis and the last part presents ideas developed in the literature that are used as a "design toolbox" to feed the brainstorming phase in the idea generation.

2.1 Ergonomics Field

Developing complex technology requires deep knowledge on how the human user will interact with it. For engineers, studying human-machine interaction can help increase the product quality and improve the reliability in production (Ivergård and Hunt, 2009). This discipline is called Ergonomics in Europe and Human Factors in the United States.
The International Ergonomics Association (IEA) defines the ergonomic field as "the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimise human well being and overall system" (IEA, 2000). Ivergård and Hunt (2009) also adds that one of ergonomics aim is to avoid sickness, injury or any fatigue. A complementary definition is given by Chapanis (1996): "Human Factors is a body of information about human abilities, human limitations, and other human characteristics that are relevant to design."
The information provided by Human factors should be used for the design of tools and machines, but also for tasks and jobs,
A holistic understanding of the entire system is necessary in order to design a safe and comfortable environment which can provide effective human use (Chapanis, 1996).

2.2 Cognitive Ergonomics

Cognitive ergonomics is related to the cognitive aspect that influences a user's performance. The studies are derived from former psychology studies. Quoted by Ntuen et al. (2006), Norman relates the cognitive engineering as finding what is behind user's action and performance in order to find a relation with engineering activities. The field systems engineering is the action of analysing and designing systems (Chapanis, 1996). An association from the last two areas defines the cognitive systems engineering as a combination between cognition, human knowledge about task (procedures, activities, behaviours, structure) and should be the main source when developing cognitive aids (Ntuen et al., 2006).

2.3 Ergonomics in control rooms

A control screen should present different forms of information to the operator (Ivergård and Hunt, 2009). An other way could make the system too opaque for the operator (Noyes and Bransby, 2001). The operator movements should not lead to physical pain, and that is why the information should be easily located. Noyes and Bransby (2001) add that the information shown on the display should be readable from any viewing position.

2.4 User's Mental Model

The human user is part of the human-machine system. According to Chapanis (1996), not taking into consideration the human user could lead to unsafe or uncomfortable system to use. Besides, knowing skills, knowledge and some other characteristics about the user could support the designers' work and the customers (Chapanis, 1996).

The definition of an operator's mental model helps the designer understanding the reasoning behind the interaction with the control system.

Different mental models

Mental models are, by definition, evolving models, not always fully accurate and defined with clear boundaries, so they are incomplete models that continuously updates such as at the beginning of a shift depending on the actual plant's situation (Norman, 1983; Endlsey & Hoffman, 2002; Andersson, 2010; Vicente et al., 2004).
In his argumentation, Norman (1983) defines different kind of models related to learning, understanding of physical systems, the reasoning behind actions and predictions and also the designer's model.
Young (1983) stresses that designers should define the conceptual model according to performance (timing, errors), learning methods, reasoning (prediction, system's behaviour) and design (good guidelines). The mismatches between user's mental model and designer's model can lead to some improvements on the user's model, but the designer needs to understand where these differences might lead to.

In the thesis, the mental model is considered as an evolving model that describes the user interaction with the interface and the actions he can take until the automation system takes over. This definition is supported by the conceptual model explained in detail in chapter 3.

Mental models and personal experience

Chapanis (1996) highlights that personal user habits impact directly on the mental model. This argument is relevant during data gathering when the designers need to separate user's needs with user's preferences.
Control room operator often learns from more experienced operators. Some work habits will pass through the learning. It is relevant to express that some habits are not adapted anymore with new and modern interfaces.
A skilled operator has a more precise mental model of the process and the structure behind it and can take appropriate decisions (Ivergård and Hunt, 2009). On the other hand, the newcomer reaches the human ability maximum for learning in a short time due to an overload of information and can not take the best decisions. The standardization of control room interface should enhance learning, user flexibility for both beginners and experienced operators and therefore reduce the impact of transferring wrong working habits.

2.5 Situation Awareness

The following definition for Situation Awareness is used in the thesis:
"Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995).
A simpler but familiar definition, Situation Awareness is defined as "What is going on" in the process (Endsley, 1995).

Level of Situation Awareness

Endsley and Hoffman (2002) argue the need for the human to operate the situation awareness at different levels:

- Level 1 SA: Perception of needed information from available data according to operator's goals;
- Level 2 SA: Understanding the meaning of data by creation of mental model;
- Level 3 SA: Prediction of future states of the system.

Figure 2.1 (Endsley and Hoffman, 2002) highlights the relation between the different levels of situation awareness.
Situation awareness should be accomplished through the three levels for an improved performance and operator's decision-making (Endsley and Hoffman, 2002).

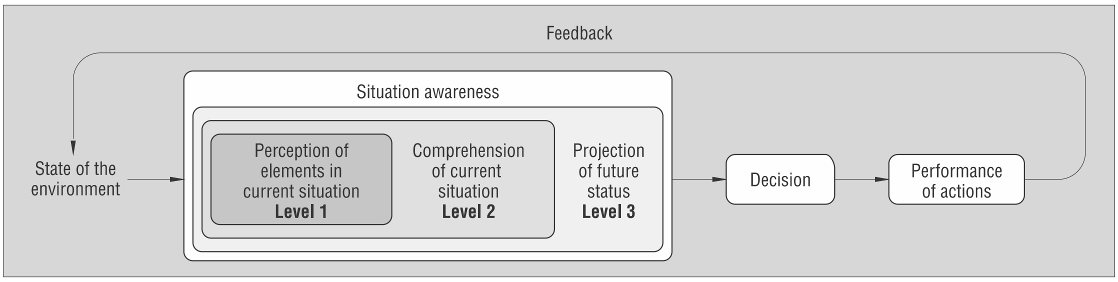


Figure 2.1. SA 3 levels (Endsley and Hoffman, 2002)

Designing for Situation Awareness

A situation awareness system interface to support the operator's SA by reducing his cognitive effort is defined with eight principles (Endsley, 1999, Endsley & Hoffman, 2002, Endsley et al., 2003):

Principle 1 - Organize information around goals (Level 1 SA)
Designers should focus on defining goals-oriented display. After defining operator's clear major goals, the information associated with these goals should be co-located on the screen.

Principle 2 - Present information directly to support comprehension and projection (Level 2 SA)
The information needs to be presented for high level SA (comprehension and projection) instead of providing low-level data to the operators that need further calculation for interpretation. For example, if the operator needs to know the deviation between a current value and the required value for a parameter, instead of providing both value the deviation number or even better a visual representation should show him the meaning of the information. It will leave him more mental resources for other tasks.

Principle 3 - Provide assistance for projections (Level 3 SA)
Projections of future states require a well-developed mental model which does not exist yet for newcomer operator. The system needs to anticipate the possibility of happening of future situations. By analysing the component dynamics, the system should display project estimated component behaviour.

Principle 4 - Support Global SA
The operator needs to visualize the global situation "high level overview of the situation across operator goals" with detailed information for each goal. This screen needs to be visible at all times. It enables the operator to manage the different goals depending on their priority and supports the projection of future system events.

Principle 5 - Support trade-offs between goal-driven and data-driven processing
Principle 1 (Goal-driven process) and principle 4 (Data-driven process) should complement each other.

Principle 6 - Make critical cues for schema activation salient
The main cues need to be highlighted on the display so the operator develops an improved decision-making process during critical situations.

Principle 7 - Take advantage of parallel processing capabilities
When the operator's attention is shared between different tasks, it is important to not overload him with only visual information. The system should be multi-modal to support not only visual senses but also auditory or tactile.

Principle 8 - Use information filtering carefully
The system should filter the information needed at a specific time for the operator in order to narrow his attention. This principle can be applied by experienced operator to improve the system for newcomers.

Situation Awareness in the Petrochemical Industry

During their task, control room's operators need to control a large amount of parameters or related pattern representation. Understanding and prediction of actual and future process states should be supported by an effective SA display to improve effectiveness (Endsley, 1995).

In its ethnographic study in different sites, Husøy et al. (2010) highlights that alarms were continuously running (with different ratio) since they were used not only for alarms but also for monitoring by the operators. A new interface should then separate the different alarm situations but also support the operator by a new overview which provides updates to the operator about the running tasks to monitor key parameters. It might be important to keep the connections from the overview with the actual process to reduce the abstraction level since it is difficult to work with abstractions for operators (Ivergård and Hunt, 2009). Thus the designers should be careful when developing such abstracted displays because on one hand, it gives the operator the opportunity for quick monitoring but on the other hand he can lose the sense of the information if it is out of context (Husøy et al., 2010)
According to Husøy et al. (2010), a better visualization by presenting the information in context and their interrelation where changes are easier to detect could increase the SA. Deeper information can be found about information visualization in the related sub-chapter of this theory chapter.

2.6 Decision-making

The operator's decision-making is defined in the literature as the choice by a human being of a sequence of action from different possible alternatives (Chapanis, 1996).
During the completion of their job, the operators interact with the machine, and have to control it. Operators are not "deterministic input-output devices" (Rasmussen, 1983) but supervisors of automated system that need support from a helpful display to show them the useful information so they can take the right decision at the right time.

SRK Model

According to Rasmussen (1983), decision-making can be defined with 3 levels (Figure 2.2):

• Skill-based level (SBL): where unconscious, automated and sensorimotor actions takes place. This level can be achieved with a long period of training;

• Rule-based level (RBL): where the operator use a rule to do a task selected from previous experience with similar tasks; This level can be achieved over knowledge training (Ivergård and Hunt, 2009);

• Knowledge-based level (KBL): where the operator deals with unfamiliar situations, with no know-how or rules to use. The user needs to test and sometimes fail to understand the function of a system in order to help him predicting future status.

Users make decision on the three different levels (Bligård, 2010) so understanding on which levels of decision-making strategies the operators are and the factors that influence them to perform a task are useful information for future customers of automation system (Osvalder & Ulvengren, 2009; Chapanis, 1996).

Different authors also discuss about the relation between the display (interface), the way the information is presented and the users' decision making; designing helpful interface should support the decision-maker (Osvalder & Ulvengren, 2009; Kertholt, 2002).

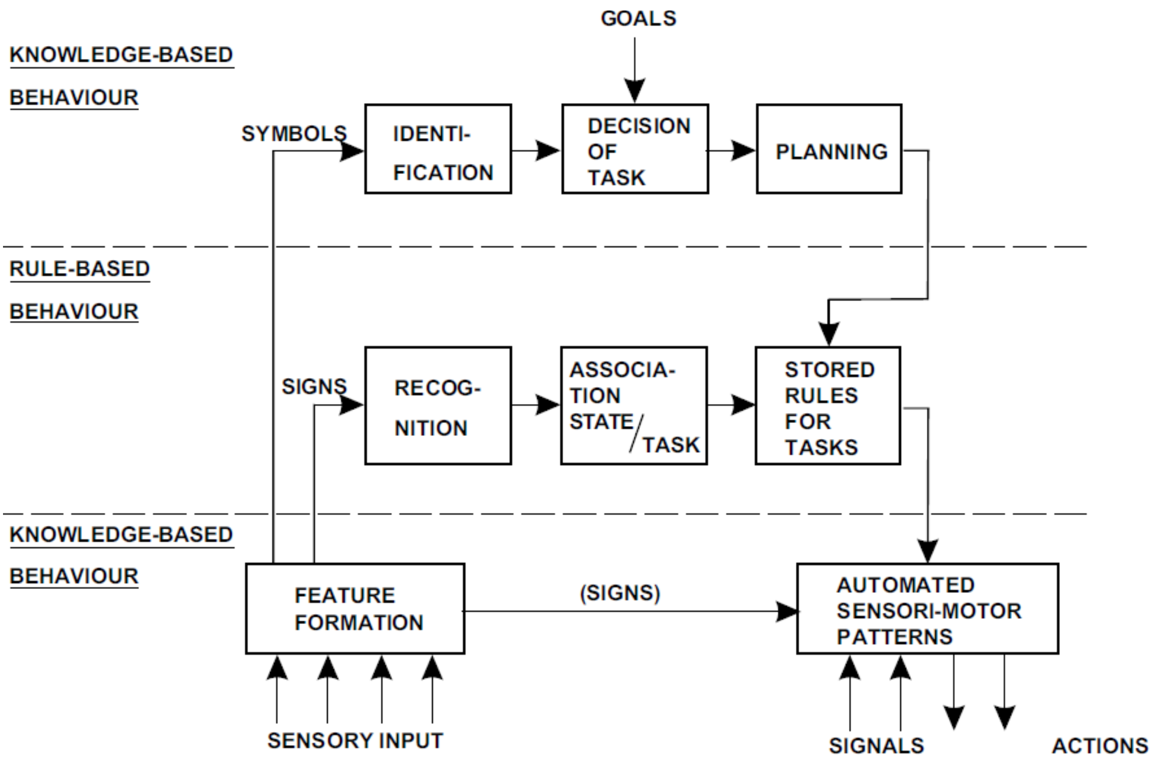


Figure 2.2. SRK Model (Rasmussen, 1983)

Training and experience

An experienced operator pays more attention to deviations and have a quick response time (Noyes and Brandby, 2001). However, according to Kertholt (2002), even with the same training the users will not develop the same decision-making. With training and experience, an operator can probably move the decisions from a knowledge-based level to a skill-based level. Moreover, working on a skill-based level leaves more memory chunks for more complex tasks so it might be better to work on that level, even if it requires, before, an effort to "move" the task from a KBL to a SBL.

Dekker (2004) discusses the idea that human errors should not be seen as causes themselves but as consequences of deeper causes in the system. It argues that human errors and mechanical failures are difficult to distinguish one another. When using a human-machine system, it is delicate to fully understand the relations between the system components which will bias the diagnosis. In order to take the best decision, the operator needs a deep understanding of the dependencies between the decisions and the consequences on the work domain (Kertholt, 2002). While procedures and automation are a popular engineering solution to errors, the judgement of skilful people on how to use and adapt procedures is more efficient to reduce errors and enhance safety (Dekker, 2004). A solution for beginners is to adapt these procedures depending on the improvements made by knowledgeable operators.

Situation Awareness and Decision-making

Endsley (1995) links the situation awareness to the decision-making. The situation awareness impacts on the decision-making process and the ability to solve problem both by the way the problem is presented and the solution proposed by the system (Endsley, 1995). It is difficult to present both the detailed situational information (Level 1 SA) and how the different parts of the puzzle overlaps one another (Level 2 SA) to direct efficiently the decision strategy selection (Endsley, 1995).

Improve Decision-making

For improving operator's decision-making, it is important to understand on which level the operator is working on in order to design a predictive decision-making support. The supportive system could be paper-based (eg. checklist, procedure) or computer-based (eg. past history, predictor displays) that helps in providing quickly understandable information and avoid unnecessary analysis (Osvalder and Ulfvengren, 2009; Chapanis, 1996).

2.7 Automation

Automation was introduced as an help to improve task performance, but also as a tool to possibly reduce mental workload (Young & Stanton, 2002).

Increasing the level of automation involves a shift in the operator's work from controlling towards monitoring (Osvalder & Ulfvengren, 2009). More automation can be introduced for critical tasks to improve the efficiency, the quality and the safety aspects related to the work (Osvalder & Ulfvengren, 2009). Engineers needs to take into consideration the importance to explain changes before implementation for operator's acceptance (Osvalder & Ulfvengren, 2009).

When the level of automation increases, the lack of feedback from the automation system can lead the operator to misperceive different states of the system and later on to lack of trust in the automation, mismatch between operator's mental model and the actual technical model and maybe to decreased performance (Young & Stanton, 2002; Andersson, 2010).

Level of automation

Eight levels are defined to describe the level of automation of a human-machine system. It starts from no automation support (level 1) to full automated system (level 8):

1. No assistance;
2. Suggestion of multiple alternatives and highlights the best ones to the human;
3. Selects and suggests one alternative to the human;
4. Carries out action if gets approval by the human;
5. Carries out action if no veto in a limited time by the human;

6. Carries out action and then informs the human;
7. Carries out action and then informs if asked by The human;
8. Full automation, no feedback to the human (Stanton, 2002 in Osvalder and Ulfvengren, 2009).

User/Control System
One of the reason for adapting the level of automation of the interface is to improve the flexibility for users to work differently. The designer should take into consideration when designing interface that human being are efficient in perceiving pattern changes and got the ability to use all kind of information sources (Osvalder and Ulfvengren, 2009). According to Osvalder and Ulfvengren (2009), the automation system can process huge amount of information and present it in a way that the user understands it. The automation also be flexible so the user can get multiple possibilities for the same action.

It is important to remember as a design engineer that in a human-machine system, the human is the system component that should be supported (Chapanis, 1996). Thus the designers need to make a trade-off between too much automation and not enough. The interface should be able to prevent the loss of skills in a company due to retirement leave of an experienced operator. The operators should be included in the interface improvements as early as possible during the development (Santos and Zamberlan, 2000).

2.8 Abstraction-Hierarchy Model

The actions of a control room are related to its work domain so it is necessary to describe the work domain before starting a design (Burns and Hajdukiewicz, 2004).
This model helps defining the work domain and is supported by five levels that describes different layers of constraint of the work domain:
1. Situation Level: Overall work situation and contextual influences;
2. Task Level: Performed actions to reach intended goals;
3. Function Level: Abstract functions and physical laws, Causal structure of the process;
4. Process Level: Connection between physical components;
5. Structure: Physical objects and their position (Bennett and Flach, 2011; Jamieson & Vicente, 2001).

This part of the model determines the resolution of the work domain: moving on a higher level answers the question “why?” and the resolution becomes coarser and moving to a lower level answers the question “how?” and the resolution becomes finer (Andersson, 2010).

The representation of a human-machine system at several levels of abstraction is helpful when mapping the iterative relation between the multiple physical configurations that can fulfil a specific purpose and vice-versa (Rasmussen, 1983).

2.9 Display Concepts

A number of theoretical and practical display layouts exist today below follows a short description of the various types.

Task-based Display
At the beginning of the thesis, it was introduced that some tasks were paper-based while they most likely could be computer based. An analysis by Braseth et al. (2009) shows that

around 60% of the operators prefer computer-based procedures over paper-based procedures. There is probably a need for a predefined task design directly integrated in the operator's interface .

Function-oriented Display

The functions of the work domain are used to support the design of the layout and different features of this display (Ahlén, 2009). A top-down decomposition method is necessary for identification of function achievements (Braseth et al., 2009). The functional and physical components should be designed to give early access to process deviations to the operator.

Ecological Interface Display

EID is a framework to develop more effective displays. The aim of EID is to show the information explicitly, the boundaries of an operation and parameters correlation to the user (Noyes & Bransby, 2001; Welch et al., 2007).
Jamieson and Vicente (2001) developed a concept taking into consideration the abstraction-hierarchy model to support skill-, rule-, knowledge-based behaviour of operators in the petrochemical industry.
The concept produced three improvements:
1. It supports problem-solving of unanticipated events due to the AH structure;
2. It improves operator's learning by the creation of a transparent interface both for the causality between variables and the connection between goals and the physical structure;
3. It enhances work collaboration since each layer can help the understanding of the actual status for different stakeholders.

Model-based Predictive Controllers

Guerlain and Jamieson (2002) highlights that today's interfaces often present large amount of numbers to the operators as a mean of information and they do not support them in the creation of a correct mental model.
The elucidator user interface tries to answer these problems. The display (Figure 2.3) is separated into three zones so the operator can act on three levels during a shift:
1. Monitoring: The operator gets a quick overview to check if the process is running effectively;
2. Diagnosis: This part shows the cause-effect relationship between parameters for improved decision-making;
3. Control: For every variable that the operator wants to trend over time. The operator only need to select the variable in the diagnosis part and the control part will change to present the information related to this parameter (Guerlain and Jamieson, 2002).

The solution proposed is supposed to reduce the complexity of operator's tasks by a higher level of automation. Three types of variables are defined for a mid size MPC:
- Controlled Variables (CV): Process variables to keep within constraints or at setpoint;
- Manipulated Variables (MV): Variables to adjust in order to keep all the CVs within their constraints while trying to meet optimization objectives;
- Disturbance Variables (DV): Variables that impact the process but can not be controlled. Knowledge about the DV can induce changes on the MV or the CV(Guerlain and Jamieson, 2002).

Event Driven Timeline Displays

The operator needs to be supported when taking decisions during system failure. Potter and Woods (1991) describes a display that gives feedback to the operator about system investigation of different hypothesis during system failure or process anomalies. It is

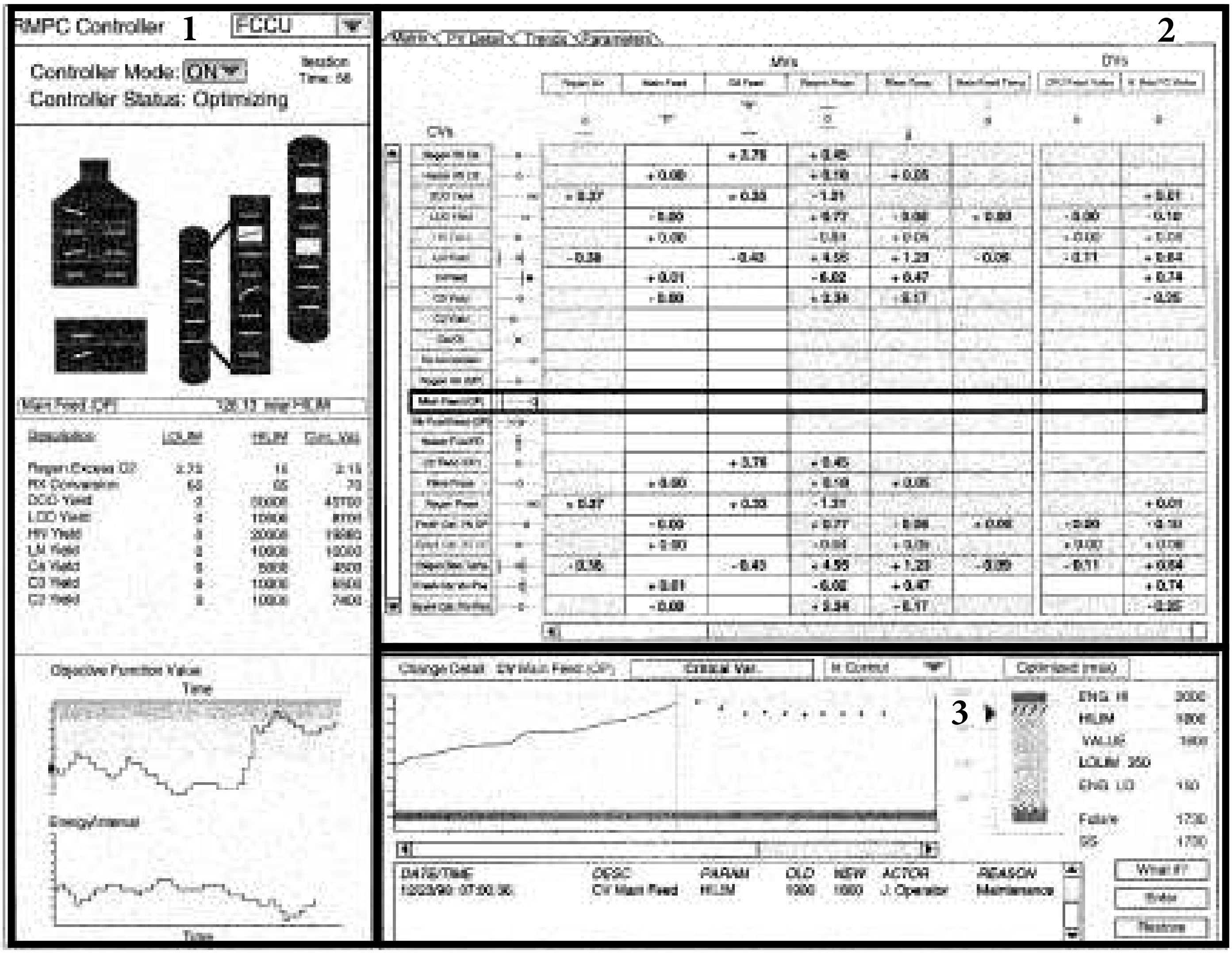


Figure 2.3. MPC Elucidator (Guerlain and Jamieson, 2002)

composed of three parts: anomaly, diagnostics message and recommended responses. This display highlights the automation reasoning to the operator to foster an understanding of the correlation between faults and corrective actions (Potter and Woods, 1991).

2.10 Information Visualisation Theory

Hollifield (2008) argues the difference between raw data and information; "Data is not information, information is data in context made useful". Notions of context and manipulation to create a meaning are here expressed by Hollifield. The visualisation of the information can reduce user's mental calculations by providing information that he can use easily (Burns and Hajdukiewicz, 2004).
Several authors argue about the necessity to present the information in a better way to get a better understanding at the relation at stakes. For example, the Graphics Semiotics uses the properties of the visual image to bring up the relations of resemblance and order between data (Bertin, 2000). Dubakov (2012) expresses the main advantages of developing information visualisation: it gives a better understanding of unnoticed correlations; it gives faster answers than a long list of data in a table; the manipulation of data improves the investigation of cause-effect relationship; it increases the data density (Tufte, 2010).

2.11 Design Principles

From the literature review, some guidelines were found to be useful to define the requirements for the development phase. They are summarized into 10 categories to keep in mind when defining the requirements list and designing concepts.

1. Visual Clarity In order to reduce confusion and possible mistakes, the graphics should be intuitive, distinguishable and display only relevant information, especially for alarms and unusual situation indicators (Hollifield, 2008), so to be easily understood by the operator (Jordan, 1998). The graphics should show the process state and conditions in a clear way (Hollifield, 2008). Furthermore, the layout of the interface should enhance pattern recognition and consider human abilities (Gestalt Laws).

2. Consistency To achieve a consistent interface, designers should develop standardized or at least similar graphical elements so the interface navigation is logical and easy to learn and use for the operator (Rogers et al., 2011; Shneiderman & Plaisant, 2010; Hollifield, 2008).

3. Feedback Information about actions should be sent back to the operator, so the operator can acknowledge what has been finished (Shneiderman & Plaisant, 2010; Rogers et al., 2011). The level of feedback depends on the importance of the action: the higher important it has, the higher the response should be (Hollifield, 2008; Shneiderman & Plaisant, 2010). The feedback can use all types of interaction or a mix of them (Audio, tactile, verbal, visual) but it should not be a source of overload as then it will not work as an extra-support for the operator (Hollifield, 2008; Rogers et al., 2011).

4. Flexibility The chosen design should be flexible enough to adapt to future changes (Stanton and Baber, 2006) that the user makes (from novices to expert) to the workflow (Shneiderman & Plaisant, 2010) in order to support the decision-making in the most efficient way (Ntuen et al., 2006).

5. Explicit Causality Tufte (2010) stresses the importance of showing to the user the causality, the structure behind the process. Jordan (1998) and Stanton & Baber (2006) both highlight that the operator should understand the meaning of each function in the interface and its relation to system performance.

6. Decision-Making Planning The tasks should be organized into groups with a clear beginning and end so the user can visualize the planning process. The interface should support both an efficient decision-making process and gives the operator satisfaction to finish one task and the support to prepare the next one (Ntuen et al., 2006; Shneiderman & Plaisant, 2010).

7. Information Visibility The content should always take over on the form (Tufte, 2010). Thus the interface should support to make it easily understandable for the operator (Rogers et al., 2011). The design should be done with a combination of words, numbers, images and diagrams to achieve efficient information support (Tufte, 2010).

8. Errors Prevention and Recovery In case there is an error, the system should detect it and then offer support for recovery to the operator (Shneiderman & Plaisant, 2010). It will take off some stress from the operator by allowing to undo actions and/or a group of action (Shneiderman & Plaisant, 2010). The interface should be designed in a way to minimize the likelihood of errors (Jordan, 1998), which can lead to restricting some of the user interaction for a specific time so the operator does not have access to it. To prevents incorrect selection by the user, thereby reducing the number of mistakes (Rogers et al., 2011)

9. Multivariate Comparisons The information in a control room is multivariate data, just like in the rest of the world (Tufte, 2010). It is then interesting to focus on comparison and highlighting the differences between the different data in a logical way (Tufte, 2010). This reasoning could be done by predictions over time for the operator (Stanton and Baber, 2006).

10. Reduce Short-Term Memory The same information used in different menus should be entered either on a unique menu or use an internal software from one menu to another to avoid having the operator to remember information from different screens (Shneiderman & Plaisant, 2010).

2.12 Design Research

This section is mostly based on the main findings from the literature concerning graphics. Ideas and inspirations from the internet can bee seen in appendix C.

Graphics performance

This section is based on the findings from Bill R. Hollifield *«The High performance HMI handbook»* (2008).

Idea 1 : 4 displays hierarchy

This global window (Figure 2.8) displays the Key Performance Indicators (KPI) and other important parameters of the controlled process and their associated values, trends and deviations (Hollifield, 2008). If the operator wants deeper information about a specific reactor (Figure 2.9), the operator should be able to click on the reactor to go on the level 2. The operator is able also to visual the major equipment status and the highest priorities alarms (top 2 of 3 highest priorities).

Idea 2: Planning visualization

The operator can visualize the shift between the plan and the actual time with an analog indicator. An additional function can be to give access to the operator to the plan when he clicks on it. That way the operator can visualize it on another display with more information such as time completed, left and time comparison between run plan and actual plan and percentage of completion of the task.

Idea 3: Analog Indicator for trends

Hollifield (2008) describes the analog indicator as a powerful tool since it shows data in context:

- The different working range: desirable operating range (within the dashed lines), the operating range (the white part), the critical part (the grey one);
- The trends over time: tendency over a short period of time (eg. 10min) or a longer one (eg. 1h).

Hollifield (2008) describes the possibility to have one analog indicator instead of two to express the flow difference between “IN” and “OUT”. One graph can summarize all the information, showing ε=Flow_out-Flow_in on the indicator and the flow values before and after the indicator just like on figure 2.6. This system is supportive when the main goal is to keep a constant relation between flows, and not only the flow in or flow out.

Idea 4: Alarm System

There is an Alarm indicator that appears with a priority level from 1 to 3 and an associated colour to catch the attention of the operator on the problem on one part of the display (Figure 2.8). It can appear in the upper part or the bottom part of the indicator.

Idea 5: Global process view

What the authors call the “Global Process View” is however the important parameters shown in an circular way (Figure 2.8). Each 1/12 of the circle corresponds to the value of a parameter. In this example, 12 parameters are analysed for A1 and A2. The operator can visualize quickly upper limits (dashed lines) and actual values which is a ratio since the dashed line are constant. It depends on the scale for each parameter. All the actual values create an “image of the process” (represented in white). The information is a percentage or a ratio, and not the actual value. The representation gives a quick support for the operator to monitor the process, and it is also easy to describe the process during the past shift since key parameters are shown in the same graph.

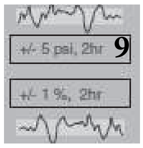


Figure 2.5. Sparklines (Hollifield, 2008)

Figure 2.6. Sparklines (Tufte, 2010)

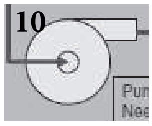


Figure 2.7. Dynamic System (Hollifield, 2008)

Idea 6: Trends
The KPI are directly shown in the overview display (Figure 2.8). It shows the trends over a period of time (12h in the figure 2.8). However, it does not show the expected tendency. It is possible to see that the Y-scale fits automatically to the graph since there is an auto-range function for a better visualization.

Idea 7: Valve Faceplate
This faceplate is directly integrated into the process picture. It highlights to the operator the valve opening setting, the required flow, the valve current flow output and the mode.

Idea 8: Possibility to go to the other menus from this level
The operator has an easy access to the other menus from the same level or to go to another level. With different buttons on the bottom on the screen, the operator can do it.

Idea 9: Use of sparklines
Tufte (2010) defines sparklines as *"small, high-resolution graphics usually embedded in a full* context of words, numbers, images" and they are "datawords" which means "data-intense, design-simple, word-sized graphics". Nowadays, sparklines are used for financial data such as currency exchange rate (Figure 2.5). However, it should be noted that the red is used to describe the oldest and newest rates, and the turquoise-blue to the low and high level over time. These colours should not be used like this since the red is restricted for alarms. In this book "Beautiful Evidence" Tufte (2010) describes the main guidelines to use sparklines for designing information visualization:
1. Aspect ratio: hill-slopes average 45° since variations are best detected for that angle
2. Presentation: A sparkline should be associated with an implicit "data-scaling box". In figure 2.6, this box is composed by beginning/end, high/low points.
3. Vision: Adapt the line weigh and the contrast between data and background
4. Resolution: For environments such as financial trading or control rooms, 500 sparklines could be visualized on 25x45cm (A3 paper).

Sparklines visualization have 5 to 100 times higher resolutions than conventional association of graphics, tables and other kind of text. It can support pattern-finding, comparison between data and monitoring (Tufte, 2010). According to the authors, it can improve the operator's decision-making since it improves the probability to understand right a data shown on the screen.

Idea 10: Status depiction for dynamic system
An easy choice is to use bright colour to describe the pump status such as green for "running" and red for "stopped" like in a traffic situation. However, the red colour is associated to emergency situations or alarms and should not be used in that case. The pump status should not catch the attention of the operator but just give him an information.

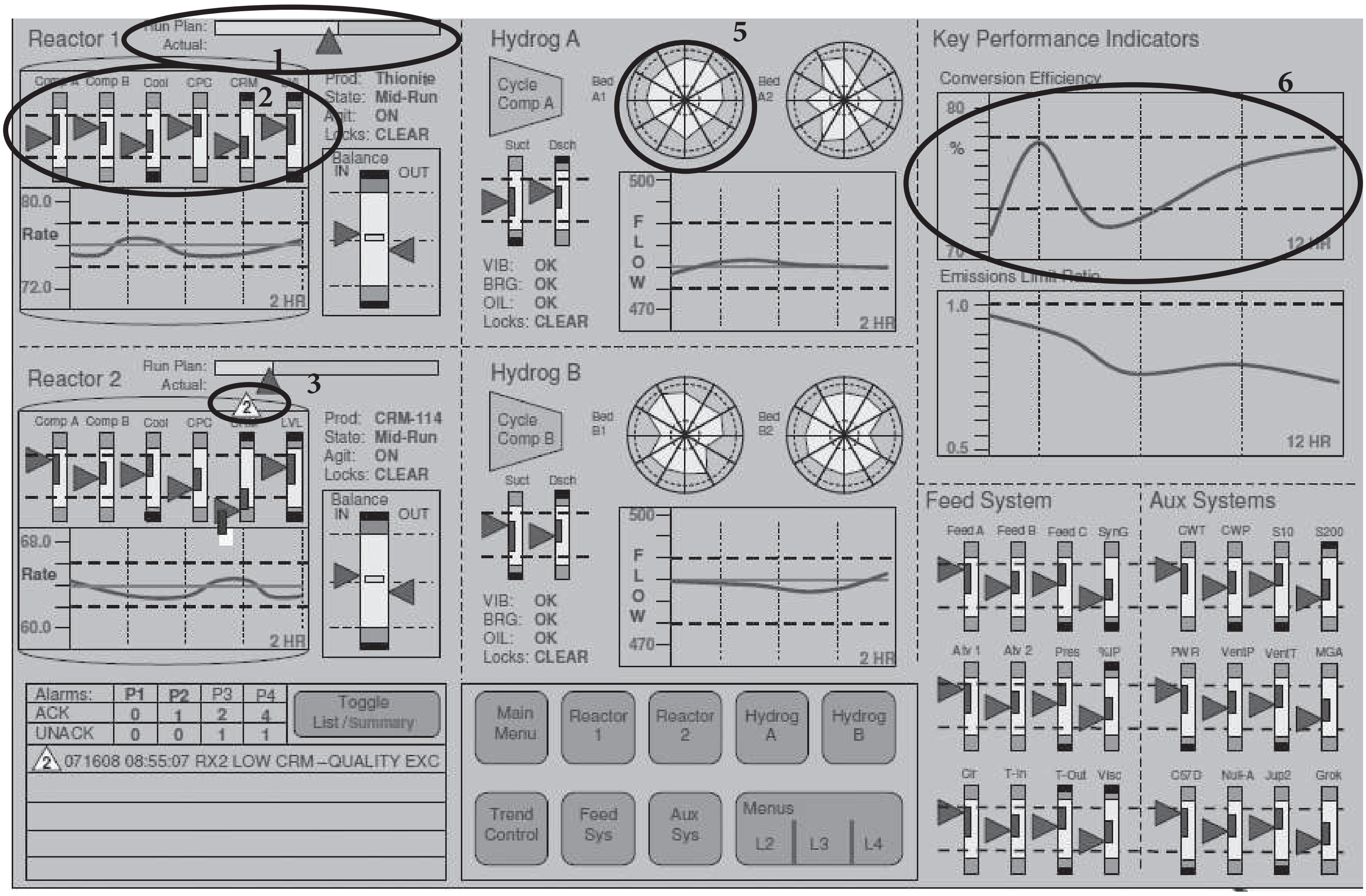
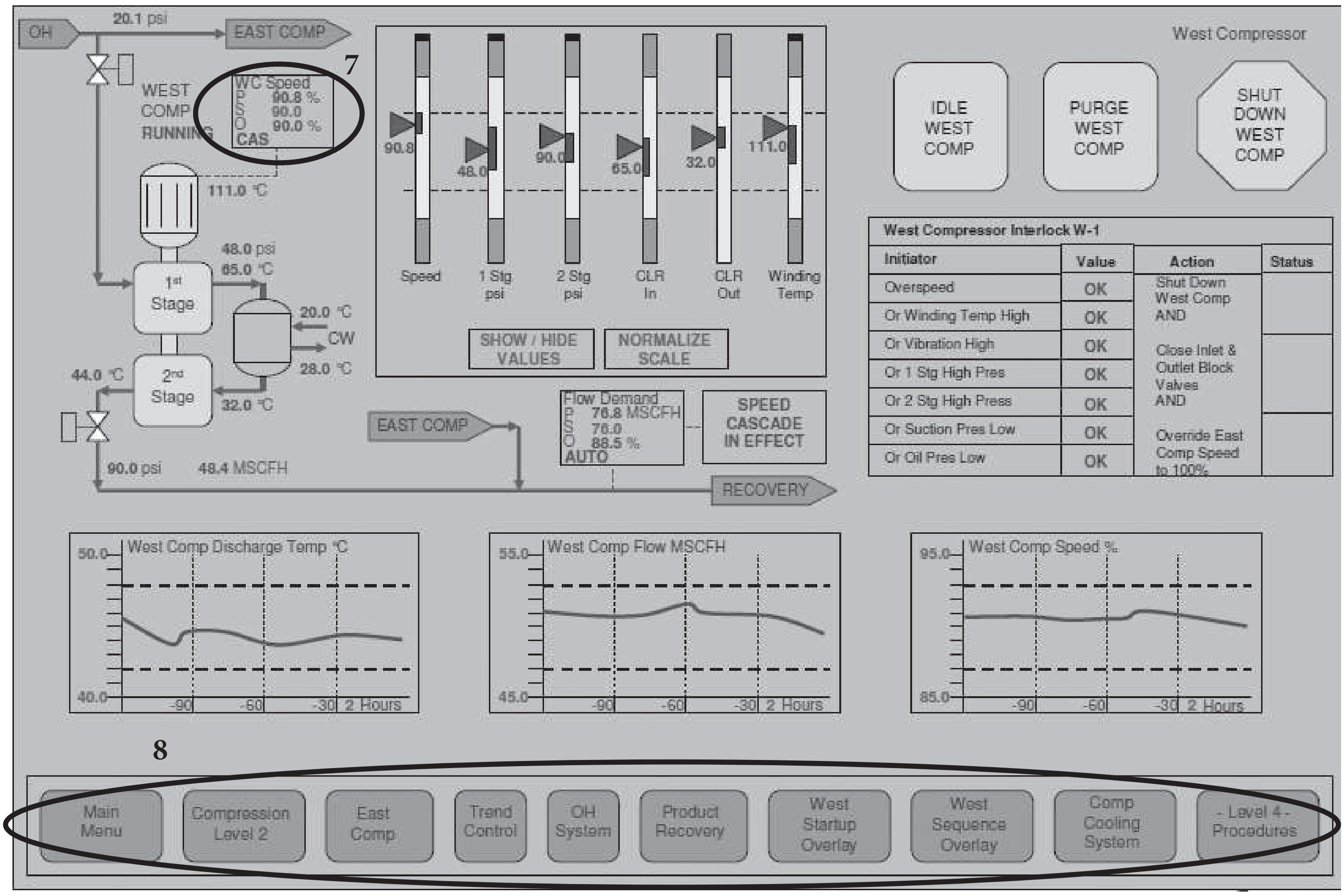


Figure 2.8. Overview Display (Hollifield, 2008) (Above)

Figure 2.9. Process Unit Display (Hollifield, 2008) (Underneath)



Making Control System Visible

Liu et al. (2004) stresses that human-machine designers have to represent functional primitives in an easy and reliable way such as the operators can understand the relations between the different variables very quickly. They mention that graphical representations should not increase mental workload but improve understanding.

Liu et al. (2004) defines a library of basic graphical presentation. Some might be useful for this thesis work especially if they are associated with one another.

Graphical presentation 1 (Figure 2.10)
It is a simple representation to control where the parameter x stands compared to its set-point x_{set}.

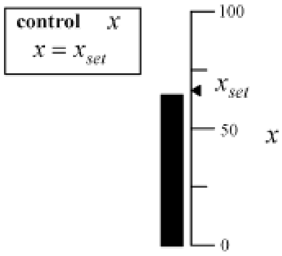


Figure 2.10. A graphical representation of function control (Liu et al. 2004)

Graphical presentation 2 (Figure 2.11):
The rate control visualizes the changing rate of x in the graphics. This representation can be used to visualize both x and x'.

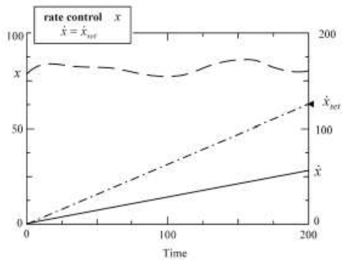


Figure 2.11. A graphical representation of functional primitive rate control (Liu et al., 2004)

Graphical presentation 3 (Figure 2.12)
It shows the different mode possible for a specific process. It is either manual choice (a) or automatic (b) and then the graphics are showing the information to the operator.

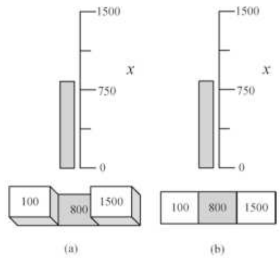


Figure 2.12. Graphical Representations of functional primitive mselect aslect (Liu et al., 2004)

Graphical presentation 4 (Figure 2.13)
It selects a value x depending on the minimal value of x_1, x_2 and x_3. The graph allows the user immediate comprehension about the function.

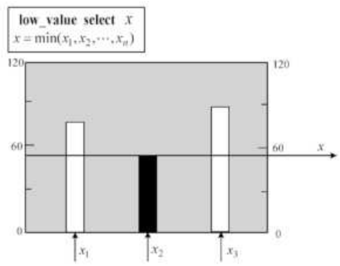


Figure 2.13. Graphical Representations of functional primitive low_value_select (Liu et al., 2004)

Graphical presentation 5 (cf. Figure 2.14)
This graph shows addition of subtraction of three values and gives the output to the user.

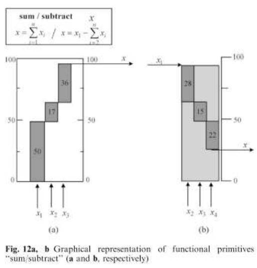
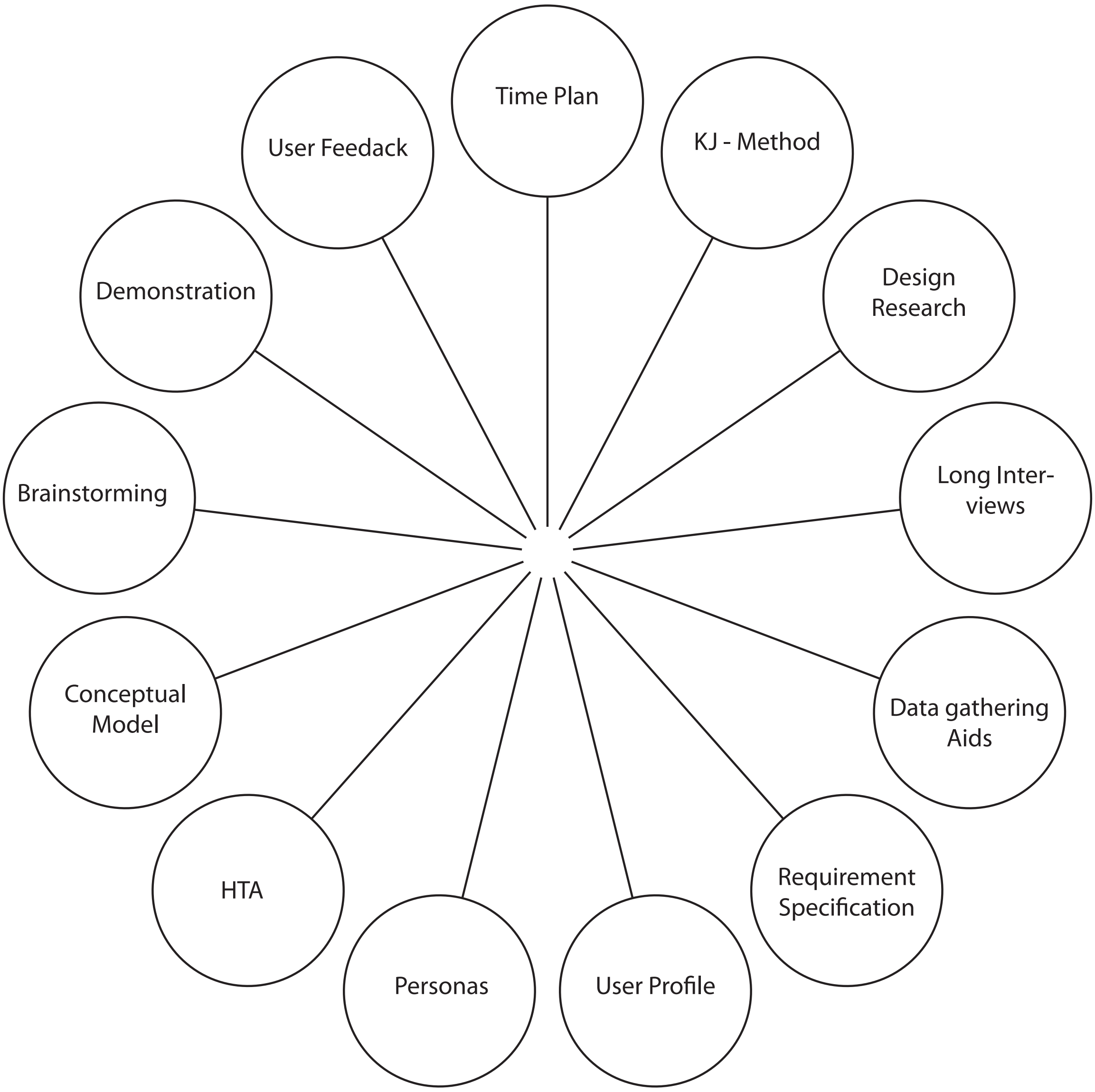


Figure 2.14. Graphical Representations of functional primitive sum substract (Liu et al., 2004)



CHAPTER 3
METHODS

This chapter gives an overview of the human factors and product development methods used in the thesis.

3.1 Time Plan

The Gantt chart's horizontal axis is the time span of the project, divided into increments which are specific to the project. Activities are displayed on the vertical axis on the left part. Bars of varying lengths are plotted on the chart representing the order, timing and length of time for each activity. Gantt chart is easy to create, to understand, to implement changes and provides a supportive schedule baseline (Pinto, 2010).

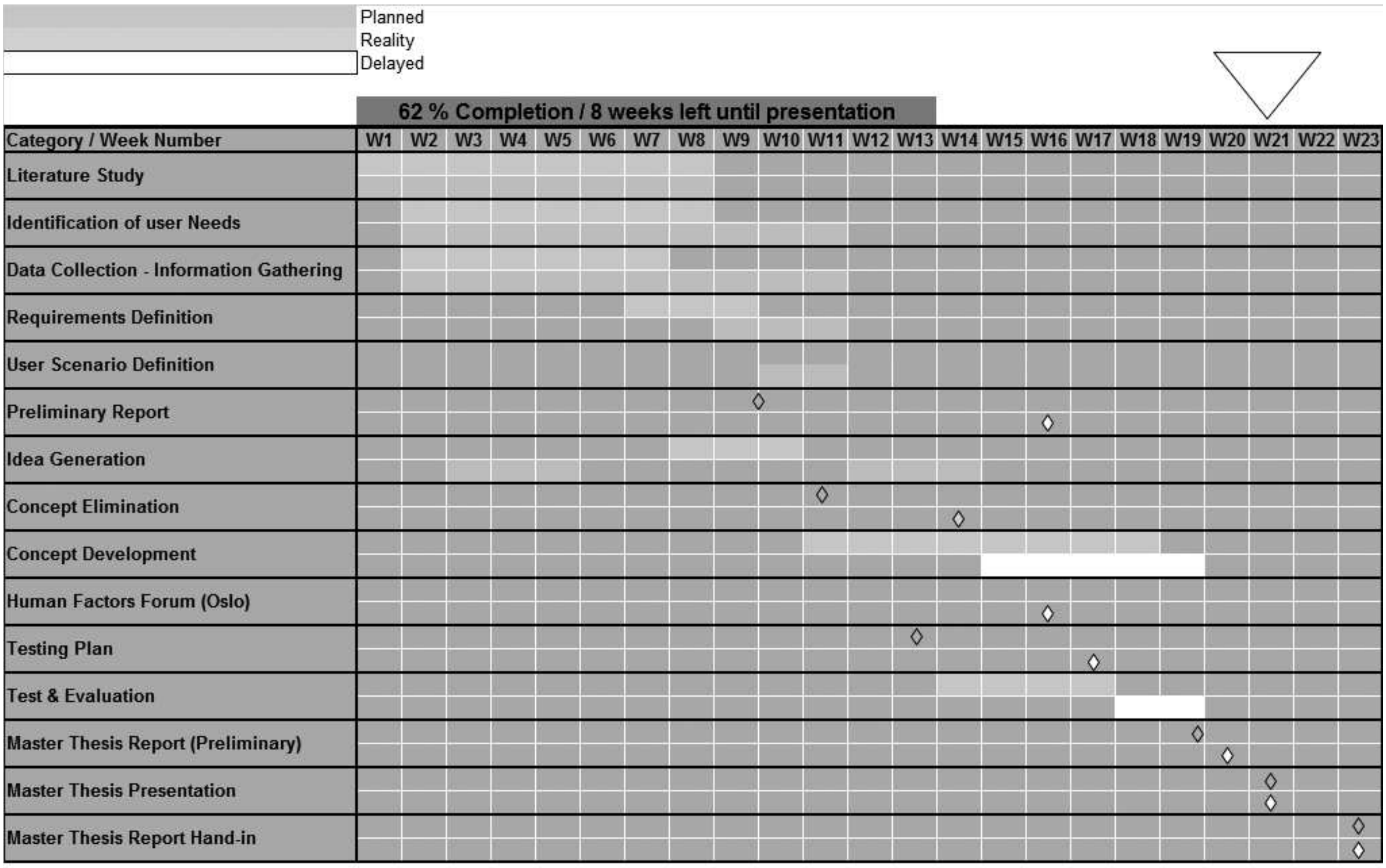


Figure 3.1. Rectified Gantt Chart after 13 weeks of master thesis work (Microsoft Excel).

3.2 KJ-method

The KJ-method (or affinity diagram) developed by the Japanese Jiro Kawakita maps the key information by associating them. It also facilitates discussion between team members and help organize the information by grouping them under different main topics (Bergman and Klefsjö, 2010). It was then computerized and structured for writing the report with Citavi.

Figure 3.2. KJ method on the office's wall.

3.3 Semi-structured long interviews

As a method for gathering information, long interviews are useful for gaining insight into the end-user needs. When performing an interview it is helpful to only mildly guide the discussion and let the users lead it to the direction they want in order not to narrow the scope of the discussion (Karlsson, 2010). Showing interest in the operator's work and the problems they encounter is a key issue to gather useful information.

3.4 Data gathering aids

Checklists and questionnaires about information presentation aids the interviewer in collecting relevant information as most of the time the data is not given one after another. Notes are taken over the duration of a visit to pick up information the initial checklist and questionnaire misses. These notes are then transcribed the next day to get a reliable description of the interview (Ulrich and Eppinger, 2008). Pictures are taken if permitted. However, some of the more valuable data is not directly said but rather seen or experienced.

3.5 Requirement Specification

The requirements specification describes the main demands the product should meet (Almefelt, 2011; Ulrich and Eppinger, 2008). It captures generic needs from theory and specific user's needs from study visits. Different principles, guidelines and laws found in the literature review are applied to define the final requirements list.

3.6 User Type

This method identifies the different users of the interface in a control room (Janhager, 2005).

3.7 User Profile

A user profile describes the needs of the main user (Janhager, 2005; Bligård and Osvalder, 2010). It summarizes the main common characteristics of the operators gathered during study visits and extracted from company documentation.

3.8 User Relations

This method describes the different relations between the different user types when using the interface (Janhager, 2005).

3.9 Hierarchical Task Analysis (HTA)

A HTA defines the work done by the operators for different tasks. The analysis breaks down and organize tasks, goal and sub-tasks (Ainsworth, 2004, Bligård & Osvalder, 2010). The HTA supports the design during the concept development phase as it structures the definition of scenarios and then concepts.

3.10 Human-Automation Interaction Model (H-AIM)

This part describes how the H-AIM aids to define the user's mental model. Andersson (2010) has developed a model to describe the human-machine system which is related to the project. According to Andersson (2010), the model (Figure 3.5) should be used as a mediating tool to facilitate system thinking. It can be useful for analysis of an actual automation system but also for designing improvements for a system.
The H-AIM includes five main theories.

Abstraction-Hierarchy Model
This model is explained in detail in the subchapter 2.8.

Perception-Action Cycle
This cycle (Figure 3.3) is divided in three steps and is applied to the abstraction-hierarchy model giving it a new axis of work.
The first step, perception, highlights the assessment of the information by the human-machine system (Andersson, 2010).
The second step, analysis and decision-making, relates the information analysis and the reasoning behind the decisions to take. A difficult perception (mismatch between the system and the user) of the state of the machine can lead to misinterpretation and then wrong evaluation by the user (Osvalder, 2009).
The last step is related to the actions performed after the decision-making phase. The designer can here highlight if there is a mismatch between the intentions of the users and the system support to take the execution of these actions (Osvalder, 2009).
In the figure 3.5, perception-action cycle information for each level is highlighting in dark grey.

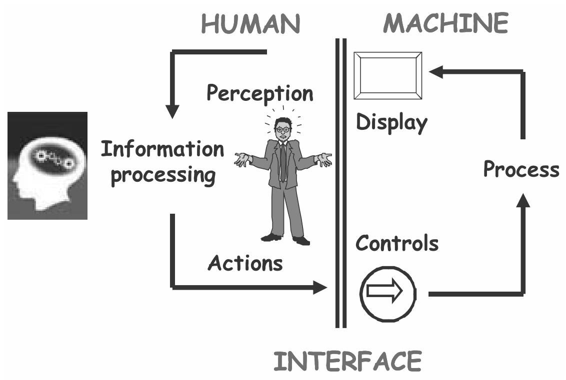


Figure 3.3. Perception-Action Cycle for a Human-Machine Interaction (Osvalder, 2011)

Control Loop
The control loop (Figure 3.4) highlights the continuous influence between the different levels of abstraction. By showing the relation between the different levels, it helps the designer to design an interface that take into consideration the 5 levels of abstraction since a single change in one level impacts on the 4 other levels. In the figure 3.5, control loop information for each levels is highlighting in light grey.

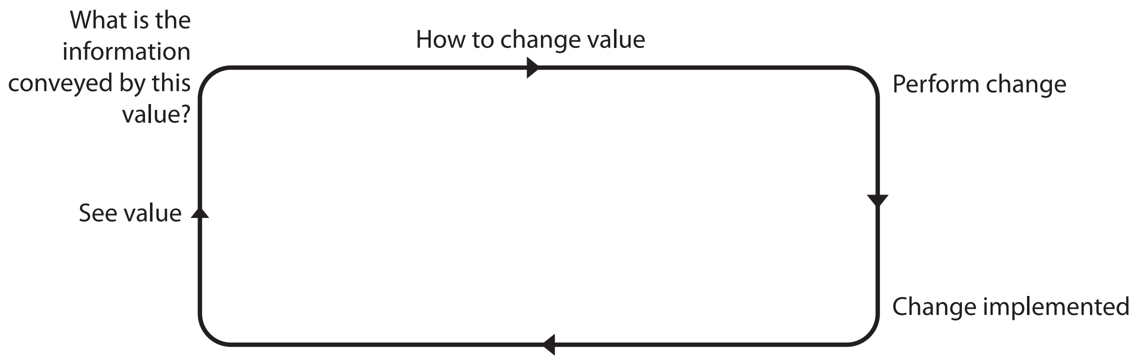


Figure 3.4. Control Loop Example for changing the value of a variable

Performance Influencing Factors (PIFs)
These factors affect performance and highlight the likelihood to create an error with the

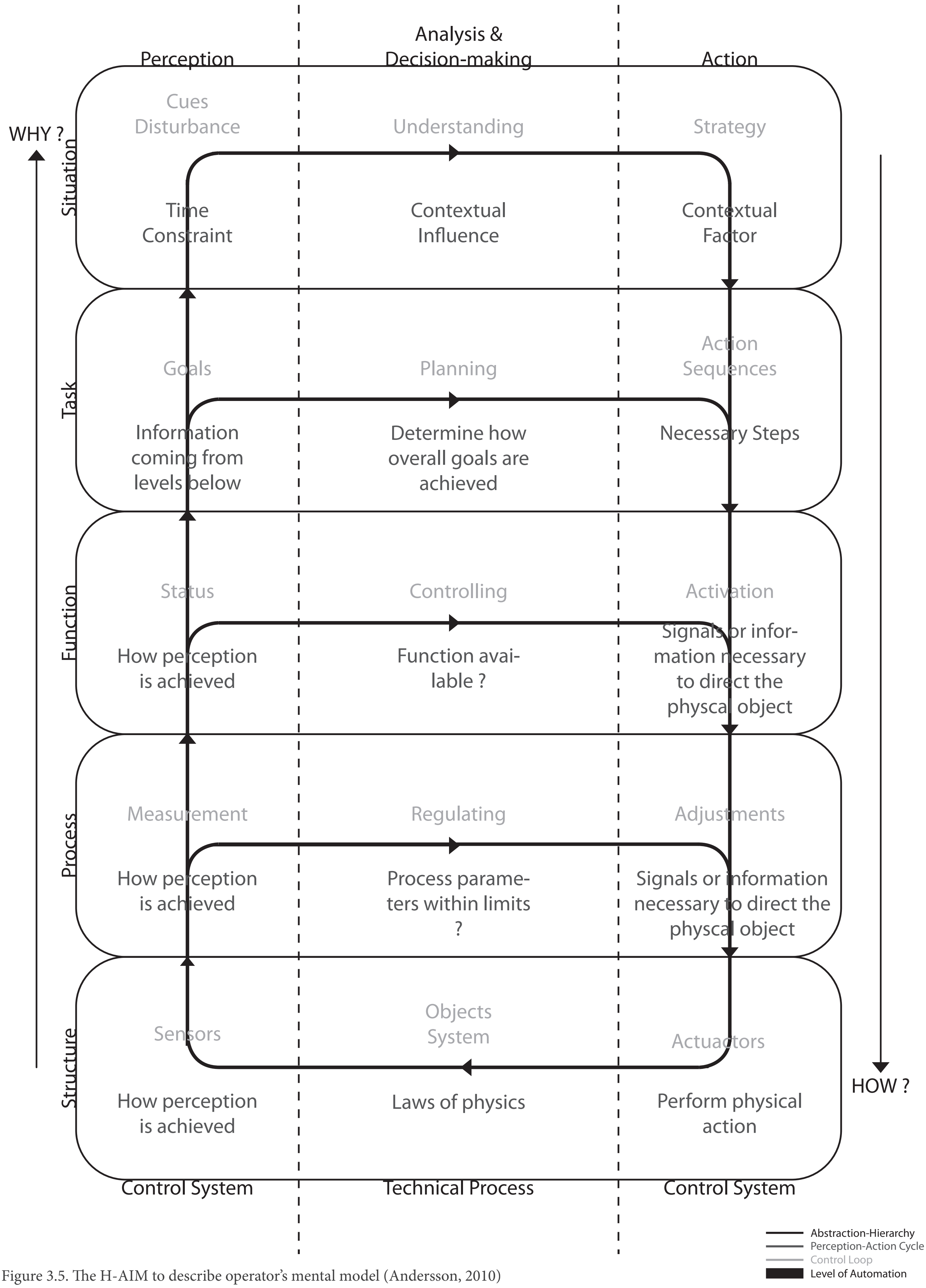


Figure 3.5. The H-AIM to describe operator's mental model (Andersson, 2010)

system interaction. This part of the model will not be used for the authors' analysis. Indeed, Andersson (2010) did not elaborate how the PIF should be fully integrated to his model to predict human performance.

Level of automation
The LoA is visualized in the model by drawing a thick line between the different levels of abstraction. The part above the line is considered as the operator work, and the part underneath the line is supposed to be integrated in the automation system. No real guidelines are provided to define the LoA.

Procedure
Andersson (2010) advises human factors engineer to divide the work in two phases. The first phase is to analyse the actual human-machine system and the second one is to use the H-AIM for improved design of it.
Both phases starts with the description of the system through the abstraction-hierarchy model by defining the goals the user wants to achieve, what tasks need to be done to achieve the goal (Allendoerfer et al., 2005) and then the functions to support the tasks, the process and physical structure related to these tasks.

Due to the difficulty of separating human and machine, it was decided to interpret the model in a different way. The model analyses the entire human-machine system and the focus is on the separation between the automation support and the human role.
Instead of describing two models, one for the machine and one for the human, one overall model of the entire human-machine system describes the current interaction design and the expected interaction design for improved decision-making and situation awareness.

3.11 Brainstorming

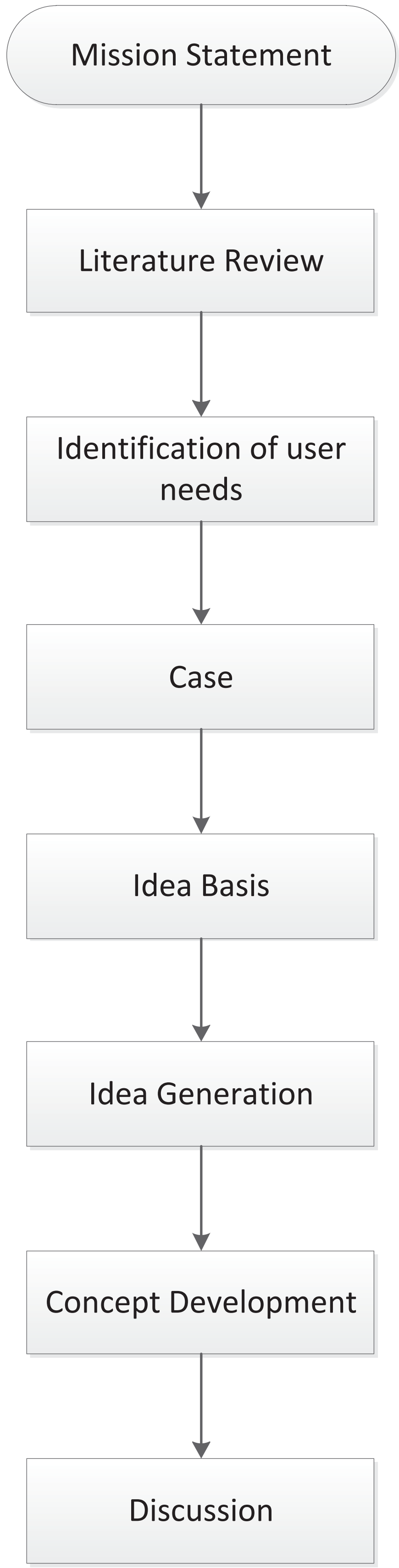
Brainstorming is a creative method to generate concepts and solutions for a project and encourages participants to design freedom by welcoming any idea (Johannesson, 2011). It is performed by drawing sketches and having discussions about them.

3.12 Concepts Implementation

The most innovative concepts are developed in parallel to delay the decision when the best information is available and to explore as much as possible different design possibilities (Ward et al., 1995; Alfredson and Söderberg, 2010).
The graphic design is realised with Adobe Illustrator CS5 and the interaction design is realised with Microsoft Expression Blend 4.

3.13 Demonstration - User Feedback

Ulrich and Eppinger (2008) suggests concept testing and demonstration as a way to elicit feedback information about various concepts throughout the various stages of the process. A demonstration (Demo) is a simplified version of the final product showing the main aspect of the concept. The demo can then be shown to the user to rely on his feedback to improve the concept and not only on the judgement of the development team.



CHAPTER 4
PROCEDURE

This chapter presents the way the product development process has been carried out. The procedure was defined according to Ulrich and Eppinger (2008), Almefelt (2011) and Elmquist (2011). It aims to define the different stages of the development and to describe how and where the various methods were applied.

4.1 Literature Review

A deep literature study was performed to get a good foundation into the area of control rooms and control screens. Some of the more interesting findings can be seen under the theory chapter.

Design Research

The Design Research is made up of two parts. The first part is mainly gathered from the literature review and the second part is inspired from outside sources found on the Internet.

4.2 Identification of User Needs

To identify the needs of the users and to keep the relation to the user several methods were used. Study visits were performed to gather information about the user from different process industries.

Data gathering

During the study visits the data was gathered with checklists which were then compiled and grouped after similar themes and compared using a colour scheme. This provided an overview on the topics and helped in sorting out irrelevant information (Appendix A).
Due to the difficulty in receiving access to control rooms and operators no short interviews were performed. As a method for gathering data during the visits long interview were used with some observations. The operator's station was often used as a mediating tool to help probe the operator. Normally when one is trying to identify user needs it is desirable to perform short interviews to get more insight into specific areas.

Requirement specification

The requirements specification was done by taking points from both the literature study and the study visits and by reformulating them in to requirements. The requirements specification is useful both as a tool to guide the design work but also as a way to check if the end-product meets the demands. The requirements specification is a living document and is subject to change as the project progresses and new information is acquired.

User type

By identifying the different types of users involved in the control room, one can see what user should be the primary focus. It also gives an idea over what other types of user might be affected by changes.

User Profile

The user profile describes the needs for the main user of the system. The layout was based on data gathered from the study visits. It summarizes the main findings shared across the different study visits. The user profile is useful as it fosters an understanding about the operator and helps to establish the characteristics of the operator.

User Relations

The user relations describe how the different user types interact. This method identifies the people affected by the control screen.

4.3 Case

The use case with the process flow and the HTA aid in building an overall case to work with. The different parts work as mediating tools when developing concepts as it helps the design process in various ways. One example is that it allows the designers to discuss a concept and to explain how it would work with a case.

Use Case

The use case contains a short description of a task that an operator performs followed by a list of the steps that are involved in it. It works as the foundation for the process flow and the HTA. It was decided to make two cases for one operator to reflect the work done by one operator at a station in a control room for the Oil & Gas Industry.

Process flow

The process flow gives a graphical representation of the actual process. It is useful for structuring the case. It is also useful for making the case feel more realistic.

Hierarchical Task Analysis (HTA)

Like the process flow the HTA helps to structure the case. It shows the connection of the different steps that the operator does. It also gives detail to the case and makes it more enveloping.

4.4 Idea Basis

The H-AIM is used as a basis when developing the concepts. It analyses the interaction between the operator and the system. It intends to describe the actual design of the control rooms and a future design based on the H-AIM and highlights the main improvements concerning situation awareness and decision-making aspects.

4.5 Idea Generation

This stage amalgamates ideas from the theory, study visits, user needs and cases to create different concepts based on the idea basis chapter.

Brainstorming

The brainstorming was done in one major session and a shorter one. In the major session the authors made concepts and discussed them. In the shorter session another thesis group was brought in and was given a short description about the purpose and background in order to generate new ideas from a different angle of view. The ideas generated during the major brainstorming meeting were shown and then discussed.

4.6 Concept Development

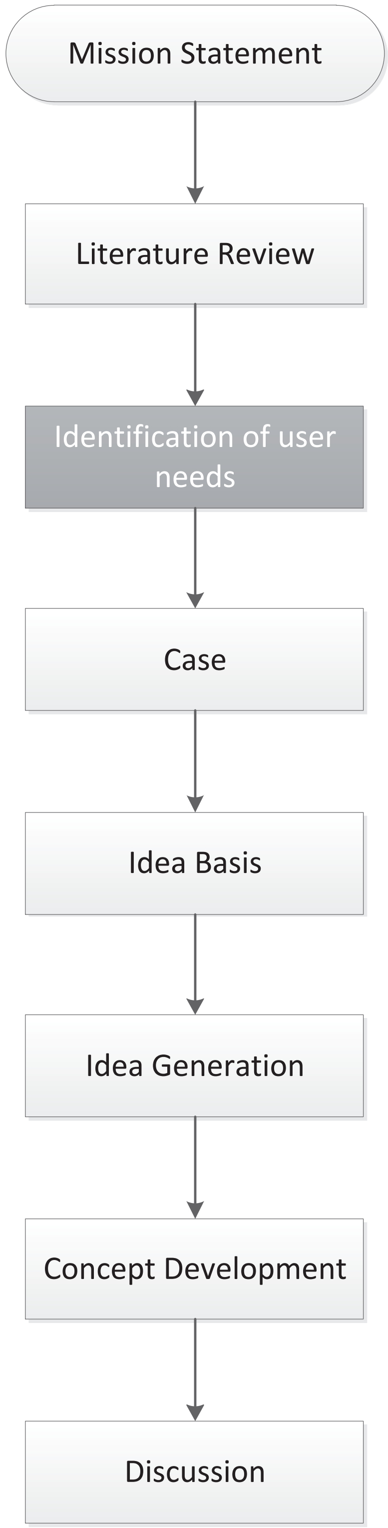
This part concerns the design implementation of a prototype.

Concept Implementation

The graphic design is realised with Adobe Illustrator CS5 and the interaction design is realised with Microsoft Expression Blend 4.

Demonstration and Feedback

By showing an operator a demo of the conceptual solution and asking for their opinion allows for an early input on what could be a problem and what they perceive as a possible improvement. This could act as an indicator if one should continue the development or go back and do changes.



CHAPTER 5
IDENTIFICATION OF USER NEEDS

This chapter deals with the different steps to define the main user's needs. The first section, Data Gathering, presents the company visited. The second section, Requirements Definition, is the requirement specification composed out of demands (requirements) and wishes (guidelines) which will be used for the concept development. The third section describes the human users operating the system.

5.1 Data Gathering

The study visits took place at five companies representing five different industries. All the control rooms were different in size (number of displays) and systems used (ABB, others or an association of both). This allows for an overview from similar control room system in different processes even if the primary focus is the Oil & Gas Industry.
The data gathered during the interviews on lists were grouped after similar themes and then compared using a colour scheme (Appendix A).

Swedish Match
Göteborg
Process Industry
Swedish Match was founded in 1992 by merging two companies from the early 1900's. It produces snuff and snus (such as the Göteborg Rapé, Figure 5.1) for the Swedish and American market (Swedish Match, 2012).
The control screen interface was developed in-house. From the control room the operator manufactures different recipe by mixing different type of snus and boiling of it. He is also in charge of cleaning the tanks through another system. He is in charge both for automated steps (control room) and manual steps (workshop).
One operator was leading the study visit by explaining the process on the workshop and discussing about the interface.

Figure 5.1. Göteborgs Rapé

Vattenfall Ringhals
Väröbacka
Electric Power Industry
Vattenfall is a Swedish power company generated by either fossil fuel, nuclear power or hydropower. Ringhals is a nuclear power plant and produces 20% of the total Swedish electricity with four reactors (Vattenfall, 2012). The training instructors from KSU were leading the study visits through the different simulators, either with analog indicators on the wall or next-generation of LCD screens.


Figure 5.2. Ringhals seen from the sky

Figure 5.3. Kalundborg Refinery seen from the sky

Statoil
Kalundborg
Oil & Gas Industry

Statoil, founded 40 years ago, is a norwegian-based energy company with worldwide operations in more than 30 countries (Statoil, 2012). The refinery in Kalundborg refines crude oil and light oil to petrol, jet fuel, diesel oil, propane, heating oil and fuel oil (Statoil, 2012). Denmark and other Scandinavian countries such as Sweden are the main customers for the oil produced in Kalundborg. The plant is controlled by one control centre that is separated in four different stations, a 15 years-old Honeywell system, controlling different parts of the plants. During the full-day visit, 3 operators from 3 different stations were interviewed during two shifts.

Figure 5.4. 800xA in Borås

CGM-ABB
Borås
Simulator "Paint factory"

The authors also got the opportunity to test the 800xA EOW-3 for 3h in Borås control room simulator. It gave them some insight into the operator's work and problems. The authors were asked to control a virtual paint factory and to create recipe out of paper-based checklist.

Figure 5.5. Fresh water Coming out from a faucet

Göteborg Vatten
Göteborg
Utilities

Göteborg Vatten is responsible for the fresh water cleaning and distribution in Göteborg area. The authors were able for half-day to visit the control room but also to see the treatment steps on the plant for the city water and to get an overview about the controlled process. Most of the work is automated and controlled from the control room but can also be controlled manually near the different stations. The operators are in charge of different systems and can also solve some technical problems.

Södra Cell
Värö
Pulp and Electric Power Industry


Figure 5.6. Södra Cell 2nd Control Room

Södra Cell is implemented in Värö since 1972. It is one of the world's leading manufacturers of paper pulp (Södra, 2012). Södra Cell is organized as a cooperative owned by 55 000 people. Moreover, the site is an association of multiple factories separated into different parts: cutting woods, producing black liquor, steam power.
The visit took place for the first two parts with three operators in total. In the first control room (Figure 5.6), two operators are controlling a process-based display. Besides, one of them guided the authors around the plant which aided in understanding the operator's work both in and out the control room.
The last operator, for the black liquor process, detailed his actions for controlling the process and gave to the authors some print screens for further analysis. The authors were also able to observe the shift handover in the middle of the day in the second control room.
The shift leader told the authors that the average age of the plant was 46 years old, and that the people stayed for 25 years in average so the operators were experienced ones but the company might have problem when training new user.

Control Screens today

In the picture Figure 5.7 one can see part of a fairly typical station in a control room. It is made up of eight different screens divided into two sections of three screens for controlling and monitoring the process and two screens for performing desktop-based work and administrative work. On the screen a graphical representation of real process is displayed (process level in the H-AIM).

Figure 5.7. Part of a station in a control room at Södra cell.

From here the operator controls the process (Figure 5.8 and 5.9). This is done by turning different parts like pumps on and off. On the interface this is done by clicking on the green circles in the ABB system. It is also from this view that the operator monitors the process by looking at the numerical values displayed near the specific object.

5.2 Requirements Definition

The requirements specification was formulated from the information gathered during the study visits and from the theory and can be found on the appendix F.

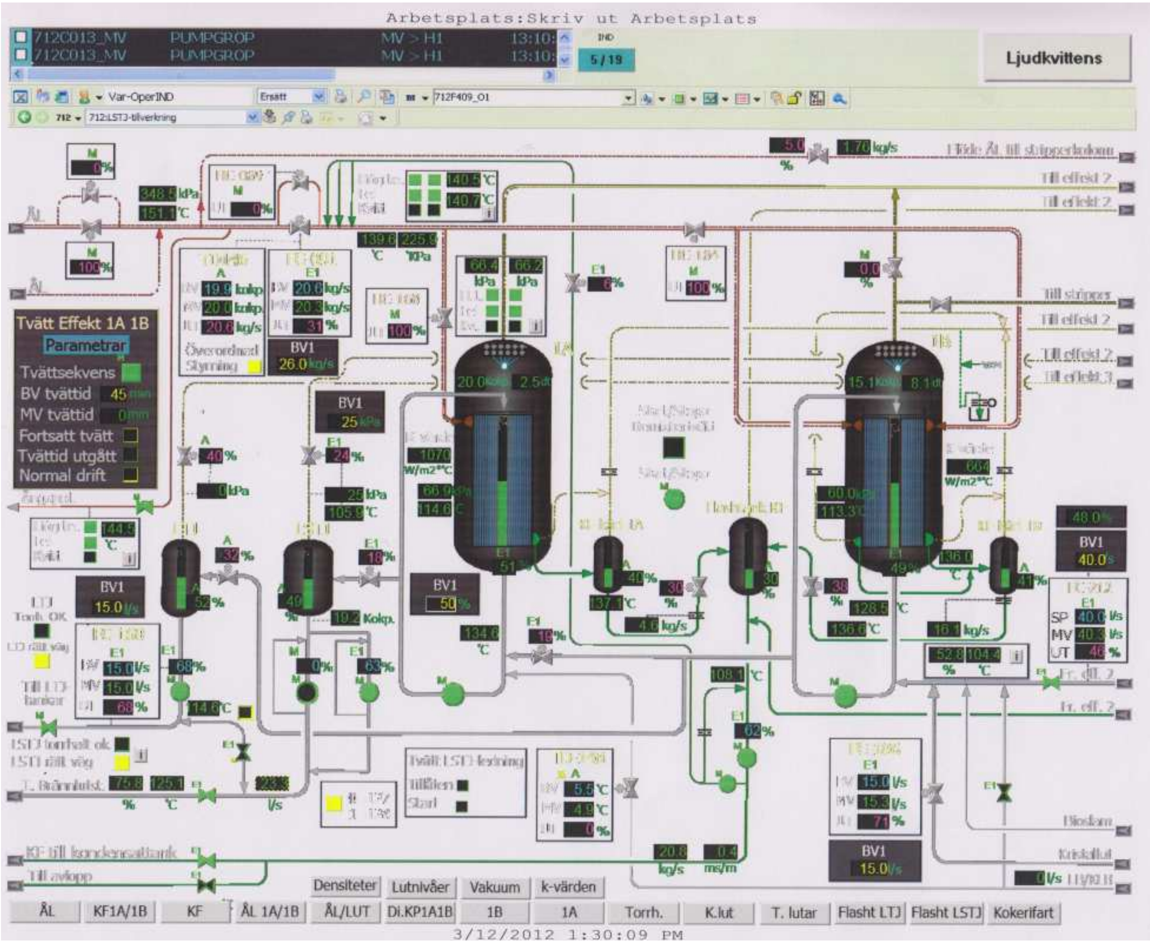


Figure 5.8. A graphical Representation of part of a process at Södra cell

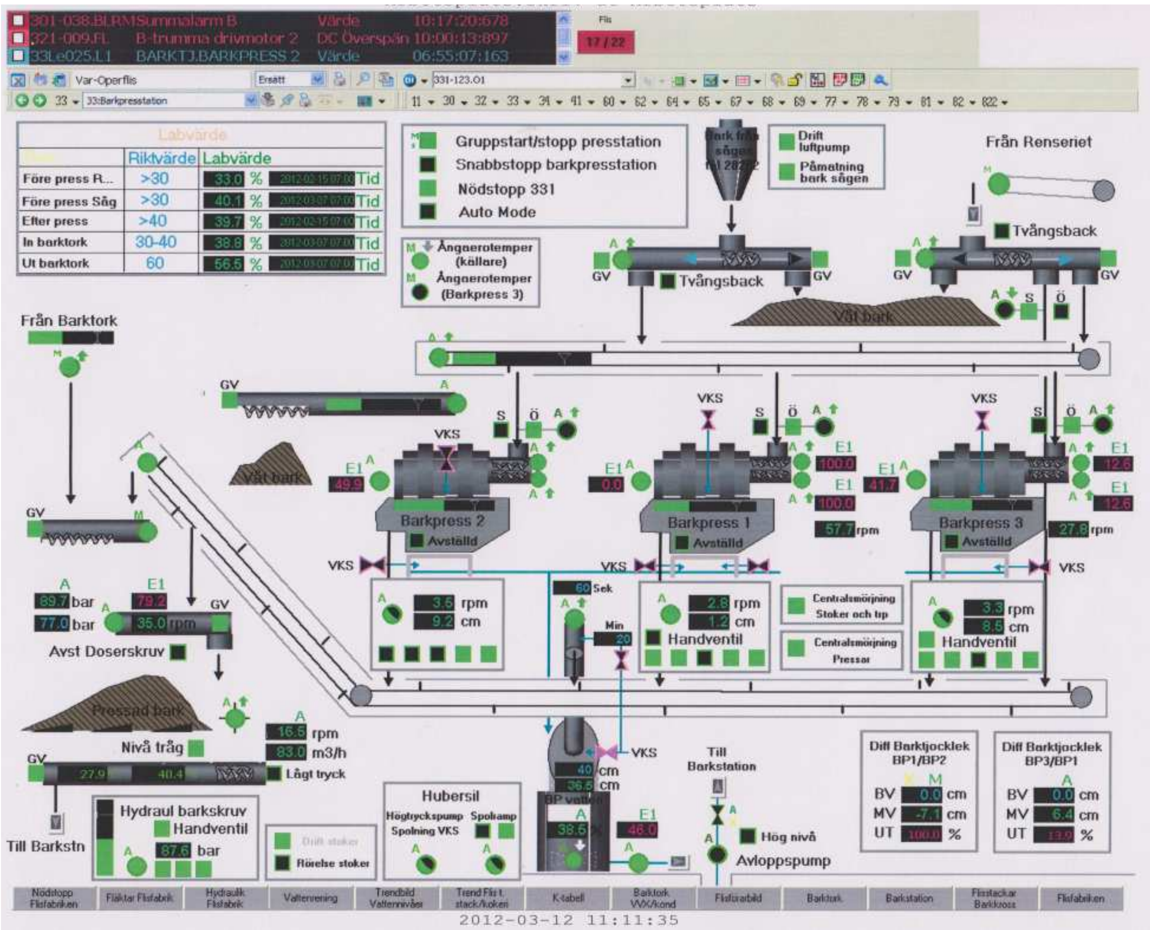


Figure 5.9. A graphical Representation of part of a process at Södra cell

5.3 Users

User Type

When talking about the "users" several different types of users should be considered. The following table shows the users (Appendix G for a vividly description with personas) that are somehow affected by control room and control screens in the different companies the authors visited:

Table 5.1. User Types

User type	Definition	Description
Primary User	Uses the product for its primary purpose	Operator
Secondary User	Uses for the product but not its primary purpose	Shift Leader
Side User	Affected by the product (negatively or positively) in daily life but without having decided to use the product	Other operators in the control room
Co-User	Co-operates with primary or secondary user without using it.	Field technicians

User Profile

A user profile is created for the primary users (the control screen operators) by identifying the degree of performance in a table of use categories (Figure 5.10). The user profile is then explained deeper according to detailed categories (Table 5.2).

High extent

Low extent

	Categories	Degree of performance	Extent of importance of the product
Use experience	Length of use and education	Newcomer Experienced Specialist	Easy to understand and use
	Frequency of use	Rare Occasional Frequent	Ergonomics Stress factors
Influence on and responsibility of use	Influence on the choice of product	No influence Some influence Great influence	Adaptability
	Influence on the use situation	No influence Some influence Great influence	Physical ergonomics Confidence
	Responsibility in use	No responsibility Some responsibility Great responsibility	Reliability Confidence
Emotional relationship to the product	Ownership	Use of general product Use of rented product Use of owned product	Easy to use Characteristic Adaptability
	Social aspects	Of little importance Of some importance Of great importance	Aesthetics/sense Characteristic
	Mental influence of product	User with no mental influence User with some mental influence User with great mental influence	Semantics Aesthetics/sense
Degree of interaction with the product	Cognitive interaction	No cognitive interaction Some cognitive interaction Great cognitive interaction	Semantics
	Physical interaction	No physical interaction Some physical interaction Great physical interaction	Physical ergonomics

Figure 5.10. User Profile of Primary Users

Table 5.2. Detailed User Profile (Next page)

Background	
Type of actor	Primary User and possibly sometimes Secondary User (for maintenance, worker on the field)
Age:	Between 40 and 60. Mostly around 50.
Gender:	Mostly Male. 1 female out of 9 interviewees.
Education & Previous Background:	Electrical, Mechanical Workers. Worked on the system before the full automation and still work on the field.
Language understanding:	Swedish or Danish, English.
Use	
Experience with control rooms:	More than 15 years. Two companies were training two people: 1 year.
Experience with THIS control room:	8 interviewed people only worked with their control room. Only one person worked in another control room abroad.
Systems used:	In-house developed system, ABB System, Cactus System, Honeywell TDC300.
Knowledge needed:	Knowledge about the process. Most of them are still working outside, depending on the shift layout.
Frequency of use:	Daily, depending on shift.
Influence on and Responsibility during use	
Activities	Produce Snuff / Cut wood / Produce Black Liquor / Clean and distribute Water / Produce Oil & Gas Product.
Influence on the choice of product:	The order comes from the production plan.
Influence on the use situation/ Tasks sequence:	Responsible for managing how to use different tanks and in which order depending on the production plan. Responsible for the quality of the end-product (Acting on results from lab analysis).Responsible for dealing with external systems (Entrance Gate / Ships coming & Oil Distribution).
Influence on the interface's flexibility:	ABB System: Usually, one person got feedback from the operators to add something on the process. In one company, the operators were able to add directly their own alarms. Other systems: None.
Responsibility during use:	A mistake could lead to waste of material and financial loss for the company. The optimization of the process could improve the quality of the end-product. In Göteborg Vatten, the operator is responsible for the water distribution for all inhabitants in Göteborg.
Emotional Relationship to the machine	
Ownership:	The company owns the control rooms but operators might see it as their own since they are the ones using it for improving the automation of factory they know by "heart".
Social aspects:	Being an operator in a control room could be seen as a promotion for people who used to work every day in the factory or on the field.
Mental influence of product:	Some mental influence on operators that occurs when the information is presented in a bad way on the screen.

Degree of interaction with the machine

Cognitive interaction:	High. Interface developed without any consideration for good usability / In charge of 4 inconsistent separate systems / Needs for remembering too much information (values but also names) / Lack of support from the interface (not intuitive).
Physical interaction:	Low. Need for walking sometimes due to boredom or mistrust of measurement system.
Permissible Impairments	Accepted in some industries.

Like/dislike

What do you like in the actual interface?	"Process-based" interface. ABB system more intuitive than other. Analog indicators more intuitive than just number on a screen because the operator feels more in control. Alarms Screen where all the alarms from the process can be visualized (ON/OFF Mode) "I don't like it but I HAVE to learn to like it anyway" "It does the job, that is enough".
What do you dislike in the actual interface?	Interface too old. Other systems less reliable (often crashes). No overview screen to display the entire process. Speed of the interface (eg. faceplates takes too much time to show up)
What is missing in the machine to work in an optimal way?	More information about the workflow (instead of keeping the current activities in mind) More information when it is the same product or a similar one with historical changes, or process optimization done in the past but not yet implemented. "Carry" the interface via a tablet (eg. Ipad) near the machine in order to solve a problem and start the process again. A windows-based platform would be more efficient.

Additional Questions

Errors for a novice?	Hard to take the right decision in case of emergency situation due to the lack of support from the interface. Dealing with two systems, and the phone and other systems. Too much information to remember, easy to loose track for a novice, especially in emergency situation.
Critical Cues for the Job?	Check on multiple documents (paper-based, business software, cleaning machine, automation system, laboratory results). Monitoring with homemade alarms. Use a bigger screen to keep track of the key parameters and some trends. Keeping in mind all the names of the physical process (eg. tanks, valves, pumps) to know what process is running. Checklist of all parameters at the beginning of each shift in order to compare the evolution of the parameters during the last two shifts.

User Relations

There are different kinds of relations between the different users. The forthcoming schematic and paragraph highlights these relationships for our system:

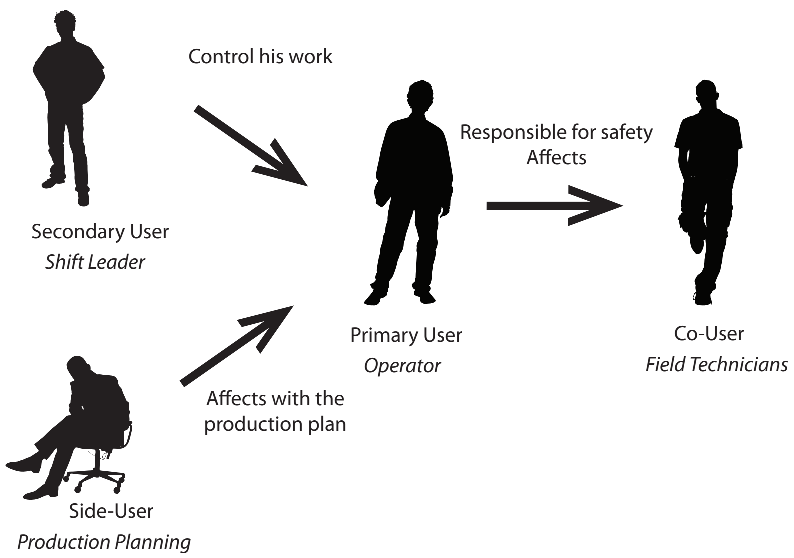


Figure 5.11. User Relations: Control

Control

The operator is the central person in the control room. He is affected by the shift leader, in charge of the control room and the different operators for the shift, but also by the production planner (Side-user) who decides the workflow during a shift. On the other side, the operator is responsible for the associated field technician (co-user), affecting his tasks (eg. maintenance) but also for his safety. An experienced operator told the authors that he always keeps in mind that behind the screens, there is someone on the field that he needs to take care of, especially if the system goes down.

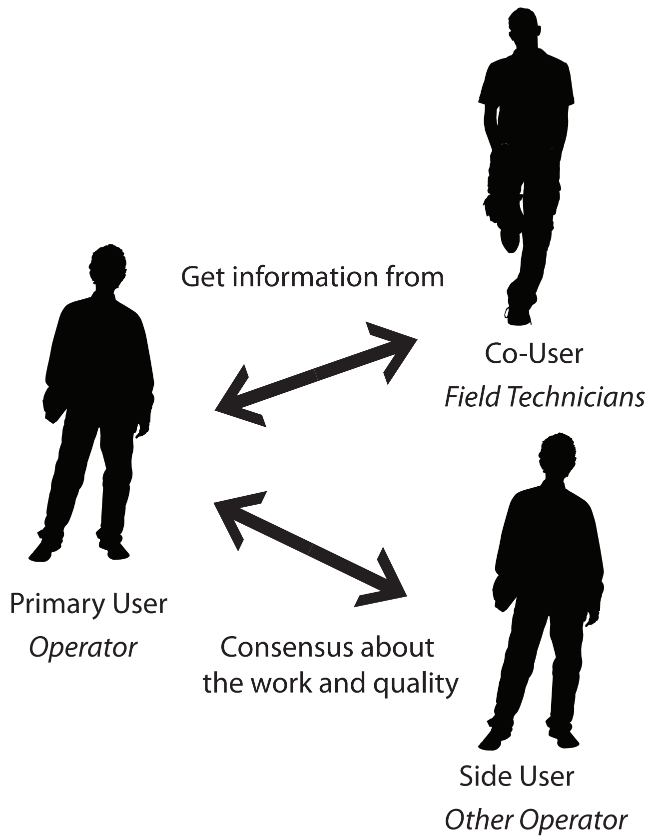


Figure 5.12. User Relations: Collaboration

Collaboration

The operator in the control room is collaborating with other operators present inside the control room. It could be for different reasons. The first one is that there are two people working on the same station. The second reason is that there are multiple stations in the control room and the different operators then exchange on how to improve their work (eg. end-product quality) since they share the same work space. The operator also collaborates with field technicians (Co-user) to get visual information from the field or maintenance status.

Demonstration
In some companies, new operators were trained by experienced people. They taught them for around a year on how the interface works by demonstration and explanation. The interface design should support and facilitate learning.

Meeting
The operators meet in front of the control screens because they share their workplace to exchange information during a shift or during shift handover. The interface should then be easy to adapt during meeting time so every actor can understand easily and quickly the information displayed.

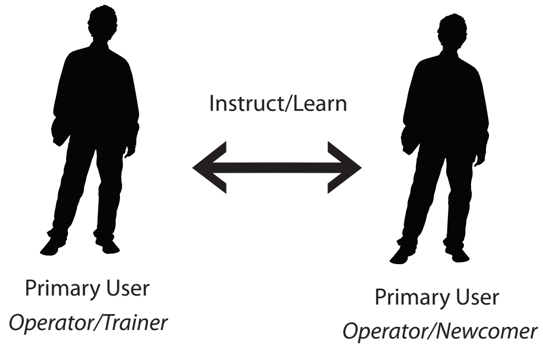


Figure 5.13. User Relations: Demonstration

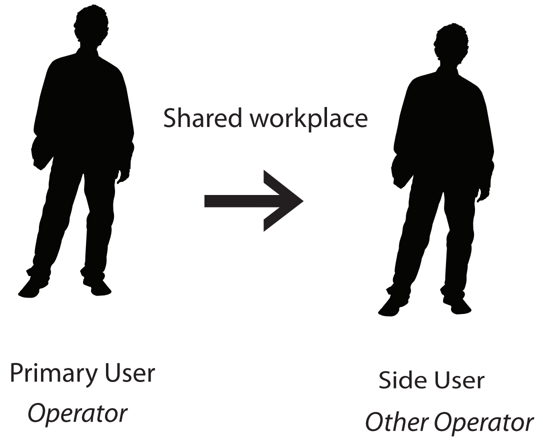
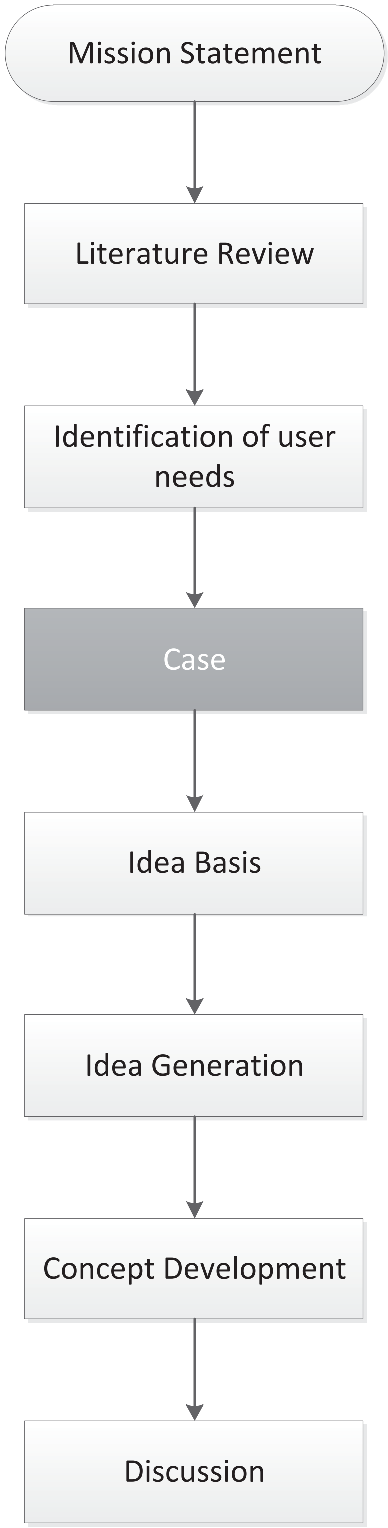


Figure 5.14. User Relations: Meeting



CHAPTER 6
CASE

This chapter presents the two scenarios used for supporting the development of ideas.

The user scenario are a simplification of a hypothetical plant based on the refinery in Kalundborg (DK). For the two cases, a short description explains the general function and the procedure, a process flow shows visually the process the operator is dealing with and a hierarchical task analysis decomposes the operator's interaction with the automation system by breaking down the tasks and goals into sub-tasks and goals.

6.1 User case 1: Managing incoming crude oil and distribution

The operator receives crude oil from the harbour. The crude oil is then pumped to the different tanks. From the tanks there is then a continuous pumping of crude oil out to two process lines. It is crucial that there always is a flow to the processes, as otherwise the process will stop and a length shutdown and startup procedure would be needed to be performed. The operator tries to balance the out/in -put evenly over the different tanks to keep an even level and pressure in the tanks.

Actors: Primary user (operator of screens) and probably co-user (field technicians).
Precondition: Incoming boat with crude oil in the harbour.

1. Oil is brought in from the harbour
2. The operator follows the distribution instructions given from the planning department.
3. The operators opens one valve after another to set specified flow path (V 101-119).
4. Start the pumps (P 101-104).
5. Monitors the flow values in the pipes and valves.
6. Check the level in the tanks (T 101-104).
7. If the level between different tanks is too large.
8. Stop the pump (P 101-104).
9. Close the valve (V 101-119).
10. Open another valve to steer the flow to a different tank (V 101-119).
11. Start the pump (P 101-104).
12. Repeat step 7-11 to keep the levels balanced as crude oil is being pumped to the production

Process flow

The process flow for this scenario can be seen picture 6.1.

HTA

The HTA related to this scenario is presented with the picture 6.2.

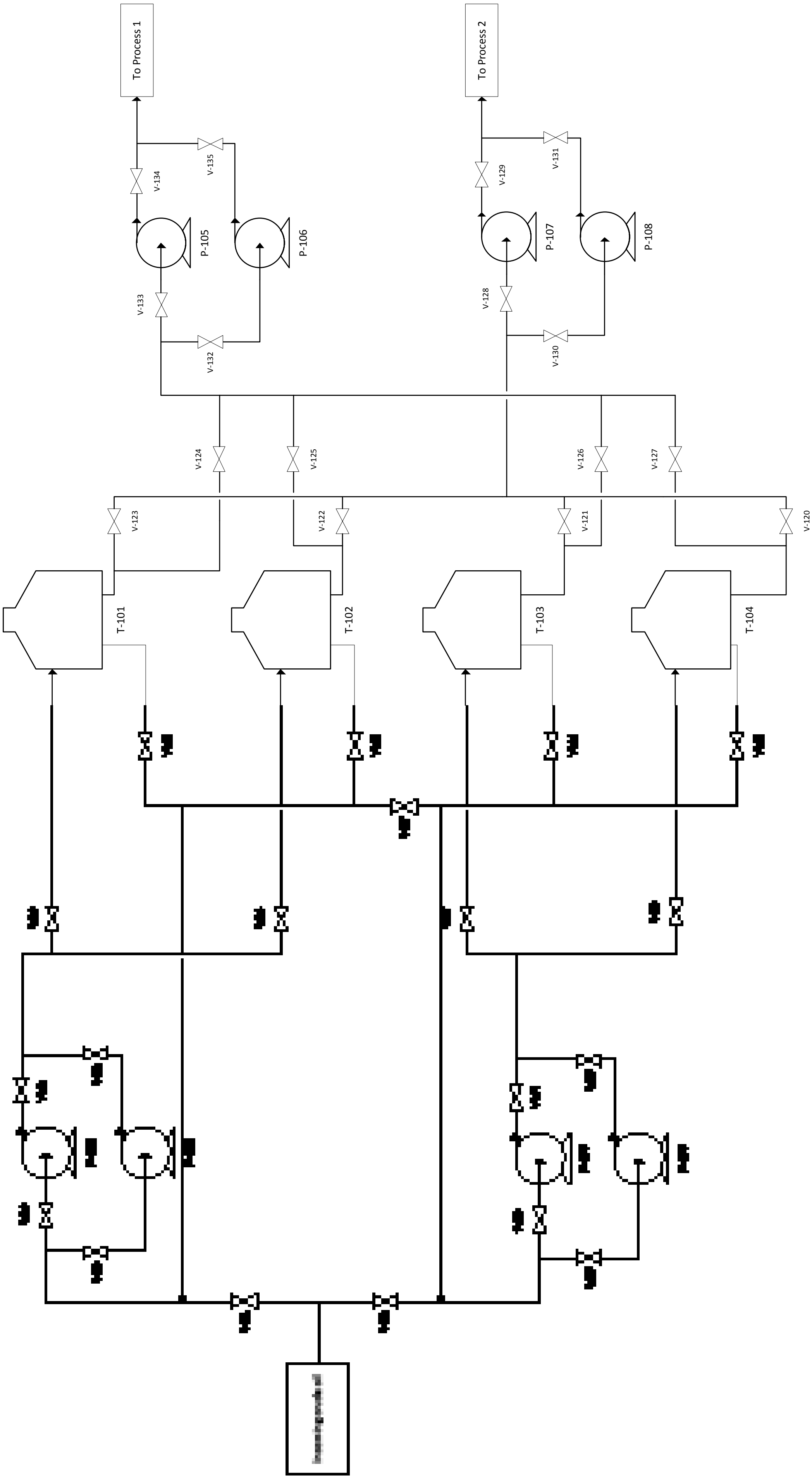


Figure 6.1. Scenario 1:
Process Picture

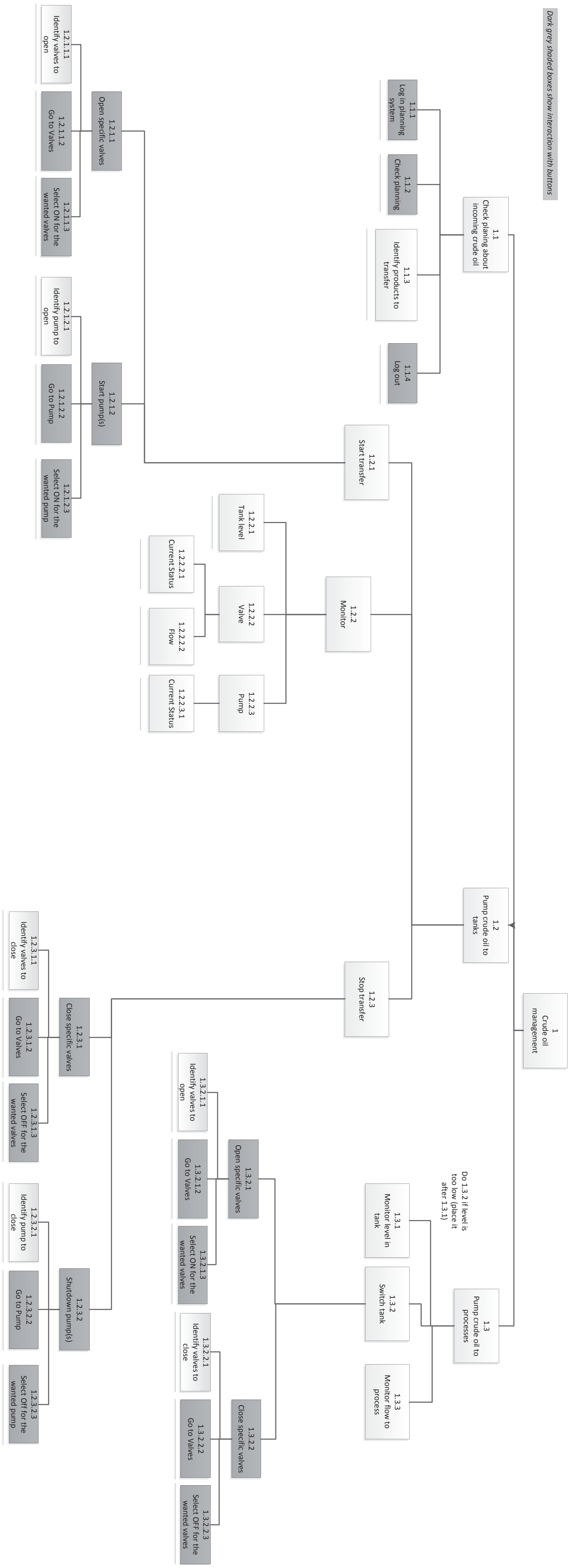


Figure 6.2. Scenario 1: HTA

6.2 User case 2: Distribute Finished Products

The operator needs to transfer different finished products to different tanks depending on the type of product (Diesel, Gasoline or Kerosene) and transportation system: via boat, via tube to Falskstad, or to temporary storage (stocks). He needs to keep an eye on the tank storage capacity and the flow between the different tanks during transfer.

Actors: Primary user (operator of screens) and probably co-user (field technicians). The secondary user and the side users might also interact with the primary user during the process.
Precondition: Product has been manufactured and send to one of the buffer tank and needs to get transferred.

1. The operator identifies a tank where there is some end-finished product.
2. He checks with the planning documentation system the instructions to follow (where to send the product).
3. He decides to open the specific valves.
4. He starts the necessary pump in order to transfer the product from one tank to another.
5. During that time, he monitors the tank level, valve flows, pressure, temperature...
6. He stops the pump if the desired level has been reached.

The operator can run multiple tasks at the same time, eg. transferring kerosene and diesel or transferring gasoline to two different tanks...

Process flow

The process flow for this scenario can be seen picture 6.3.

HTA

The HTA related to this scenario is presented with the picture 6.4.

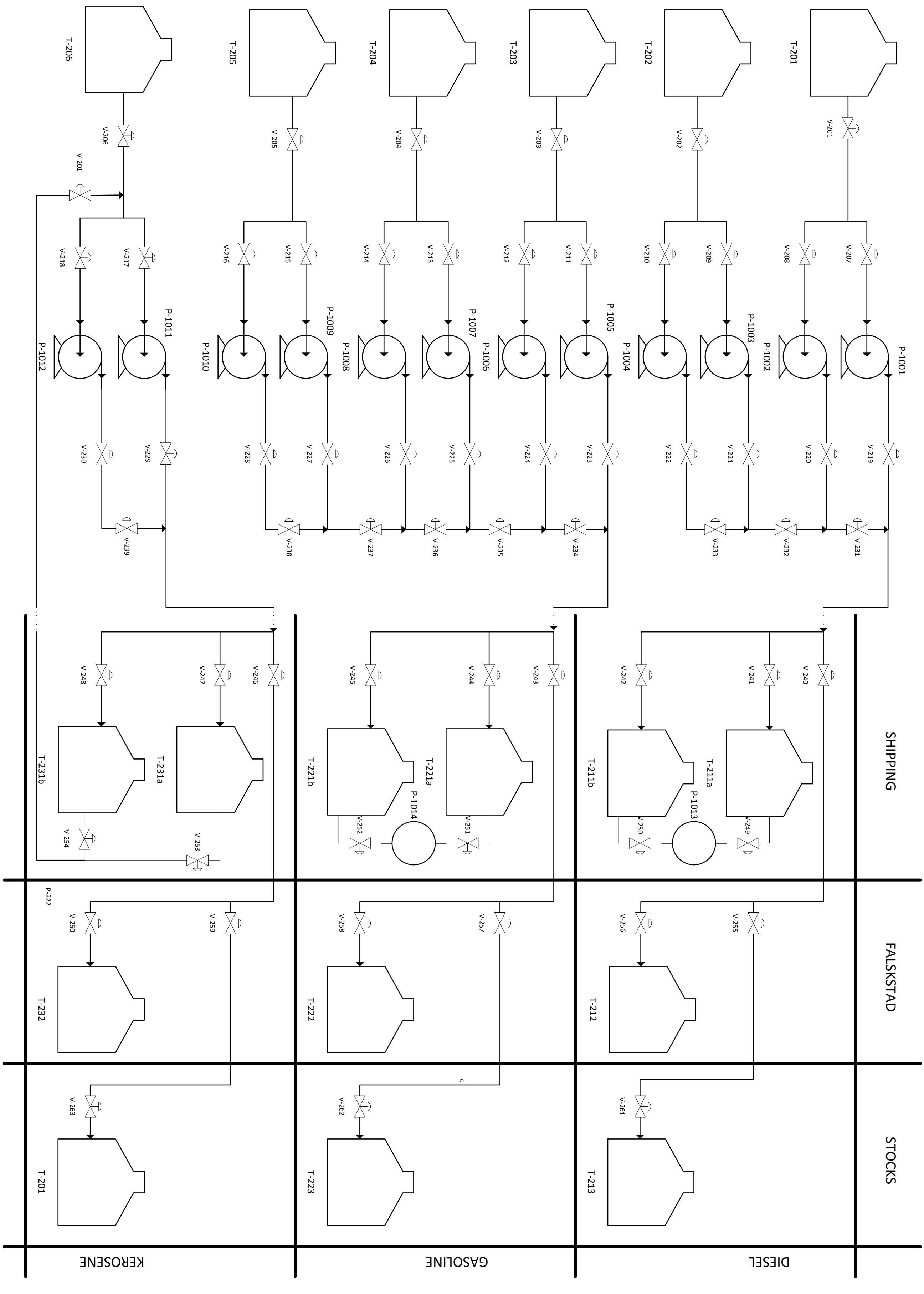


Figure 6.3. Scenario 2:
Process Picture

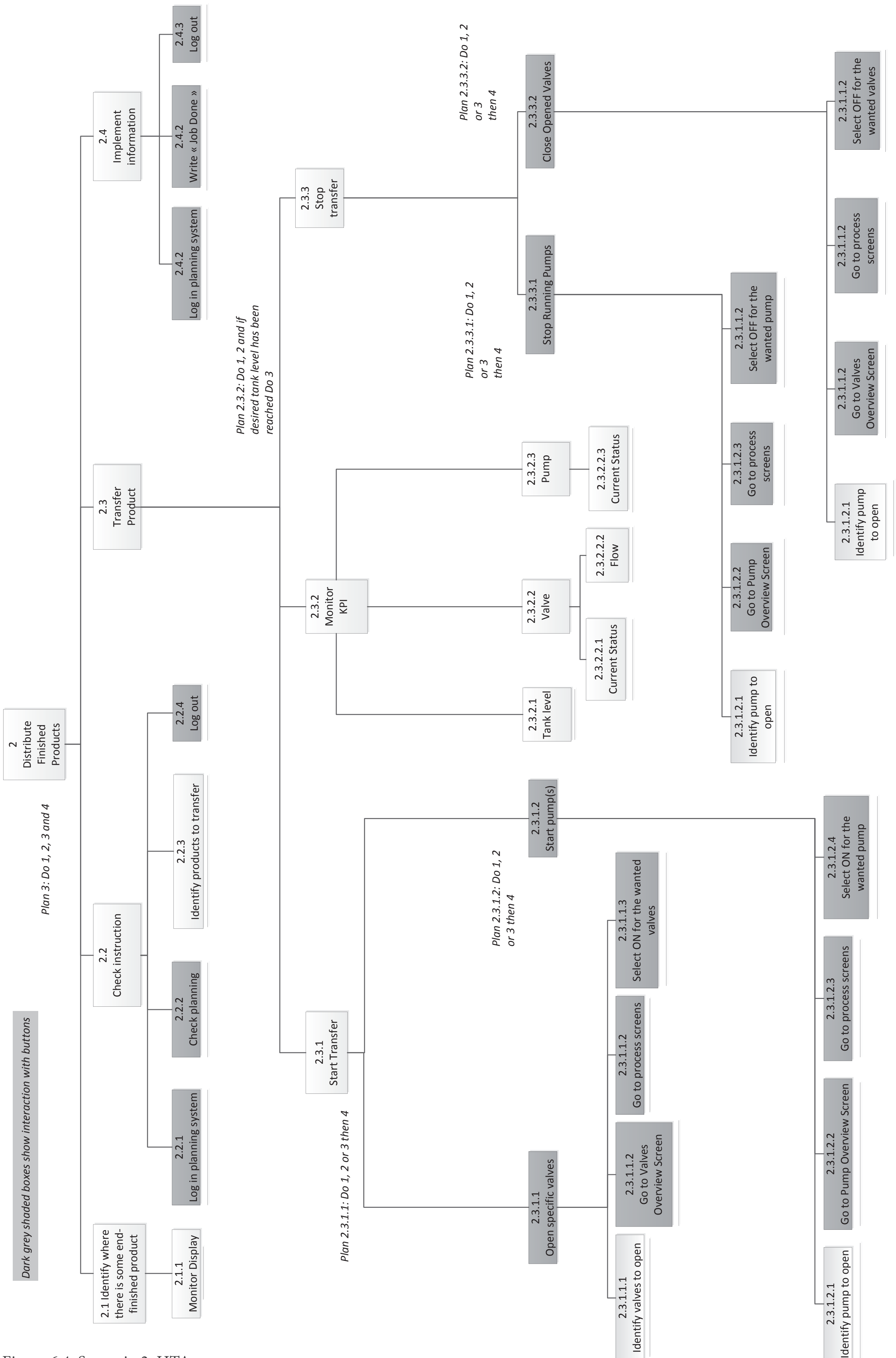
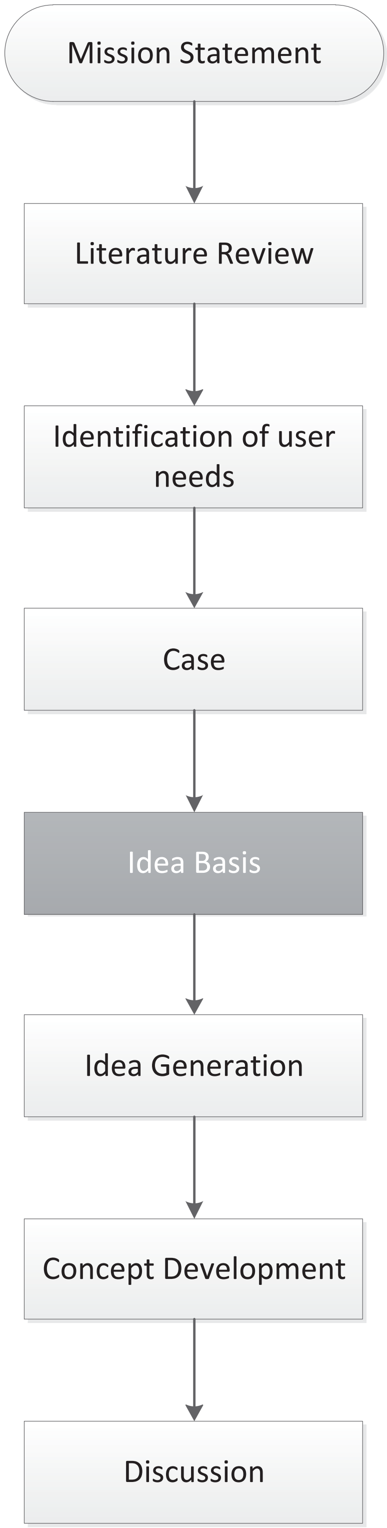


Figure 6.4. Scenario 2: HTA



CHAPTER 7
IDEA BASIS

The H-AIM is used to analyse the operator's mental model and how the system supports his thinking process. For readers with human factors background, it might be unfamiliar to use this model to develop concepts, however this chapter will provide some clarification.

7.1 Work Domain Description

The analysis starts by defining the work domain for each level of the AH and takes into consideration the three phases of the perception-action cycle. It is more fruitful to define the interaction and the connection between the human user and the automation system as a whole. The description also intends to support an improved situation awareness.

Structure Level: Component-Centric

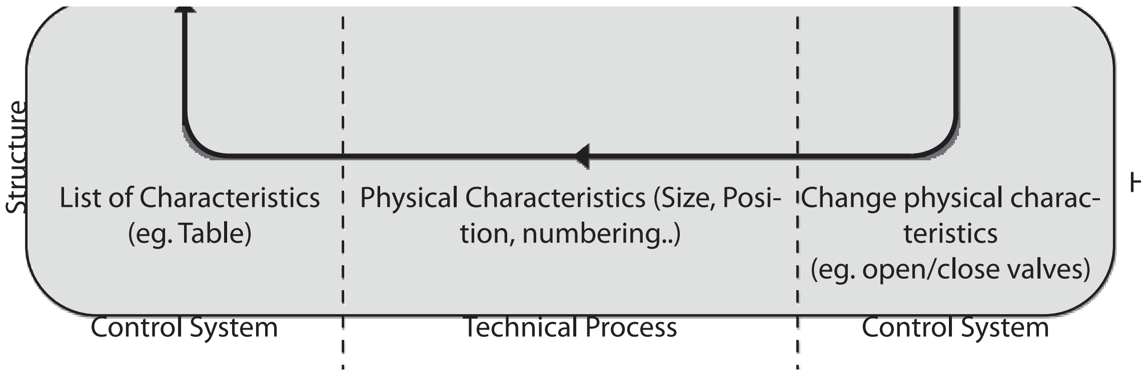


Figure 7.1. Structure Level

The bottom part of the model represents the structure level where the user can find a lot of data (not information) about the plant. This level is component-centric because the data concerning appearance or location are displayed at this level. On the screen the operator perceives the data via a table or a map. He controls the components by opening "manually" (but still through the interface) a valve for example. This level is considered as fully automated (Light grey on the figure 7.1).

Process Level: Physical Relationship

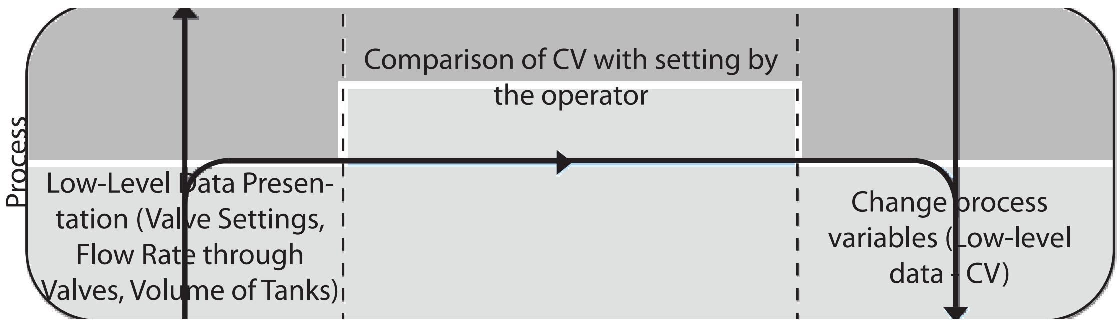


Figure 7.2. Process Level

This level represents the physical relationship between the different components of the plant. For the scenario in the thesis, the process level is represented in a simplified way by figures 6.1 and 6.3 with process lines. The operator can also connect each component with low-level data on the process picture. These data are mostly controlled variables that the operator have to set to achieve an efficient process.
In figure 7.2, the white line represents the level of automation in actual control screens. The part underneath the line in light grey represents operations that the automation sys-

tem takes over from the operator The part above the line in grey represents the actions of the operator. In the actual interfaces, he has to compare the current value with the setting. Most of the operators from the study visits perceive the information from a process-based display where digital values and trends are integrated. The data presented is on a low-level and there is a lack of relationship between the values, the running tasks and the plant goals.

Function Level: Theoretical Engineering and Causal Relationship

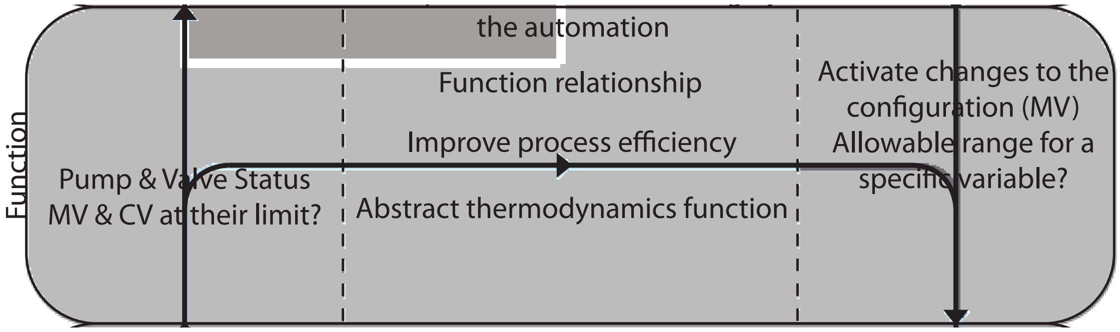


Figure 7.3 Function Level

This level is defined by two sub-levels:
- The theoretical functions of the different engineering disciplines such as thermodynamics or chemical;
- The relationships that explains the plant efficiency and the causality between the different components and functions.

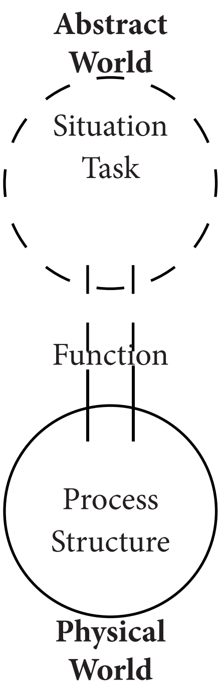


Figure 7.4 Function Level: Bridge between the abstractions

This level acts as a bridge (see Figure 7.4) for the operator between the physical world characterized by the structure and process levels and the abstract world that is composed with the task and situation levels. Defined in that way, the function level will reduce the abstraction when working on the higher levels and increases the situation awareness of the operator about the impact of one level to another (SA Principle 6).
The function level should provide meaningful information (flow and other key parameters such as deviations between settings and current value with a graphic element and not low-level data (SA Principle 2). The automation system should reduce useless mental calculations and prepare the information to be meaningful. The operator need to understand if the variables that he controls and manipulates are near a alarm range or are within acceptable operating range.

Another aspect of the function level is to give the opportunity to the operator for projections. He needs to understand the structure behind and the impact of possible actions (SA Principle 3). The operator needs to have a support from the automation system to analyse and evaluate future change in component dynamics. Showing the correlation between the different functions around the plant can allow him to get assistance before changing a parameter and to evaluate the impact of this change. Creating a cause-effect visualisation gives him a better understanding of unnoticed correlations and it becomes easier to visualize what really impacts the quality of the end-product (SA Principle 6).

The function level is critical for supporting the creation of beginners' mental model concerning the causality of the technical process.

Task Level: Task Management

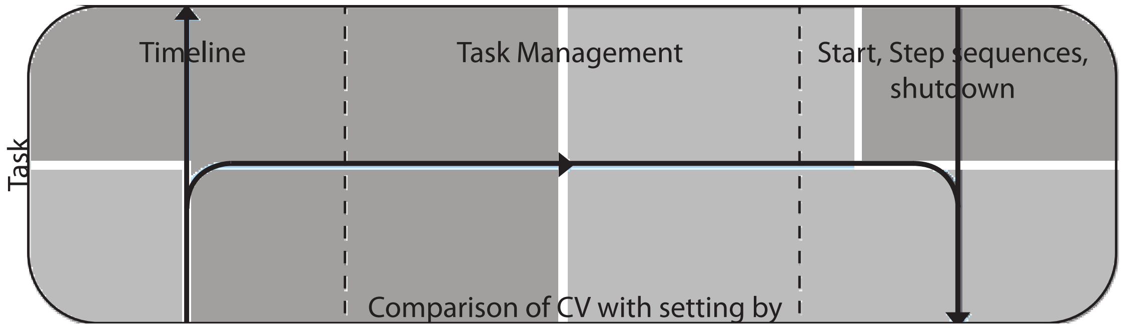


Figure 7.5. Task Level

From the study visits it was observed that the operators have difficulties with multitasking since the workflow support from the automation system is nonexistent in the existing solutions.
The operator needs at this level to visualize the timeline where the workflow is situated for the different tasks he is doing compared to the planning system (SA Principle 3).
For making analysis he needs to have a tool that he can use to manage the different tasks so he can acts depending on their priority and plan his work.
This leads him to take actions to start and stop task and on a lower level to control a list of sequence.
Computer-based procedures need to be defined over paper-based procedures. The main difficulty is the unclear border between procedure, task, sub-task and sequence. The operator uses right now checklist and sequences actions. These sequences might be grouped as sub-task. This adaptation might be difficult for continuous process such as the main processes of the petrochemical industry but it might be possible for some part of the process that are batch-based such as the two scenarios previously explained. It is possible to have tasks such as “Transfer to Falkstad” or “Transfer from Tank Alpha to Tank Beta”.
Another example from the Paint Factory at CGM in Borås corresponds of the multiple steps for manufacturing a new painting like “Customer Order 6437” with subtasks like “Mixing colour pigment” then “Transfer to quality level”, “Transfer to Storage”, “Clean tanks”.

The time allocated for each task should be defined to be consistent with the actual process. In other industries such as the automotive on manufacturing lines, engineers tried to define the amount of time needed for each step of the manufacturing process by timing operators and calculating a mean value. It gives the operator a target time to plan his work and to allocate his cognitive load between different activities. Beginners can use it as an aid to plan their actual work but also predict future tasks.

However, a procedure system will not solve all human errors. This tool provides a way to have different procedures on the system but they might need to be adapted over time and it should be specified how to use them with extra-comments by knowledgeable operators.
Skilled operators need to be involved in the continuous improvement of the human-machine system.

Situation Level

This level describes the overall work situation and the main goals of the operator’s work.
High-level data is used at this level such as the deviation between the real value in the process compared to the command. The operator needs to perceive the disturbance variables on the automation objectives.

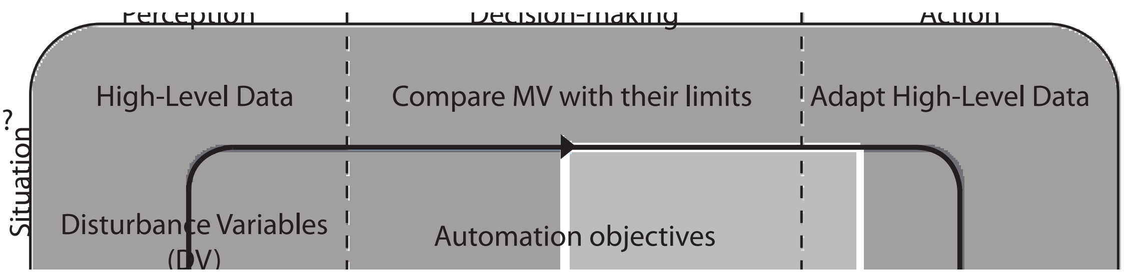


Figure 7.5. Situation Level

Graphic elements should provide information for both high-level data and the disturbance variables which will reduce the cognitive load for the perception of the key information. Analysis should be supported by a decision-making tool that propose correct action to the operator depending on past experiences with the system.
The situation level is supported by defining goals with the main information related to it (SA Principle 1). By creating a screen, visible at all times, with the different goals, the operator can get access to a goal overview and manage them depending on their priority (SA Principle 4). The information presented at this level should be filtered from the other levels to narrow the operator's attention to specific goals at specific times (SA Principle 8).
Metaphorically, this level acts as the brain of the system and directs the user to the different levels to get different information depending on its needs.

7.2 Work Domain Control Loop

After describing the work domain it is necessary to explain the improvements coming from the addition of the control loop on the abstraction-hierarchy.

Reduce abstraction feeling

Figure 7.7 presents the connections and influence between the different levels due to the addition of the control loop. It reduces the abstraction feeling for the user. The operator will get the feeling that actions taken on a high-level of abstraction (goal-driven process) will impact directly on the physical world and the actions taken on a low-level of abstraction (data-driven process) will impact directly the abstract world. The interface should provide support to visualize the relation between the levels by highlighting the resolution of the work domain changes (SA Principle 5).
The border that exists in a traditional abstraction-hierarchy disappears due to the control loop for the control room operator. There is a permanent connection between the abstract world and the physical world that the operator visualizes.

Multiple navigation

The system should present different forms of information to the operator. Different users might find information they need at different levels. Thus the control loop for an interface represents the multiple ways of navigation for the operator. The operator can move back and forth from one level to another to get different information and still understand the relation that connects the levels.

7.3 Level of automation

In figure 7.7 and in some of the previous figures, two white lines that both represent the

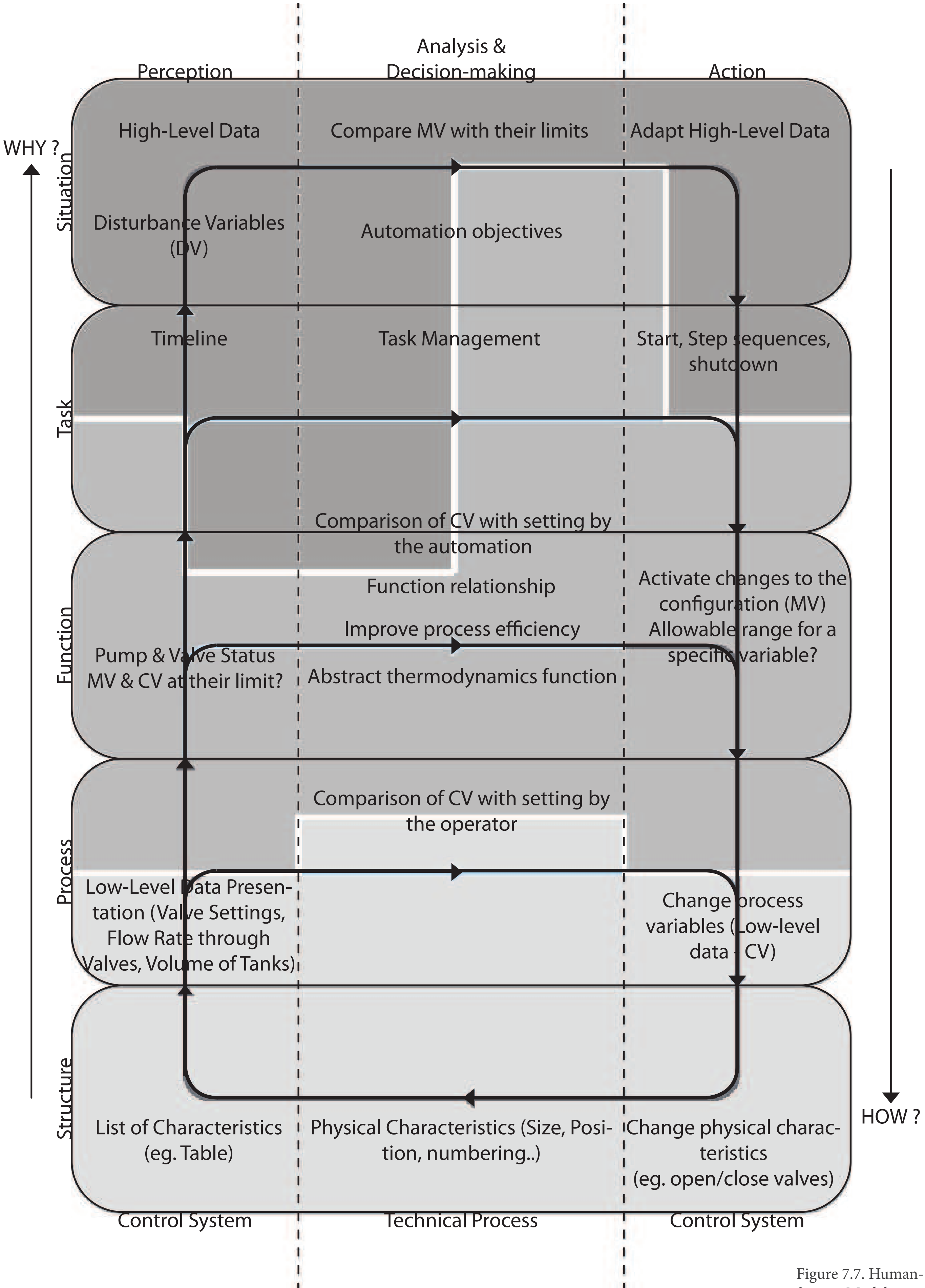


Figure 7.7. Human-System Model

level of automation can be seen. Everything above the line is done by the operator; everything underneath is carried out by the automation system.

Actual Design

The first white line represents the level of automation for todays interfaces and the automation system works only on the light grey part of the picture. Most of the work is done from the process view where designers try to fit as much data (information?) as possible. The decision-making is situated in a higher level between process and function level because experienced operators try to understand the causality between the different part of the plants to answer their problems or to make the process more efficient. At this level it is difficult to keep track of the different task and it is often that operators writes down on paper or post-it notes what the different task running are. The operator has to remember too much data such as current value, operating rages, alarm range or component numbers.
In the existing control rooms the automation system does not assist the operator enough and it can be considered as being between Level 1 and Level 2 (out of 8 levels) on the Stanton's scale.

Future Design

The second line represents the expected level of automation in a future design and the operator will work only on the dark grey part of the picture. The reader might be confused by the shape of the automation system. It zigzags between task level for perception and action, function level for perception and decision-making and the situation level for decision-making and action.
One reason to adapt the level of automation to the different levels of the H-AIM is because the operator got information needs from different levels that have to be treated before it can be presented in a correct way (such as the function level).
From the task level the operator needs to perceive the running tasks and the shift between the actual timing and the planned one; from the functional level the operator needs to be able to perceive (in a graphical way) the causality between the different parameters, but also the deviations of these parameters with the settings (analysis and decision-making); from the situation level he needs to understand the difference between the situation goal and the actual measurements presented in context and to take actions linked to this information; and if needed the he changes the course of a task or list of sequences according to the analysis from of the current situation.
The level of automation on Stanton's scale is situated between 2 and 4 (out of 8) from suggesting multiple alternatives and showing them to the human user to carrying action if the system gets approval from the user depending on the situation and the sequence step.

7.4 Global Overview Screen - The "What is going on?" screen

From the three higher levels of abstraction - function, task and situation - it is possible to create a global overview screen (Figure 7.7) from where quick monitoring is conducted.

An advantage of adding this screen to the automation system is the reduction of operator overload. Today's operators deal with multiple systems (automation, planning system and memory-aid on paper) to remember the currant and future tasks. The operators also control key parameters with the alarm system which reduce the efficiency of the alarm system also. With this level, parallel processing capabilities of the operator are increased since the

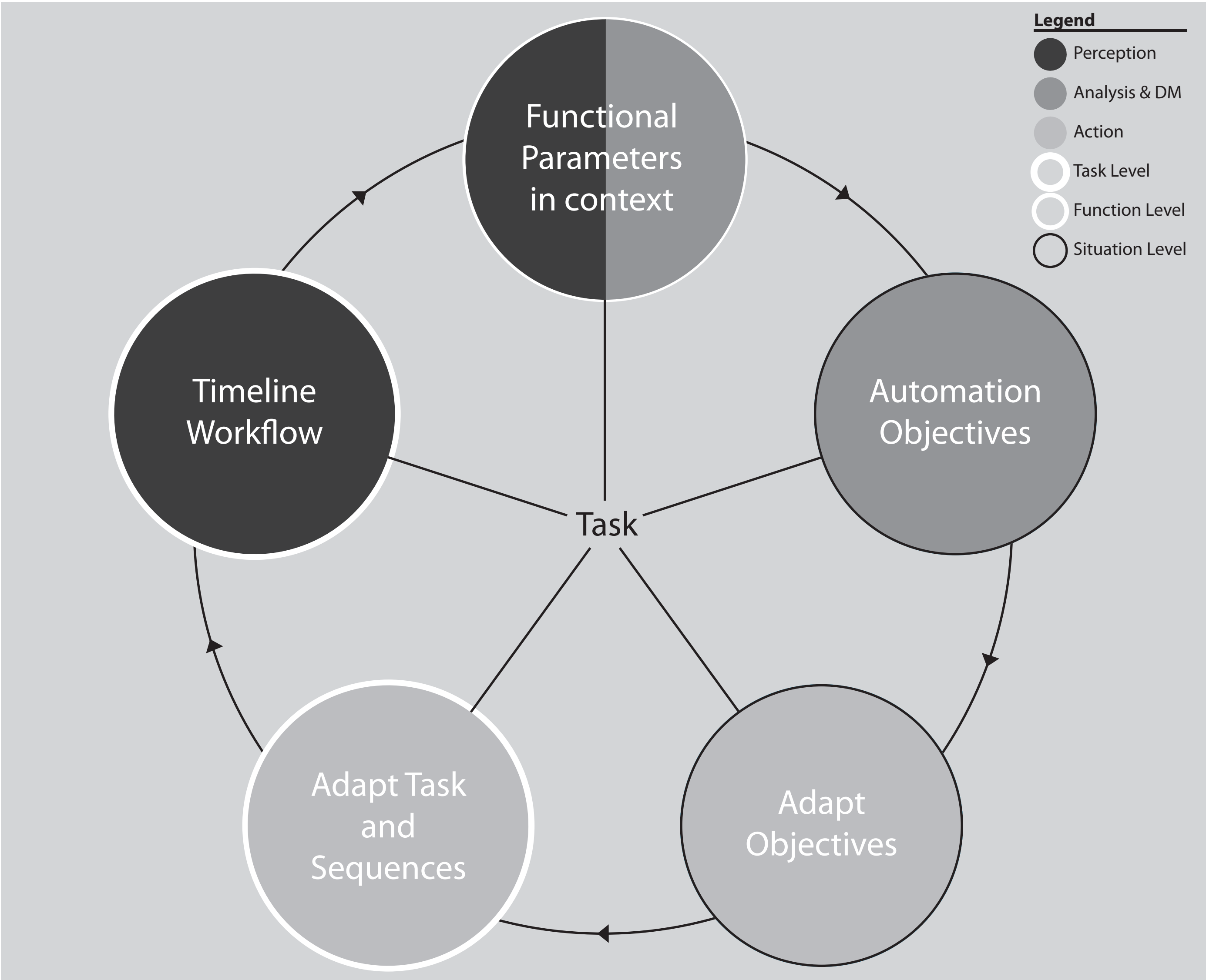


Figure 7.8. Overview screen structure 2

operator gets access to information in different ways on that level but the design also reduces the auditory overload from the alarms (SA Principle 7).
Concerning the monitoring part the screen gives the operator an understandable overview of the different tasks.

Figure 7.8 presents the perception-action cycle for the overview screen and highlights the system thinking behind the screen and an idea about how to sequentially present the information related to one task.
The interface should be separated depending on the different tasks and organize the information depending on the different goals. Graphics should present an analysed information to support quick monitoring of both the functional parameters and the automation objectives. This last part will help to highlight the critical cues to monitor (SA Principle 6). The situation overview screen should be visible at all time and can be considered as the master screen to navigate between the different tasks (SA Principle 1).

7.5 Operators learning and collaboration

Another aspect of the study is related to improve learning for newcomers and to support user relations with the interface. The H-AIM provides a basis for supporting the different user relations defined in chapter 5: control, collaboration, demonstration and meeting. The different levels of the H-AIM are used to represent the information required for the different users and the different relations.

Learning system for newcomers: Structured workspace and function causality

The conceptual interface provides a basis for learning by defining a structured workspace. This representation allows the operator to navigate into the different features of the interface to get different information. The interface is more transparent than the current ones, the operator can do the job in different ways and has different way of navigation. Moreover it supports the operator in working at a high level of abstraction.

An improved feedback will enhance learning about the physical system, the causality and the interface. This feedback will help creating a efficient mental model since the operator will understand the relationship between his actions and the automation and technical repercussion.
For example the interface will display the functional relationship in a graphic way which will decrease the degree of complexity for the operator. Thus the operator will understand the characteristics of the actions taken.

Collaboration and demonstration during shift

For the control part the task level supports the operator's workflow visualization during a shift.
The overview screen and the function level with the causality supports operator discussion about issues such as end-product quality, with other operators in the control room. The other operators can then quickly understand the context and the relations at stake.
The levels from the H-AIM and the information displayed concerning perception, analysis and actions possibilities allow different individuals with different roles in the control room to work with the process in different ways but still connected thanks to the control loop.
For example maybe a shift leader would like more detail about the workflow and working with the task level, it will provide him the specific information related to one task. Another example is during a discussion between operators, one operator advises to another operator to change one parameter to improve product quality, but the second operator would like to see the impact that this change will have on the rest of the plant and as such works at the function level for the time needed to see the impact. When an operator monitors an unknown deviation due some graphics on the overview screen, he can quickly get access to the deficient component due to the top-down access to the structure level and send the field technicians to check for further information.
The different levels support different representations of the work domain for various stakeholders depending on the information they need but by always keeping track of the same context.

7.6 Improved Situation Awareness

The situation awareness is globally increased with the addition of a function, task and overview level to the actual process-based displays. Most principles defined by Endsley are supported with the three new levels. The table 7.1 summarizes the relation between situation awareness and the expected interface. It also highlights the improvements due to the overview screen as a combination of the advantages from the function, task and situation levels.

Table 7.1. Situation Awareness Principles applied to each level of the H-AIM

Levels	Situation Awareness Principles							
	P1	P2	P3	P4	P5	P6	P7	P8
Function		**X**	**X**		**X**	**X**		
Task			**X**		**X**			
Situation	X			X	**X**			X
Overview	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

Level of Automation and Situation Awareness

The proposed theoretical design as explained will have a higher level of automation and also a higher level of abstraction for the workplace both for a situational overview screen and a task management system. However, the level of automation takes control from the operator to the automation system but in return it gives more situational awareness to the operator.

7.7 Link to Decision-Making

Supporting the operator's situation awareness by an improved interface should lead to a better decision-making and then reduce human errors. This part explains how the three levels of decision-making can be supported.

Skill-based Behaviour

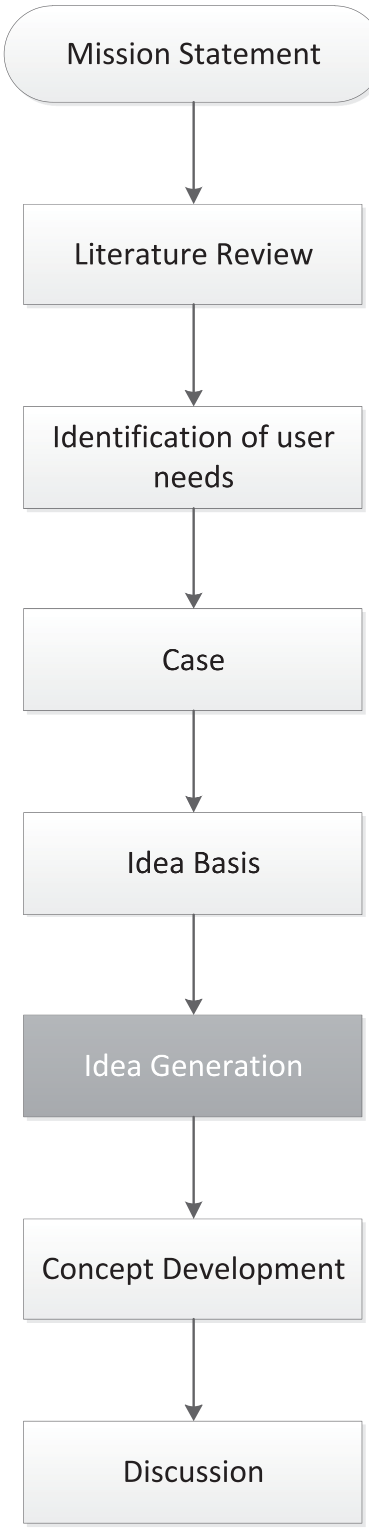
The operator navigates directly on the display through the different levels to gather different information. By monitoring only on the overview screen, the operator gets an idea about what is happening in the plant. By selecting one of the goals on the overview screen, the operator can act to get further information on the specific task. The operator should be able also to act directly on the process output by defining settings graphically.

Rule-based Behaviour

By showing the causality between different parameters and predictions the impact of an actions on some part of the plant, the function level presents the consequences of an operator's actions. The rules used for prediction can be defined with the previous operator experiences.

Knowledge-based Behaviour

The structure of the new interface with the H-AIM supports the creation of the operator's mental model by providing structural relationship about the process.
Structured with the five levels, the interface should help dealing with unfamiliar situations since the overview screen will help him monitoring and the function level will help his analysis by showing the main relations of parameters.
The designed concept most probably support more the knowledge-based level than the two other ones.



CHAPTER 8
IDEA GENERATION

This part of the report presents the main ideas that came out from the brainstorming sessions. The four forthcoming areas are supported: task management, smart analog indicators, holistic view indicators, global overview displays. It ends with a design related to the H-AIM.

8.1 Link With Operator's Mental Model

From the operator's mental model, two categories should be supported by the idea generation phase:
- Task Management : Workflow visualization with Analog Indicators;
- Global Overview Screen - Support Situation and function monitoring with holistic view indicators.

The concepts are presented by a combination of text, drawings, sketches and pictures.

8.2 Task Management - Workflow Visualization

This subchapter presents the concepts developed for supporting the operator's workflow visualization.

Vertical bar task management

The idea is shown figure 8.1 and is composed of the five following elements.
(1) Several tasks: It shows three tasks at various stages. The left one is near the end. The middle one is just started and the right one is just finished.
(2) Task head: It displays the name of the task and order number.
(3) Single task: The operator goes through this single task from top to bottom.
(4) Step: A single step in a given task, when the step is done and confirmed it will go from gray to blue. By clicking on the step a faceplate come up showing relevant information and allows for control of the process. (Start a pump, close a valve).
(5) Bar: At the active step the user is prompted to configure the given step and whether to proceed to the next step.

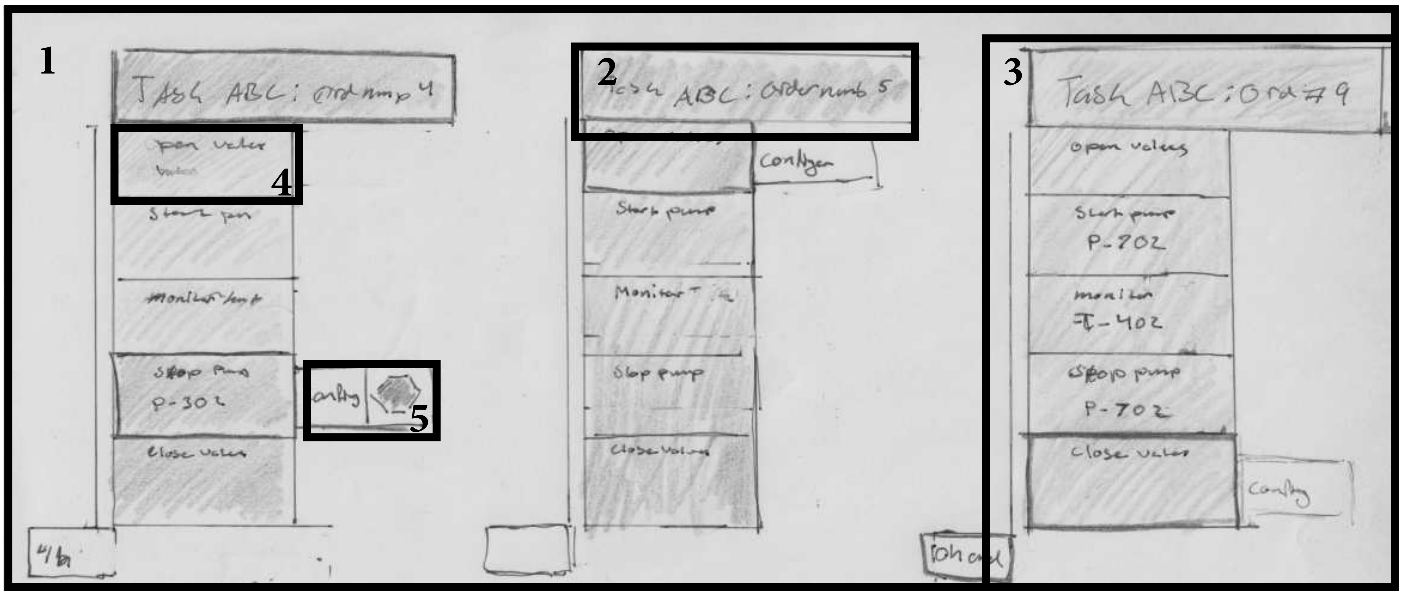


Figure 8.1. Vertical bar task management

Circular task management

The idea is shown figure 8.2 and is composed of the six following elements.
(1) Several tasks: Three task tare at three different stages of completion. The two to the right is the same type of task, while the one on the left is of a different type.
(2) Step: A completed step changes colour from gray to blue to indicate that it is complete. By clicking on the step a faceplate comes up showing relevant information and allows for control of the process (Start a pump, close a valve).
(3) Bar: A bar prompts the operator to configure and confirm the start of the step.
(4) A single task: The operators goes though each step one by one in a clockwise manner.
(5) Task head: It displays the name of the task and order number.
(6) Overview area: It displays dynamic information about the task and steps.

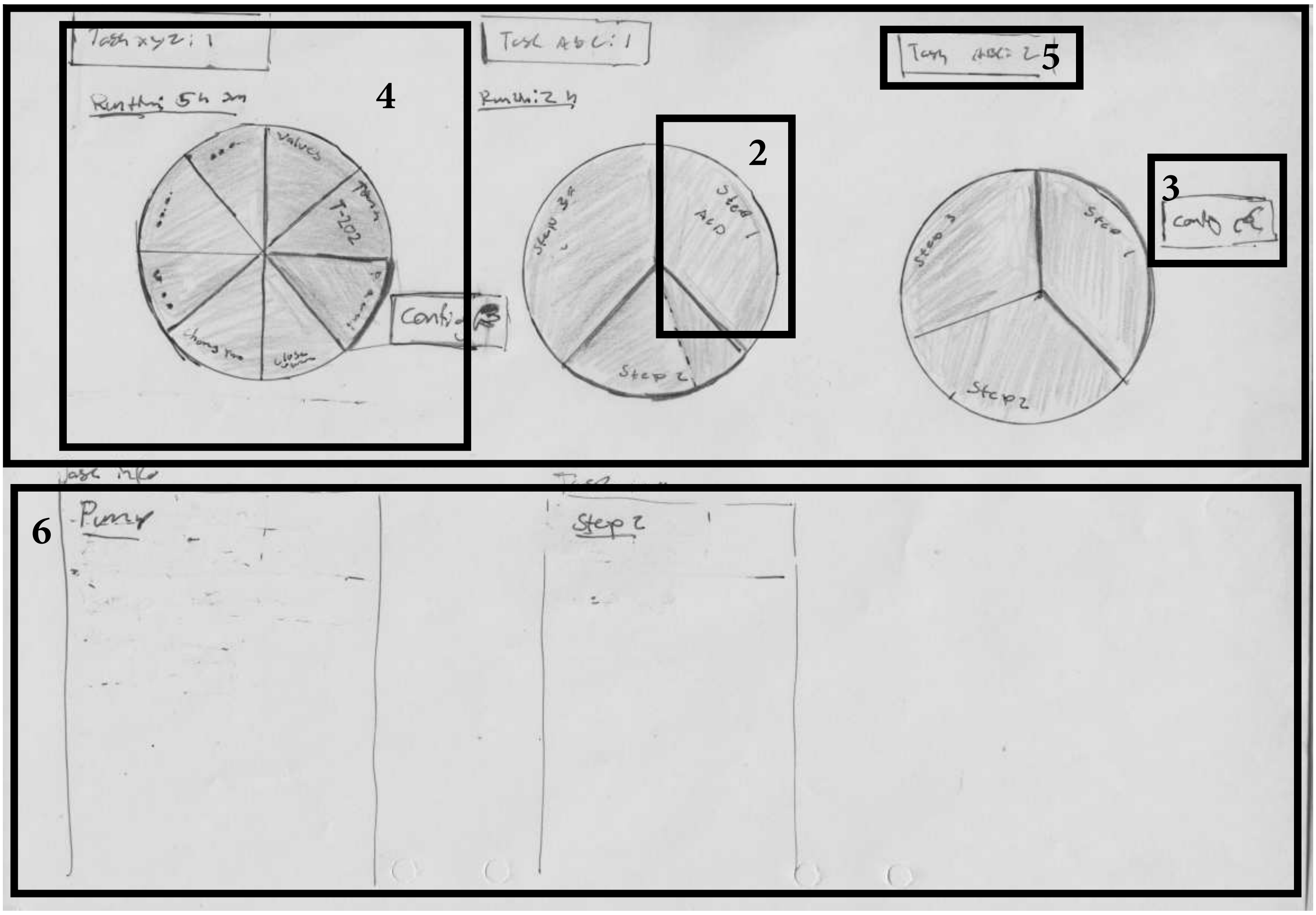
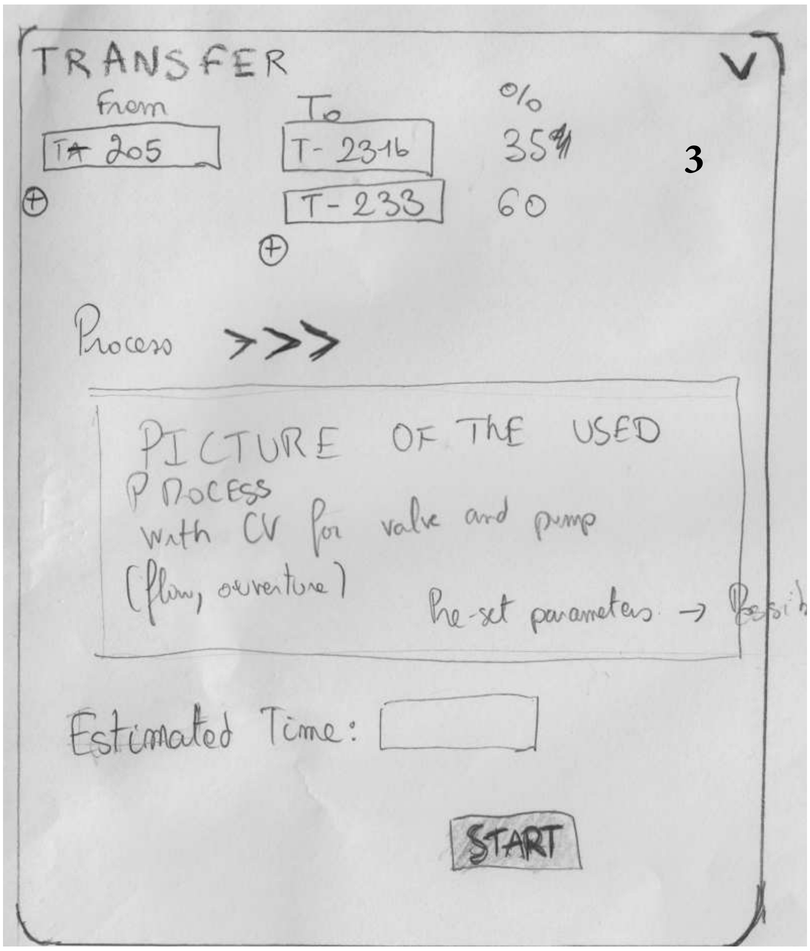


Figure 8.2. Circular task management

Horizontal Task Workflow

This idea is shown figure 8.3 and is composed of the three following elements.
(1) Tabs: On the layer, the reader can relate the five tabs to the levels of the abstraction-hierarchy model.
(2) Task Workflow: From this screen, the operator manages the tasks. He can see where the past tasks were accomplished (in blue). In green, the operator can see the actual task. He visualizes which tanks are controlled with the task. Mean value (μ) and standard deviation (σ) are calculated taking into consideration all the valves in use. Then the system compares these two characteristics with the theoretical one. This is a drastic and abstract way of presenting the information in an "unified" factor but maybe some statistical process control theories could be applied to the representation. A small indicator could be added when a parameter is too close to an alarm limit for better context presentation. Deviations are presented to the operators and not the value itself to increase the situation awareness.

(3) Transfer Control Faceplate: When the operator wants to start transferring product from one tank to another, the operator can pull down a transfer control faceplate (Figure 8.3) that shows the tanks that start and end the process and the percentage related to each one. Besides, a picture highlights the physical components the operator will control from the process layer by showing in green colour the physical components (tanks, pumps...) but also the precalculated controlled parameters according to the most efficient way for the automation system. In addition it shows the estimated time for completion of the task. In that case, a higher level of automation is used since the automation system presets the main characteristics of the task and the operator needs to agree to carry the task (Level 4 in LoA). The operator can also improve the parameters with his experience and implements them in the system for the next similar task.



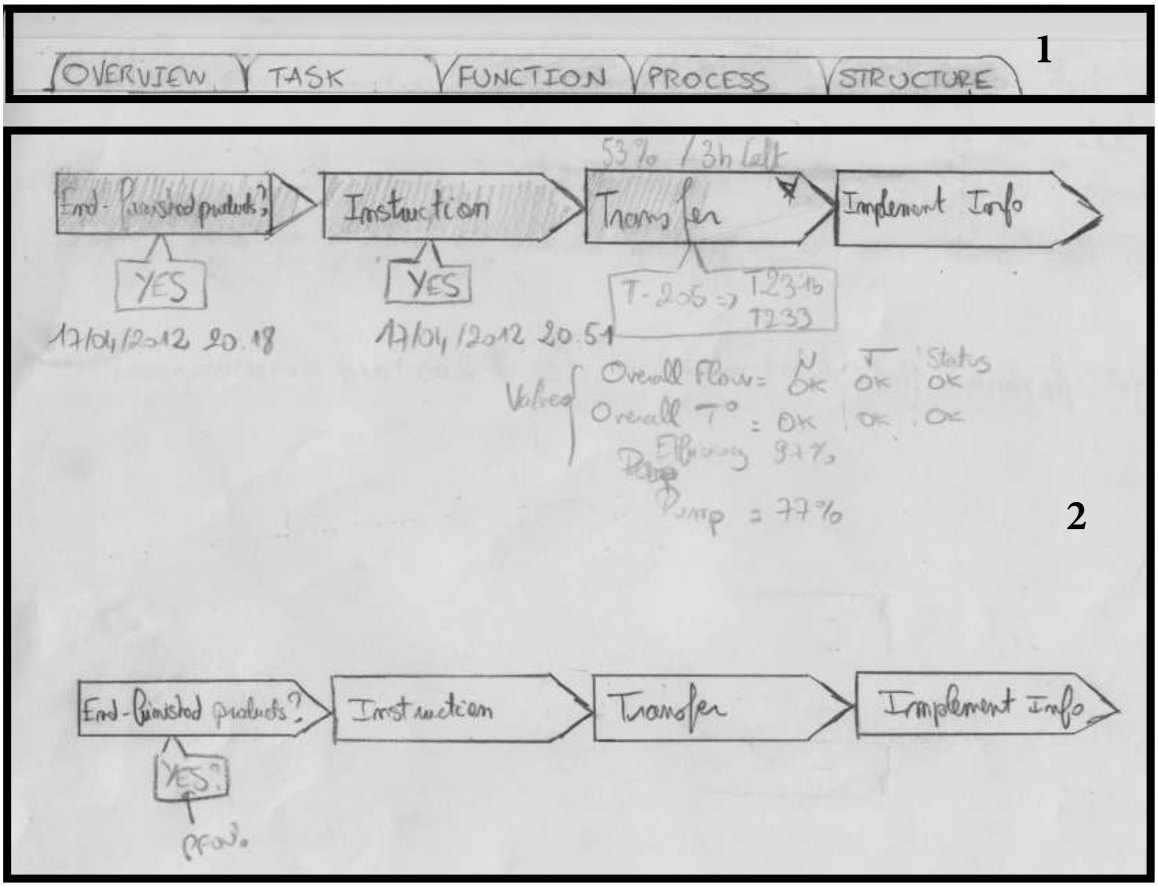


Figure 8.3. Transfer Control Faceplate (Above)

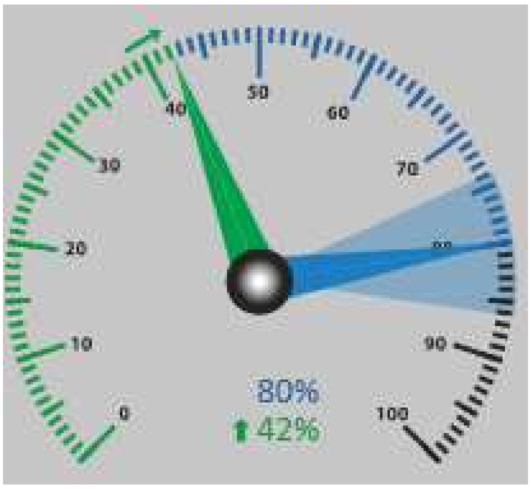
Figure 8.4. Horizontal Task Workflow (Left)

8.3 Smart Analog Indicators

Operators expressed a lack of control and feedback feeling when looking at digital values compared to analog indicators from old control stations. This part of the thesis intends to provide ideas on how to solve this issue by designing indicators that provide the same feeling as analog ones but by compressing even more information into it.

Figure 8.5. Car Indicator - Sketch (Above)

Figure 8.6. Car Indicator - Blend (Underneath)



Car Indicator

Figure 8.5 represents a version of an analog gauge. The design is taken from a car console. When presented in this way the information becomes more visual. The indicator adds to an analog gauge data values (in the middle of the gauge) and the tendency over a short period of time with the arrow. On the figure 8.5, one gauge represents one data type (Tank level, temperature, pressure...). It could be useful to combine gauges into one gauge with multiple needles there by being able to show multiple tanks with the necessary information (temperature, pressure...). This indicator gives more control feedback to the operator and increase his situation awareness since he visualizes different information in an area related to his sequence.

Figure 8.6 represents the idea implemented in Expression Blend for a valve output. Two triangles show two different values to the user: the blue triangle represents the control value, the blue shadowed envelope shows the operating range and the green arrow represents the actual value. The green arrow shows that the value is increasing. The digital value are still present in the middle of the indicator with a redundant arrow to show that the value is increasing. Moreover, the scale is black if the value linked to it is above the setting value, blue if underneath the setting value and green if underneath the actual value.

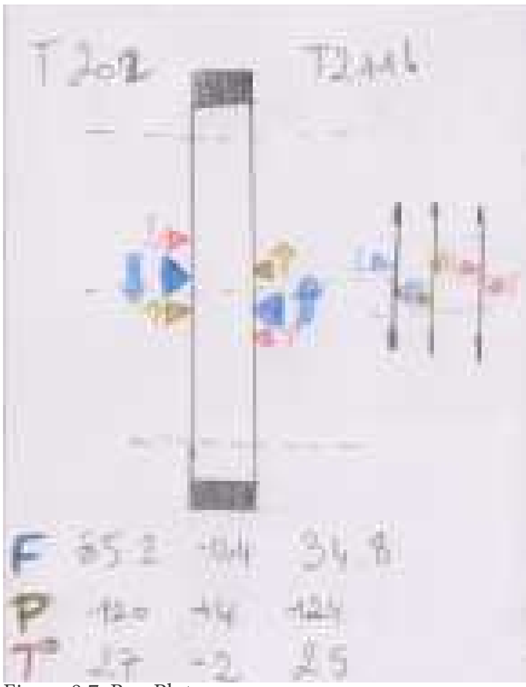


Figure 8.7. Box Plot

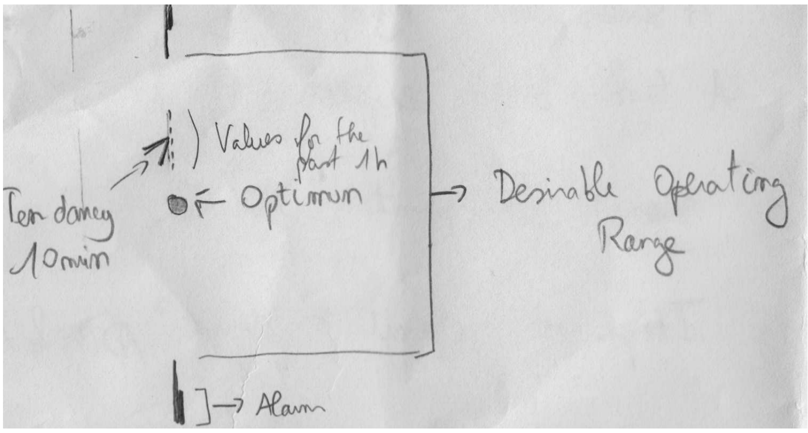
Bar Indicator

The bar indicator sketched in figure 8.7 shows for a selected tank the information related to it and the tanks connected for a task. On the bar graph, the operator can see the alarm range (black zone), the operating range (dashed lines), the optimum value and the changes for a defined time for three parameters: flow, pressure and temperature for example. The main advantage of this multiple representation on a simple bar indicator is to allow the operator to visualize the impact of one variable on the others one.

Line Indicator

Tufte (2001) explained that one of the keys to compress information and to increase the information density on a screen is to reduce the ink of the indicators. Thus Tufte re-designed a box plot by taking away the graphical information not needed by the reader, while still retaining an acceptable level of understanding. Following the same process, a bar indicator (Figure 8.7) was re-designed as a line indicator (see Figure 8.8). This part of the report explains the different sketched line indicators and for different situations.

Figure 8.8. Line Indicator - Sketch 1



Line Indicator 1 - Tendency

The first line indicator (Figure 8.8) shows different information around the line and mainly the tendency for a specific time (in the different figures 10 min).
Figure 8.8 and 8.9 are hand-sketched and represents the first two ways the line indicator was designed.
Figure 8.8 highlights the alarm zones points by a thick line (top and bottom), the desirable operating range by a lack of the line and the other black line represents the rest of the operating range. The green point represents the optimum value for this parameter. The dashed line shows the operator the range for a long period of time (eg. 10h). The arrow represents the tendency for a short period of time (eg. 10min). The arrow points to the value of the parameter.
This indicator got the advantage to present contextual information to the operator in a close area due to the ink reduction.

Figure 8.9 got one difference to 8.8 instead of the arrow, a plateau is used to represent in a more dominant way the value with two wings on the right and left to show if the parameter is going up or down during a short period of time.

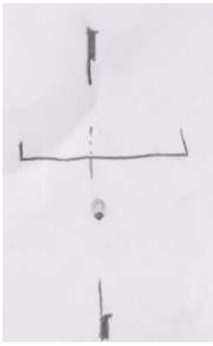
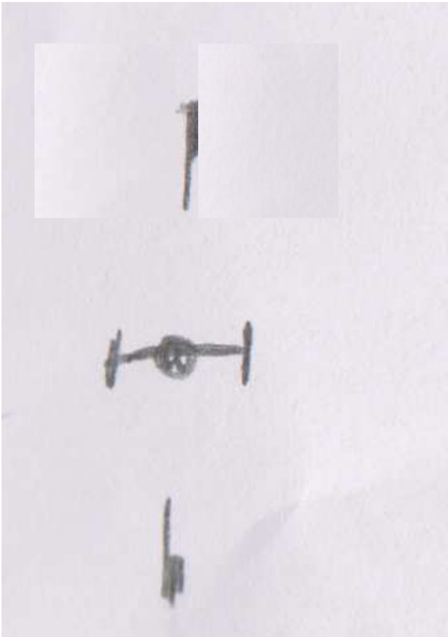


Figure 8.9. Line Indicator - Sketch 2 (Left)
Figure 8.10. Line Indicator - Illustrator Sketch 1 (Center-Left)
Figure 8.11. Line Indicator - Illustrator Sketch 2 (Center-Right)
Figure 8.12. Line Indicator - Illustrator Sketch 3 (Right)

The line indicator was designed with illustrator (Figure 8.10 to 8.12). The main change was the colour of the optimum value. Green can lead the operator to interpret that the parameter is okay at all time even if the parameter is rising fast. However, blue, a cold colour does not express this feeling and the operator can interpret it as a colour setting.
Moreover figure 8.10 to 8.12 present three ways for representing the tendency for a short period of time: arrow on the side of the graph (Figure 8.10) which is useful if text is related to the arrow next to the graph, plateau (Figure 8.11) and arrow directly on the graph (Figure 8.12).

Line indicator 2 - Variable constraint to setpoint
If a variable is constrained to a specific value (setpoint), the operator needs to visualize that the value is locked by the automation system such as in Figure 8.13 and 8.14.

Line Indicator 3 - Variable constraint to be maximized or minimized
If a variable is constraint to be maximized (Figure 8.15 and 8.16) or minimized, the operator needs to visualise graphically that the value should not pass a specific level such as with a line.



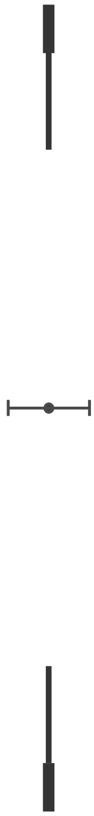
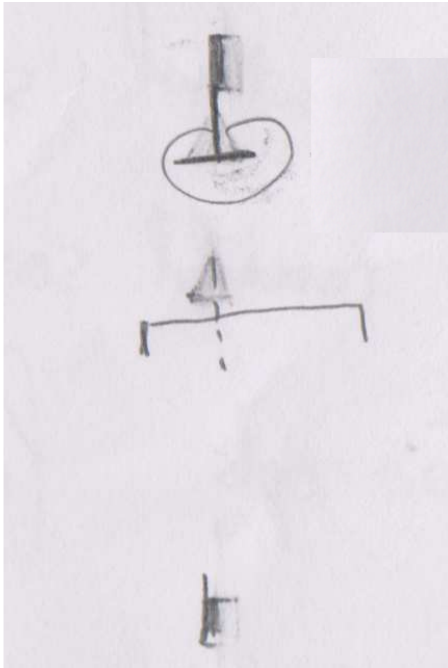


Figure 8.13. Line indicator 2 - Variable constraint to setpoint - Sketch (Above)

Figure 8.14. Line indicator - Variable constraint to setpoint - Illustrator Sketch (Right)



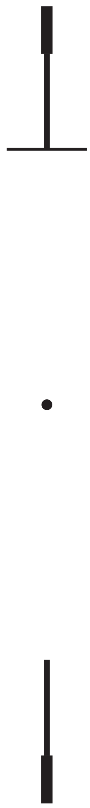


Figure 8.15 Line indicator 2 - Variable constraint to be maximized - Sketch (Above)

Figure 8.16 Line indicator - Variable constraint to be minimized - Illustrator Sketch (Right)

Line Indicator 4 - Alarm Prevention
The line indicator also support error prevention. Before the value reaches an alarm level, for example in figure 8.17 if the value is more than 0,1% of the operating set value, the arrow that indicates both past tendency and actual value turns to the colour of the alarm, yellow in figure 8.17. The operator is aware just by a change of colour that something is happening and that it needs to be taken care of.
If the operator does not prevent the problem when the value becomes more than 1% beyond operating set value, the arrow stays yellow, the dashed line becomes yellow and the alarm priority number (2 in figure 8.18) appears on top of the indicator.

8.4 Holistic View Indicators

These indicators intends to increase the global SA by either relating different parameters or showing the parameters of one type (eg. tank levels, flows or pressures) for different measurement positions around the plant.

Web visualisation

Three webs were sketched to support the visualisation of different information. The web representation should use percentage or ratio format to create a contextual scale.

WebVis 1

Information about the different tanks of the process is highlighted with this web (Figure 7.19). It shows only one characteristic such as the tank level. It gives the operator the ability to choose between different tanks when moving product or to adjust a tank level if over-pressure appears in another one. The tanks used for the task (in figure 8.19 two tanks) are shown to the operator by a green square.

Each tank indicator shows the level with the green line, the tendency for the past hour with the green arrow and the alarms level with the dashed lines. The combined points creates a pattern for the operator of the situation about all the tanks being controlled.

It is worth noticing for the reader that each tank indicator is actually the line indicator defined in the previous part and that their association create this circular representation.

WebVis2

For one specific task, the web shown Figure 8.20 presented in a clockwise manner the different point of measurement the output efficiency. The operator can therefore follow the behaviour of the process from the beginning to the end of it.

Parameters Correlation

The forthcoming graphics intend to present to the user the correlation between different parameters and/or functions. They will most probably be integrated in a future function level. These different graphics provide to the operator a way to build his system knowledge and to understand the causality behind the system response to his actions.

Circle Relations

In the figure 8.21 an operator can visualize the relation between the different tanks. Each task will get a specific colour. The tanks on the left are the ones that the operator should take to the production. The tanks on the right are the ones where the product is sent.

Multi-variables Graphics

There are two components in the figure 8.22.

The first one is a multi-variables bubble graph where the bubble is the valve outputs, the x-axis the positions in the process and the y-axis represents the flow. With two colours, the operator can see the optimum (green) compared to the actual value (blue).

The second graph is a multi-variables parallel graph. The y-axis displays ratio or percentage of different variables presented in the x-axis - Flow in and out, pressure, temperature for a tank in the figure 8.22. The operator can select five variables of interest to graph for a specific component for example or related to a specific function.

These two parts are linked to each other like a dashboard; every change on one part will be implemented on the second one.

Figure 8.17. Line indicator 4 - Value within 0,1% of the operating set value - Sketch (Left)

Figure 8.18. Line indicator 4 - Value more than 1% beyond operating set value - Sketch (Right)

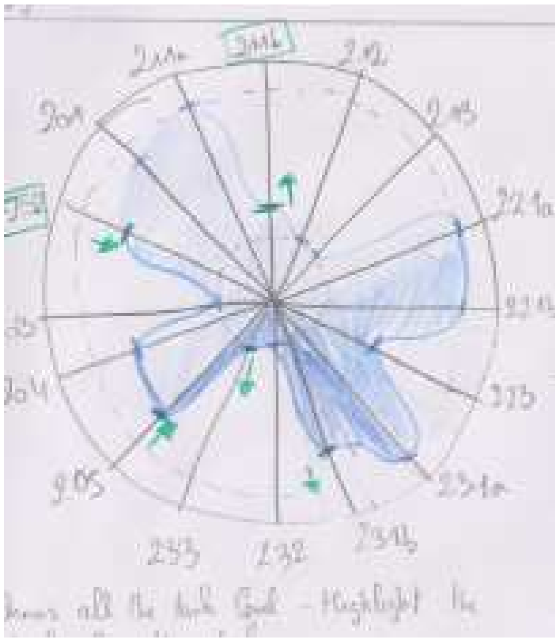
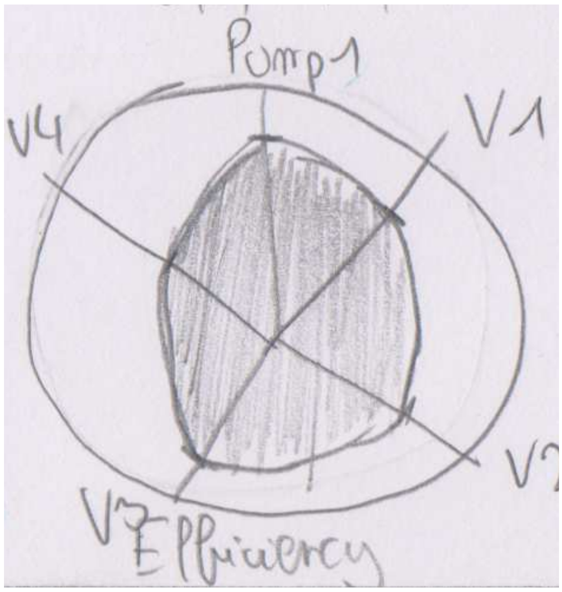


Figure 8.19. WebVis1 (Above)

Figure 8.20. WebVis2 (Underneath)



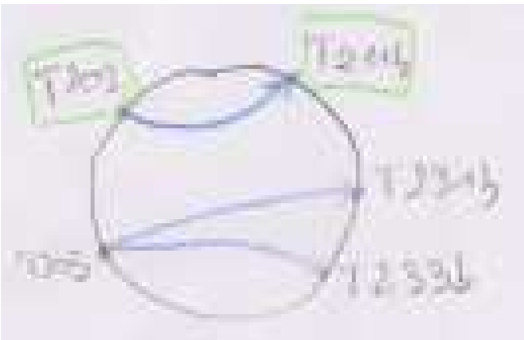


Figure 8.21. Circle Relations

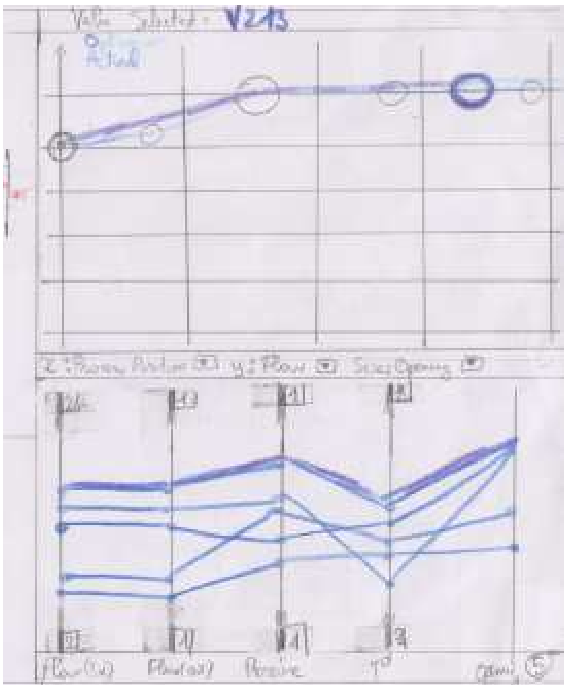


Figure 8.22. Multi-variables Graphics

8.5 Global Overview Displays

This part presents the four main overviews display that were sketched to support the H-AIM interface design explained on chapter 7.

Overview Display - Square Tasking (OD1)

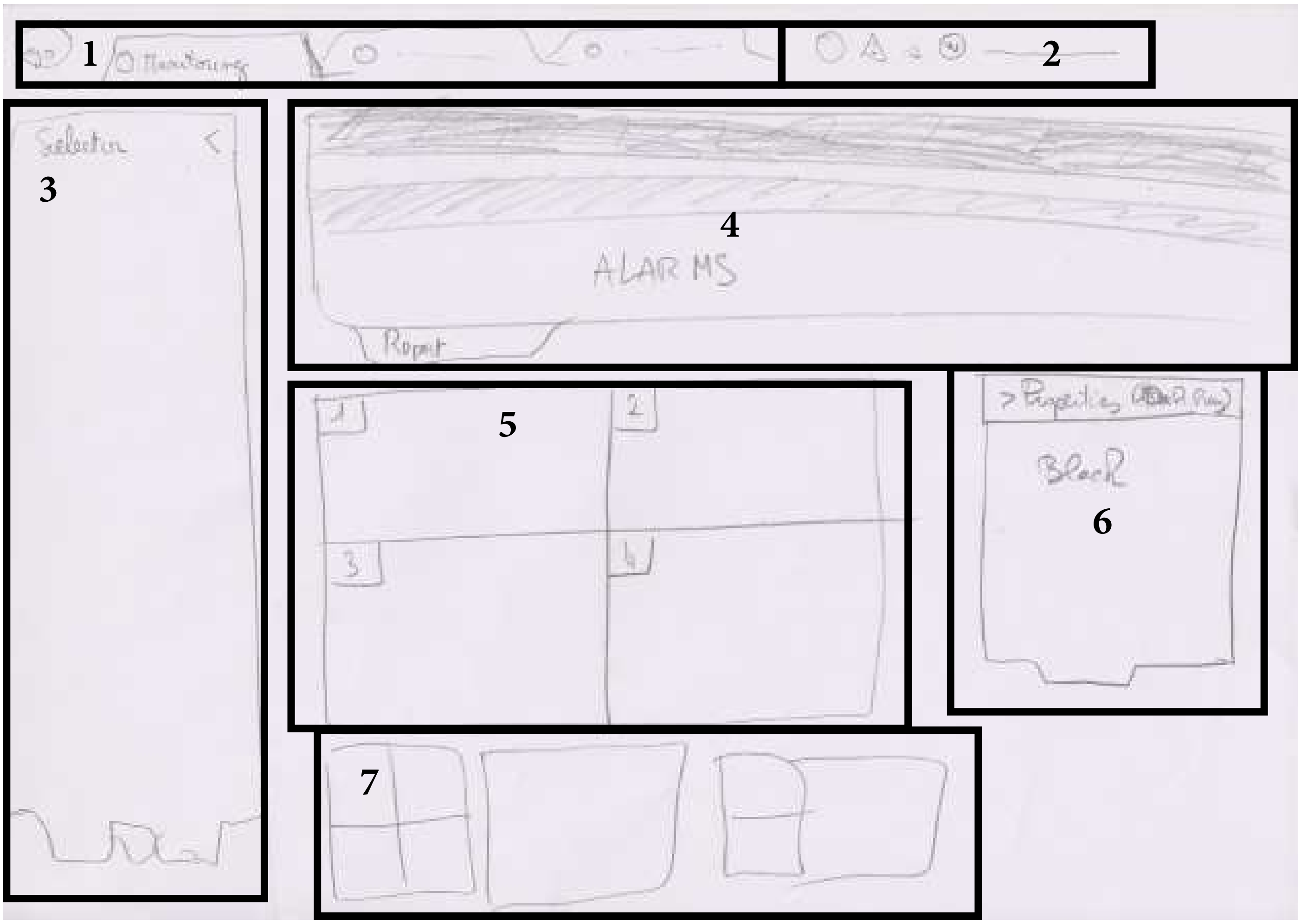


Figure 8.23. OD1

(1) Navigation Tabs: They are used to navigate between the different displays. The actual one is the monitoring display that supports the operator in monitoring the main running tasks. The actual tab should be highlighted while the other ones should become shadowed.
(2) Navigation Icons: The icons are for a quick navigation.
(3) Selector: It allows the selection of new tasks by clicking and then dragging them towards one of the position in the 5th part of the display.
(4) Alarms: The alarm system is the same as the one used by ABB displays.
(5) Task Navigator: It allows to visualize the 4 running tasks (the maximum number of tasks that one operator can run is up to 4) with their name. The main problem for this concept is that the user does not have all the information for the 4 tasks at the same time. The 6 and 7 are not close to the 5 in such a way that the operators knows quickly to which task it is related.
(6) Task Properties: By going with the mouse on one of the 4 tasks, the main properties show up on the properties block.
(7) Task KPI Comparison: By selecting at least two similar tasks, the key parameters indicator are compared in one the box. It is then possible to narrow the selection depending on the variables the operator want to compare (temperature, pressure, viscosity...).

Overview Display - Smart Analog Indicators (OD2)

(1) Date & Time: It shows the date and time to the operator on top of the display.
(2) Search Function: This function is to look for information, for a valve number, for the help guide or for a specific display.
(3) Tabs: It presents the different tabs that are an overview screen at the beginning, a process picture (like in most of the actual display), and a list of historical events. The last one could be the different tasks that were ran and it can indicate the different alarms.
(4) Actual Transfer: This window indicates the tanks used to transfer some products. The circle is the one presented in the subchapter 8.4 in Parameters Correlation.
(5) Monitoring Visualization: See Car Indicator in subchapter 8.3.
(6) Transfer Tasks Management: The operator can visualize the past transfers. He can see the future transfers to support his preparation and plan his work.
(7) Alarms List: In this concept, the alarms are not on the top but on the right. Here, the alarms should be summarized and the operator could get more information by clicking on the window. It might be against ergonomics basics since the most important information should be on top of the display and not on the right.

Overview Display - Dashboard (OD3)

(1) Alarms: The alarm system is the same as the one used by ABB displays.
(2) Tanks - Beginning of the process: It shows information for the tanks used at the beginning of the process. The lines get bigger when used, and associates with the estimated time for completion.
(3) Tanks - End of the process: Shows information for the tanks used at the beginning of the process. The lines gets bigger when used, and associate with the estimated time for completion.
(4) Bar Indicator: See Box plot in subchapter 8.3.
(5) Pump Efficiency: It presents graphically the pumps with their efficiency. Shadowed when not used, red if out of order.
(6) Dashboard: This part is composed from the multi-variables diagram explained in parallel correlation in the subchapter 8.4. The dashboard supports the operator in seeing and getting an analysis about the information in two ways and when it changes one parameter in one, the other one will implement the change.
(7) Task Management: The operator can visualize by a colour code if the task was completed or not: blue for completed, green for running and white for future task. For the past tasks, he can see the estimated time and the time of completion so he can compare his work efficiency. For the running task, an indicator shows the completion of the task associated with a %. Moreover, for each task, the operator needs to approve start and stop operations.

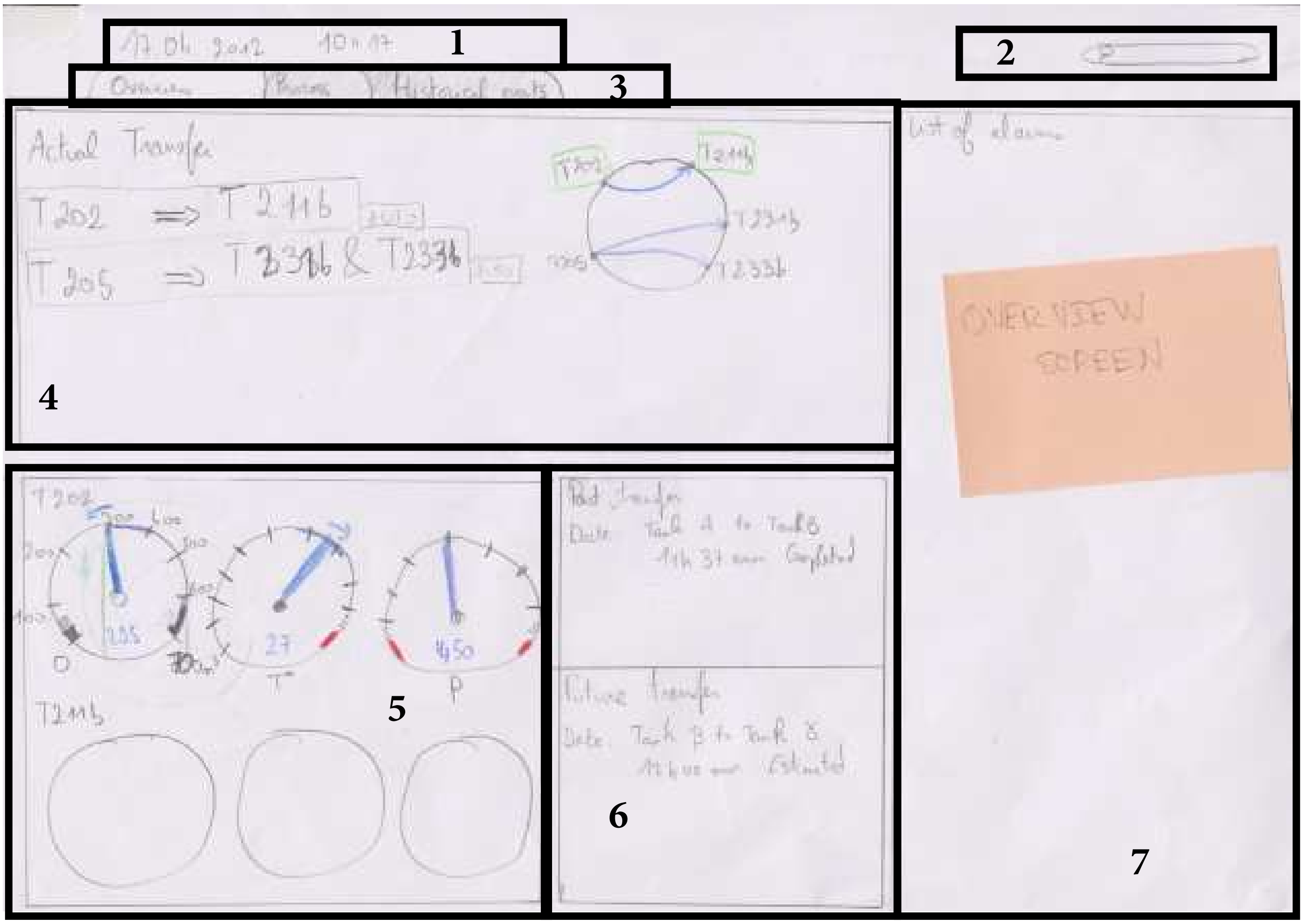


Figure 8.24. OD2

Figure 8.25. OD3

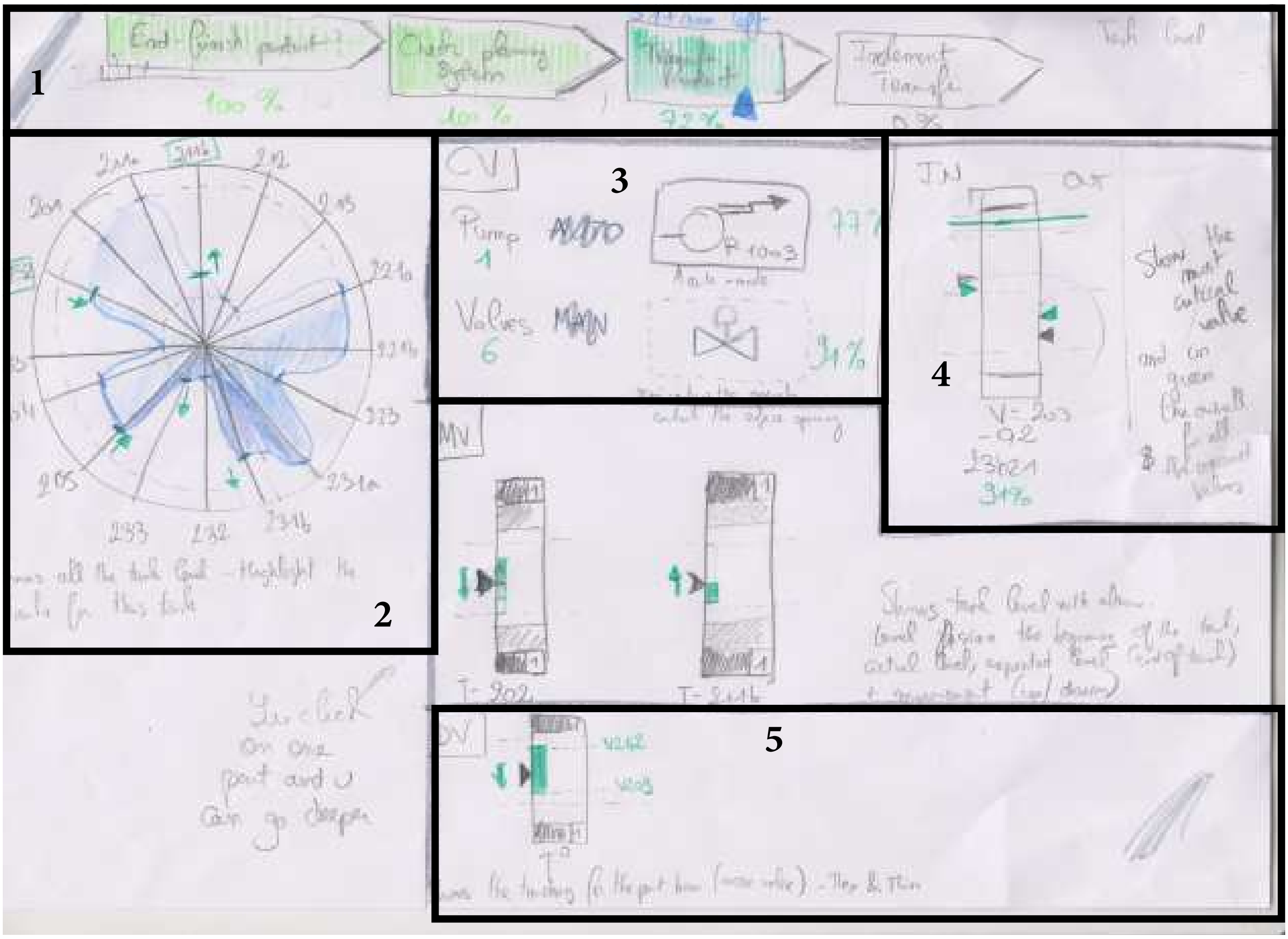
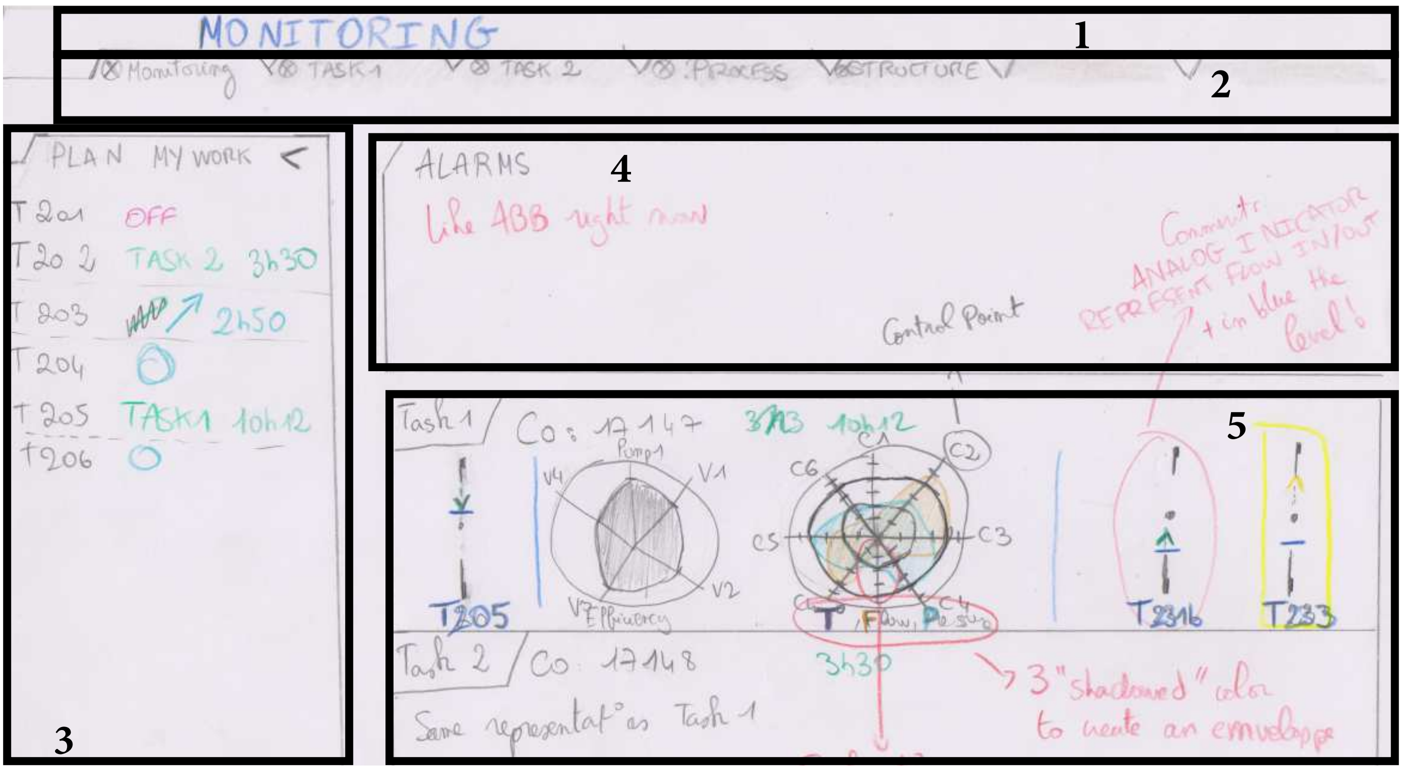


Figure 8.26. OD4

Figure 8.27. ZID - Overview



Overview Display - "Control your flow & web your tank level" (OD4)

(1) Task Management: Considered as the most important information the workflow visualization should be on top of the display. The operator can visualization the completion of each task, and the status on the current task. Two greens colours are used, one for the task done and one for the running task. A small blue triangle indicates visually where time position.
(2) Web Visualization: See Web Visualization in 8.4.
(3) CV - Controlled Variables: The main controlled variables can be visualized and changed in this part of the display. It shows the number of Pump (here 1) and Valves (here 6) used by the process and their mean output value. By clicking either on the pump or the valve, a pop-up window appears to present the characteristics of the physical structure.
(4) Bar graph: The bar graph shows in detail the actual tank level with on the left the flow coming in and on the right the flow coming to visualize the difference. The focus is not on the value but on visualizing the flow difference.
(5) DV - Disturbances Variables: In that area, the operator can see the tendency for a disturbance variable on multiple tanks.

8.6 Zigzag Interaction Design

This part intends to define an interface following the description of the user's mental model explained chapter 7 with the H-AIM with the five levels of AH through perception, analysis and decision-making and action. It expresses a zigzag interaction .
The ZID - stands for Zigzag Interaction Design - expresses the idea that the operator zigzag between three levels of the AH and three phases of the perception-action cycle to get improved SA on the global overview screen.
The important aspect is the connection created between the different levels that gives the ability for the operator to choose the place to work on since the operator can visualize the impact of one level on another.

ZID - Overview Display

(1) Tab Title: It shows the actual tab window name.
(2) Tabs: It allows him to navigate between the different tabs. He can either open or close them depending if he needs them or not at the moment.
(3) "Plan my work": This is a function can be used as a memory-aid. The operator can use it the way he prefers. He switches on and off the function by clicking on the arrow.
On the example, it shows the current status of the different tanks: OFF if not connected to the network, task Name if used by a task and the time left before completion, the tank level tendency and 0 if not used.
(4) Alarm System: Same as ABB right now. Just the position changes since it is not on top anymore. The navigation icons took over the alarm system.
(5) Task Overview: In the example, two tasks are currently running so they both get a separate part of the window. It shows the information in the same direction as the process: from the left to the right: tank level indicator with alarm level, tendency and actual level just with a line, web to represent the valves output, web to represent parameters superposed (depending on a colour coding) at 6 different measurements in the process (Web visualization in 8.4). And it ends on the right with the tank level.

ZID - Task Level

The task level is the Horizontal Task Workflow (Figure 8.3).

ZID - Function Level

This level is defined by a HTA as shown in picture 8.28.
Actually, it was defined with the wrong angle of view during the brainstorming because figure 8.28 shows a screen that represents sequence management since it is a short description of a task with sequence such as open/close valves, start/stop pumps.

The authors did not have enough knowledge at the time when drawing the function level.

The function level of the concept implementation phase should focus more on the representation of the functional relationship related to control a tank or to transfer product.
The part 6 of the OD3 which represents a dashboard of the key characteristics of each measurement point with some indicators should maybe be included in the function level to compare theoretical influence and practical interrelations between the different parameters.

ZID - Process Level

This screen (Figure 8.29) shows the relation between the different physical components. The components in use are highlighted in green. The components in red are out of order. The tank representation is used as a display to represent the levels and their size for example. Near the valves and pumps, their efficiency and power is displayed so the operator can visualize the main characteristics for starting a task.
On top of the screen, in blue, the operator can see in which block part of the plant the process is being shown on the screen.
On the bottom left part of the process, a small map represents the entire process and the

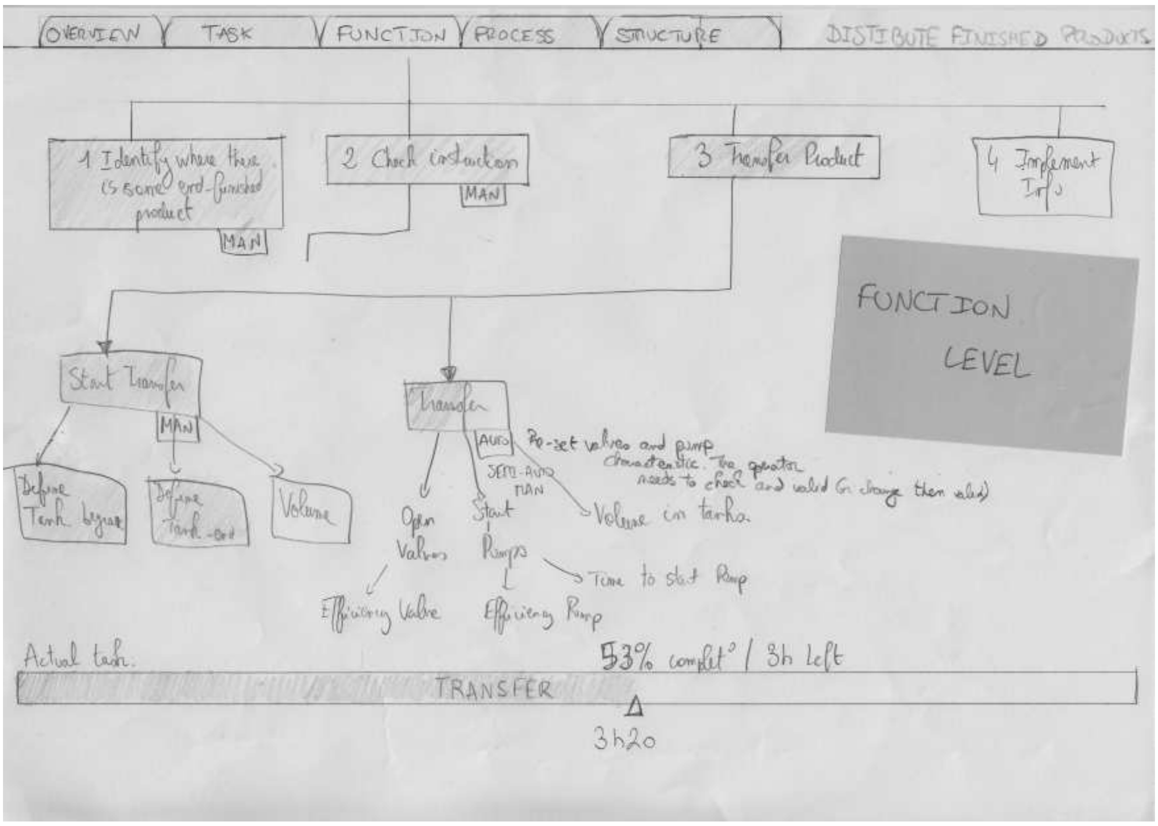


Figure 8.28. ZID - Function Level

operator can navigate through the entire process and check the position of what is showed on the screen.
Figure 8.30 represents a screen when the operator zoom in.
The operator can move up, down, left and right with the black arrows to visualize another

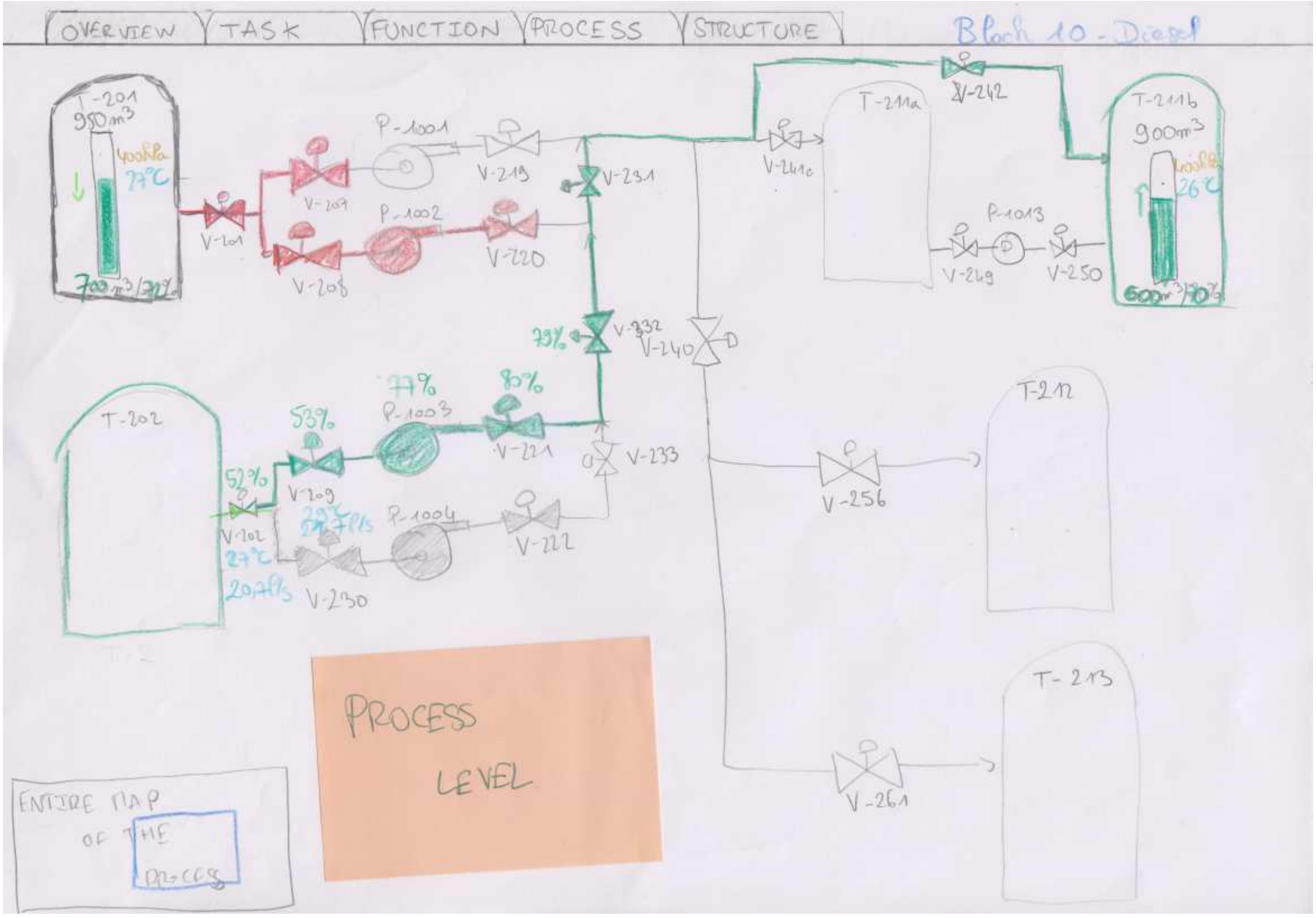
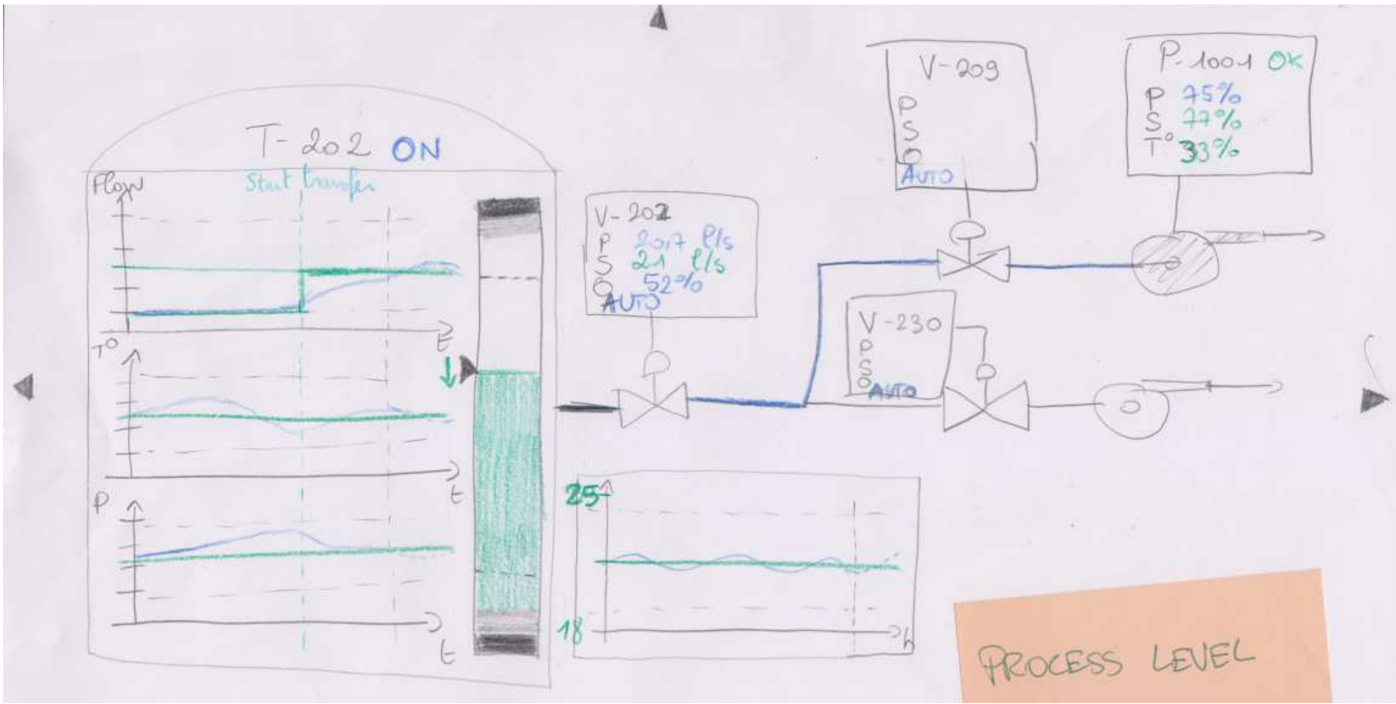


Figure 8.29. ZID - Process Level (Above)
Figure 8.30. ZID - Process Level - Zoom-in (Underneath)



part of the process.
When the operator zooms in, more detailed information directly on the physical components is given.
For example, the tank representation is used as graph display to trend temperature, viscosity or pH which puts information in process context. The operator can see a more accurate visualization of the tank level with the bar graph. For each valve, the operator can see the flow commanded, the actual flow, the valve output and the mode (auto/manual). By clicking on the valve, the operator can get a graph that trends the flow over the past couple of hours. In that screen, blue and not green are used to highlight that this part of the process is used. From the study visits, the colour coding that should be used is not well defined since some industries use either green or red for "component working" status. Blue could be used as an "intermediate" colour to show a process currently working under good operating conditions. Then the colour can change to red when part of the process encounter problem or possible alarm to alert the operator on future possible incidents.

ZID - Structure Level
This figure 8.31 displays the raw data about all the physical components of the plants. The representation can be a table. With this layer, the data is out of context and the operator needs to be able to create context around. This screen should not be used for decision-making.

The screen "Plant Map" (Figure 8.32) shows the position on the map of the different physical components such as tanks or water reservoir for sprinkler system. It can help the control room operator when contacting a field technicians. In case of emergency, the operator can send the field technician right away towards the right place.

8.7 Eliminated concepts

More concepts such as other displays or sketched icons for the display were developed but they were considered as not relevant for the reader in the report. They are listed in appendix H.

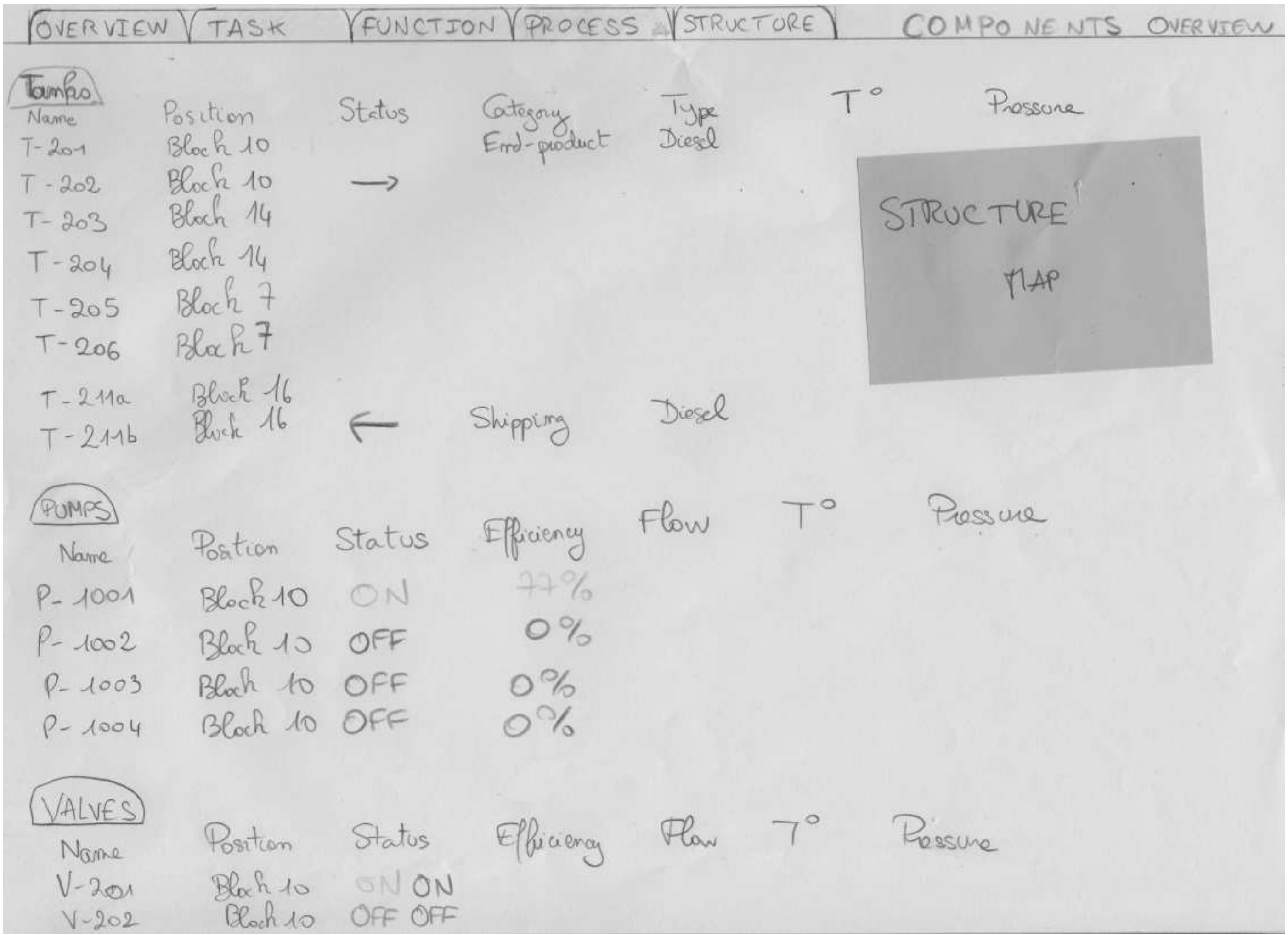


Figure 8.31. ZID - Structure Level

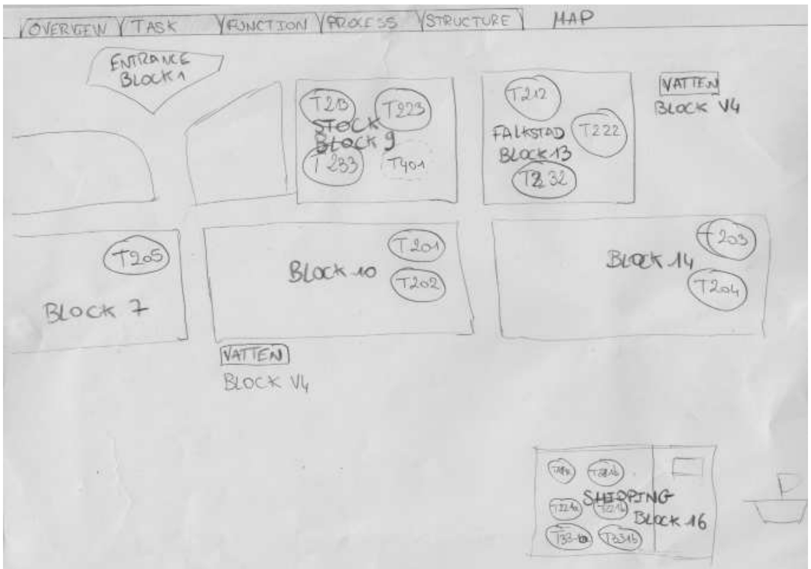
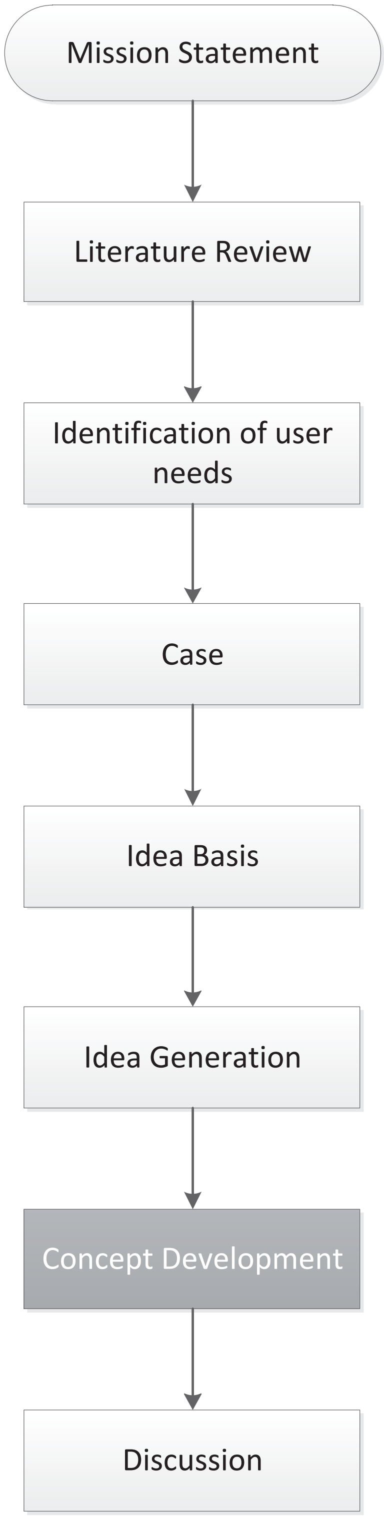


Figure 8.32. ZID - Structure Level - Plant Map



CHAPTER 9
CONCEPT DEVELOPMENT

This chapter presents the different aspects of the implemented concept. It highlights the overall structure of the concept and the main functions. It also presents the feedback from the users.

9.1 The Concept

The design of the concept supports the users' needs defined in chapter 5 and the user cases defined in chapter 6. The structure is inspired by the five levels of the abstraction-hierarchy with the addition of a home screen that can be used either for testing pre-made scenarios or as a starting screen for the concept. The structure can be compared to a pyramid (Figure 8.1). The bottom floor represents the structure level where the user can get the more data (not information) about the plant and then by going up in the pyramid coarser information will be given in a clearer context. This structure narrows the area of attention for the operator and improve the overall situation awareness.

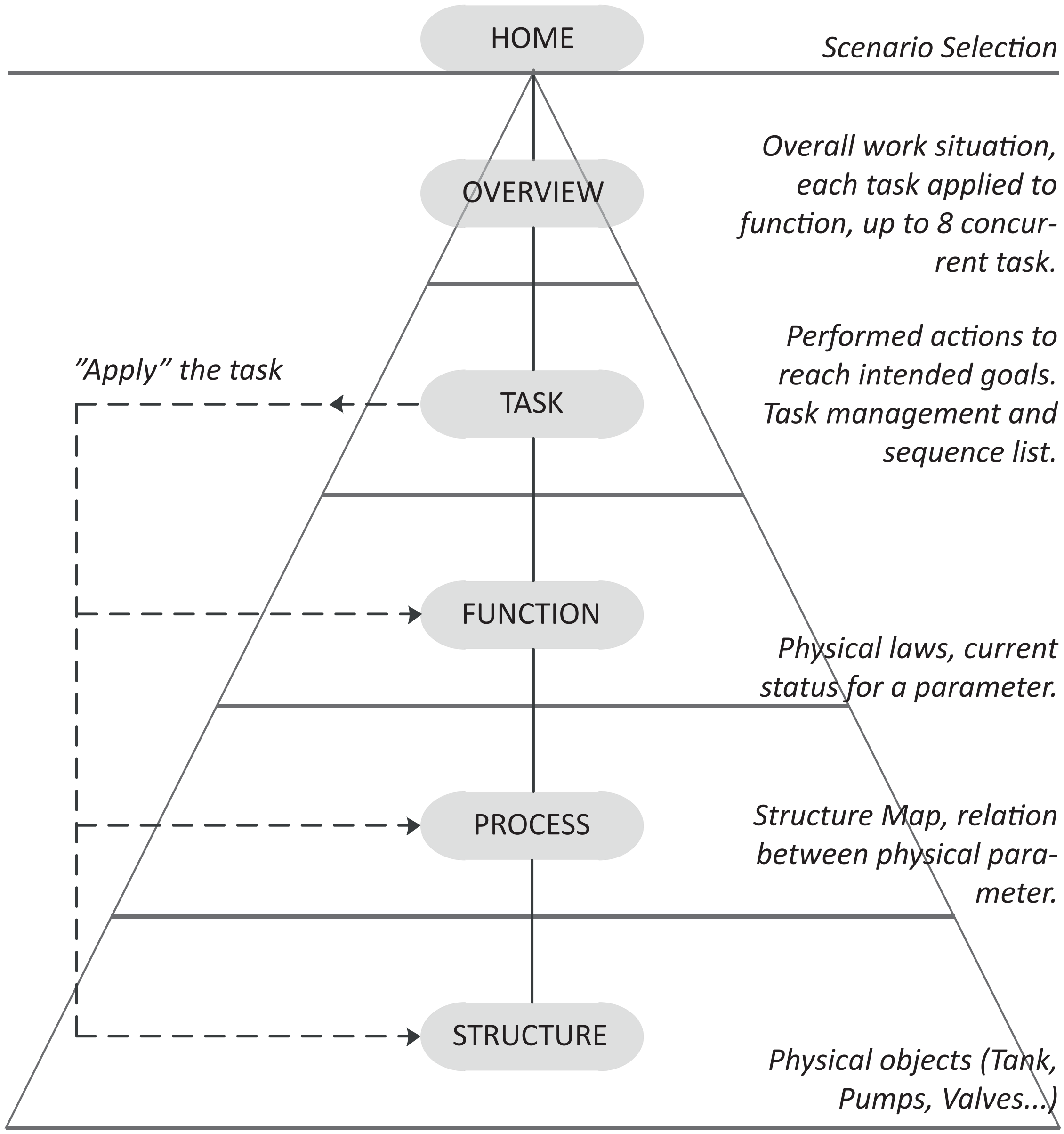


Figure 8.1. Concept Structure

Concept interface

This structure supports the concept development and the future integration of the different functions. Figure 8.2 shows a view of the concept with the different areas.

In the industry today it is common to use buttons with text descriptions to move between the different screens sometime they are even long expressions. The idea here is that icons can support quicker movement inside the interface. They should be designed to help visual recognition. However, in the main screen, the number of icons should be limited to avoid the interface to be cluttered.

Icons are grouped into two categories. The ones on the top look like the existing solutions on the market today, eg. alarm system, favourites, and the ones on the left support the navigation throughout the hierarchy for an improved interaction through the pyramidal hierarchy.

Navigation Icons

Five icons are situated on the left side of the screen to support the operator to navigate quickly from one level to another. Each icon leads the operator to a specific screen.

Figure 8.2. Basic layout of the concept

Home Icon: Scenario Start
The icon leads to the start screen where scenarios can be chosen (Figure 8.3).

Overview Icon: Quick Situation Monitoring
The overview screen is a combination of multiple levels from the H-AIM: the situation level, overall plant goals; task level, actual workflow; the function level, current status of main parameters by improved indicators (Figure 8.4).
The "quick monitoring" of the plant takes place here. This screen can be considered as the master screen of the concept.

Task Icon: Task Management
The task management takes place here. The operator can start, pause, stop a task (association of sub-tasks), a sub-task (association of sequences) but also a sequence. It is also possible to selects manual/auto if there is a need for a change (Figure 8.5).
Part of the screen is allocated to the workflow and the other is related to sequence management support.

Function Icon: Trends
The operator can visualize the different parameters, their values, but also their relation between each other depending on engineering theories (Figure 8.6).

Process Icon: Improved Process-based Display
On this screen, the operator gets the same process-based display as actual ones in the different industries.
The main improvement is the possibility for the operator to highlight one running task on the process display helping the decision-making when starting sequence, but also as a reminder during long procedures (Figure 8.7).

Structure Icon: Physical Objects List
The operator gets a list of all the physical structure (Plant, Pumps, Valves) of the plant and all the information related to it such as current state (Figure 8.8).

Figure 8.3. Home Icon

Figure 8.4. Overview Icon

Figure 8.5. Task Icon

Figure 8.6. Function Icon

Figure 8.7. Process Icon

Figure 8.8. Structure Icon

Top Icons

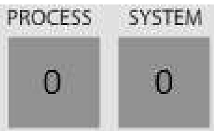


Figure 8.8. Alarm

Multiple icons are situated on the top part to highlight alarms, events to the operator. Other icons are related to operator’s preferences and help.

Alarm System

Figure 8.9. Task & Sequence event

Since the focus of the thesis is not on the alarm system, the ABB Alarm system is used with a top box to list the alarms and two types of alarm that pops-up, process ones and system failures (Figure 8.8). The level of priority is also included (with colour coding). For the past alarms, it should noted how they were solved to support the operator with a solving-aid.

Task & Sequence Event


Figure 8.10. Favourites Icon

The concept proposes a procedural approach to do an operator’s work. This higher level of automation should not lead the operator to lose control over the automation system. It should be notified when a sequence or a task is done so the operator can approve or disapprove the result. The event box shown in figure 8.9 provides feedback to the operator about the completion of a sequence or a group of sequences, by clicking on it the operator can visualize the event list where the name of the completed task will be listed. It is considered less disturbing to add a number in the box when a task or sequence is finished than a window that pops-up and disturbs the operator’s current action.

Favourites Icon

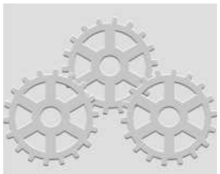


Figure 8.11. Settings Icon

The operator should be able to customize the overview display so it can adapt to the operators’ experience and preferences. If five operators are using the same station maybe each part of the star (Figure 8.10) can represent an operator and to switch the operator has to click on the corresponding part of the star.

Settings Icon


Figure 8.12. Help Icon

On the screen, the operator can modify the main settings by clicking on the icon shown figure 8.11.

Help Icon

It provides a help guide to the operator. Another help could be to switch on/off some information presented on the process screen such as names (Figure 8.12).

Search Function


Figure 8.13. Search Icon

It allows the operator to search for a valve, a task or a past alarms for example and leads him to the page where he can find the information(Figure 8.13).

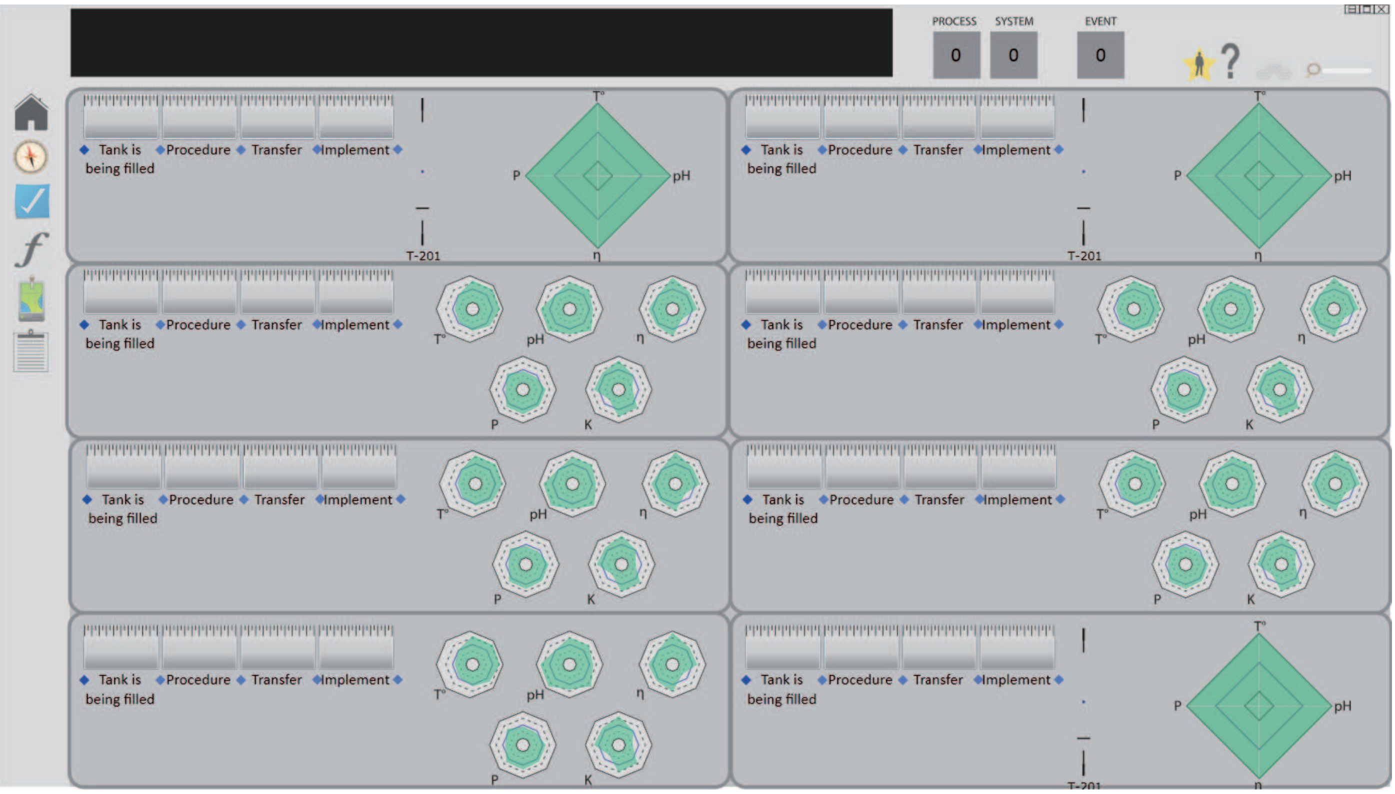
Overview screen

On the screen below one can see a basic set up for the overview of screen. In total eight tasks can be monitored from one overview screen (Figure 8.14). The overview screen works at several levels of the H-AIM. It works at the situation level giving a sense of the overall situation and goal of the plant. It acts at the task level by showing where a task is and with the addition of indicators it works at the function level depending of what is presented.

Each task is separated into two parts. The left part of the task is for seeing at what step a task is at and the right part is for presenting critical parameters associated with the current task step for monitoring (Figure 8.15). The task progress bar is separated into different steps. For each started task the percentage of completion is shown and the time left to completion for the step is also available. Between each step there is a gate (the blue and green diamonds). The green indicates that a gate is done. When it is possible to start a new step, the gate will change from blue to dark blue and a number will be added to the event icon. By clicking on the gate the task management screen will open on another screen and the operator can control the sequences in that step from that screen.

The indicators shown are just there to give an idea over what can be placed in that area on the figure 8.14. The main point of the indicators is not to give precise numerical values about the process, but rather provide a sense of the current situation of the different tasks.

Figure 8.14. Overview screen



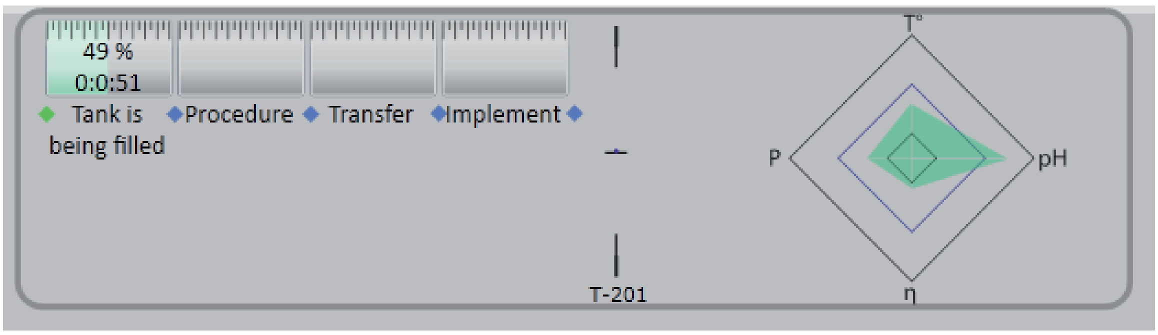


Figure 8.15. One of the tasks in the overview screen

Task management screen

The task management screen (Figure 8.16) can be separated in two main parts: task management (Figure 8.17) and sequence or sup-task management (Figures 8.18 and 8.21). The task management screen works mostly at the task level in the H-AIM but depending on what Indicators are displayed it can to some extent work at the functional level. The Sequence part can be divided into two sections, the first is a sequence list where the different sequences for a sup-task is shown and controlled. The second part (lower right part in figure 8.16) is for sequence specific information and actions presented via indicators or confirmation boxes.

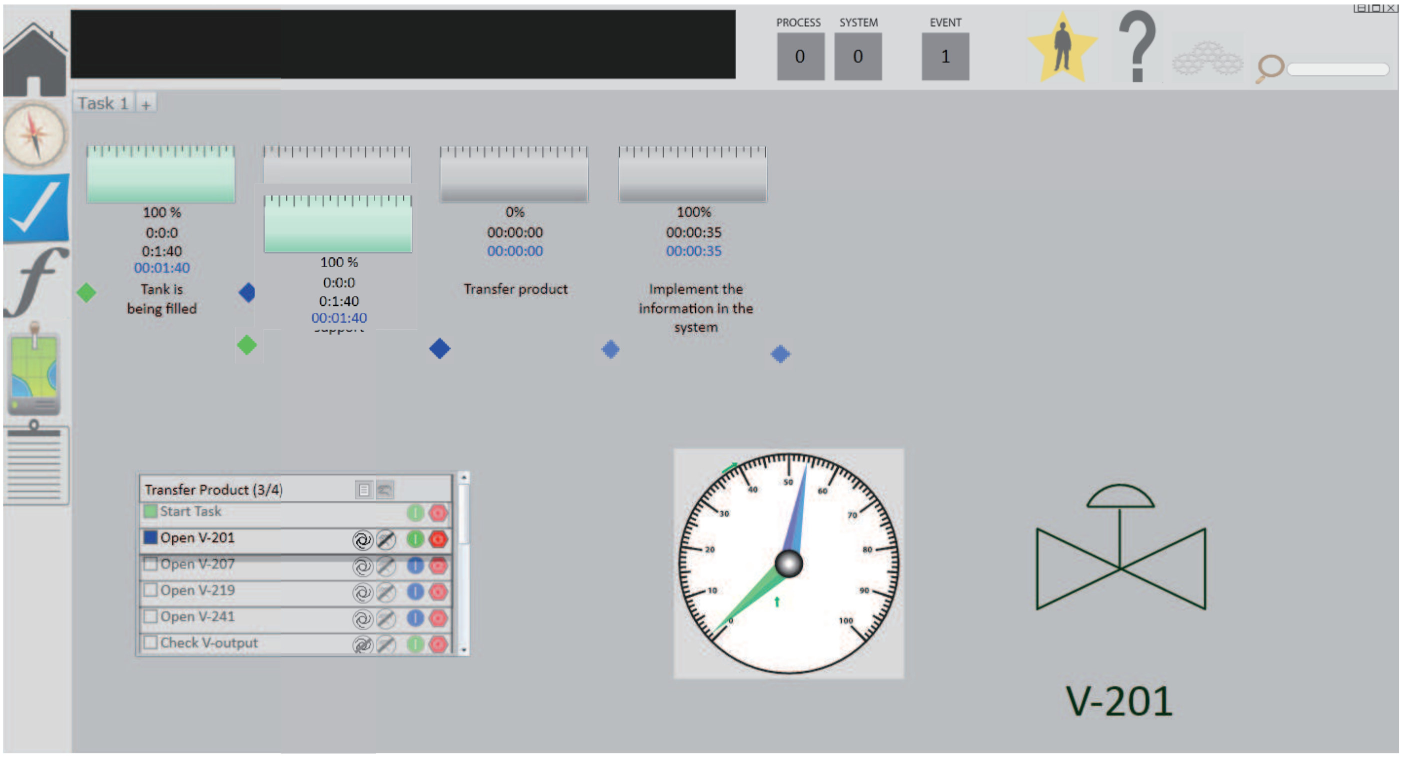


Figure 8.16. Task management screen

To start a new task the user clicks on the plus-sign in the upper left corner of the screen (Figures 8.16 and 8.17), this will prompt the user with a pop-up window that allows him to select between different tasks.

A close up of the task status bar can be seen in figure 8.17 similar to the one in the overview screen. Here the operator can see the percentage of completion, runtime and estimated time for completion. Just like in the overview screen gates in different colours indicate if a step is passed or is ready to start. The starting of and ending of a gate is done from the sequence list.

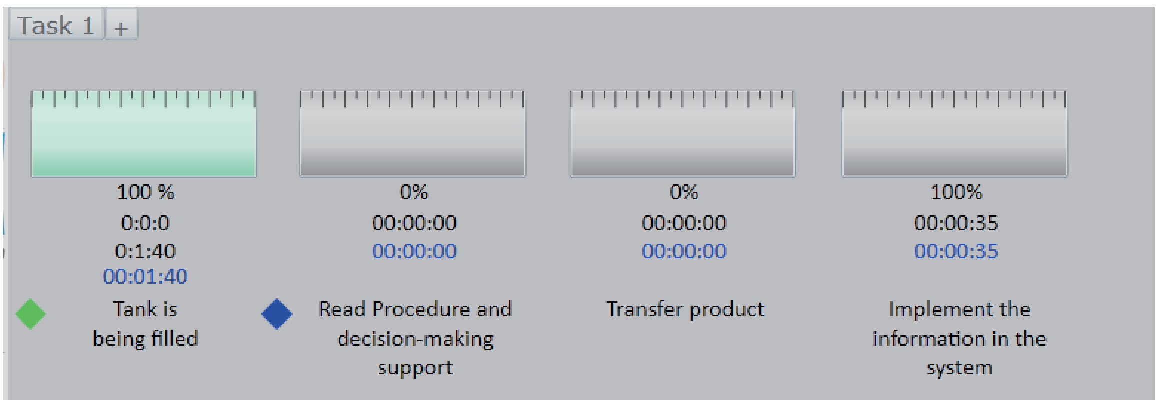


Figure 8.17. Task status part of the task management screen

In figure 2.18 an example of a sequence list can be seen. In the top part of the list the name of the sub-task that is associated with the sequence is displayed.
Buttons for bringing up documentation and putting the sequence in to manual-mode is also situated here (Figures 8.22, 8.23 and 8.24).
Below all the different sequence steps are displayed, in case there are more steps than what can shown at the same time a scroll-bar can be used to change what steps are to be shown.
On the left side of the sequence list the square indicates the status of a sequence step. A green square indicates a completed step (Figure 8.19), a blue one indicates a running step (Figure 8.20) and gray is for steps not reached yet.
On the right side going from left to right is; icon indicating if the sequence step is in automation and icon for if the sequence step is manual. Further to the right two buttons for approving the start of a sequence step and disapproving a sequence step. Before a step is approved the start button is blue when the button is double clicked it will turn green. The reason for the double clicking is for preventing errors and miss-clicks. It also gives the user an indication that the system has registered the input of the operator.
In the lower right half of the task management screen (Figure 8.16), the area for presenting sequence specific information is situated. In the example image shown in figure 8.16 and figure 8.21 the flow through a valve is shown and the control value via an analog indicator. A graphical representation of the valve is also shown, when the valve is opened it will turn green, further more the name of the specific valve is displayed to let the operator know which valve is being controlled.

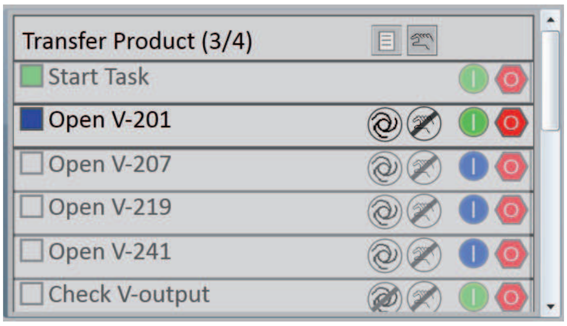


Figure 8.18. Sequence list

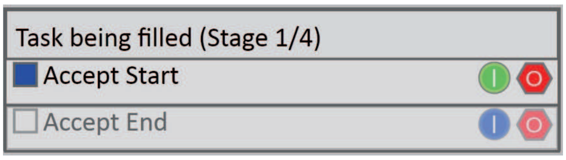


Figure 8.19. Sequence list with a sequence step ready to be confirmed

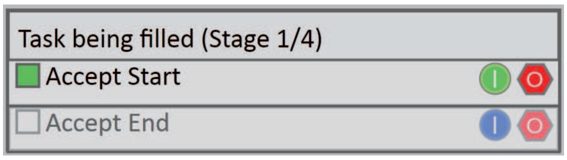


Figure 8.20. Sequence list with a sequence step confirmed

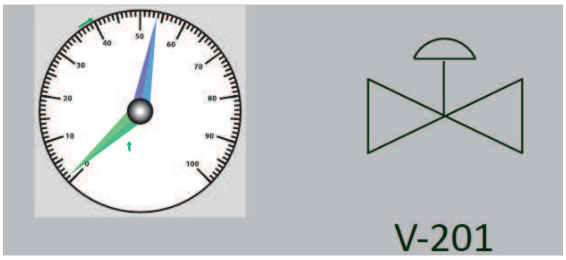


Figure 8.21. Sequence specific information.

Figure 8.22. Sequence specific information.

Procedure documentation button
Clicking the button brings up a window with the written documentation for that specific task.

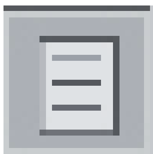


Figure 8.23. Procedure documentation Icon

Manual control button
Turning manual control on allows the operator take over control over a automated sequence.

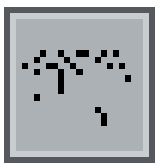


Figure 8.24. Manual control Icon

Function screen

On the function screen the operator can visualize how the different parameters are connected, but also how the real values relate to theoretical values. This can help the operator to understand how different factors are connected and see if there is some potential improvement. He can also use it to see how one parameter change propagates out and affects other parameters (Figures 8.25 and 8.26). In the figures the T1 parameter is selected and the parameters that is affected by it is highlighted in the boxes. The relations are also shown in the form of bars on the left side of the screen. To see how different values of T1 would affect the other parameters the operator just need to move the slider in the centre.

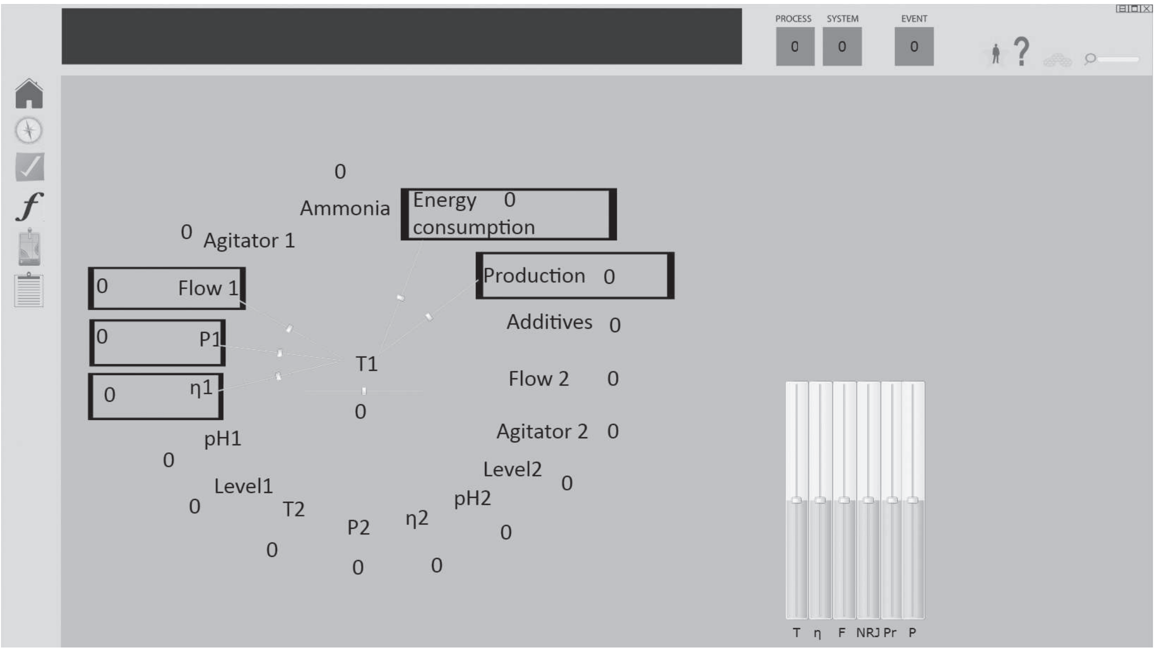


Figure 8.25. Function view screen

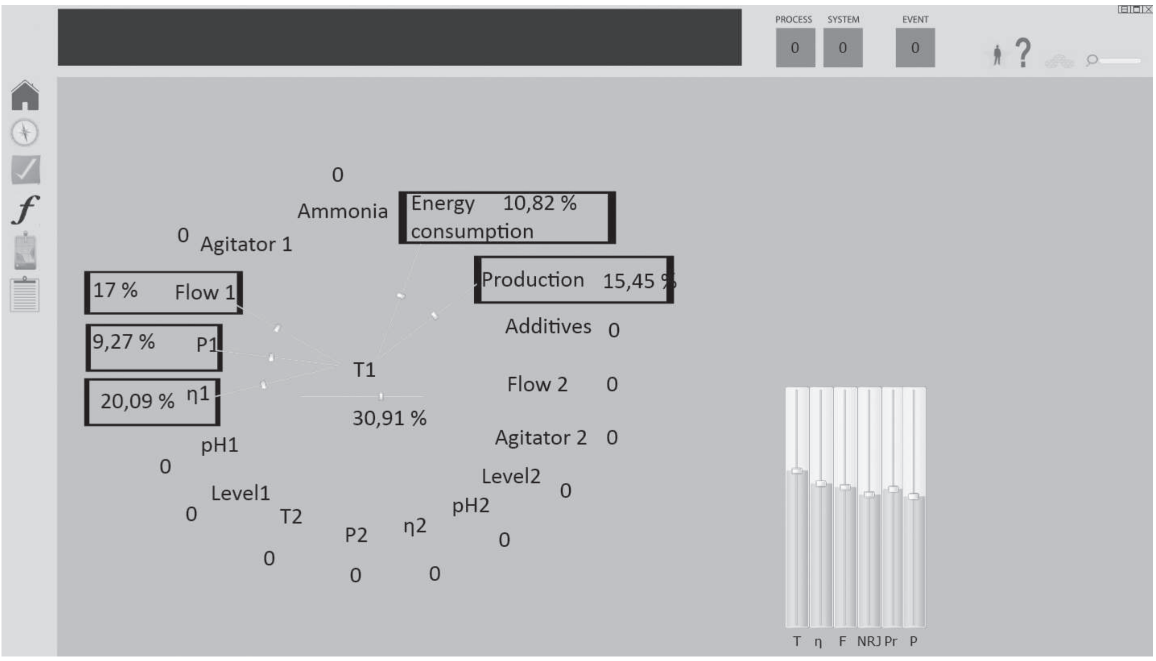


Figure 8.26. Function view screen in use

Process screen

From the process screen the operator can see a schematic graphic representation of the physical structure. From this view the operator can control various aspects for the process such as opening/closing valves and starting/stopping pumps. In figure 8.27 a very basic process image can be seen, this is not how a finished process screen should look like, see figure 5.8 and 5.9 for a more correct representation of what the graphics and layout of a process screen could look like. What is new with this view compared to existing process-based screens is how it is connected to the task and how the automation system highlights the path it is selecting in the process.

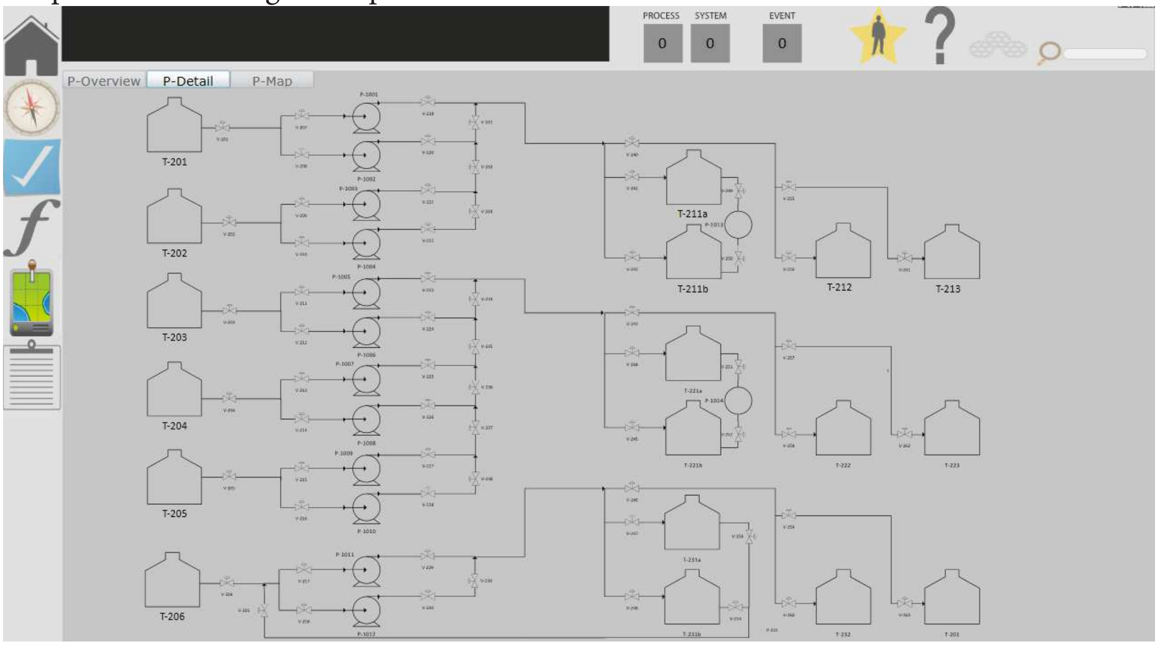
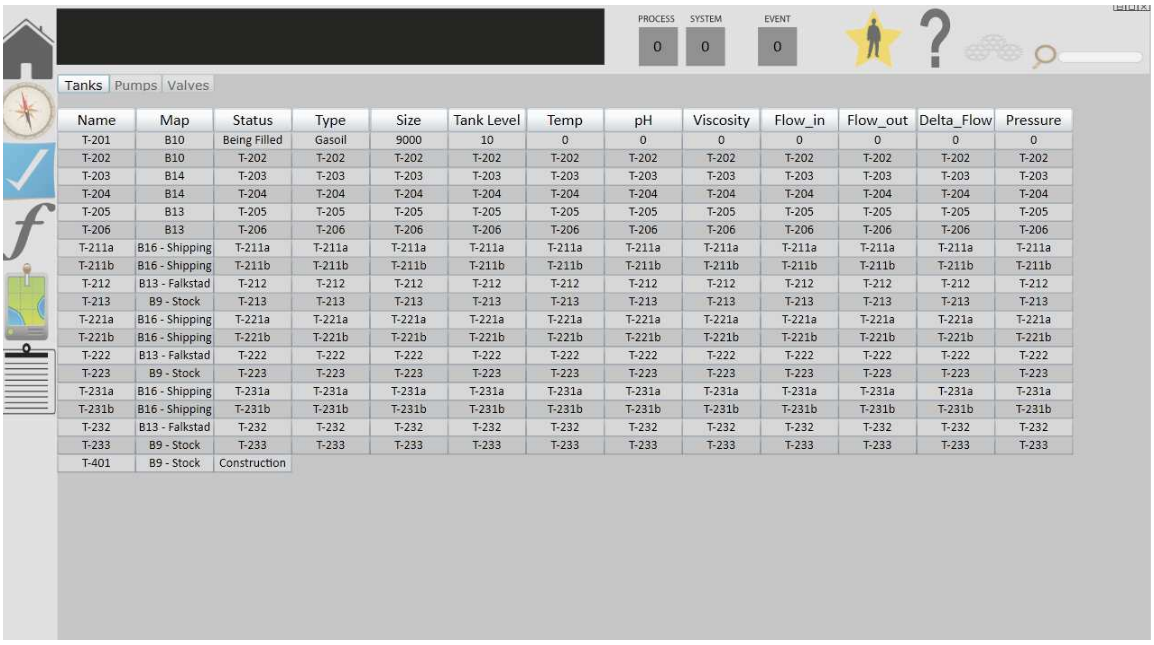


Figure 8.27. Process view screen

Structure screen

The last of the different screen views is the structure screen (Figure 8.28). In the structure screen all parameters for all structures in the process or a specific part of the process is shown. In this view data not information about the different parts is presented. The structure view can be useful if an operator quickly need a specific value about several similar process entities for example the pressure in all tanks of the plant. It can also be useful if the operators are doing a meticulous check of all the parameters of the process.



PROCESS SYSTEM EVENT
0 0 0

Tanks | Pumps | Valves

Name	Map	Status	Type	Size	Tank Level	Temp	pH	Viscosity	Flow_in	Flow_out	Delta_Flow	Pressure
T-201	B10	Being Filled	Gasoil	9000	10	0	0	0	0	0	0	0
T-202	B10	T-202	T-202	T-202	T-202	T-202	T-202	T-202	T-202	T-202	T-202	T-202
T-203	B14	T-203	T-203	T-203	T-203	T-203	T-203	T-203	T-203	T-203	T-203	T-203
T-204	B14	T-204	T-204	T-204	T-204	T-204	T-204	T-204	T-204	T-204	T-204	T-204
T-205	B13	T-205	T-205	T-205	T-205	T-205	T-205	T-205	T-205	T-205	T-205	T-205
T-206	B13	T-206	T-206	T-206	T-206	T-206	T-206	T-206	T-206	T-206	T-206	T-206
T-211a	B16 - Shipping	T-211a	T-211a	T-211a	T-211a	T-211a	T-211a	T-211a	T-211a	T-211a	T-211a	T-211a
T-211b	B16 - Shipping	T-211b	T-211b	T-211b	T-211b	T-211b	T-211b	T-211b	T-211b	T-211b	T-211b	T-211b
T-212	B13 - Falkstad	T-212	T-212	T-212	T-212	T-212	T-212	T-212	T-212	T-212	T-212	T-212
T-213	B9 - Stock	T-213	T-213	T-213	T-213	T-213	T-213	T-213	T-213	T-213	T-213	T-213
T-221a	B16 - Shipping	T-221a	T-221a	T-221a	T-221a	T-221a	T-221a	T-221a	T-221a	T-221a	T-221a	T-221a
T-221b	B16 - Shipping	T-221b	T-221b	T-221b	T-221b	T-221b	T-221b	T-221b	T-221b	T-221b	T-221b	T-221b
T-222	B13 - Falkstad	T-222	T-222	T-222	T-222	T-222	T-222	T-222	T-222	T-222	T-222	T-222
T-223	B9 - Stock	T-223	T-223	T-223	T-223	T-223	T-223	T-223	T-223	T-223	T-223	T-223
T-231a	B16 - Shipping	T-231a	T-231a	T-231a	T-231a	T-231a	T-231a	T-231a	T-231a	T-231a	T-231a	T-231a
T-231b	B16 - Shipping	T-231b	T-231b	T-231b	T-231b	T-231b	T-231b	T-231b	T-231b	T-231b	T-231b	T-231b
T-232	B13 - Falkstad	T-232	T-232	T-232	T-232	T-232	T-232	T-232	T-232	T-232	T-232	T-232
T-233	B9 - Stock	T-233	T-233	T-233	T-233	T-233	T-233	T-233	T-233	T-233	T-233	T-233
T-401	B9 - Stock	Construction										

Figure 8.28. Process view screen

Interaction

An important factor when it comes to the interface is how the operator moves between different screens and how they connect to give specific information. Beyond being able to click on the buttons to switch between the screens one can navigate by other means and get access to more specific task related information. When a task is running and one is in the overview screen simply clicking on one of the gates will bring up the task screen for that specific task (Figures 8.14 and 8.15).

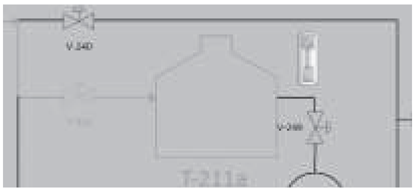


Figure 8.29. Return icon from process view

When the operator is in the process view and after seeing the process suggestion from the automation system, he can come back to the task screen by clicking on a button shown in figure 8.29.

Moreover, a "drag and drop" function allows the operator to select a task and acts on the function, process and structure screens. The operator needs to clicks and holds one of the task buttons and then drag the selected button to the level and releases the mouse button to drop (Figure 8.30). When the task is dropped the screen will change to the selected view. The main difference now is that the different parts associated with the task will be highlighted in various ways. In the function view only the parameters connected to the task will be presented. In the process view all the components that are in the task is going to be highlighted so the operator can easily find what is connected to a specific task and only focus on that if needed (Figure 8.31). In a similar fashion when a task tab is dropped on the structure view only the specific tanks, pumps and valves will be shown.

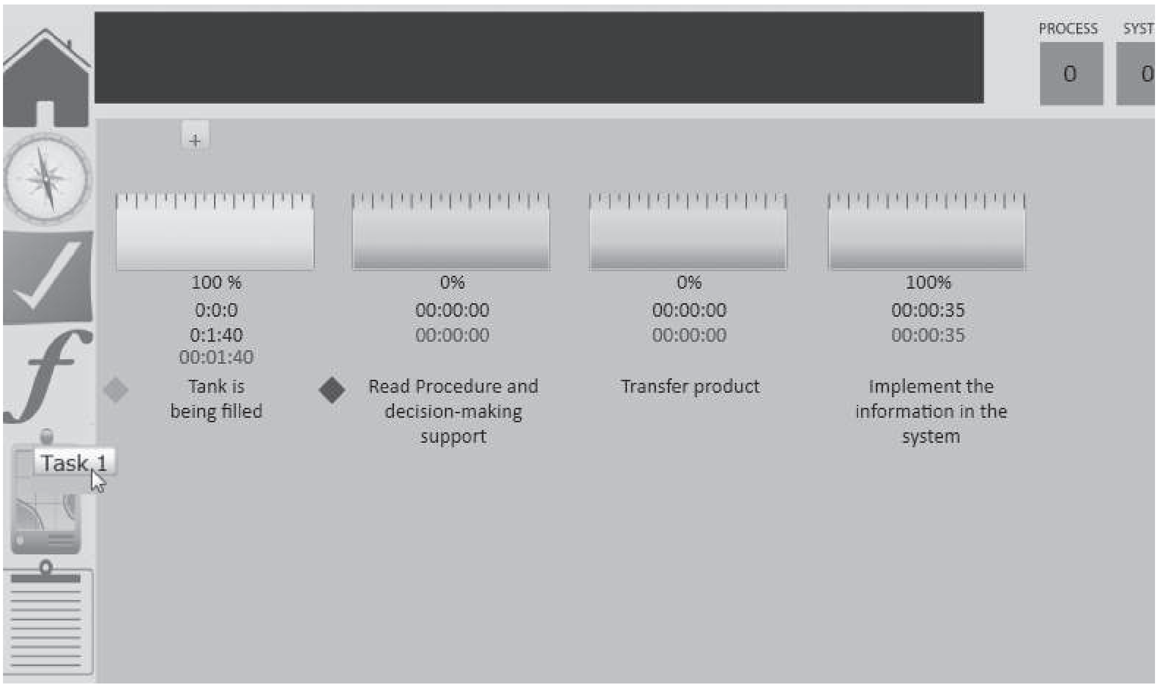


Figure 8.30. First part of the drag and drop

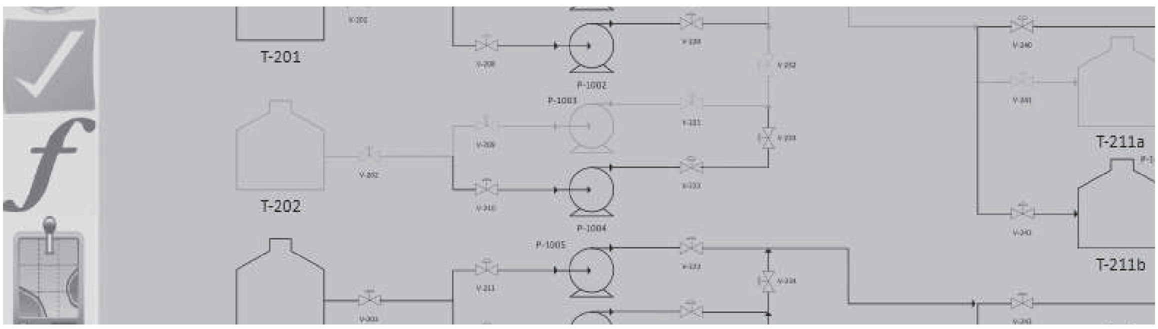


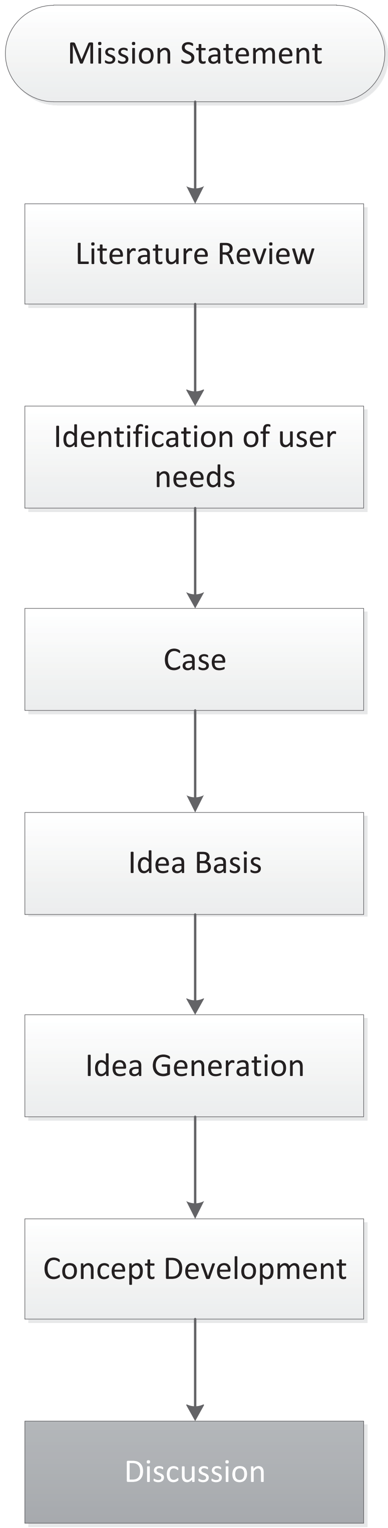
Figure 8.31. The effect of the drag and drop

9.2 Feedback

The feedback was gathered to get inputs on the concept from three operators from three different industries with a short demo presentations were performed.
The overall response from the operators was positive but with some concerns. One thing an operator was concerned about was screen real estate but that came mostly from how the current setup was in the operator's control room. Another issue was related to the task-based functionality since it could be difficult to implement it to continuous flow process with unclear defined tasks to monitor.

While operators' opinion and focus were different, there were still some correlation between them. The general opinion was that the overview and task screens could be a useful addition and would most likely be of benefit in batch-based processes. It was appreciated that steps in the sequence could be controlled manually and not like today in the ABB system that it only tells the operator where in the sequence the automation currently is. Operators perceived a positive potential when controlling different steps from the task screen. The indicators were met with a mixed opinion on one hand the operators saw that there was a potential use for them, but generally they thought that graphs plotting the trend were enough.

The operators also made some suggestions for further improvements. The first one is the addition of a log function for the sequence that would allow an operator to see how a previous operator has solved a potential problem. The second one, in the structure level, is to add an arrow next to the digital values that would change length and direction depending on the direction of change and the speed of the change. This last addition would give the operator more knowledge about what is happening in the plant when looking at the structure screen.



CHAPTER 10
DISCUSSION

The discussion comprises a reflection on the methods and evaluates the end-results based on the research questions defined in the introductory statement of purpose. In addition, this chapter presents suggestions for future developments to carry on the topic.

10.1 Methods Reflection

This subchapter reflects the different methods used during the thesis for future team projects.

Time Plan

Gantt charts are effective in giving a clear illustration of project status but its main weakness is that it does not highlight task dependencies.

Literature Review and KJ-method

The literature review was probably too deep due to the a lack of knowledge about control rooms when initiating the thesis work and the uncertainty about the expected outcome. However it gave a critical view for planning the study visits and gathering information from the operators. Moreover, it gave a framework to analyse the quality of the concepts.

Design Research

The best design ideas extracted from the literature and the internet were very helpful to feed the idea generation. Looking for interesting designs from the beginning of the thesis until the development phase was very supportive to develop ideas in context during the study visits or to connect it with theoretical background when reading articles.

Semi-structured long interviews

In general the interviewees were very helpful and the only real problem was receiving access to control rooms and operators. Another issue is related to the language barrier since the interviews were performed in English and not in the operator's native language, some information might have been lost.

Data gathering aids

The various aids used during the visits were helpful in that they assisted in noting down the more relevant information without having to take down all of what was said. However if more interviews are performed one should consider revising some of the points and question to take in to account the knowledge gained during the project.

Requirement Specification

A requirement specification serves different functions in the various phases of a project and should be regarded as a kind of living document. As such changes to it will occur as the work progresses and more knowledge is acquired. In the development phase the requirement specification can be viewed as an aid to see what is needed of the concept, towards the end of the project it is more useful as a tool to assess if the concept meets the requirements put on it by the user needs. As the concept in the thesis is not a finished product the last aspect of the requirements specification has not been used and as that is the more important function of the requirement specification it hard to say much about it as it has yet been fully utilised.

User Type

This method was not exhaustive but it helped defining the different categories. Thus it is used as a basis to define the user profile and the user relations which were found very helpful.

User Profile

This method was very helpful to keep in mind the main user needs in mind. This method is presented in only 2-3 pages which is very helpful in giving a quick overview of the main needs of the visited operators. This table was an aid for implementing some of the operator's issues in the final concept.

User Relations

This method was very interesting to give a broader view of the relations between the user at stakes. It allowed to define new function to enhance meeting and collaboration in the control rooms.

Hierarchical Task Analysis (HTA)

The Hierarchical Task Analysis developed in the report was not very extensive since it was based on a simplification of a task from the study visits. It was found difficult to run a task analysis during the operator's work-time without disturbing the operator's work and still gathering all the required information in a somewhat limited time span. However the HTA supports the definition of tasks, sub-task and sequences that gives the operator's workflow in the implemented concept.

H-AIM

This method was found very supportive to structure the analysis of the interaction human-automation system. At the beginning it was used as a thinking tool depending on the data gathered during the study visits and related to the cases. But further on by seeing the impact that the level of automation could have, it was used as a basis for idea generation and had a impact on shaping the concepts.
There is here a shift between the way the model was supposed to be used - analysis of actual design, expected design and then analysis of the gap between both - and the way the authors used it - unified description of the actual and future interaction of human operator with automation system and the impact of the level of automation. The novelty of this model provides drawbacks since the authors were the first ones to use it and handle it for analysis. On the other hand, it provides the advantage to have a freedom to handle it by adapting it carefully to the thesis' needs.

Brainstorming
This method is useful since it allows an open mind when generating ideas. The generated concepts were not all at the same phase of development, but it allowed the merger of some concept during the concept implementation.
It was also useful to get feedback on the brainstorming ideas and the H-AIM from a brainstorming workshop with another group.

Demonstration - User Feedback
The user feedback is an interesting phase when developing human-machine interface. The interface is developed for the user so it is important and helpful for the designers to involve user at the beginning of the project via study visits and during the concept implementation phase by demonstration of prototypes. The user feedback on the concept can be viewed as positive, since it agrees with the direction taken by the thesis for the interface in control rooms. It should however be taken into consideration that the input was gathered from a limited sample and more feedback should be gathered and more demonstrations should be done before continuing on with the project.

10.2 Procedure

One of the major problems the project experienced was to be able to perform study visits to get firsthand experience with the control room operators. During the planning phase the authors thought they had allocated enough time for performing study visits. There was a large inertia in the process of doing a study visit from the initial contact to the visit in the control room.
Another source of delay is due to the fact that the thesis project was partly a research project which brought some uncertainty due to the limited experience of the authors in this field.

10.3 Results

The results presented in the previous chapter shows that the work efficiency of operators can be improved by an additional support from the automation system. The proposed concept does not solve all the problems. It will be more adapted for batch-based process than for continuous process due to the difficulty of defining a clear task. However improvements are proposed to support the operators in managing the task with a task management system and by giving tools to visualise the interdependency of functions and to create his own mental model of the technical process. The concept supports normal operations work but provides an aid for collaboration and meeting (such as shift handover) with other operators.

10.4 Conclusion

The thesis work addressed the issue of multitasking activities for operators in control rooms. The lack of support in today's control room leads to difficulties in working efficiently.
A product development process was carried out to develop a concept of an interface. Literature review and study visits were done to learn deeper information on the limitations and possibilities when developing an interface for the Oil & Gas Industry.

End-Result

The solution provides contribution to both the research area and the industry.
For the research area, the H-AIM was used as a system thinking tool to find possibilities for reducing the gap between the operator's mental model of the system and the actual system by analysing the human-machine interaction as a whole.
For the Oil & Gas industry, the suggested concept is one of the first that proposes to work in a more abstract level without losing the relation with the physical world. Most current overview screen are a compilation of the key parameters presented in a digital format. The conceptual solution goes further than the interfaces presented in the theory chapter by providing a clear structure for the operator to work with, by highlighting the importance of the information visualisation to explicit the causality of the Human-Automation System and by enhancing computer-based procedures. Moreover, the proposed Global Overview Screen is used for its first purpose: giving an overview of the plant without too much details to the operator.

Research Question

During the introduction, three research questions were defined. This section intends to summarize the answers provided by the end-results to these questions.

1. What should be and should not be simplified in information presentation compared to existing solutions in the market

The solution simplifies the information presentation by providing a hierarchy-based interface. This question is answered by comparing the different systems studied during the company visits. As presented in the figure 8.1, the solution intends to add three levels to the pyramidal structure of an interface: overview, task and function. The structure of the interface becomes bigger than the existing solutions but it might simplify the work of the operator because it will provide the operator with different information depending on the level. Each level intends to support perception, analysis and decision-making and actions in different ways. And the operator will be able to see the consequences of his actions at one level on the other levels.

2. Investigate how improved information visualization design can be used to exploit the different screens to give the operators better support

This question was answered by the creation of holistic view indicators integrated to the global overview screen and the function level. These indicators will improve the situation awareness of the operators by highlighting the causality in the plant structure and also providing an efficient support for quick and easy monitoring.
It should be added that when working with the ABB 800xA, the global overview screen should be always open on one of the big screens to be able to monitor at any time the different running tasks. From this screen the operator is able to select new windows that will open on other screens without closing the overview screen.

3. How the operators' workflow with the control screen can be improved

The operators' workflow is mainly supported by the addition to the existing solutions of a task management screen. The operator will be able to control each task and visualize the number of task he is controlling. The operator's decision-making will be improved thanks to a greater support from the automation system.

10.5 Further Work

User Feedback

Feedback from control room operators was gathered but in a limited number. It is necessary for further development to get the opinion of more control room operators especially from the Oil & Gas Industry to verify the possible implementation.

Simulator integration

Further validation of the concept would be done by integrating it to a simulator to allow for realistic testing in order to assess the strength and weaknesses of the concepts. It is also a possibility to investigate if one could do a deeper study into the different aspects of the concepts to see how the different parts perform.

LIST OF FIGURES

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LIST OF REFERENCES

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APPENDICES

Appendix A - InfoVis From the Internet

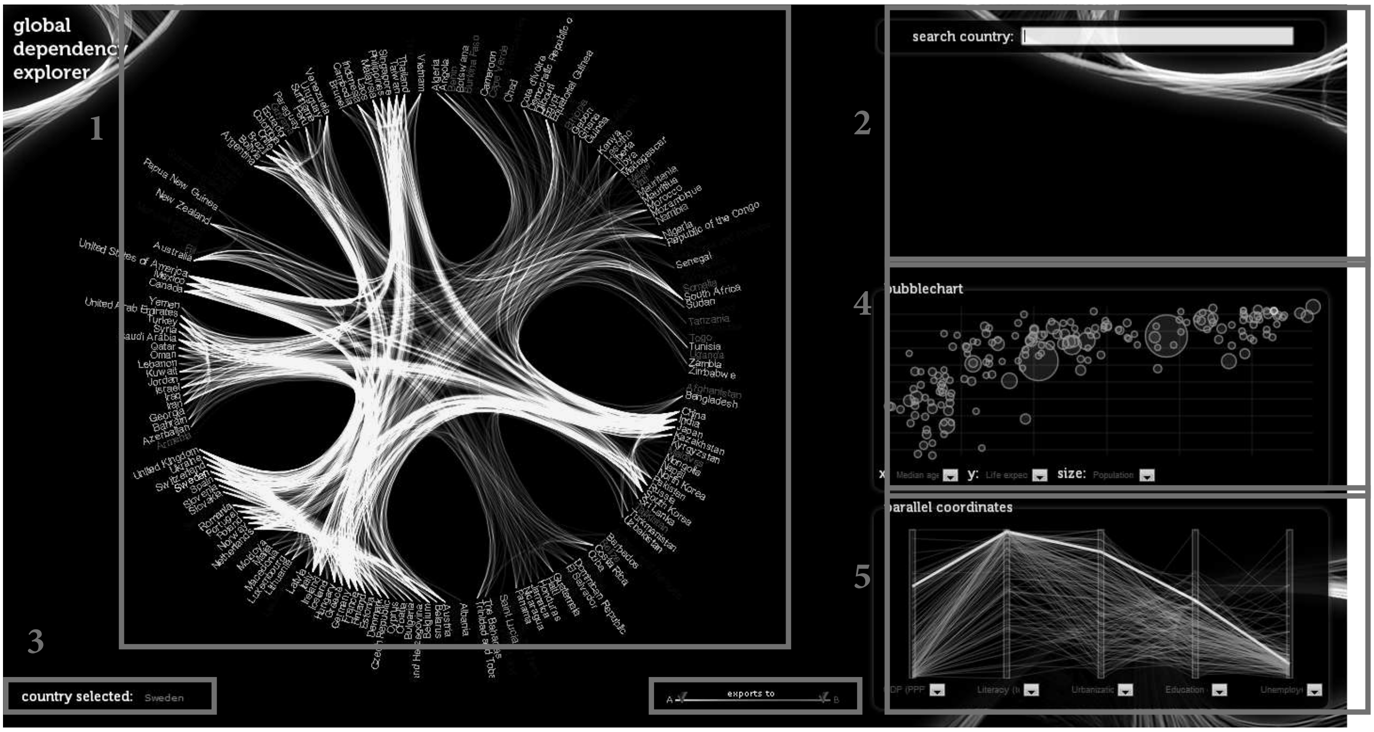
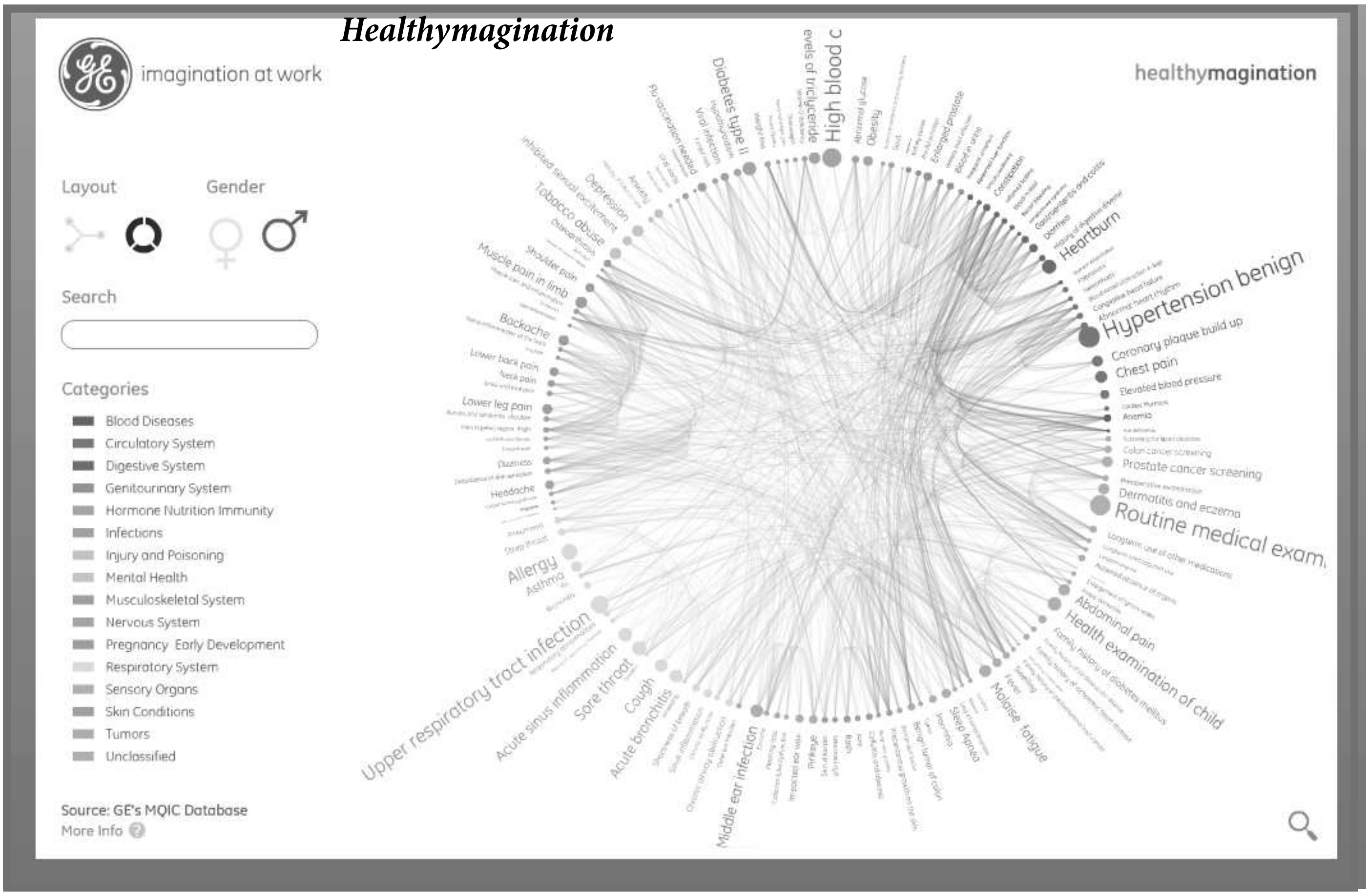


Figure : Global Depency Explorer (from http://cephea.de/gde/)

Global Dependency Explorer

Authors	Master Students
Location	Amsterdam, Netherlands
Year	2010
Function	Commercial relations for most countries around the world
Comments	There is only one page on this website but it is very rich in information. There are 6 functions and they are all related. The first one (1) is the wheel where the user can visualize the commercial relations between all the countries depending on the code color (6) which represents the export value (the warmer the color is, the bigger the relation is in value). The function search (2) allows the user to look for a specific country (eg. Sweden) and can have feedback that this country is selected (3). When a country is selected, the country is highlighted from violet to yellow on graphs 4 and 5. Graph 4 is a bubble diagram where the user can select the X, Y and size representation. It can be facts such as the GDP, the land area, the number of airports. It is up to the user to choose what he wants to see. Some choices might be more interesting than other ones; In graph 5, the 5 bars represent 5 different coordinates. Each characteristic is indexed on the country with the maximun value. It is an interesting representation for pattern recognition. Parallel coordinates allows to show more than 2 characteristics on a 2D-plane. Moreover, a characteristic can be represented on only one bar and is excluded from the others topdown list when choosen by the user.



Healthymagination

Figure : Healthymaginat(from http://visualization.geblogs.com/visualization/network/)

Authors Dominik Dahlem, Eric Baczuk, Kiaoj Chen (MIT for General Electric)

Location USA

Year 2010

Function Tracks different diseases depending on their categories

Comments Here again, the representation is a radial convergence diagram. However, it can be adapted to have only node. The radial representation was found in multiple representation on the internet to track relations between parameters.
The user can select the graph representation (1), select the gender (2) which will change the shape of the drawing can look for a specific disease and visualize its relations (3) and can highlight a specific disease category (4). Every change is immediately implemented in the wheel (5).

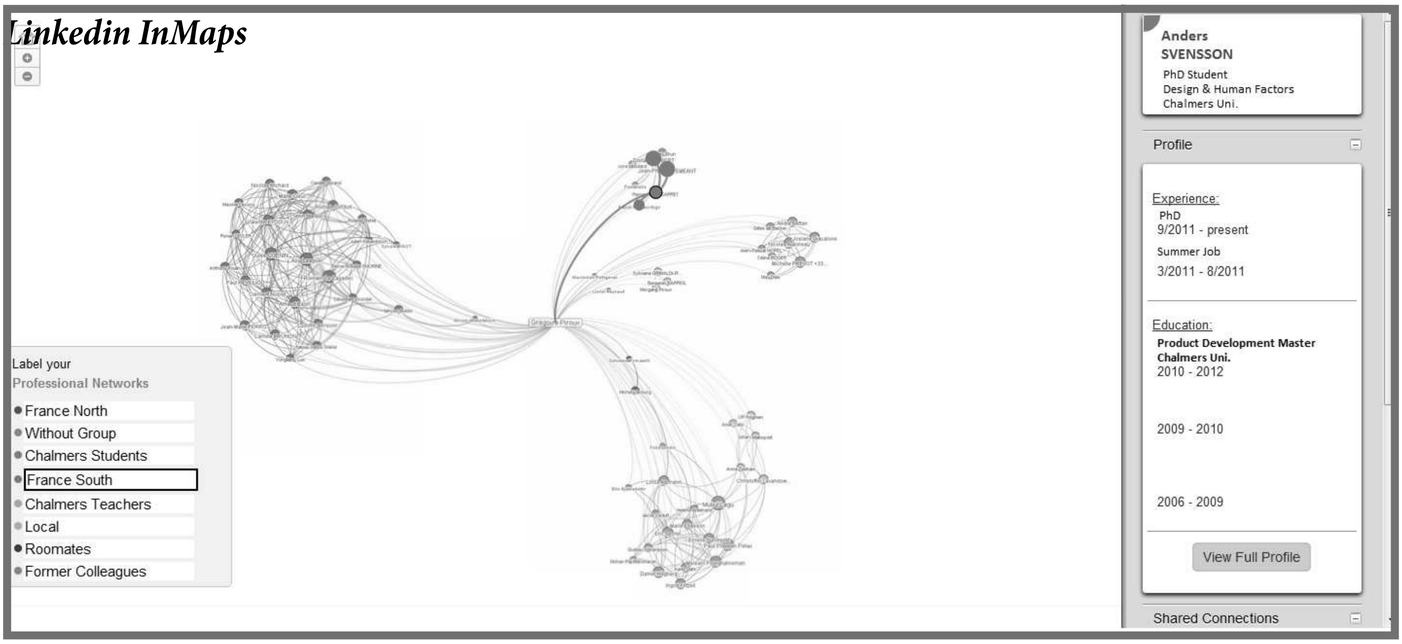


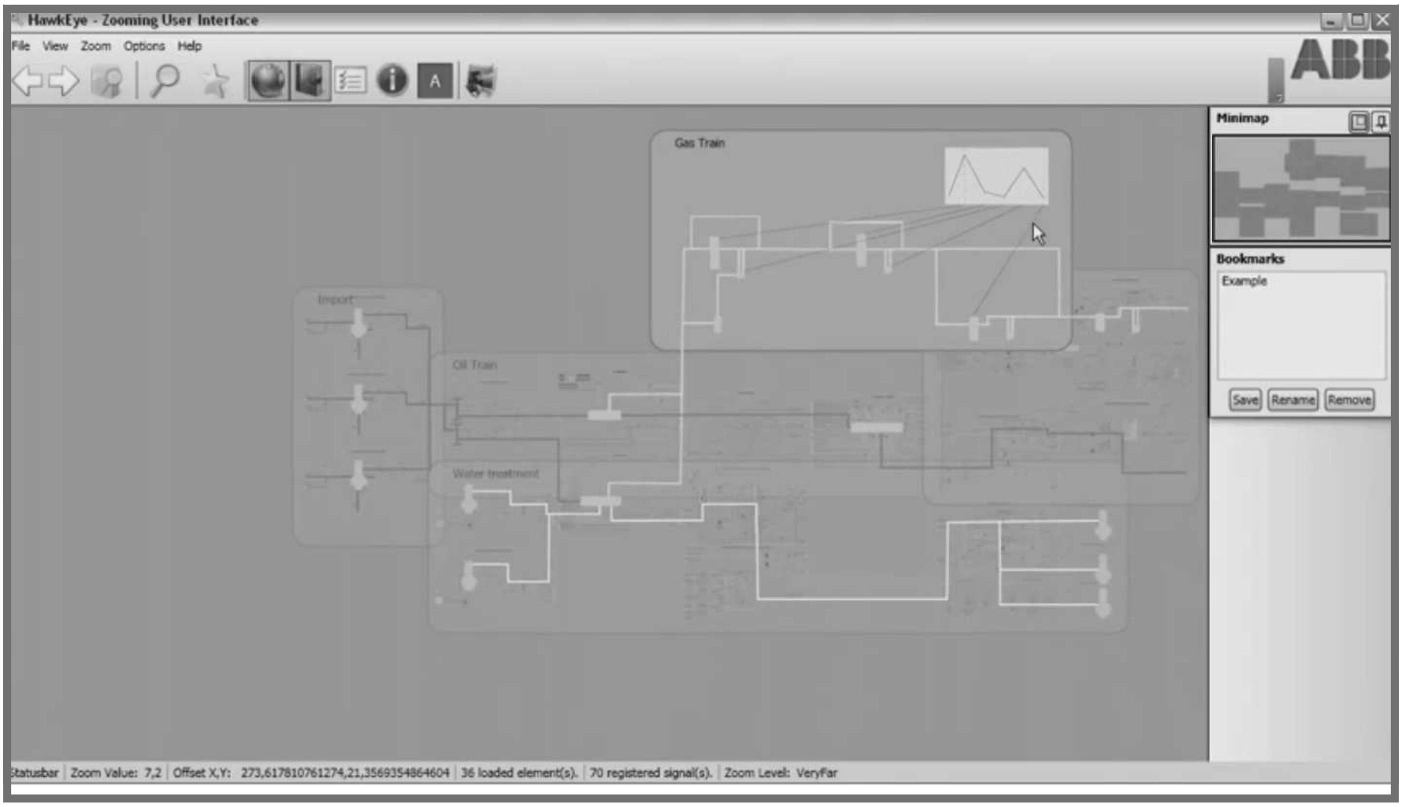
Figure :

Linkedin InMaps (from Grégoire Piroux's connection, http://inmaps.linkedinlabs.com/network)

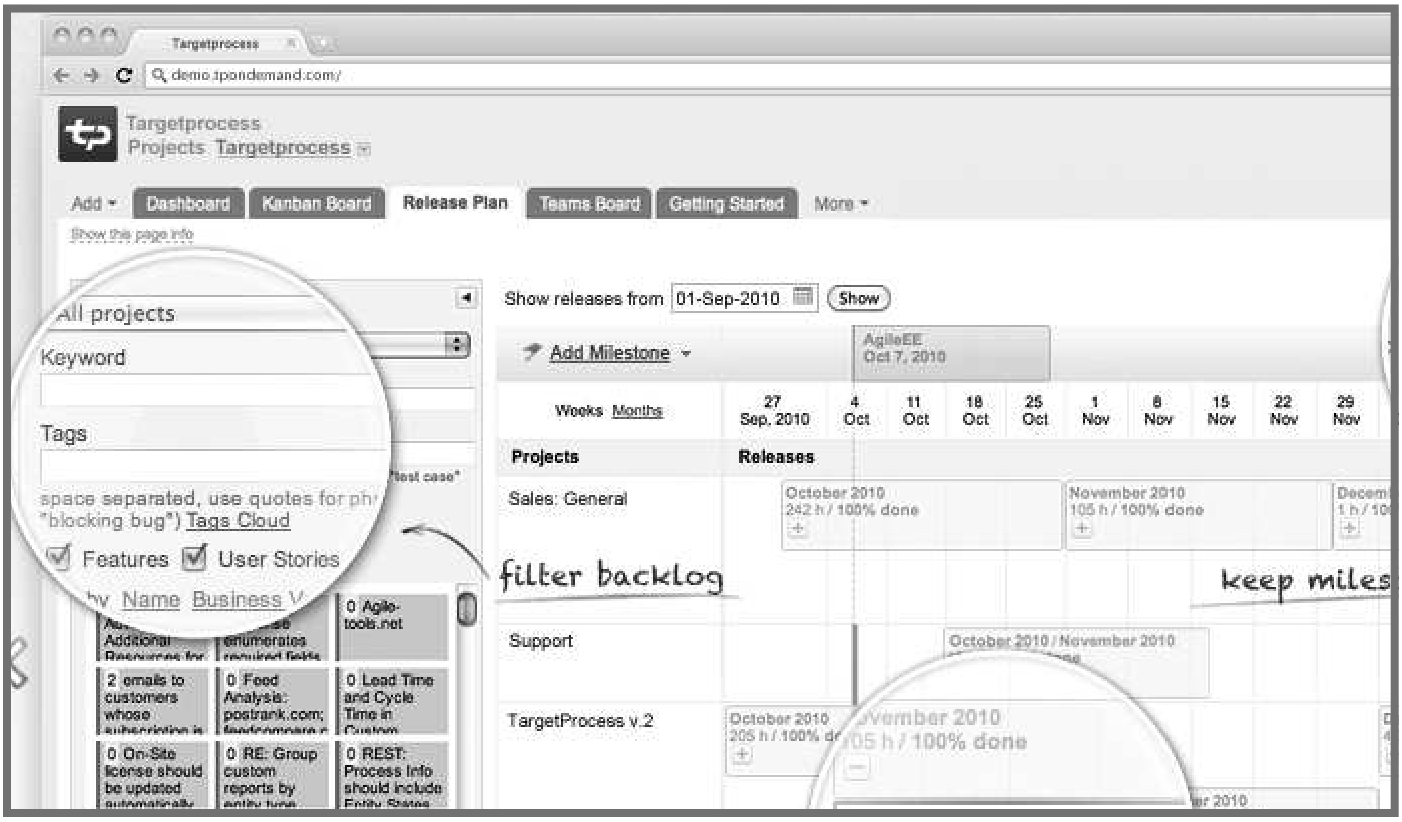
Linkedin InMaps

Authors	Linkedin Labs for Linkedin
Location	USA
Year	2011
Function	Visual representation of professional network
Comments	By connecting to Linkedin InMaps, a Linkedin user can visualize his professional network depending on a unique color coding for each group. By clicking on a profile, a pop-up window will appear on the right presenting his professional card (the one figure XX was changed to be a fake character) extracted from his profile such as name, current job, phone, education, past jobs and shared connection.

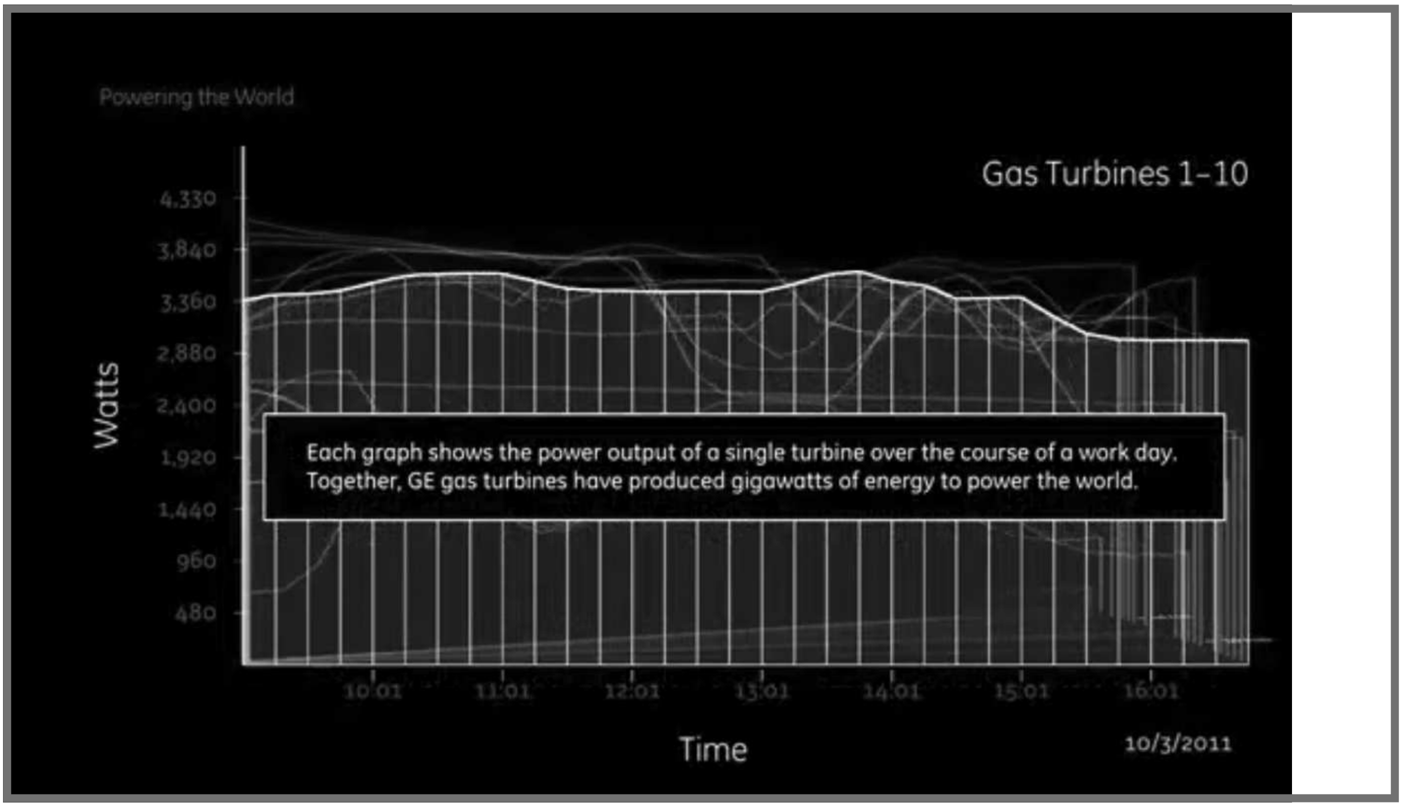
ABB Research Concept - Hawkeye



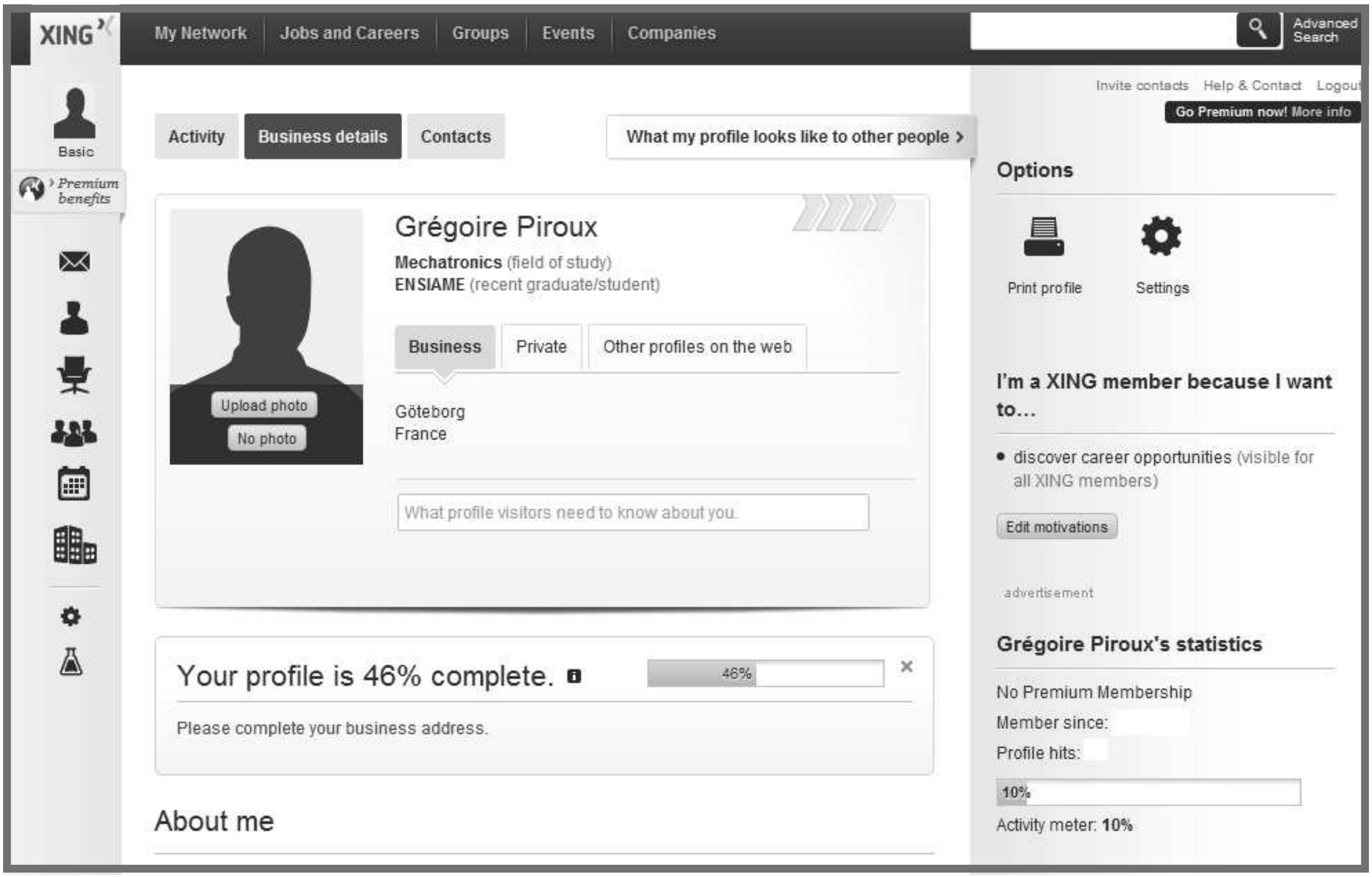
Target Process - Agile project management software



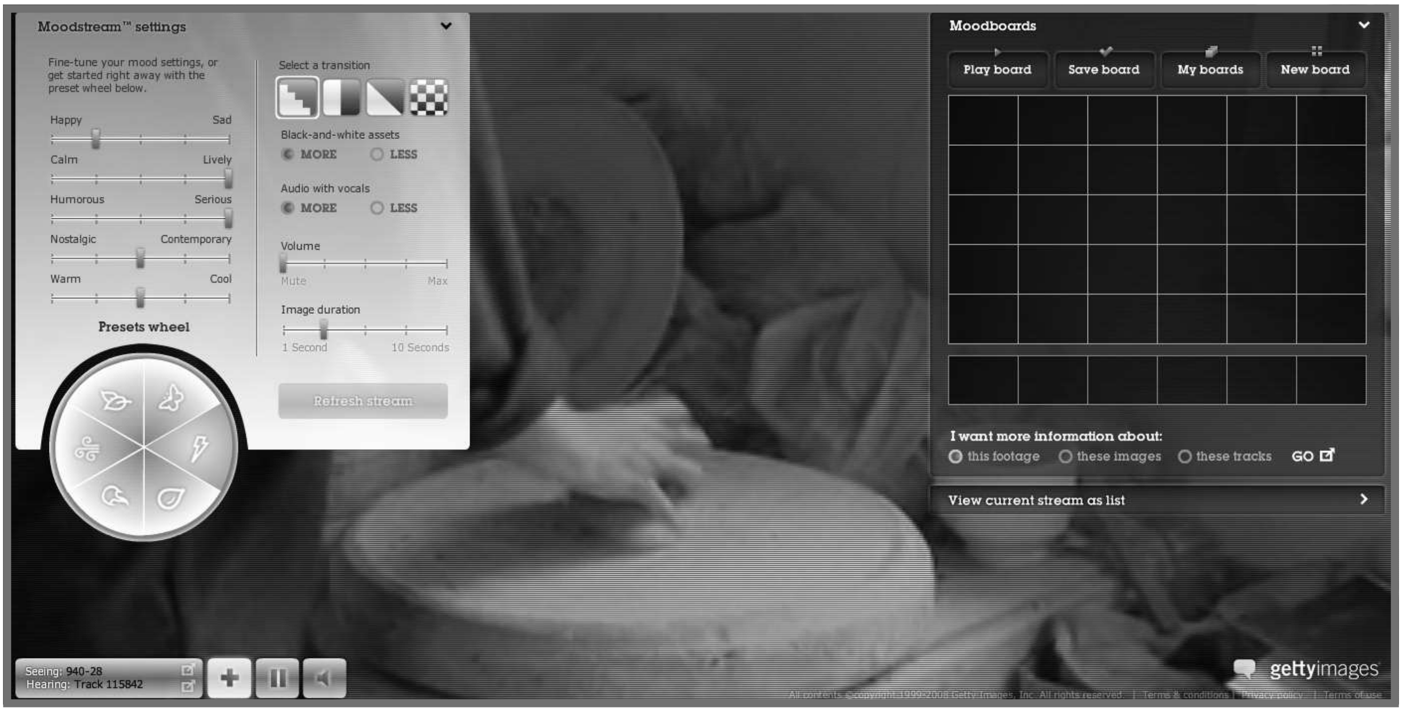
General Electric Infographics



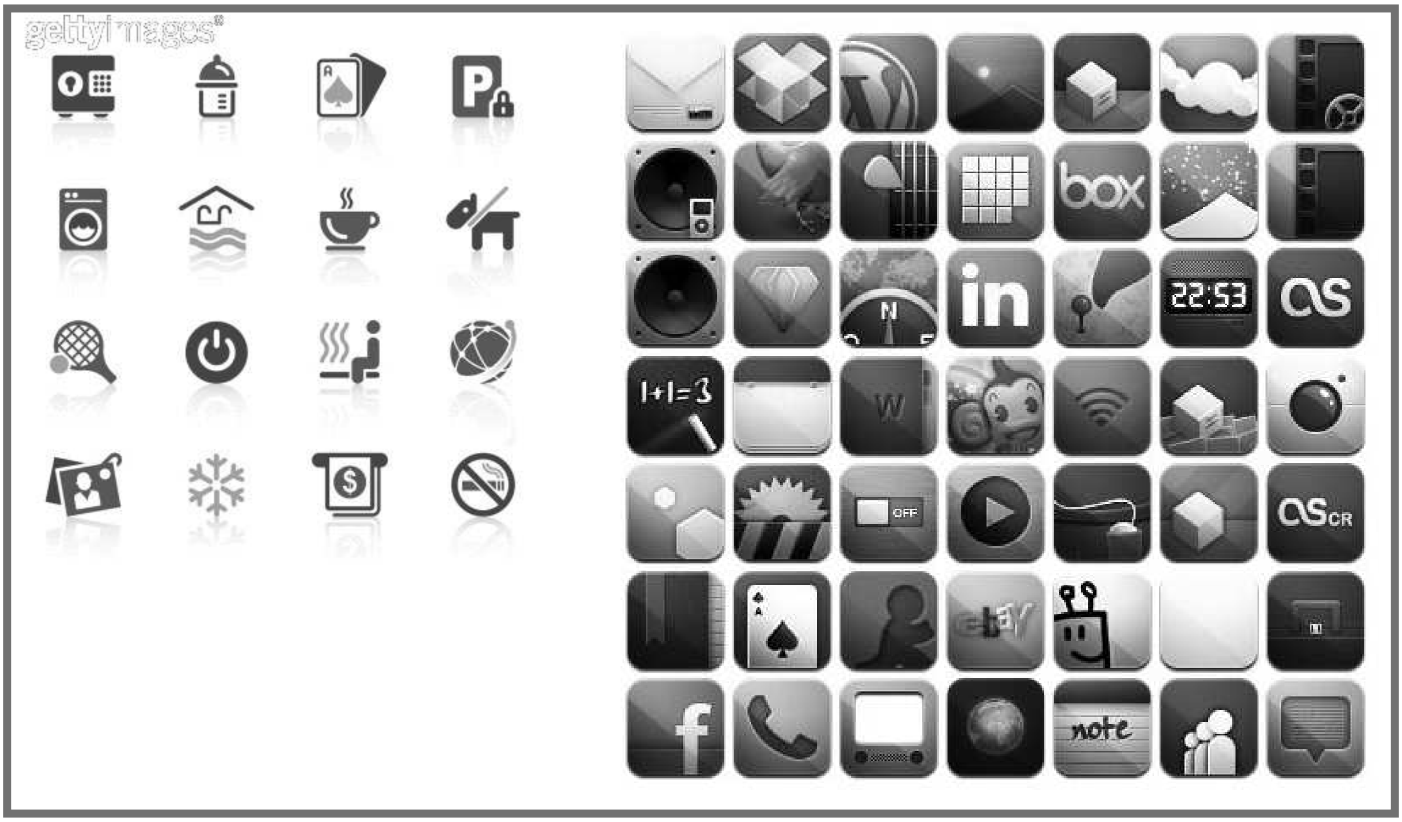
Xing - Job Platform



GettyIMages Moodboard



Icons



Mobiface - Timeline UI

you can view events from the past

and from the future

easy filtering of events by type

- all
- calls
- messages
- photos
- events
- music
- applications
- starred (shortcuts)

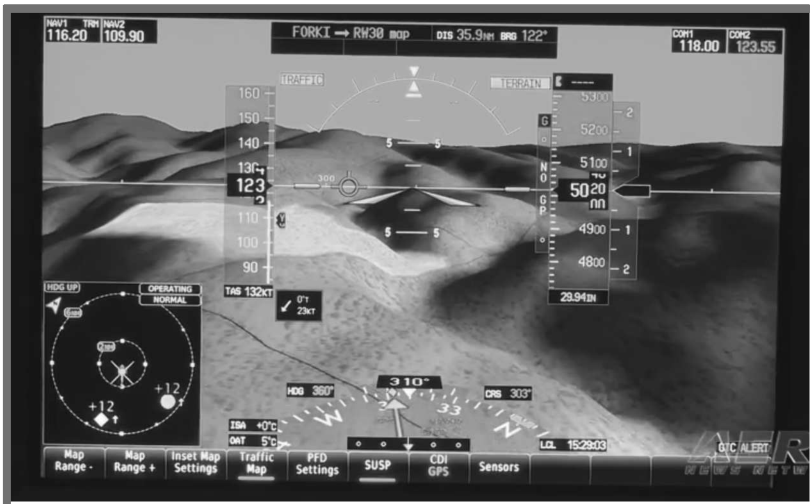
you can view calls in a single click

or you can make an instant search

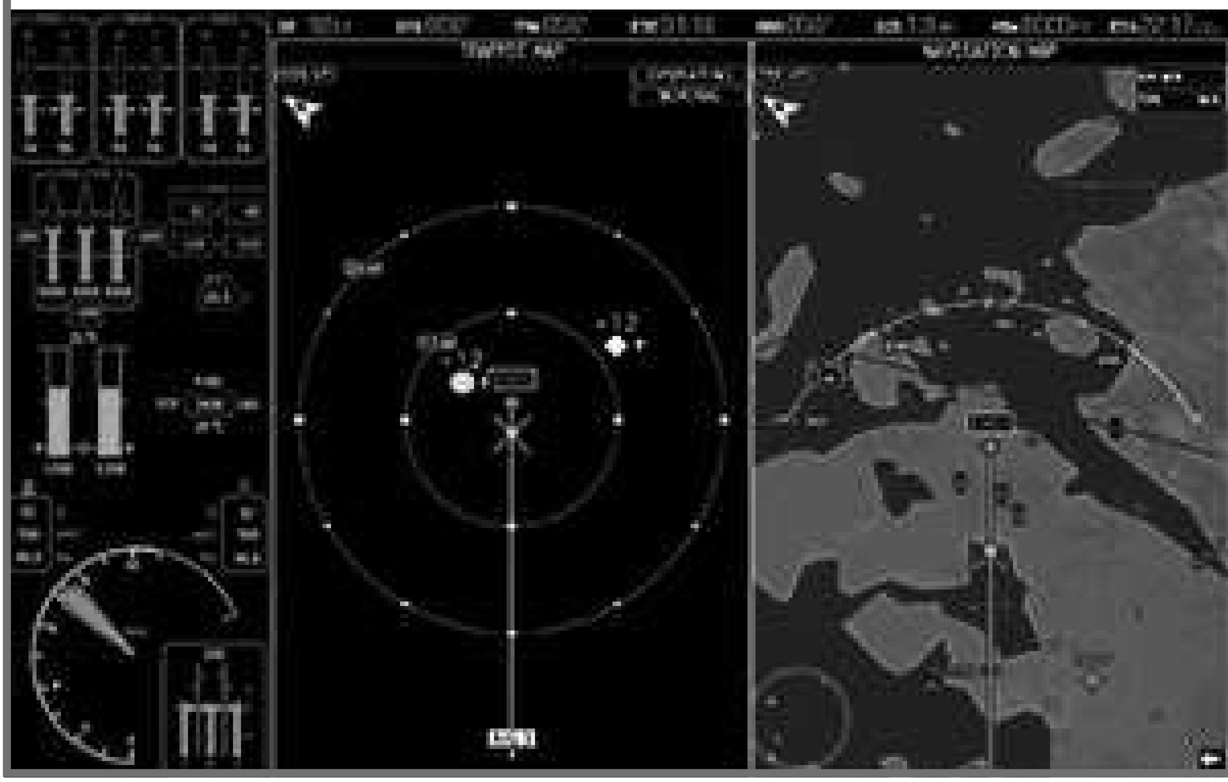
Imagine the interface as a timeline of events, which you can easily browse and filter. Every event has the same priority, so there's no more hierarchy and multi-level menus.

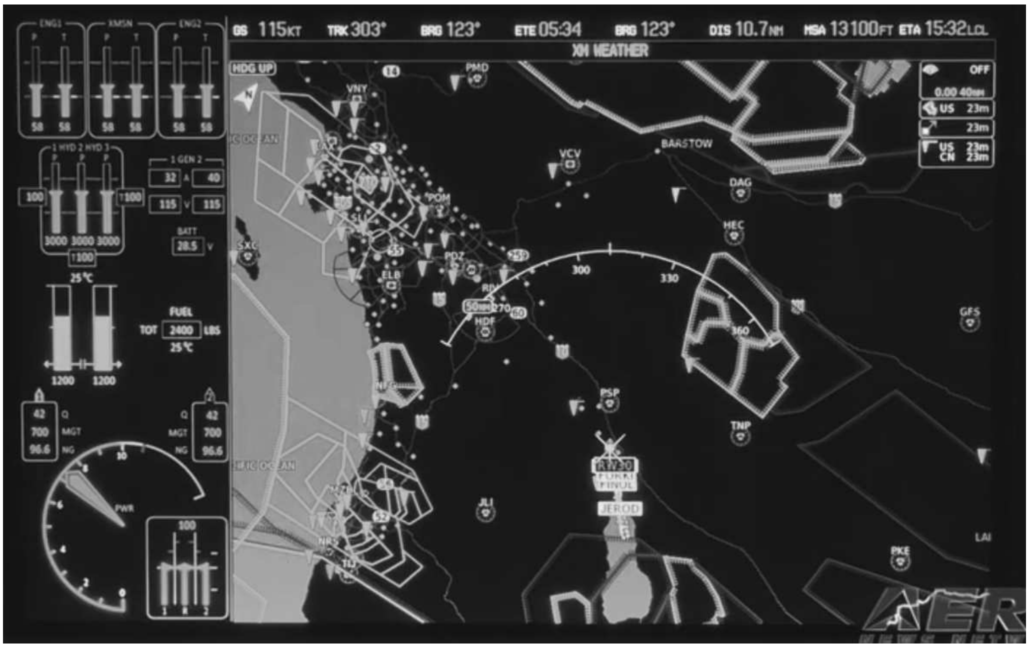
mobiface
next gen mobile interface thoughts

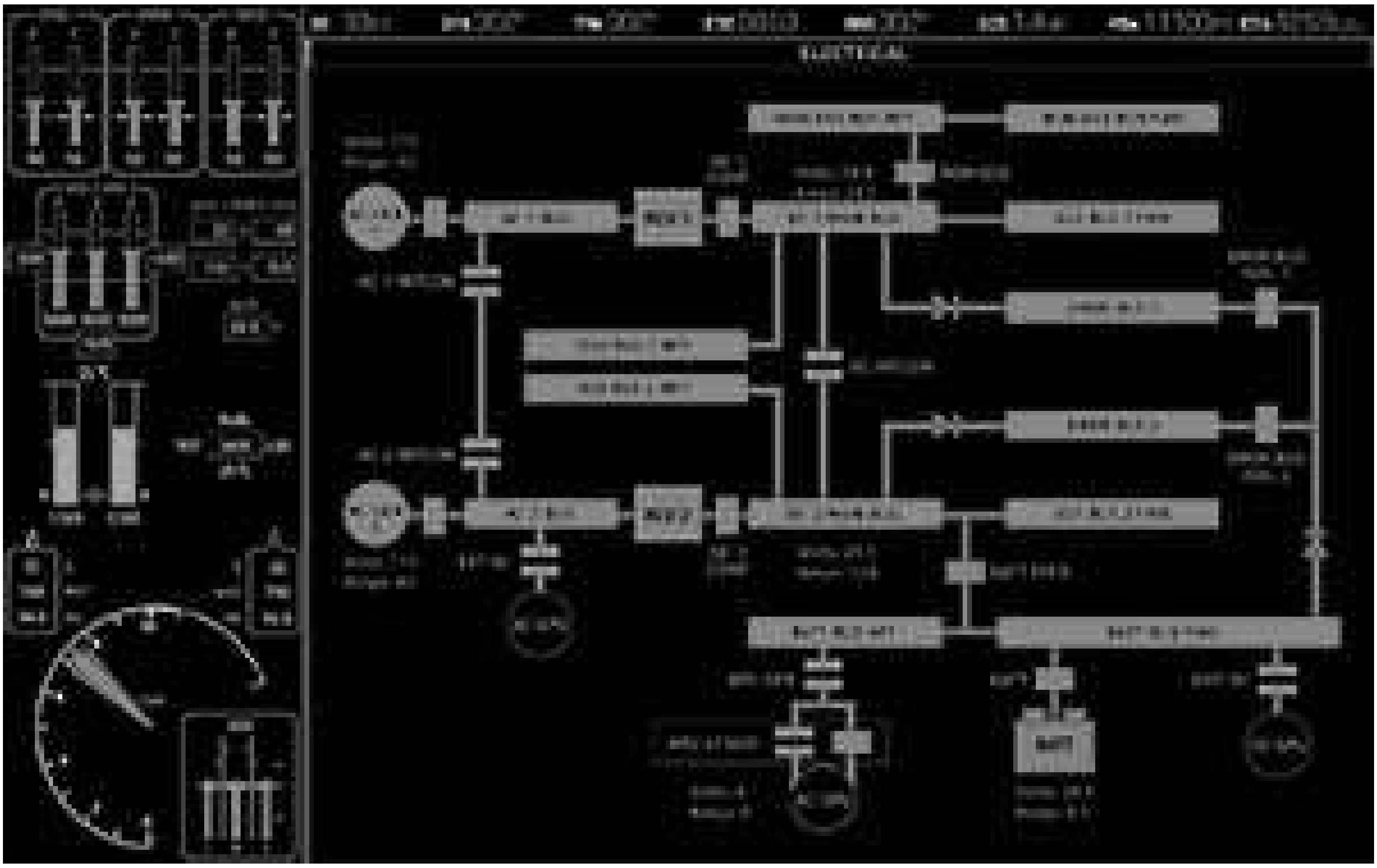
also the events lineup can be less formal



Bell Helicopter 525 Relentless Cockpit with Garmin G5000H




GS 115KT TRK 303° BRG 123° ETE 05:34 BRG 123° DIS 10.7NM MSA 13100FT ETA 15:32LCL
XM WEATHER
HDG UP
BARSTOW
FUEL
TOT 2400 LBS
PWR



Appendix B - User Profile (Study Visits)

Master Thesis Work about Control Ro
User Pro

CHALMERS

Background

Age:

Education:

Language understanding:

Use

Experience with control rooms:

Experience with THIS control room:

Knwoledge needed:

Frequency of use:

Influence on and Responsibility during use

Influence on the choice of product:

Influence on the use situation/ Tasks sequence

Influence on the interface's flexibility

Responsability during use

Kasper Nolkrantz, Grégoire Piroux
Chalmers University of Technology

Emotional Relationship to the machine

Ownership:

Social aspects:

Mental influence of product:

Degree of interaction with the machine

Cognitive interaction:

Physical interaction:

Disabilities (colour blindness, missing fingers, deaf, lenses, ear protection...)

Like/dislike

What do you like in the actual interface?

What do you dislike in the actual interface?

What is missing in the machine to work in an optimal way?

Appendix C - Checklist(Study Visits)

Background has muted tones? (Light grey is good, alarm colours should be avoided.)

Yes|__|No|__|

Use Shadowing as a method for subdividing a display?

Yes|__|No|__|

Use black outlines to highlight objects?

Yes|__|No|__|

Text is a standard font?(Use San serif fonts for on-screen clarity – e.g. Arial.)

Yes|__|No|__|

Text size is large enough to read at a distance? e.g. Arial 16.

Yes|__|No|__|

Does more detailed text show up as pop-up windows, 'tool-tips' or faceplates .

Yes|__|No|__|

Is the System Alarm status visible on all displays?

Yes|__|No|__|

Is the Alarm status displayed across the top of the display?

Yes|__|No|__|____

____

____

Are the Colour combinations chosen with care and use appropriate colours and contrasts?

Yes|__|No|__|____

____

____

What colour convention has the alarm? (Red = alarm, Yellow = warning, green = status OK.)

Yes|__|No|__|____

____

____

If red & green are used for 'Running' & 'Stopped' indications, Does it then have added text to make it clearer?

Yes|__|No|__|____

____

____

Does the alarms use additional non-colour dependent indications; position, text, etc.?

Yes|__|No|__|____

____

____

Does the alarm flash when an alarm is unaccepted?

Yes|__|No|__|____

____

____

Does the alarm automatic switch screens on alarm? (This should be avoided.)

Yes|__|No|__|____

____

____

Is dynamic data positioned on scanned areas of the screen; i.e. across the top, centrally and lower right?

Yes|__|No|__|____

____

____

Is the data should be grouped logically? (might be hard to judge)

Yes|__|No|__|____

____

____

Is the data presented with an appropriate resolution? (Avoiding too many decimal values)

Yes|__|No|__|____

____

____

Are the navigation buttons obvious and large enough to select quickly?

Yes|__|No|__|____

____

____

Is the 'Next Screen' button at the lower right side of the screen?

Yes|__|No|__|____

____

____

Is there a 'Home / Overview' button on each screen? (ideally lower left corner).

Yes|__|No|__|____

____

____

Does the Control buttons invoke a 'confirm action' dialog box?

Yes|__|No|__|____

____

____

Appendix D - Semi-structured Interviews (Study Visits)

Is the physical arrangement of the screens satisfactory? If not, how could it be improved?

____
____
____

How many screens do you usually keep with the same fixed display format and how many do you vary?

____
____
____

What display do you keep up all of the time? (Such as Alarm Summary, Critical Parameter Display, Overview, and so forth.)

____
____
____

Do you find it easy to navigate through the screen hierarchy?

____
____
____

Can you display all the information you need, in steady state conditions, to do your job?
What is missing?

____
____
____

Do the displays show the information you need during start-ups and shutdowns?
What is missing?

____
____
____

Do the displays show the information you need during abnormal and upset conditions?
What is missing?

____
____
____

Is the amount of information generally displayed on each graphic too little, too much (cluttered), or about right?

____
____
____

Do you often find yourself needing to trend a certain value and having to generate the trend “on-the-fly”? If so, for which parameters?

____
____
____

Do process values on the screen show the proper number of significant digits? Provide examples where not true.

____
____
____

Is there a mechanism set up for you to make comments on necessary graphic changes and improvements?

____
____
____

Do graphics clearly show the operating state and condition of any Advanced Process Control system in place?

____
____
____

Is there a documented shift change procedure indicating the specific items and situations to be covered? Is it followed? Is it paper-based or computer-based?

____
____
____

What do you think of the color background?

____
____
____

What do you think of the process lines? Their size?

____
____
____

What kind of indicators do you have? Analog-type indicators? Numbers on the screen only?

____
____
____

Is the interface flexible enough to be customized for each operator?

____
____
____

Can you visualize Past Trends? Under which conditions?

____
____
____

Can you visualize Future Trends? Under which conditions?

____
____
____

Can you have a quick idea about how the process is going on? (Parameter Combination Visualization)

____
____
____

Appendix E - Study Visits Matrix

Question	Swedish match	Göteborg vatten	Södra	Kalundborg		
Is the physical arrangement of the screens satisfactory? If not, how could it be improved?	One operator had one desktop screen and an other had two	No, place the screens better.	Yes	No, small screens. Its hard to get a overview of the flow.	*Provide overview of the flow*	
How many screens do you usually keep with the same fixed display format and how many do you vary?	The station with two screens usally keep one screen fixed	Two screens with main info about the system,	The keep most screens fixed, but they can go deeper in to the process if they like	Two screens were dedicated for priority one alarms, then they hade two other screens that they could change around to view the process		
What display do you keep up all of the time? (Such as Alarm Summary, Critical Parameter Display, Overview, and so forth.)	The overview screen of the tanks was the one that was mainly showing,	Overview screen fix on a larged display, then it differs from operator to operator. Which they prefer to have open	The alarm is on the top of most of the screens and always so that the operator can see it.	Alarm		
Do you find it easy to navigate through the screen hierarchy?	Not really, becasue it was hard to follow the hierachy of the flow on the control screen	Yes and no. Due to the screen layout its hard to follow the flow. But its some what easy to navigate	Yes	It is easy because of the physical buttons. It is also possible to jump between screens via the clicking on the name of the out or in process name.	*Easy hierarchy between the screens*	*It should be easy to navigate between screens*
Can you display all the information you need, in steady state conditions, to do your job? What is missing?	Not if you are on the station with only one screen	Yes.	Yes	Yes		
Do the displays show the information you need during start-ups and shutdowns? What is missing?	Yes, as the proceess is done in batches it is a constant start up and stop. There is how ever room for improvement	They have and older system with analog controls and gaues that they use for start-ups because they feel they have more control and can respond faster.	Yes	-	*Prefer analog indicators over digital*	*The operator feel more in control of the system*
Do the displays show the information you need during abnormal and upset conditions? What is missing?	No, but that has to do with bad sensors.	yes	In someways no beause they have to look att cctv to see some aspects of the flow	-		
Is the amount of information generally displayed on each graphic too little, too much (cluttered), or about right?	The infromation displayed can in some cases be to little, and its a bit unorganized	They would like more info on each screen as that would decrees the amout of screen changeing they need to do.	It is about right	Due to the small screen size it is abit clutterd		
Do you often find yourself needing to trend a certain value and having to generate the trend "on-the-fly"? If so, for which parameters?	Have to keep diffrent times in the head. Batch time, cleaning times etc	No, they can take any value and turn it into a graph	No	They follow graphs, some keep some values in their head, due theire experince	*Show task time*	*Avoid the operator to remember the time left, or running time for each task he is doing*
Do process values on the screen show the proper number of significant digits? Provide examples where not true.	Yes.	Yes	Yes	-		
Is there a mechanism set up for you to make comments on necessary graphic changes and improvements?	There is a technican that can do changes, but the operators can't do it.	In the abb system they have an operator that will add things if they ask for it	Yes, they can do their own changes and ask a operator with experince to do the changes.	No.		
Do graphics clearly show the operating state and condition of any Advanced Process Control system in place?	-	-	-	maybe		
Is there a documented shift change procedure indicating the specific items and situations to be covered? Is it followed? Is it paper-based or computer-based?	The operators talk, and make some notes on a piece of paper	Talk , notebook/logbook	informal talking, logbook, paper notes	The logged the information of what they did in the computer, filled in a sheet with number. They also talked and showed on the screen		
What do you think of the colour background?	The background was white so it could get a bit strainful	The gray is good on the eyes	Dark gray, nice and easy on the eyes.	Black/dark gray.		
What do you think of the process lines? Their size?	-	okay	Good, they made some changes to the process lines. Blue lines to show that it is water	It looks old, uses low resulotion	*Lines should show what is in transfer*	*For example, if the operator is transferring water, the process lines should become blue.*
What kind of indicators do you have? Analog-type indicators? Numbers on the screen only?	Tank/mixer that showed how full it was / analog . Then digital values	on the screen it was almost only numbers and no gauges or analog representaion	Digital numbers, Some bar-graphs	in a few cases there were a analog tank to show the level and a small bar to ilustrate the % of a control valve		
Is the interface flexible enough to be customized for each operator?	No	Operators have the possbility to use custom screens that are layed out to their liking, but they dont use it any more as the basic layout have been improved	To some extent	No	*Possibility to customize screens depending on operator's habits*	
Can you visualize Past Trends? Under which conditions?	-	Yes , with graphs. Take any dynamic value and they can plot it over a set timeframe.	Yes	Most of the values can be shown as graphs		
Can you visualize Future Trends? Under which conditions?	No	Yes, but not used so much they can estimate the water usage. Old operators don't feel the need it but the newer one asked for it	No	On specific graphs screen there are graphs that can predict future trends		
Can you have a quick idea about how the process is going on? (Parameter Combination Visualization)	No	Overview screen shows the most importet values of the diffrent areas of the plant	-	In a narrow way they can do it with there graphs.		
	Positive	Negative	blank			

Appendix F - Requirements Specification

Category	Description	
1 Colours		
1.1 Alarm System	Should be clear that it is an alarm/ Difference between difference alarm	
1.2 Color Background	Gray 3 (RGB 221, 221,221) or Gray 4 (RGB, 192,192,192). Gray backgrounds have minimum interference with other color choices.	
1.3 Clear Code Colour	The colour should not be confusing for the operator. They all should have a meaning so the operator knows what is looking at just with the color, and without any further explanations.	
1.4 Use flexible color coding	Adaptable for each process industy	
2 Text		
2.1 Consistent (Size, Colour)		
2.2 Text should be readable from a distance of 2m from the screen		
3 Lines		
3.1 Process lines	Dark gray or black	
3.2 Line Thickness	Max 3 line thickness	
3.3 Line Types	Max 3 line types (solid, dotted, dashed)	
3.4 Highlight Transfer	Process lines should show what they transfer	
4 Navigation between screens		
4.1 Hierarchy Displays	The display should be created depending on a detailed hierarchy.	
4.2 Easy navigability	The operator should be able to navigate in an easy way from one screen to another.	
4.3 Integrate a “before”, “next” , “up” and “bottom” button to navigate through the displays		
4.4 Have a “Home/Overview” Button in each screen to visualize the overview screen		
4.5 Flexible Interface to fit each operator’s needs		
5 Process - How to show physical things in the process such as tanks, vessels, containers, boxes…		
5.1 Understandable visualization of the process	Process flow should be visualized from the left to the right, Vapors up and liquids down, consistent representation of data and exit entry.	
5.2 Clear distinction between systems working, stopped, and with problems		
5.3 Uniformly shaded		
5.4 No animation associated with vessel internals		

	Requirement/Demand	Validation
	R	Hollifield (2008), Visual Clarity
	R	Hollifield (2008), Visual Clarity
	R	Study Visits, Visual Clarity
	D	Study Visits, Visual Clarity
	D	Study Visits, Consistency
	D	Study Visits, Information Visibility
	R	Hollifield (2008), Visual Clarity
	R	Hollifield (2008), Visual Clarity
	R	Hollifield (2008), Visual Clarity
	D	Study Visits, Visual Clarity, Explicit Causality, Feedback
	D	Information visibility
	D	
	R	Study Visits
	R	Study Visits
	D	Study Visits, Flexibility
.		
	R	Hollifield (2008), Study Visits, Explicit Causality
	R	Study Visits, Visual Clarity
	R	Hollifield (2008), Visual Clarity
	R	Hollifield (2008)

Category	Description	
6 Graphs		
6.1 Sparklines - Hill-slopes average 45°	Variations are best detected for an average angle of 45°	
6.2 Sparklines - Add-on Information	The sparkline should not be left alone. Some information easily understandable should be associated to the graph.	
6.3 Sparklines - Adequate line weight and contrast	The line weigh and the contrast of the data should be adapted so its fits the chosen background	
6.4 Sparklines - Maximum Resolution	500 sparklines maximum could be visualized on 25x45cm (A3 paper).	
6.5 Size of a graph	Graph presentation should follow the golden rectangle - Width (b) and Height (a) : Optimum: Best:	
6.6 Numbers Representation	Proportional to the numerical quantities represented	
6.7 Shown Dimensions	Show at maximum the same number of dimensions in the data. STM= between 3 and 7 memory chunks so variable_dimensions_max probably 7	
6.8 Minimize the number of tables	Graphics should be preferred to table	
6.9 Easy and reliable for operators	Direct perception of the relationships among variables and avoid increasing operators' cognitive workload and misunderstanding	
6.10 Prefer analog indicators over digital	The operator feel more in control of the system	
7 Information Presentation		
7.1 Visualize Time plan	Workflow visualization (time), actual information about the job	
7.2 Intuitive interface	In phase with operator's mental model	
7.3 Reduce task repetition to reduce the number of slip errors	For example, if a data is used in a display and should be used in another one, the operator should not have to remember, the machine should do it for him. It could be related to the example of the paint factory.	
7.4 Association of multiple presentation	Words, numbers, images and diagrams	
7.5 Support Monitoring		
7.6 Support Diagnosis		
7.7 Support Control		
7.8 Support different levels of automation at the same time	Separate the screen in different parts for different tasks	
7.9 The process level should be displayed as the physical process flow		
7.10 Window should pop-up for supporting decision-making during alarms		
7.11 Alarms should be depicted either on all the screens (top of it)		

	Requirement/Demand	Validation
	D	Tufte (2010)
	R	Tufte (2010)
	D	Tufte (2010)
	R	Tufte (2010) $\frac{a}{b} = \frac{b}{a+b}$
	R	Tufte (2001) $b = a * \frac{1+\sqrt{5}}{2} \Rightarrow b = a * 1.618$ $1.6 < \frac{b}{a} < 1.8$
	R	Tufte (2001)
	R	Tufte (2001), Bligard (2001), Reduce Short-Term Memory
	D	Tufte (2001)
	D	Liu et al. (2004), Multivariate Comparisons
	R	Guerlain et Jamieson (2002)
	D	Study Visits, Feedback, Visual clarity, Decision-making planning
	D	Reduce Short-Term Memory
	D	Consistency, Decision-making planning, Errors Prevention and Recovery
	D	Information visibility, Multivariate Comparisons
	D	Visual clarity
	D	Decision-making planning
	D	
	R	Conceptual Model (Jonas Andersson), Multivariate comparisons
	R	Study Visits
	R	Study Visits
	R	Study Visits

Appendix G - Personas

The personas do not represent any operator the authors talked with but are a representation of the two main group of users: newcomer (Linnéa Larsson) and domain expert (Peter Jørgensen) with some experience.

Linnéa Larsson

Company: Götoil AB
Location: Göteborg

Background
34 years old, female.
Single.
Lives in Västra Frölunda.
Completed apprenticeship as a mechanic.
Can speak Swedish and English.
Worked at Götoil AB since she was 21, mainly on the field.
In training with the control room with the past year from her trainer.
Likes to learn new ways to optimise her workflow.

Attributes
Young.
Novice in control rooms but experienced about the different process inside the company.
Some experience in the field.
Fluent in English.
Open to use new technology to improve her daily work.
Experiences with computers and Internet.

Customer Needs
Modern and easy interface that enhances learning and efficient working.
More supportive interface.
Less information-consuming interface for better diagnosis.
Alarm screen for better monitoring.
Help function and/or handbook with tips to optimise workflow.
Consistent system.
More information about the actual workflow
Check if key parameter are okay.
Learning tools.
Simplicity and ease-to-use.

"The control room? I like it because I have to like it."

Story
Linnéa is not a new worker in Götoil AB: after school she started to work there and never left. She worked in different part of the company, working mostly with the machine as a mechanic. She has been very optimistic about her career and saw last year the training offer for the control room as a opportunity to get promoted inside the company.
She deals with working with the actual interface but thinks that it could be improved since it is quite old. She is been learning for a year on it, so she is getting used to it. Her main problem is the amount of information to remember for a newcomer. She sometimes feel disappointed when she does not understand all the data displayed on the screen. But anyway, she has to deal with it in order to not waste material. She has not dealt that much with a big crisis situation and hope she will be able to handle it correctly by managing the different screens around her.

Peter Jørgensen

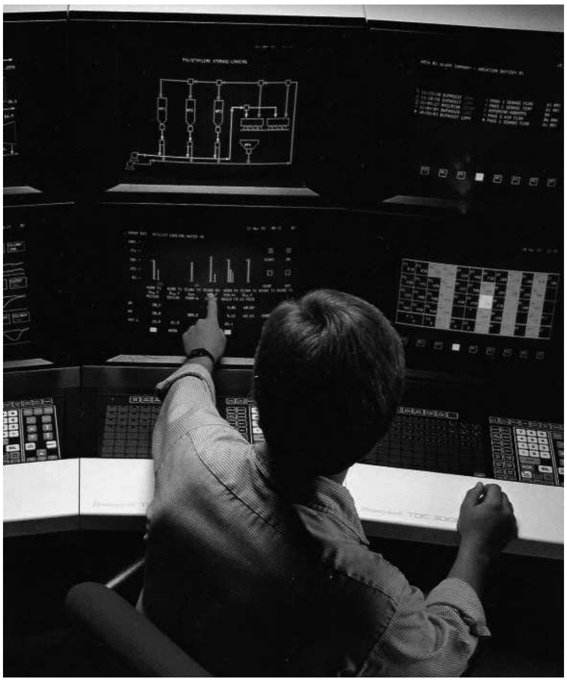
Company: Götoil AB
Location: Kalundborg

Background
56 years old, male.
Married, 3 children.
Lives at the beginning of Kalundborg Fjord.
Can speak Danish, English, Swedish and understands quite well Norwegian.
Completed apprenticeship as electrician.
Can work more or less everywhere on the process.
Started working at Nordic Olie as mechanic for 10 years.
Worked 4 years as a mechanic for Götoil AB (after they bought Nordic Olie)
Worked for 10 years in the control room in Göteborg (Sweden)
Working for the past 12 years for Götoil AB in Kalundborg.

Attributes
Experienced.
Team spirit.
Have experience from working abroad.
Worked shift in the field and in the control rooms.
Full knowledge about the process.

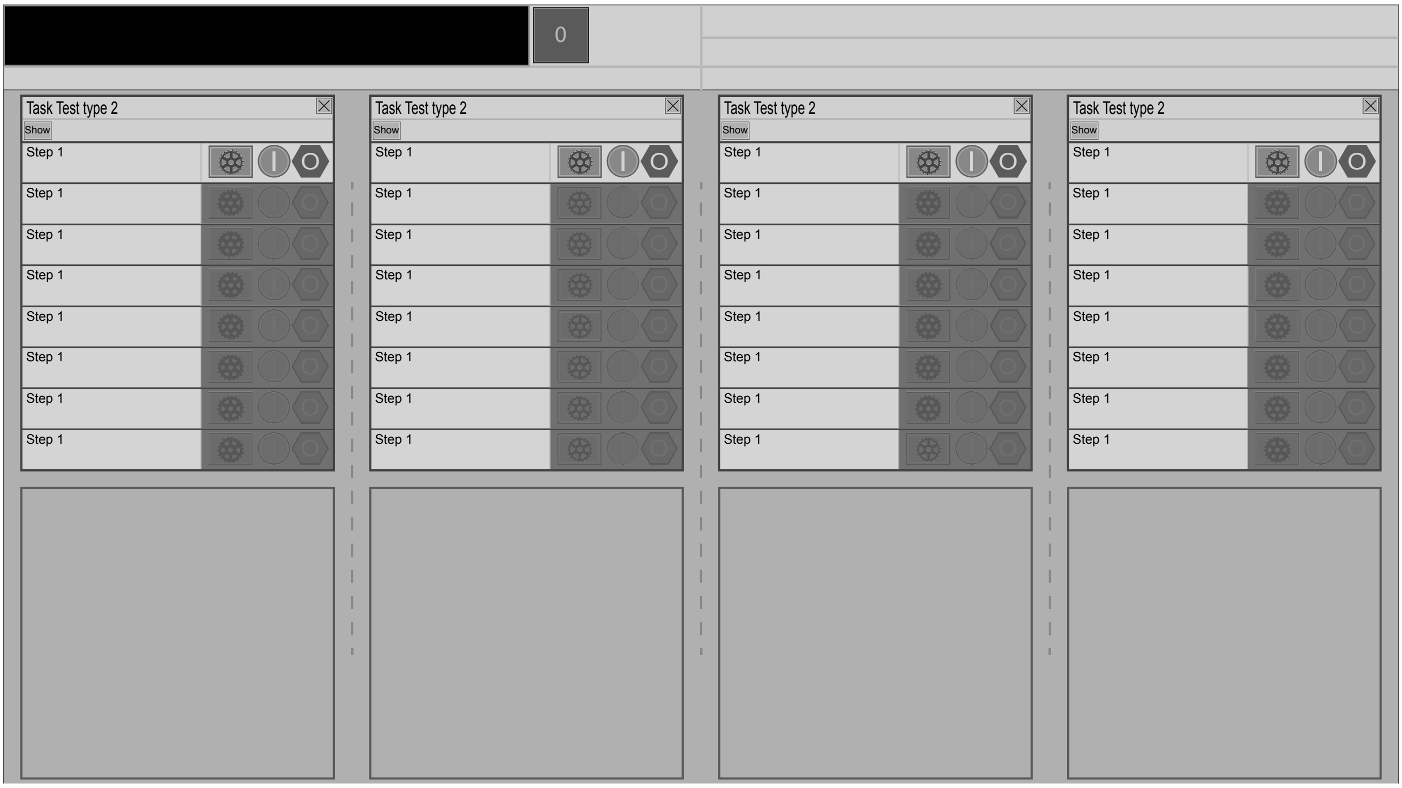
Customer Needs
Improve shift handover thanks to system support.
Better use of trend: should inform and not just make the control room nice.
A screen dedicated to the alarms.
A windows-based system.
Reduce the number of documents and/or systems to deal with to run a job.

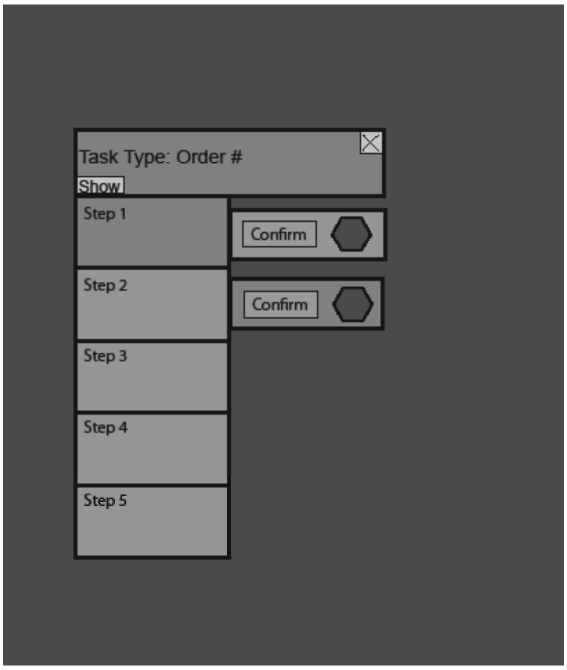
"We are responsible for the work-flow management"



Story
Peter started working when he was 20 at Nordie Olie since it was "a company near home and that pays relatively well for the job" by the time. 10 years after (1986), Götoil AB bought Nordic Olie and in 1990, he got the opportunity to be trained in order to become a control room operator. But the job was in Göteborg. He took the opportunity and stayed in Sweden until 2000 when he came back to Kalundborg. He has been working there since.
He thinks that the interface could provide a better support during shift handover when he and the previous (or next) operator have to discuss about the main problems during the shift. It might also possible to have a checklist reminder in the computer instead of the paper-based document he created.

Appendix H - Sequence List

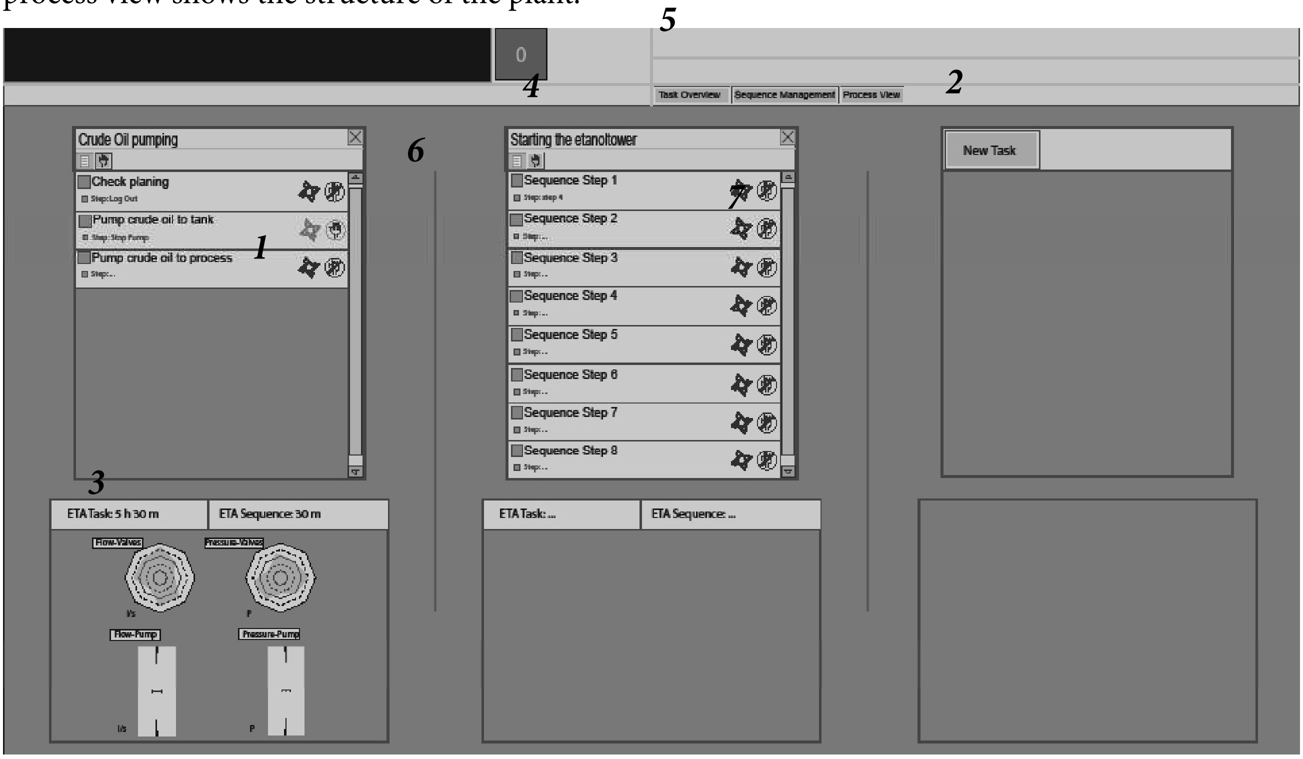




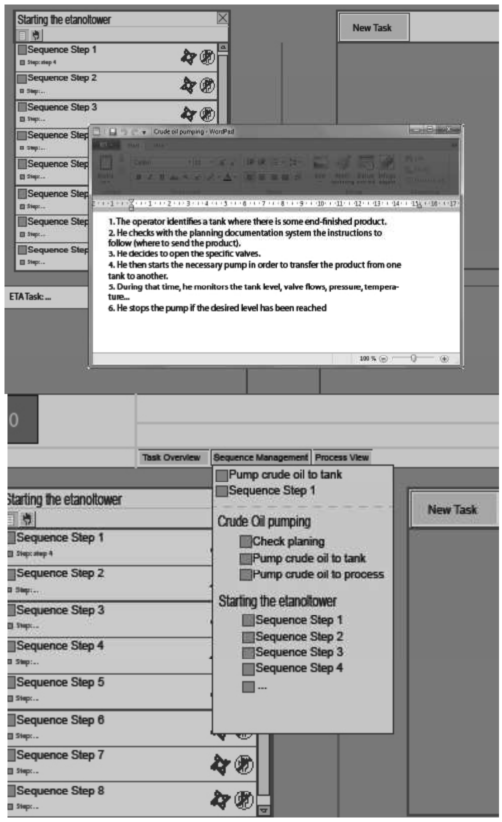
Task management/overview
Two ways of showing tasks.

Interface layout: Task overview/management

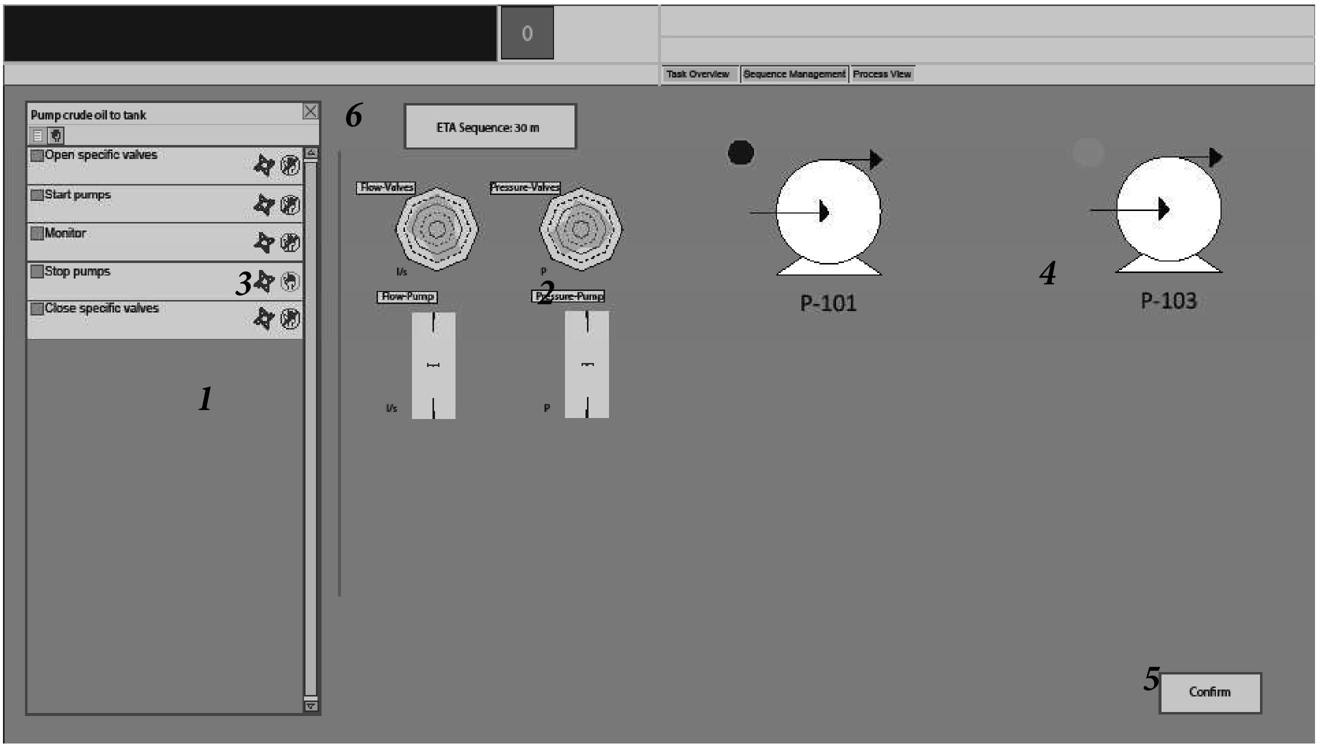
There are three screen views; Task overview, Sequence management and process view. From the task overview screen high level task or procedures are started and monitored. In the Sequence management the operator can manage sub-tasks or sequences. The process view shows the structure of the plant.



Task Overview

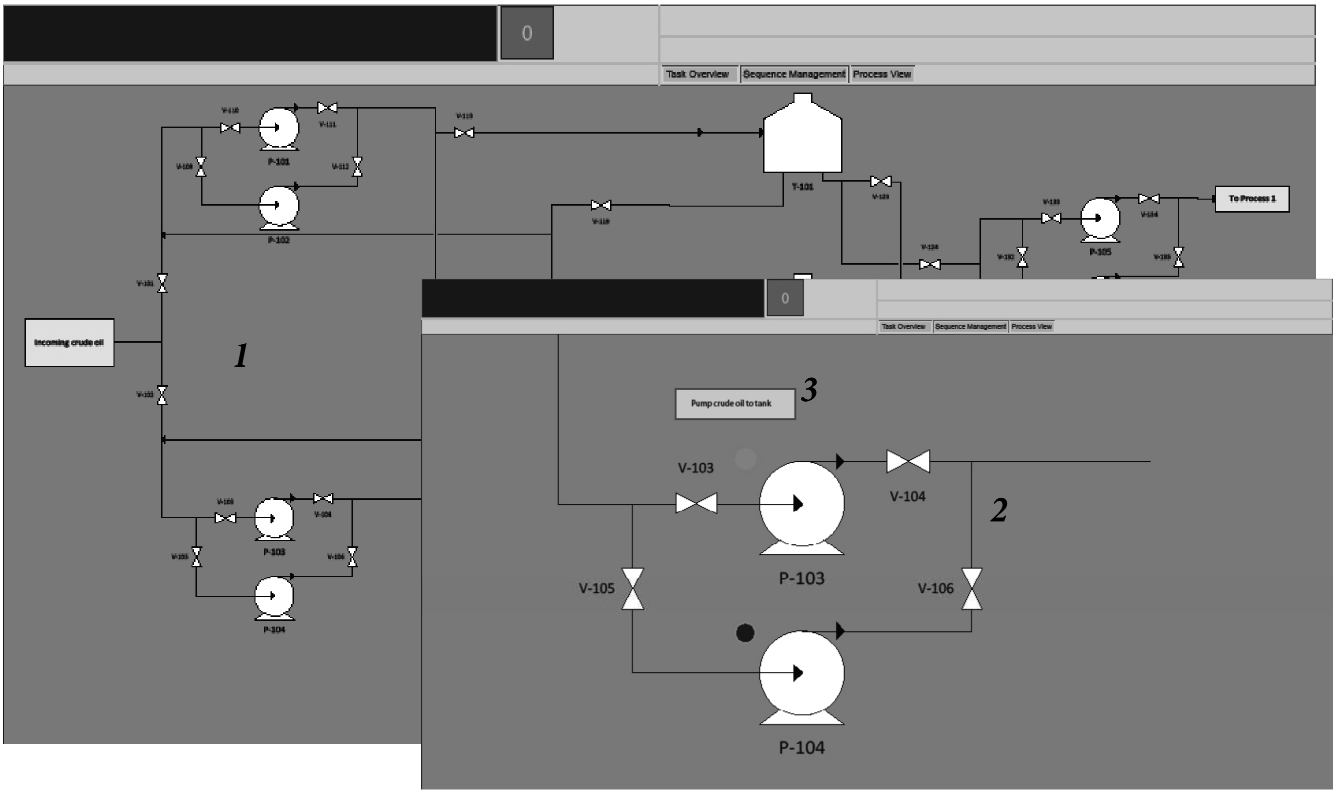


1) Shows a started task. The top part displays the name of the task and below the name of the different steps are displayed. The green square in front of the different steps indicates that the task i proceeding correctly. One can also see what sequence the task is in and if it okay. Clicking one one of the steps will bring up the sequence view for that step.
2) Button for starting a new task.
3) Overview area were critical parameters for the current part of the task are displayed. The estimated time for completing the task and the specific sequence step is shown.
4) Button(left one) for opening the written documentation for the selected task, Top right image shows the documentation pop-up window. The button to the right sets the task to manual control.
5) Buttons for changing between the different screen views. Lower right image shows the drop down menu for the sequence management view. Then menu is separated in two parts, the top part shows the currently active sequence steps, the lower part shows all sequence steps for the each task.
6) Scroll panel in case the task has more steps then what can be shown at one time.
7) Symbols for showing if the step is in auto mode (propeller) or if manual control is active(hand).



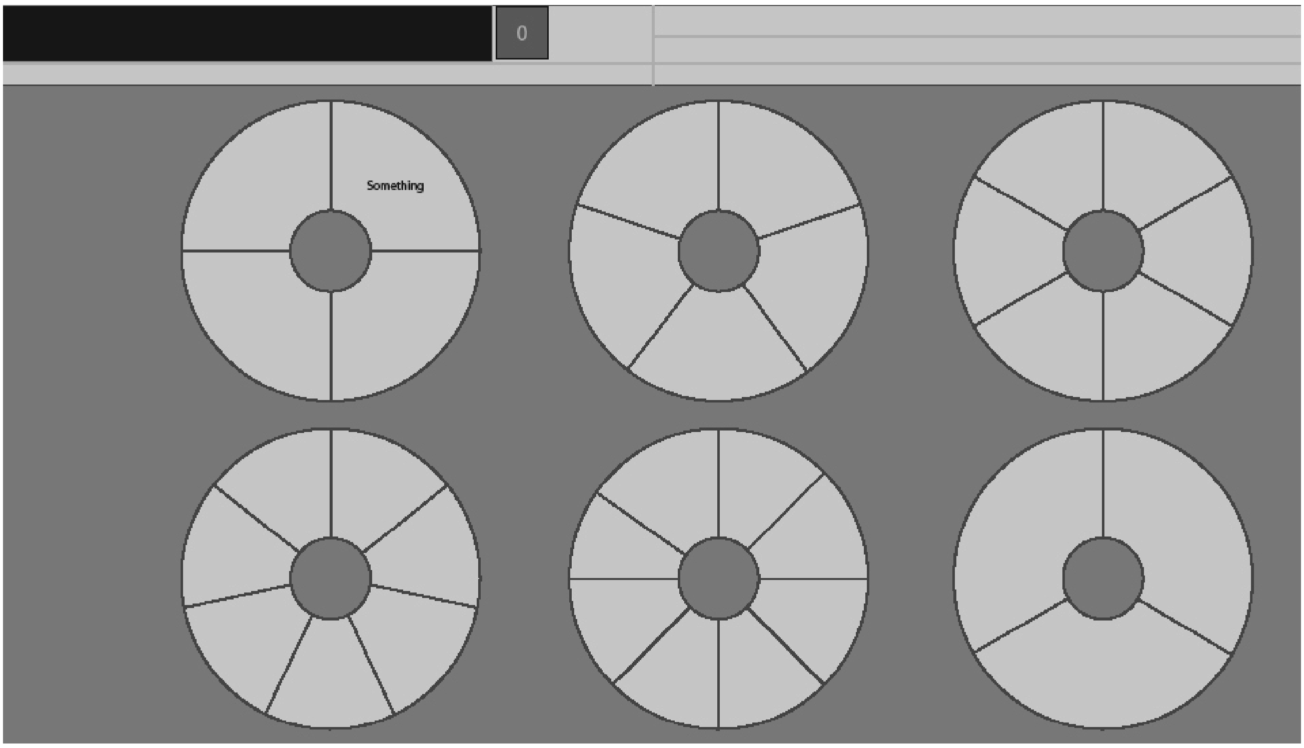
Sequence management

1) Area that shows the steps for a selected sequence. The top part shows the name of the sequence and the boxes below shows the name of the step and the status of the step. Green good, red bad and grey as a not yet active step.
2) Overview are that shows information about the given sequence,the estimated time to completion is also displayed
3) Symbols showing if the step is in auto mode (propeller) or if manual control is active(hand). The step that is under the number is currently set to manual control.
4) Control boxes appear here when a step is set to manual control. When in automated mod this area is shaded.
5) Confirm button for confirming that the step is done, when in manual control.
6) Button for opening the written documentation for the sequence (the left). The button to the right sets the sequence to manual control.



Process view

1) A standard process view screen similar to existing solutions on the market.
2) Shows another screen of the process view, when focusing on a specific part of the process.
3) A button that indicates to what sequence this part of the process is connected to. When the button is clicked it will bring up the sequence view indicated on the button.



Circular task

A set of circles that make up tasks of with a different number of steps.