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FACULTY OF TECHONLOGY

User Interface Design of Advanced Process Control System for Causticizing

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ABSTRACT
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Abstract

The aim of this thesis was to design new interfaces for Valmet Automation Oy's causticizing Advanced Process Control-product. The goal for the research was to determine how pulp mill's operators' needs and Valmet's engineers needs from the user interface can be taken into account and how the interface can be implemented into ongoing project.

The thesis describes the user interface design principles and best practices with human factors and ergonomics. The theory describes the causticizing process and how it is controlled with the advanced process control. From the technical theory, the thesis moves on to describing user experience and user interface design in depth. The human factors and ergonomics are elaborated from design point of view, and how the interface can support and enhance operators' work ergonomics. The thesis also describes how the design process should be carried through. Aim of the theory part is to elaborate what are the design principles and best practices, and how they can be utilized in industrial interface design.

The practical part of the thesis was conducted by interview research. The research was done with two user groups: with Valmet's engineers who are responsible for the Advanced Process Control products, and with operators who are the main end users of the product.

Presented theory and conducted interview research was utilized in the interface design with Valmet UI system. The design was done in cooperation with project's stakeholders. As a result, separate interfaces were designed for operators and for control tuning. Operators' interface was designed to support their work and the overall operating system design. The designed operator interface includes only the essential elements of the top-level control system which are supportive for operator decision making process. The designed control tuning interface was made to include more information which is relevant for the engineering work.

Keywords: Interface design, User experience design, Advanced Process Control

Additional Information

TIIVISTELMÄ OPINNÄYTETYÖSTÄ Oulun yliopisto Teknillinen tiedekunta

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Tiivistelmä

Diplomityön tavoitteena oli kehittää Valmet Automation Oy:n kaustisoinnin Advanced Process Control -tuotteelle uusi käyttöliittymä. Tutkimuskohteena oli selvittää miten sellutehtaan operaattoreiden ja Valmetin insinöörien tarpeet käyttöliittymältä saadaan huomioitua, sekä miten käyttöliittymän suunnittelu voidaan toteuttaa toimitettavaan projektiin.

Työ avaa käyttöliittymäsuunnittelun teoriaa ja perusteita yhdessä inhimillisten tekijöiden kanssa. Teoria esittelee kaustoinnin prosessikuvauksen ja kuinka sitä ohjataan Valmetin ylätason kehittyneellä säätömenetelmällä. Teoria etenee teknillisistä kuvauksista käyttäjäkokemuksen esittelyyn sekä käyttöliittymäsuunnittelun perusteisiin ja käytäntöihin. Työ avaa mitä inhimillisiä tekijöitä käyttöliittymäsuunnittelussa tulee ottaa huomioon, jotta käyttöliittymä tukisi operaattorin työergonomiaa, sekä kuinka käyttöliittymäsuunnittelu tulisi toteuttaa kokonaisuutena.

Kokeellisessa osassa toteutettiin haastattelututkimus, johon osallistui kaksi käyttäjäryhmää: Valmetin insinöörit, jotka ovat vastuussa Advanced Process Control -tuotteista, ja operaattorit sellutehtaalta, jotka ovat tuotteen pääkäyttäjiä.

Diplomityössä esitelty teoria ja toteutettu haastattelututkimus toimi pohjana uusien käyttöliittymien suunnitteluun Valmet UI -järjestelmään. Käyttöliittymien suunnittelu toteutettiin yhdessä projektin sidosryhmien kanssa. Työn tuloksena suunniteltiin erilliset käyttöliittymät operaattoreille ja ylätason säädön viritykseen. Operaattoreiden käyttöliittymä suunniteltiin tukemaan heidän työtään ja kokonaisjärjestelmää mahdollisimman hyvin. Operaattoreiden käyttöliittymä sisältää vain ylätason säädölle olennaiset elementit, jotka tukevat operaattoreiden päätöksentekoa säätömenetelmää vaihtaessa. Säädön viritykseen suunniteltu käyttöliittymä on vapaamuotoisempi ja se sisältää enemmän informaatiota, mikä on säädön viritykselle oleellista.

Avainsanat: Käyttöliittymäsuunnittelu, käyttäjäkokemussuunnittelu, kehittyneet säätömenetelmät

Muita tietoja

PREFACE

This thesis research how top-level advanced process control system user interface for causticizing process should be designed in order to meet pulp mills' different user groups' needs from the control system. The work was carried out for Valmet Automation Oy between June and December 2021.

I want to thank my thesis supervisor Juuso Palonki and thesis inspector Jukka Hiltunen for the excellent guidance and support, and for letting me to take liberties with the thesis research to meet Valmet's needs. I would also like to thank Heikki Imeläinen for guidance on causticizing advanced process control, and all the project's stakeholders for excellent co-operation.

In closing, I thank my family, friends and my partner for their support throughout my studies in University of Oulu. Also, I am grateful for Oulun yliopiston Prosessikilta ry for providing me and fellow students motivating and friendly environment to study.

Tampere, 9.11.2021

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1 INTRODUCTION

User interfaces on industrial automation systems are the backbone for efficient and safe process operations. In modern industry there is growing competition between system providers. One way to rise on top of the competition is to provide system which is a pleasant experience for the users, and which also enhances user efficiency. While good user experiences can provide competition results, they also create safer environment for the industrial users. In good interface information is not lost or hidden behind clutter, plant operators are capable to make operating choices more confidently and they learn system usage faster.

Within industry 4.0 automation systems will expand into mobile applications which enables more versatile working environment and different options for remote connections. While mobile applications enable flexible environments, mobile usability makes challenges on design decisions as same interfaces should be usable with mobile and desktop devices.

This thesis was done for Valmet Automation Oy to research how top-level advanced process control system user interface for causticizing process should be designed in order to meet pulp mill's operators' and Valmet engineers' needs for the control system. This thesis presents theory on what user experience and user interface are and how they should be designed. This thesis answers questions about what operators need from the interface? What kind of tuning environment Valmet engineers need for advanced process controls? How interface design process should be conducted? And how different user group's needs can be met within same system?

The thesis includes an interview research which was conducted with pulp mill's operators and Valmet engineers separately. With interview results and presented design principles causticizing advanced process control interface is designed. This thesis also provides common reference point for human centered design process for engineers who are responsible for providing and designing of Advanced Process Control systems in Valmet.

2 ADVANCED PROCESS CONTROL FOR CAUSTIZICING

Valmet's advanced process controls (APCs) are top-level optimization systems to control multi-input, multi-output processes. APCs are based on model predictive controllers, usually referred as MPCs, and state estimative soft sensors. APCs are most often utilized in resource intensive processes where substantial profits can be gained from stable product quality, improved yields, and energy savings.

MPC based APCs control the target process by finding the optimal future control sequence through making predictions on behavior of the process. MPC predictions are based on the process model, past inputs, and future inputs. MPCs can handle multi-input multi-output systems with constraints. Due the optimization nature of MPCs, they are most often utilized as upper-level process optimizers in industrial applications. (Agachi *et.al.* 2017 s.32-42; Valmet)

Causticizing process produces cooking liquor for pulp mills' digesters from recycled chemicals generated in recovery boiler and lime kiln. In pulp mills' chemical recovery line causticizing is located after a recovery boiler, where used white liquor i.e., black liquor is combusted. In the boiler organic material is combusted and the remaining chemicals falls to smelt heap. The smelt is lead into a dissolver where it is dissolved into water. After dissolving, the mixture is called green liquor which contains the recoverable sodium as sodium carbonate and sodium sulfide (Na_2CO_3, Na_2S).

Obtained green liquor must be purified from dregs before the causticizing reaction so that dregs don't carry over into filtration systems. Dreg separation is most often accomplished with sedimental clarifiers. Usually there's green liquor stabilizer tank before clarification, which acts as a buffer for the process. The stabilization tank also enables manipulations for green liquor's properties. Most important variables to manipulate at this stage are green liquor's temperature and density.

From dreg separation the purified green liquor is lead into slaker where the main causticizing reaction occurs. In causticizing, the sodium carbonate is reacted into sodium hydroxide ($NaOH$) with slaked lime ($Ca(OH_2)$), with by-production of calcium carbonate ($CaCO_3$). Causticizing reaction is exothermic thus the fed lime ratio and green liquor's properties must be carefully controlled. Most of the reaction is completed in the slaker with retention time of 10-15 minutes, but for achieving higher causticizing efficiency the reaction is continued through multiple continuous stirred tank causticizing reactors with a residence time of approximately of 90 minutes. Also, most of the by-product forms in the slaker, from where it is collected with a screw classifier. The calcium carbonate is led to the lime kiln for recycling it into calcium oxide (CaO), which is fed again to the slaker.

From the causticizing tanks, reacted liquor-lime slurry is led into a lime mud separation, which is usually pressurized filter system. From the separator, the filtrate is purged into white liquor separation tank, where contained water evaporates and white liquor can be collected for digesters. The separated lime mud is collected and washed from chemical residues and led into lime kiln through a buffer tank. (Biermann 1996)

As a process causticizing benefits from implemented APCs as causticizing is multivariable process which product quality has significant effects on digester process. Valmet’s causticizing APC is used to optimize the production of white liquor by maximizing causticizing degree (CE%) and by increasing and stabilizing green liquor’s titratable alkali content. APC also prevents over liming of the slaker which causes scaffoldings in the process line. (valmet.com)

3 USER EXPERIENCE OF INDUSTRIAL INTERFACE

The International Organization for Standardization (ISO 9241-11:2018) defines user experience (UX) as: "combination of user's perceptions and responses that result from the use and/or anticipated use of a system, product or service". Especially in industrial applications UX has an important role in plants' control rooms where operators supervise the plant's processes. Good UX ensures that operators are efficient with the automation system and their work. Good experiences influence heavily on system learnability, decision making processes, and on overall mental images users have regarding the system. (Errington *et.al.* 2005)

User interface (UI) and UX design are often mentioned together because UI design is one major part of UX design. UI can be perceived as the face of a system, which is major part of the experience, but all other aspects what lies beneath the eye are also part of the overall user experience. (McKay 2013 p.1-11; Saariluoma *et.al.* 2010 p.14-24)

3.1 Communication

One major aspect of good user experience is good communication. Communication in context of system design is all the information exchange that happens between user and the system through UI. With fluent communication, users are prone to make less mistakes and are more confident with their skills with a system. Users should be able to predict how to communicate with the system and they should be able to predict the consequences of the communication. (McKay 2013 p.11-15) Clear and consistent communication also helps improve mental images of the system operation. Mental images and expectations have great effect on system ergonomics as they are users' predictions how the system should work. If users are expecting bad and frustrating communication from a system, they avoid using the system. (Heimbürger 2010 p.80-81)

A successful communication between human and a system can be described by few following core principles:

1. **Communicate via UI**. Human-computer interaction is essentially a conversation by which user can perform a task with a machine. A good conversation is one of

the main corner stones of a good UX. One cannot presuppose that new user can perform any tasks with a system if the UI does not communicate with the user.

2. **Communicate clearly and concisely.** The UI should communicate with the user briefly and clearly. Long descriptions of tasks are obsolete as users tend to scan through the pages for fast information. The communication style and language should be appropriate for the environment where the system is used.
3. **Be purposeful and effective.** Modern UIs consists of glyphs, icons, graphs, controls, and animations. All these elements should be evaluated if their action or communication to user is relevant. If the user is compelled to translate some guideline to something meaningful, the guideline should be already translated to the UI. Or if some element's information or action is obsolete for the user, it should be removed.
4. **Communicate with respect and be intelligent.** Human-computer interaction does not differ from the standards what we have between people. Intelligent communication usually inspires confidence in users and their abilities with the system.
5. **Intuitive communication.** Natural and intuitive conversation by means of visualization and typography is effective. (McKay 2013 p.13)

3.1.1 Intuitive Communication through UI

Nowadays almost every person on this planet has had interactions with some UI of a system. These interactions and experiences have effect on our perspectives and opinions how UIs should look and operate. In addition, cultures around the world have different communication customs. For example, in middle eastern cultures text is usually read from right to left and in western cultures in the opposite direction. Colors also have different meaning in cultures thus possibly creating intuition conflicts between possible users. All those customs and experiences construct our mental models towards how systems should operate and communicate. These mental models should be utilized in UI design, so that users would see the system as intuitive as possible. (McKay 2013 p.15-18; Rosenzweig 2015 p.18-30)

Users' mental models are always modified through pleasant or unpleasant experiences and it must be recognized in the business as pleasant experiences can enhance the potential markets for the designed system. (Errington *et.al.* 2005) In addition, intuitive human-machine interaction methods are always subject to change depending on current technological development.

Intuitive UI can be described with eight terms:

1. **Discoverability**. Starting point of context is easily found. Commands are in expected location and are distinguishable from other elements.
2. **Understandability**. Communication to the user should be clear and concise. Users should be able to make informed decisions quickly and confidently.
3. **Affordance**. UI's elements should visually indicate their actions. Users should not need to experiment how to perform an action.
4. **Predictability.** UI's elements should deliver expected actions without surprises or confusion.
5. **Efficiency.** Users should be capable to perform an action with minimum amount of effort or adjustments.
6. **Responsive feedback.** After action, the UI should give clear and immediate feedback to indicate that the action is undergoing. After the action user should be notified if the action was successful. Depending on occasion the feedback can be subtle animation or a detailed error message.
7. **Forgiveness.** Users are prone to make mistakes during their tasks and the UI should be designer accordingly. The action done should be undoable or easily fixable.
8. **Explorability.** Designed UI should be easily explorable. Users learn to use systems faster when the UI is easily explorable and users don't have a fear doing something wrong or getting lost. (McKay 2013 p.15)

"UI is intuitive when target users understand its behavior and effect without use of reason, memorization, experimentation, assistance, or training. In other words, a UI is intuitive when users can quickly figure it out on their own." - McKay

Consistency is key in UX/UI design. Users have expectations of functionality of the UI which are set by their prior experiences with all the software they have used. Designed system should be similar in some level with other systems so that the user won't experience unexpected actions during their tasks. When designed system is inconsistent and drastically different with other systems; it's unintuitive. (McKay 2013 p.11-64)

3.2 Interaction

Users interact with a system by different methods. Interactions include navigation methods within a system and task performing actions. For example, opening a menu for finding wanted tool to complete a task. When designing systems, interactions are one of the first design decisions to make, as interaction methods have effect on how the whole system works and feels. Thus, it is important to know the user – whom you are designing the system for, what interaction methods they need, which methods might limit their efficiency, and what kind of mental models they have regarding the design. Designed interactions should be intuitive, simple, and communicative. They should have clear and immediate feedback. (Shneiderman 2005 p.66-74) It is highly preferable to use existing interaction styles which are widely used in other systems. Standard interactions are easily recognized, and their actions are easily predicted. System should react to users' interactions quickly with short response times. If system is performing slowly or some actions takes significantly more time to accomplish than others, users may become insecure if they caused an error.

As humans we have a certain way to plan and do interactions for accomplishing our goals. It can be described as a cycle which can be simplified to seven-stages. The seven-stage cycle illustrates how we act when we have some goal in mind: we plan how to accomplish it, we specify the actions needed to achieve the goal, and we perform the planned actions. After the actions are performed and something happens in our environment, we perceive what is happened and we interpret it and compare it to our goals.

This cycle can be utilized in UX design by giving users clear indications if their task was successful or not. In task failures it is important to provide guidance for the users so that they are capable to modify their action sequences to accomplish their goal. (Norman 2013 chapter 2)

3.2.1 Actions

Action is every act user does when they are completing tasks to achieve their goal. Actions are done with different interaction methods e.g., pushing "ok" button when interface asks for confirmation. Some actions will be done more frequently than others, thus they are easily categorized by their frequency:

1. Frequent actions
2. Less frequent actions
3. Infrequent actions

Depending on the action category, the task completion can be as simple as pressing a button on a keyboard, or more complicated sequence with confirmation dialogs. Actions should be easy to find and fast to complete when they are frequently used, and respectively infrequent actions can be more complicated. For most frequent actions there should be shortcuts available (Shneiderman 2005 p.69-70) Often tasks require multiple steps to reach completion. Since people forget easily complex sequences, system should offer task sequences as single actions e.g., starting a certain process of a plant by opening pumps and valves in certain order with a control sequence. (Shneiderman 2005 p.76-78)

3.2.2 Navigation

Navigation through complex systems can be challenging, thus providing simple and clear navigation rules is helpful: action sequences should be standardized so that users can expect similar outcomes in similar actions. Embedded links should visually be clearly a link and they should be descriptive on where they lead. Headings should be unique and descriptive. Clear choice making action for binary choices should be provided. (Shneiderman 2005 s.61-62)

Smooth and intuitive navigation between interface hierarchies is critically important, as it helps users to remember and anticipate where they can find certain pages or actions. Often these hierarchies can be overwhelming and too complex to understand if user does not have the knowledge and skills to navigate through them. To aid novice users, it is important to include search tools and help documents. (Shneiderman 2005 p.97-98)

3.3 Visualization

Visualization is one communication method from the system to the user. With intuitive visualization of measurements, graphs, icons, and buttons users are capable understand the system with ease, and furthermore they are capable learn the system usage faster. For example, iconic Microsoft Office's Word uses easily readable taskbar, which is divided into subtabs. Users are capable to learn and intuitively conclude which representative icon or glyph visualizes which command. Thus, making the users more productive and effective. Usually, icons and glyphs are visualized together with informative short text, which enhances the learnability and error avoiding. (McKay 2013 p.65-127)

In industrial applications, operators learn usage of interfaces quickly and become accustomated to them. They become capable to read different process states easily and they can recognize process errors quickly from the data provided. When expert operators are asked about the information density on the interfaces, they often say that they would prefer it more densely packed with extra information, which leads to clustered interface. Clustered interfaces should be avoided even they might seem the easy way out for designers, but clustered interfaces limit our visual perception drastically which may lead situations where critical alarms are not noticed. (Heimbürger 2010 p.106)

Also, organizing the interface consistently and purposefully is a key feature – information should be easily readable and where the user expects them to be. If different interface pages of a system are not designed consistently, users may become confused how they should operate them. (Shneiderman 2005 p.63) Generally, in visualization there should be clear match between the system and the real world, illustrated objects should be easily recognizable as what they represent. If visualization is done poorly, users may become confused and are prone to make mistakes. (Nielsen 1994)

3.3.1 Layout

As system users, people tend to scan through digital interface pages more often than they observe them carefully. This phenomenon is more evident when user is familiar with the interface or the user needs to find actions and information quickly. Depending on the page's layout, people have different scanning patterns which should be utilized in designer's advantage when designing UIs.

Within western cultures, when a page contains mostly text and lacks strong indicators, the scanning pattern often follows a z-like movement from left to right and top to bottom. In literature this pattern is often called an immersive reading pattern. (Johnson 2014 p. 56; McKay 2013 p.129-195)

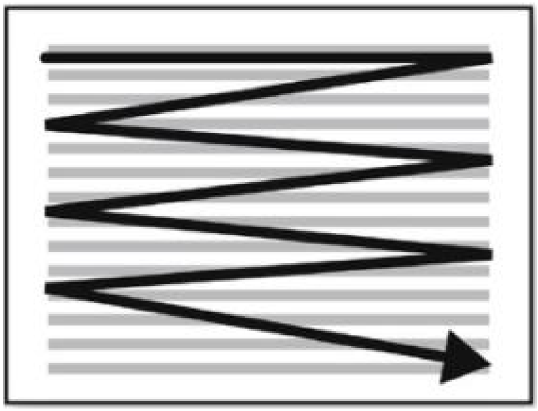

Figure 1. Illustration of immersive reading pattern (McKay 2013 figure 3.8)

Also, F-type scanning pattern is often found when people scan pages of text. In F-type scanning pattern people start the pattern by finding the most relevant heading and scanning couple of first lines below it. After those lines, the scanning pattern follows a vertical movement in page’s left side as people are trying to find relevant information quickly. (Nielsen 2006)

In more graphical UIs people tend to scan through the UI page in arching pattern: they start from the top left corner where the most important info is usually located. From the top left, people scan to the right bottom corner by following an arching pattern trying to find an action to complete their task e.g., where task confirmation buttons are usually located. Along the arch, the right top corner is called strong fallow area and the area on the bottom left is called weak fallow area, as the scanning arch won’t reach there. (McKay 2013 p.129-195)

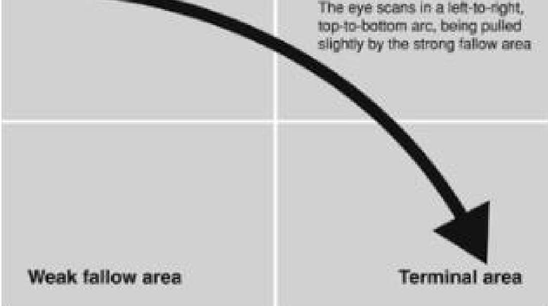

Figure 2. Gutenberg diagram scanning pattern. (McKay 2013 figure 3.9)

Users generally follow these patterns, but the patterns can be shaped by adding attention arousing elements in the UI. Usually this is done with functional elements. With modifications the arching pattern can be similar with following figure. (McKay 2013 p.129-195)

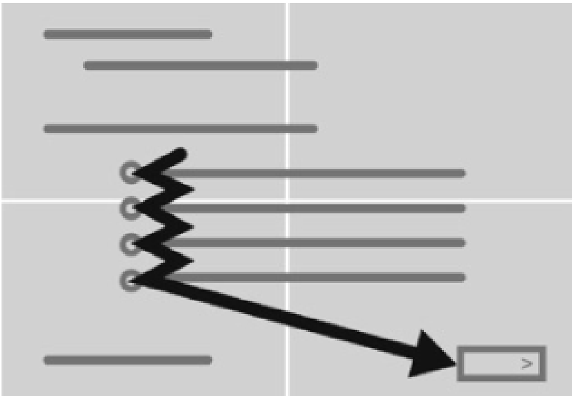

Figure 3. Interactive controls or other highlighting methods draw user's attention. (McKay 2013 figure 3.10)

These scanning patterns should be taken into consideration when deciding where to place process data visualizations on industrial interfaces, as good layout can support good readability of interface pages. (Johnson 2014 p.62-70)

3.3.2 Icons

Icons and other representations of real-world counterparts are essential elements in successful UX design. They are meant to illustrate users' mental models of actions which should ease the usage of directly manipulated interfaces. Icons are usually functional buttons which starts an action. Thus, it is important that they are quick to recognize as functional elements from the page. With clear and recognizable action illustrations users are more confident on their decisions and they find needed actions quickly. In contrast, badly done icons can make UIs challenging to use and navigate as users are not confident on their decisions and they are slow finding needed actions from the interface. Icons should always be accompanied with short descriptive texts or placeholders, so that users are certain on their decisions and they don't have need to guess the meaning of icons.

Intuitive, simple, and standardized icons can deviate from this rule, but however, they should show descriptive texts if user hovers a cursor on top of them. These standardized and generally familiar icons include for example: saving icon, printing icon, and menu icons. (McKay 2013 p.129-195; Johnson 2014 p.1-13)

3.3.3 Transitions and Animations

Transitions and animations should be used sparsely and with care. People are easily distracted on their tasks even with small animations. Movement draws our attention involuntarily as humans we are evolved to notice even the most subtle movement from the environment. Transitions are often used to make pages elements feel more fluid and refined. But if they are used extensively it usually make the usage of the UI slower and in the long run users can become annoyed by them. Page wide transitions can also make people feel sick due sudden movements. Transitions and small animations are good at emphasizing certain content from the page. For example, alarms often include blinking animations to draw users' attention. This can be made more subtle with adding a certain time limit after the animation is played. (McKay 2013 p.129-195; Johnson p.49-67)

3.3.4 Typography

Good typography enhances usability of UIs as it ensures that texts are easily readable, and letters are easily distinguished. The font, font sizes, and formats should be consistent within a system e.g., headers should be written with same font size and format, and plain text should have its own standard format. Standard typography within system helps users distinguish different elements and importance of displayed information. Important parts of text can be highlighted with color, but color usage should be considered carefully.

Alignment of text and numbers is also important as people are accustomated to reading in certain way. In western cultures, texts should be aligned to the left or justified to span the whole page. In lists, numbers should be aligned to the right to differentiate them from text. Also, long series of numbers should include spaces after three or four numbers to ease readability and comprehension of the number sequence. (McKay 2013 p.129-195; Johnson p.67-87)

3.3.5 Alarms and Errors

If alarms or errors occur, one way to reduce the loss in productivity is to provide clear and concise messages for the users. Clear and understandable messages can raise success rates in repairing the errors, lowering future error rates, and increase subjective satisfaction. (Shneiderman 2005 p.76-78)

When alarms or errors occur, it is important to mark them where users expect them to be. In industrial UIs, alarms should be marked on an updating list which should be filterable by time or severity. The same alarms should be visible in proximity of a visualization of a machine in which the error is occurring. Alarms should be marked based on their severity with decided standard icons and colors. Color coding is important with alarm messages as people have accustomated that certain colors mean different things e.g., red connotes errors, to stop, danger, and critical problems. Orange connotes moderate errors and critical notifications, and yellow connotes minor errors and attention needing notifications. Other colors like blue often connotes important non-error notifications or selections in the UI, and green connotes that something is done correctly, or something is safe.

Also, pop-up windows, sounds, wiggles, and blinks can be used to increase the effectiveness of alarms. Humans are evolved to notice movement in their environment and moving elements in UI will get our attention. But movements must be used rarely and considerably as we can become accustomated in those and become “notification blind” if UI contains them too much. Sounds are also good method to get peoples’ attention. For example, industrial control rooms are equipped with alarm systems which notifies the personnel with sound if there’s an alarm. (Johnson 2014 p.49-67)

3.4 User Errors

UIs should always be designed in a way that there’s small chance users to do mistakes and cause user errors. It is said that there is no thing as user error, it is always design error as the interface designer wasn’t capable to prevent that error from happening. To avoid user errors in the first place, the first step is to understand the nature of those errors. One perspective is that people make unintentional and intentional actions. From which unintentional actions include so called slips and lapses, and intentional actions include mistakes and violations. Mistakes can be described as wrong conscious actions done by user. Mistakes can occur for example, when user does not remember the right sequences for certain actions, or the icons are misleading. Violations are intentional acts which violates rules of the work environment. Slips and lapses in other hand are unconscious occurrences when user is intending to do certain action, but they “slip” or they remember incorrectly and do another action instead. Mistakes, slips and lapses can be seen as design flaws which can be avoided by improving system learnability, readability, and by arranging action elements in standard way and separate enough that slips are hard to occur. Violations are hard to prevent fully, but they can be minimized by providing confirmation dialogs to users that they have feeling that their actions have consequences. (Shneiderman 2005 p.76-78; Heimburger 2010 p.66-69)

User error prevention is especially important in industrial systems where errors can be fatal e.g., user should not be able to start a process machinery if there’s ongoing maintenance. Inappropriate items and selections can be grayed out from the UI so that they cannot be inadvertently selected, or forms can have automatic command completion to eliminate typing errors. Similar techniques as these do some of the mental work for the users, and thereby reduce opportunities for user errors. (Shneiderman 2005 p.76-78)

3.5 Usability

Ergonomics of human-system interaction describes usability as such: “extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”. (ISO 9241-11:2018) Usability is one of the key elements which builds the overall user experience. However, system can be highly usable while the experience is not great. Usability refers system to be designed convenient and practical, not as a good experience (Rosenzweig 2015 p.8)

Usability can be seen to be consisted of five main attributes:

1. **Learnability.** Usage of the system should be easy to learn. By ease of learning, user is capable to comprehend system’s capabilities quickly and is capable to work faster.
2. **Efficiency.** User is capable achieve high productivity with minimum effort

3. **Memorability.** The system should be easily remembered, so that after time periods users are capable of use the system with minimum reminder sessions. Also, good memorability is tied to high productivity if system's advanced shortcuts are easy to remember.
4. **Errors.** The system should have low error rate. Errors should be easily avoided, or if they occur, they should be easily recovered or undone. Further, critical errors must not occur.
5. **Satisfaction.** Users should be satisfied when using the system. Users' needs for UI should be fulfilled, so that there is no unnecessary information or actions to distract the user from their main tasks. (Nielsen 1993 p.26)

Usability studies can give information about systems different sections and functionalities. It can be used to evaluate the whole system's usability or it's sub-parts. For example, system's information architecture (IA) can be highly usable for users while the UI might lack some intuitive navigation tools and therefore being unusable for the users. Usability can be systematically evaluated by researched methods. (Nielsen 1993 p.23-42)

4 HUMAN FACTORS AND ERGONOMY

International Ergonomics Association defines human factors as such: "Human factors i.e., ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance". (ISO 9241-11:2018)

Humanistic and psychology studies are key elements in UX design as designed products are intendent to be used by humans. Technological advance is always great, but it should be remembered that the technology is made for human use and for human benefit. In a good overall system, the technical and human components are designed in roles that are most suitable for them and contributory cooperation is designed to be as fluent as possible. (Heimbürger 2010 p.54-55)

4.1 Human Capacity

Humans are limited in working capacities in many ways, which affects how our working environments and used systems should be designed. Humans have physical and cognitive capacity limits in multiple aspects, but most provident in context of UX design are sensory thresholds, attention span limits, and memory capacities.

With good physical and cognitive ergonomics, these capacities can be enhanced but they are still limited. Human capacities are more easily worsened with bad ergonomics, which in turn can lead in user errors and overall bad user experience. Thus, when designing systems and transmission of information it is important to acknowledge human thresholds and memory capacities. (Johnson 2014 p.87-121)

4.1.1 Memory

Capacity of human memory is one of the most limiting factors for humans. We are bad at remembering in short term, thus having limited calculation abilities and work memory. Work memory can be described to be our combined focus of attention: everything that we are conscious of at a given time. It is conducted that, on average humans are capable to remember three to five objects at glance, depending on their properties and arrangement. Memorability and comprehension of what is seen can be enhanced by grouping objects to similar “chunks”, so they become one object to comprehend. For example, this memory phenomenon is most often utilized in long series of numbers, by differentiating the series to three- or four-digit groups e.g., 1334665775788 to 1 3346 6577 5788. (Johnson 2014 p.87-101)

Grouped objects are significantly easier to comprehend and possibly memorize by humans. It is not important to concentrate on numbers of objects human can keep in their working memory, but in the fact that working memory is limited and it can be easily distracted by other stimuli. Information can be easily be lost and new can be gathered, it all depends on what caught our attention. Thus, information provided in UI should be easily comparable to other information e.g., in industry operators should be able to compare provided data to the overall process situation, without navigating through different pages. They should not need to remember process data while using the UI. (Cowan 2000; Johnson 2014 p. 87-101)

4.1.2 Attention Span

Without previous knowledge or skill-based automation we are also limited in attentiveness as we are capable to focus on one thing at a time. We are evolved to sense and direct our attention to movement, threats, faces of other people, and primary needs like food. Along our goals, these subjects draw our attention involuntarily. We don’t consciously attend ourselves towards them, but our perceptual system notices something attention-worthy and orients our attention towards it and only then we become aware of it. Thus, system designers should design system so that there are as few distracting elements as possible and they should utilize elements with movement or bright colors with consideration. (Johnson 2014 p.92-93)

4.1.3 Sensory Thresholds

In sensory thresholds, human vision is significant limiting factor when designing interfaces for systems. Most of our vision is peripheral and our focused field of view is small. Thus, it is important to group related information close to each other e.g., alarm messages should be located close the action that caused it or close to the visualization which it is related to. If alarm messages are shown only in one message box in upper part of the display and our eyes are focused on lower part of the display, our peripheral vision might not notice the change, and we simply won't notice the alarm message.

Also, our visual system automatically assumes structures from visual inputs, as it is evolved to perceive shapes and figures from the environment. Seen similar objects, or objects which are close to each other are often identified as a group, and items which have space between them are usually identified as different groups. These basic findings of shapes and groupings were discovered by a group of German psychologists. Thus, these theories became known as Gestalt principles as *Gestalt* means shape or figure in German. Gestalt theories should be used in favor when designing UIs. When they are followed correctly, users have more intuitive feeling when using the system. (Johnson 2014 p.11-30 and p.49-66) More about Gestalt psychology and its history can be read from an article: A Century of Gestalt Psychology in Visual Perception: I. Perceptual Grouping and Figure–Ground Organization, by Wagemans *et.al.*

Some of us also have certain limitations within their senses, some might be color blind or have hearing limitations. These aspects must be taken into consideration when designing UIs. All elements in a page should be readable and distinguishable for all users. Good practice is to design pages in gray scale and add colors to the page after if needed. This practice ensures that information is not color dependent and it is only used for enhancing purposes. Same practice should be used with sound: designed UIs should be noise independent. Some sensory thresholds are also affected by work equipment like hearing protectors. Thus, critical information alarms for example, are often enhanced with small animations combined with sound and bright notification colors. (Nielsen 1993 p.117-123; Johnson 2014 p.87-121)

People also get tired during their work which affects negatively on all human ergonomics. Tiring can be minimized with good physical ergonomics in work environment and with eye-easy design choices in UIs. Interfaces should be gentle in color contrast so that users' eyes won't get tired and important elements would be easy to distinguish from other elements.

In summary, UI design should utilize human strengths and aid with our weaknesses by providing means to ease our memory load, by providing clear sensory information with clear thresholds, and by helping us to keep our attention on the tasks we are performing. (Johnson 2014 p.87-121)

4.2 User Personas

Depending on the application and the field in which the system is being developed, users will vary in their capabilities, needs, and in tasks which they are performing with the system. Systems should be designed to be accessible, usable, and useful for all the target users. In the designing process varying human perceptual, cognitive, and motor abilities must be considered. Designed system should be universally usable for all target users. (Shneiderman 2005 p.24-40)

Fundamentally users are easiest to categorize within approximate skill levels and personas which represent categories of target users. Personas can be seen as hypothetical archetypes of actual users. Depending on users' skill levels they require different set of tools to work with. Novice users are dependent on easily available visual information and clear "emergency exits", while expert users expect a set of shortcuts and direct commands to be available for making the workflow more efficient. (Nielsen 1993 p.43-49; Shneiderman 2005 p.67-68)

In deeper level, UX persona definitions include following attributes:

Demographics: age, education level and profession
Goals for system use
Motivations for the system use
Frustrations from the system use
Behavior and tasks when using the system
Constraints and limitations for the system usage
(Rosenzweig 2015 p.47)

These attributes can be collected in a "persona card" which can be utilized in all phases of the system design process. Utilizing personas in design process is proven to be effective as it gives insights how different target users may perform their tasks and which kind of properties they need from the system. (Dantin 2005) For example, in industrial setting an automation system is used by multiple different personas: process operating personnel, production engineers, automation engineers, field engineers, and production planning personnel. Whom all require different specific information, and tools from the system or interface. (Shneiderman 2005 p.67-69)

Simple user identification can improve design process's efficiency by providing a common reference who are the system users for the whole development team. In each development step these personas can be used to evaluate if the design is moving in right direction. (Dantin 2005)

In short, in the design process differences between users must be considered. The UI must be universally usable for all target users without extensive training. The design should aim to provide different functionalities for varying skill levels while preserving ease of exploring and high discoverability. The design should provide users with right content in right context. Providing these properties to the UI, users are capable to enhance their skills with the system and learn to use it efficiently.

5 USER INTERFACE

ISO standard of Ergonomics of human-system interaction defines user interface as such: “set of all the components of an interactive system that provide information and controls for the user to accomplish specific tasks with the interactive system”. (ISO 9241-110:2020)

UI is the physical, verbal, and informative interface between human and machine. Physical component of UI covers the methods how humans interact with the system. Interaction can be performed with traditional controllers like mouse and keyboard, or it can be done by advanced methods: touch, speech, eye tracking, and gestures.

In this thesis we are focusing on UIs in displays, which are controlled with keyboard and mouse or with touchscreens. Touchscreens have now been widely available for couple of decades, but they have not seen widespread usage in industrial setting. But this might change in ongoing fourth industrial revolution. When combining users to use multiple interaction types in same system, dynamic properties are needed from the UI design. This is evident in modern web applications which are capable to adapt between touch and controller commands, and to all sizes of displays.

5.1 UI Heuristics

In literature there are multiple heuristic lists and guidelines for UI design, but the two best-known lists of heuristics are written by Nielsen and Molich (1990) and Shneiderman and Plaisant (2005). These lists aim to summarize good design methods, which make systems more usable and better experience for the users. These two lists overlap for most parts and provide quite similar guidelines for UI design. Thus, these heuristics are usually combined into a custom list which is most relevant for designers and their field of industry. These heuristics are most often used in evaluation phase of a design process, in which evaluator can check if the design follows or violates the UI design heuristics.

During past decades these heuristic lists have been modified slightly from the original by the authors, but the main idea has remained same. (Johnson 2014 introduction)

Usability heuristics from Nielsen and Molich:

1. **Visibility of system status.** Users should always be informed about system status through informative and appropriate feedback within a time limit.
2. **Match between system and the real world.** The system should communicate in user's language. Communication and information to user should be clear and concise without extensive explanations. Visualizations of real objects should be easily recognizable.
3. **User control and freedom.** The user should always feel that they are in control and they have a freedom of choice. There should always be a clearly marked exit for actions, as users are prone to perform actions by mistake.
4. **Consistency and standards.** People spend more time using other digital products and usually, their layout and communication styles are similar. Thus, users predict similar functionalities in your system. It is highly preferable to follow similar design styles as others, so users are more confident as they are capable to predict what causations their actions will have.
5. **Error prevention.** Avoid and eliminate probable error inducing situations. In critical actions provide a confirmation dialog.
6. **Minimize user's memory load.** Minimize user's memory load by making elements, actions, and options easily visible. Provide icons, glyphs, and pictures with written information. Users should not be required to remember information from one page for use in another.
7. **Flexibility and efficiency of use.** Provide hidden and visible shortcuts and allow users tailor their frequent actions to custom lists or interface pages.
8. **Aesthetic and minimalistic design.** Keep the information in the UI relevant for the user. If some element or piece of information is not needed – remove it. Every extra element in the UI makes it harder to read and reduces user's efficiency.
9. **Help users recognize, diagnose, and recover from errors.** Error messages should be informative for the user. Precisely indicate the problem and preferably suggest a solution.
10. **Help and documentation.** Provide a help menu for the user where documentation for the UI's actions can be read in detail. Ensure that the help documentation is easy to read. (Nielsen 1994, Nielsen 2020)

The Eight Golden Rules of Interface Design from Shneiderman and Plaisant:

1. **Strive for consistency.** Consistent design and action sequences should be required in similar situations.
2. **Seek universal usability.** Designed UI should be usable and flexible for multiple personas and for a wide range of user skill levels. Shortcuts and customization should be provided for expert users and easily available help and information for novice users.
3. **Offer informative feedback.** When user performs an action the state of the action should be informed to the user. The interface feedback can be modest or substantial depending on criticality and frequency of the action.
4. **Design dialogs to yield closure.** Sequences of actions should have a beginning, middle, and end. User should be notified about the state of the sequence and in the end, user should be given informative feedback if the action was accomplished for satisfactory closure.
5. **Prevent errors.** Interfaces should be designed, so that users are not capable to make serious mistakes or errors. If error occurs, user should be offered simple, constructive, and specific instruction for recovery. Also, for critical tasks confirmation dialog should be provided.
6. **Permit easy reversal of actions.** All actions should be easily reversible. Reversibility relieves anxiety in users thus they are encouraged to explore UI's actions and options.
7. **Keep users in control.** People strive for being in control of a device or application what they are using. Provide predictable and noticeable feedback for actions, so that users feel that their actions have meaningful consequences.
8. **Reduce short-term memory load.** Design the interface to assist human memorability by providing easily learnable and intuitive icons and means to save forgettable information. (Shneiderman 2016; Shneiderman 2005 p.74-76)

5.2 Trends

Today's requirements for successful UI does not fundamentally differ from previous generations, but as users people have higher expectations when interacting with modern UIs. In modern world users are anticipating fast, easily readable, and reliable information, which is in most cases expected to be customizable. People have become accustomed to having a mobile device available in all times, which is expected to have connection to internet. Humans have become accustomed in extensive data availability and it should be acknowledged in system design process.

For data visualization, digital dashboards have become popular in recent years. Their purpose is to provide fast and easily readable information for users in convenient fashion. Within industry 4.0 industrial UIs are being transferred into a web format, so that different users are capable to access plant's system's information remotely. Remote devices are usually tablets, or smartphones. These devices are equipped reasonably small displays for which dashboards are great choice for interface, as they provide the information in compact and easily readable form. With remote access and mobility, industries are capable to enhance their employee efficiency, production, maintenance, management, and planning. (Tokola *et.al.* 2016)

In industrial applications usability of mobile devices complicates the interface design process as mobile devices require more empty space in the screen to avoid accidental user slips. Also, it would be expensive to design separate UIs for mobile devices and desktops. Thus, if mobile devices are used, the UI design should proceed with mobile first method which ensures good usability with mobile devices.

6 DESIGN PROCESSES

In context of UX design, process is a methodical way of working which aids designers and system providers to deal with complex projects. With selected and carefully planned design process structure, team members are more easily kept on schedule as the process structure can be used as a checklist. With common process structure, cooperation between project roles is also easier as they have shared concept of what they are doing. Planned and executed design processes also provides organizational memory which is repeatable.

In literature there are proposed various structures and terms for design processes, depending on the domain where the system is designed. But all structures follow couple of main principles: pre-study, analyze, design, evaluate, and iterate. With these concepts in mind, the design process should be successful. Full systems of-course require multiple process cycles in different system levels: information architecture and conceptual model design, page design, and detailed UX design.

Design process can be described to be human-centered (HCD) or technology-centered. These terms describe what is the foci on the system design: HCD focuses on human ergonomics, and technology-centered focuses on providing new products to market and driving technology forward. Often human-centered design follows technology-centered designs as competition advances. (Hartson & Pyla 2012 p.47-86)

6.1 Human-Centered Design Process

ISO standard of Ergonomics of human-system interaction defines human-centered design process as: “Human-centered design is an approach to system design and development that aims to make interactive systems more usable by focusing on the use of the system; applying human factors, ergonomics and usability knowledge and techniques. The term human-centered design is used rather than user-centered design in order to emphasize that this document also addresses impacts on a number of stakeholders, not just those typically considered as users. However, in practice, these terms are often used synonymously.” (ISO 9241-220:2019)

As a term HCD is evolved to remind engineers and designers to co-operate with the end user to achieve the best UX possible. HCD acknowledges human ergonomics and capacities. HCD is keeping the design process close to the whole UX concept and the end user. Often engineers are interested only in the technological aspects of designed systems and products, and they tend to forget intended users and the environment where the system is being designed.

HCD process is built upon participatory stakeholders. Involvement of stakeholders and end users allows the design process to be more open considering the UX. (Rosenzweig 2015 s.44) Stakeholders can participate to design process by multiple different methods e.g., user interviews, social reviews, workflow games, and group reviews. (Vilpola & Terho 2008 p.38)

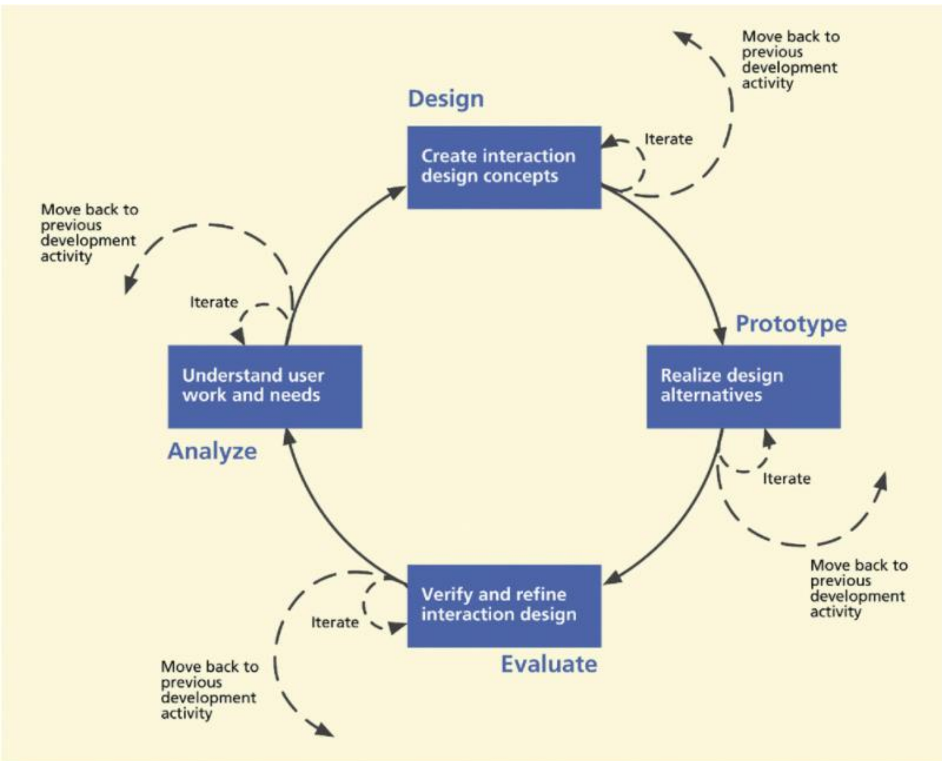

Figure 4. Process Lifecycle Wheel (Hartson & Pyla 2012 chapter 2)

The whole design process can be illustrated with a design wheel, shown in figure 4., where the design cycle begins from analyzing users task habits and user needs. The wheel demonstrates how iterative the whole design process is. However, the wheel is just a representative model as the design steps can overlap significantly e.g., each step includes some evaluation for decision making, whether to iterate the current step or to move on. Within phases, a similar inner wheel structure can be found where phase's products are evaluated rapidly, then analyzed, and finally iteration starts again. (Hartson & Pyla 2012 p.47-86)

6.1.1 Analyze

For understanding user needs, workflow, usage context, and limitations of the system domain, comprehensive pre-study and continuous analyzing must be done by the system provider. Without real understanding why and where the system is suited, the design process can't really be accomplished as it will keep bouncing from iteration cycle to the next, because users' needs aren't acknowledged, and the work domain isn't studied. (Hartson & Pyla 2012 p.47-86.; Shneiderman 2005 p.67-69)

Pre-studies and inquiries are usually done with interviews and observations with intended users in their work environment. When users articulate or show their needs for the system, and designers acknowledges them, the design process will start smoother, and it won't cycle back to initial design phases so easily. In industrial setting, system users are most often highly trained operators who have plenty of so-called silent knowledge what they cannot articulate easily. Thus, for a system or interface designer it is important to observe workers in their working environment and take note how their daily routines are. If a system is provided without any user observation or previous knowledge, provided system wouldn't probably be what the users expect or need.

Quick analyzation is also done after every process step to ensure that the design is following the context. From analyzation step, the design process can be finally finished when the system design meets all requirements. (Vilpola & Terho 2008 p.14-21)

Data gathered through interviews and observations is mostly qualitative and it is often analyzed through thematic analysis. In thematic analysis analyzer aims to find reoccurring themes regarding the research goals. These findings are subject to analyzers expertise and knowledge of the data, but they demonstrate well the key points what the study was researching. (Braun & Clarke 2006)

6.1.2 Design

Design as activity is ideation and sketching which leads to representation of target users' mental models, conceptual design, and design storyboards. Design is the brainstorming phase of the process and those ideas are built into prototypes.

Early designs can also be done in participation with users by sketching ideas with simple methods like pen and paper. Users are valuable source for designer as they are the personas whom they have studied in first stages of the process. Users are able and often interested to influence on how the system will look and feel. (Hartson & Pyla 2012 p.47-86.)

6.1.3 Prototype

To test designed systems, prototypes must be created. Prototypes can be created in various forms and phases of the design process. Prototypes can be evaluated easily with previously mentioned heuristics in early phases of the development when most of the work is not yet done. (Rosenzweig 2015 p.44)

In prototyping, design alternatives are built. These builds can be done shallow or in depth depending on the phase of the process. Prototypes can be categorized in following manner:

> Horizontal Prototype: Very board in features. Shallow in coverage and functionality. Used in early phases of the process
>
> Vertical Prototype: As much depth of functionality as possible. But only narrow breadth of features.
>
> T-Prototype: Most of the design is realized at a shallow level, while few parts are done in depth. Combines advantages from vertical- and horizontal prototypes offering a good compromise for system evaluation.
>
> Local Prototype: Detailed prototype for isolated interaction. For evaluating design alternatives in localized interactions. (Hartson & Pyla 2012 p.47-86)

6.1.4 Evaluate

Prototypes and design alternatives can be evaluated in various methods. In early iterations of the design process, heuristic evaluations are the most practical option as they are fast and cheap to conclude. In later stages when sophisticated prototypes are built, more extensive evaluation and testing should be done. Within iterations intended users should participate to evaluation for ensuring that the design will be what is desired and needed. Participatory evaluation is method which gives most insight on users' needs but is usually resource demanding and expensive to complete. Evaluating methods are discussed further in the next chapter. (Hartson & Pyla 2012 p.47-86.)

7 USER STUDY AND EVALUATION METHODS

Designers and system developers become easily entranced with their products that they might not be capable to evaluate them by themselves. Thus, it is important to evaluate and test designed systems with customers, experts, and third-party participants. Evaluating and testing requirements must be approximated by the criticality of the system e.g., national air-traffic-control system might need years of testing and evaluating cycles before launch, whereas small businesses' internal web site can be evaluated and tested within a week. (Shneiderman 2005 p.140-141)

Evaluation and testing of UX design can be done qualitatively or quantitatively. Qualitative methods focus on collecting subjective insights how people interact with the product or service. Qualitative methods are efficient tools in design process as they find most of the design problems occurring in a system. It must be taken into consideration that qualitative studies are subjective.

Quantitative methods focus on collecting metrics via measurable tests. Quantitative methods are usually more expensive and harder to complete compared to qualitative methods. But with carefully set tests and objectives more detailed information can be extracted from the functionality of a system. These details can illustrate underlying flaws from design which are not found in qualitative studies.

It is recommended that qualitative studies like interview research, are used in early phases of interface development and quantitative studies are carried out in later phases of the development. With reasonable arrangement of evaluation and testing, the design process is accurate, flexible, and cost-effective (Ó Broin 2011)

7.1 Surveys

Written surveys are familiar to most people. They are inexpensive, quick to conclude, and they are generally accepted addition for usability tests and evaluation methods. Surveys gives both qualitative and quantitative information from the design. Surveys can be used in initial user study as well as in evaluation phases. (Shneiderman 2005 p.150-162)

When conducting surveys, the goals for it should be clear and the questions should be developed to support those goals. There should be clear and concise agenda for the survey. Surveys should be prepared and reviewed with colleagues and tested with a small sample of users before the real survey. (Shneiderman 2005 p.150-162)

7.2 Interviewing and Monitoring

Interviews are great method to conclude initial user studies as they give more insight on users compared to written surveys, as people are generally more descriptive when speaking with another person. However, interviews are quite resource demanding and they might be hard to appointment on suitable times. Interviews can also last up to couple of hours depending on the quality and the number of questions, thus it is important to script the questions carefully that the interviews won't waste the interviewees' time.

The interview questions can be as simple as asking straight; "can you tell me how you do your daily work here?". The interview answers should give descriptive insights on what actions do they take, with whom do they interact, and with which systems do they interact. The interviewer can ask the interviewee to demonstrate what they do and to narrate it with stories of what works, what does not work, how things can go wrong, etc. All the questions should be open-ended questions to which the interviewee must answer descriptively. The interviewer should avoid questions which can be answered with no or yes as those questions are too subtle and they might lead the interviewee to answer in certain manner. (Shneiderman 2005 p.150-162)

Interviewing can and should be accompanied with user monitoring: the interviewee should continue their daily work routine as normal while they are monitored. The interview can also be integrated to the monitoring if it does not interfere with interviewees work. Often people are not good at articulating their activities in interviews or they don't see something as importance to mention to the interviewer, which could in fact be relevant for the system design process. User monitoring often gives useful knowledge on users' environment and their working habits, it can give a lot of extra information about target users which won't come through in interviews. However, people need to be monitored carefully and the agenda of the monitoring must be made clear for the person as under monitoring people tend to act differently compared to normal. They might avoid certain shortcuts they do in daily basis because they are afraid to get caught of doing something wrong, or they might perform significantly better at their tasks when they know that they are observed. (Vilpola, I. & Terho, K. 2008 p.14-21)

7.3 Analysis of Qualitative Data

With interviews and surveys comprehensive qualitative data can be gathered when research objectives are clear and research questions are carefully planned. Gathered qualitative data is usually in text or in recorded format. If gathered data is only recorded it usually should be transcript to text.

In relation of UX/UI design most relevant analysis method of qualitative data is thematic analysis, which aims to find reoccurring themes or categories from the gathered data which give overall insight on peoples' opinions regarding the research questions. (Braun, V. & Clarke, V. 2006)

Thematic analysis consists of six different phases where the data is studied carefully and reoccurring subjects are gathered into themes, which represents opinions of research participants. The phases are following:

Phase 1: Familiarization of qualitative data. When analyzing qualitative data, the analyst must be familiar with the data so that they are capable to recognize repeating patterns from transcripts. Usually, the analyst gathers the data by themselves, thus making the familiarization process more efficient. In the transcription process it is vital that the data remains as close the original answer as possible, collected data should not be modified by any means.

Phase 2: Generating codes i.e., interesting features in data. Code generation starts after the analyst is familiar with all the data gathered and have generated initial ideas on what is interesting in the data. It should be remembered that qualitative data is context dependent, thus codes should include some surrounding information for context clarification. Analyst also should code the data open mindedly, by coding for as many potential themes as possible. Code generation does not construct themes just yet as they are more board presentations of the data, but those codes will be placed under categories in the next phase.

Phase 3: Generating themes. Theme generation begins when the data has been coded and the analyst has a list of different codes identified from the data. Foci in this phase is to categorize codes in potential themes. Some codes may construct main themes from the data, other may form multiple sub-themes and some may be discarded completely in the next phase. Often the data has some seemingly disconnected, but interesting codes which does not fit in any theme thus it is reasonable to make a "miscellaneous" theme in which these lonely codes can be gathered. Those lonely codes are as important as every other occurring code as they can give information on minority groups and how they see the researched subject.

Theme generation phase ends with list of candidate themes and sub-themes for review phase. During this phase themes should not be discarded, nor any code should be overlooked as they are reviewed closely in the next phase.

Phase 4: Reviewing themes. This phase consists of two levels of reviewing. First level's focus is in reviewing the themed data i.e., consideration if formed themes really form coherent patterns or themes. If they do, they are moved on the next level of reviewing, and if they do not, the theme should be revised whether the theme itself is flawed, or whether some codes does not fit in the theme. During this level unsatisfactory themes may be discarded or modified, and codes may form new sub-themes.

After the generated themes are satisfactorily passed the first level, the second level of review can be started. The second level's process is similar, but the focus is on consideration if individual themes can be validated to represent the data set i.e., are the themes relevant to the research.

Phase 5: Defining and naming themes. This phase's focus is in defining and identifying reviewed themes' meanings and naming them accordingly. Each individual theme is analyzed in detail and their meaning is written up. After this phase the analyst should be able to clearly define what each theme represents within few sentences.

Phase 6: Producing report. With finalized themes, written analysis of research topic can be concluded which represent and arguments in relation of the research questions. (Braun, V. & Clarke, V. 2006)

7.4 Evaluation

Evaluation methods are convenient and powerful when used correctly. They give insights how experts and customers see the designed system and how they feel using it. Especially participatory evaluation shines on its functionality in early phases of design process when design changes can still be done effortlessly. In early phases customers' wishes are easier to take in account and accomplished, versus if customers are only able to give their opinion on later phases of the process, the design might need whole rework to meet customers' requirements. Evaluation is qualitative method thus it should be remembered that found design flaws are only subjective. (Vilpola, I. & Terho, K. 2008 p.21-38)

Heuristic usability evaluation has been one most used method in UX evaluation. During UX design process the UI's usability can be evaluated by design and system domain experts using heuristic lists. In heuristic evaluation the goal is to improve the product as much as possible during iterative design process. Evaluators revise the prototypes with heuristics lists, which are usually combinations of heuristics presented in chapter 3, and they tr

y to find number of usability errors or violations of these guidelines. (Nielsen 1993 p.23-43)

Nielsen and Molich (1990) state that heuristic evaluation is difficult for individual evaluators as it depends solely on one's opinions about the interface and some systems are easier to evaluate heuristically than others. Also, the evaluation must be done by multiple evaluators as each evaluator spots different range of usability problems from the UI. Individual evaluators usually find only 10-50% of all existing problems. But by merging all the evaluators' findings, up to 80% of usability problems can be recognized. For this aggregation method to work, there must be some authority that can read through all the individual reports and that is able to recognize the problems from each report. The authority can be a design expert or the evaluator group itself. In their study of Heuristic Evaluation of User Interfaces (Nielsen and Molich 1990) they conclude that approximately five evaluators are capable to find more than half of the existing usability problems from a system. Further, they recommend that heuristic evaluation is done only between three and five evaluators and additional human resources are spent on alternative methods of evaluation.

Heuristic evaluation can be done with help of user persona identification. Evaluated UI can be evaluated from the perspective of each identified persona. This gives more insight on how each user persona operates the interface and what properties they might need from it. (Dantin 2005)

Nielsen and Molich also recognizes disadvantages of the heuristic evaluation. Evaluators may identify problems in usability, but they are not capable to provide suggestions for improvements. The method is also biased on evaluators' mindsets and opinions and usually the method does not generate major breakthroughs in design process. Possibility of false positives is also recognized, which may lead to unnecessary discussion, which always prolongs the design process. For these reasons heuristic usability evaluation has faced criticism in literature. Thus, quantitative empirical studies should be used along the design process. However, heuristic evaluation has been recognized as a successful practice during early iterative phases of design process as heuristic evaluation is flexible and cheap to perform. Also, the number of evaluators needed is discussed widely in literature as their successfulness depends on their expertise on design and on the field of industry where the system is being developed. (Nielsen and Molich 1990; Ó Broin 2011)

7.5 Usability Testing

Usability as a term is quite old, but it has its' place within UX design. It evaluates human ergonomics and mirrors it to system design. In the past usability testing was usually done in a specific usability-laboratories, where test participants could be carefully monitored, and their actions studied through see-through-mirrors. Nowadays usability testing can be done simply with a recording device and a participant using tested system.

Usability testing can be done when system prototypes are developed enough that they can be used limitedly. In usability testing users are valuable source of design ideas and improvements as they don't see the system through designers' or engineers' eyes, thus being capable to notice inconsistencies and complexities within actions which could be simpler. (Shneiderman 2005 p.144-151)

Usability tests must be carefully planned. The plans should include the list of tasks to complete with the system, subjective satisfaction questions, and debriefing questions. The number, persona types, and sources of participants are also identified. A pilot test with one to three participants should be conducted within a week before the main test. A pilot test is conducted to confirm procedure, questionnaire, and task lists. (Shneiderman 2005 p.144-151)

Test participants should always be informed that *they* are not under a study, while the system is which they are using. If participants are not clearly informed on their role, they might act differently with the system and wouldn't answer to the questions truthfully. In the test participants are asked to perform a list of tasks and they often are asked to vocalize their actions and think aloud during the tasks. This gives insights how an average user might feel and think when using the designed system. Quantitative studies can be combined with usability tests, by measuring time how long tasks take to complete. After tests the results must be analyzed thoroughly and design decisions must be done accordingly. (Shneiderman 2005 p.144-151)

While usability testing is great method to find insights on users' thoughts it has its flaws. Usability testing emphasizes first-time use, and it has limited coverage on interface's functionalities. During one to three-hour testing period the participants are only learning the system and their thoughts are mostly their first impressions of the system. One cannot predict how their performance would be after a week or a month of regular system usage. Also, participants are only capable to test limited amount of system's features because of limited time window. Further criticism is that participants might act drastically different under testing conditions compared to their natural environment. (Shneiderman 2005 p.144-151)

8 INTERVIEW RESEARCH

This thesis conducts two interview research: interviews of engineers who are responsible for designing and tuning the APC applications. And interview of operators from a pulp mill who are the end users. Goals for this research is to understand current design methods and how the engineers approach the UI design process, and how they use the interface themselves when tuning APC controls. Also, essential elements from the applications will be gathered which may not come through from end user interviews. From the operators, goal is to learn when and how they use Valmet's APCs and how the interface should be designed for them.

After the interviews, thematic analysis of the data was concluded. The conclusions are presented in table 1 and 2. As a result, interfaces for causticizing APC will be designed, which can be used as a design reference in future projects as well as in the ongoing project.

For the engineer interviews, five Valmet's employees were interviewed in four sessions by one interviewee. Purpose was to interview all participants separately, but due work schedules two of the engineers were interviewed in same session. Four of the sessions was held remotely through Microsoft Teams and one was held face to face. For all sessions 1,5h time slot was reserved. The interviews were held in casual manner with aim to spark genuine conversations about current design methods and existing UIs. For conversation support, interview questions were prepared.

Because of ongoing pandemic, interviews with operators were hard to schedule remotely and pulp mills prohibited any visitations. Thus, one interview was held remotely through Microsoft Teams. The interview was held with one relatively new operator and with their foreman. For the interview 30 min time slot was reserved. Also, the foreman gathered written opinions about their current interfaces from other operators during shifts.

8.1 Valmet's Engineer Interviews

From the thematic analysis (table 1.) can be concluded that Valmet's current APC products for pulp mill have different looking UIs, which lack uniformity between them. The engineer team would highly benefit from clear guidelines and references, which could be utilized in future projects. These interviews also gave preliminary information about how operators use these interfaces and how they see them.

Theme	Representative sentence for the theme
UI creation and modifying	Usually, engineers only modify existing UIs to suit our customers' needs. This is usually quite low effort work and can be done relatively quickly.
Communication	Engineers does communicate with operators about the UIs, but operators usually don't give much information what they would need. But after couple weeks of use, they often give some feedback.
Feedback	At first operators see the UIs confusing, but when they are familiar with them, they see defects and give improvement suggestions. Often, they would like to see more information on the pages.
Design principles	APC team does not have real proficiency in UI design. They make design choices through their work experiences.
Uniformity	All APC products have different UIs, and they don’t have any real uniformity between them as the engineers don't have rules regarding UI design.
Current UIs	APC UIs are often used as a main display for a process area, where status of the process can be read easily, and optimizations can be selected accordingly.
Trends and graphs	Engineers see graphs as essential parts of UIs. From trends and graphs consequences of actions and process events can be easily identified, which helps them and the operators on their work.
Old vs. New	Valmet’s new UI software arouses worry as it will operate differently than the previous DNA Use. Also, engineers don’t

	know how to design pages to contain less, but more concentrated information in regard of UI design principles.
Usage	Engineers use APC interfaces for control tuning. While tuning they use trends for monitoring the process. They also need information on states of process components (valves, pumps, motors, etc.)

Table 1. Thematic analysis of engineer interviews

8.2 Operator Interviews

As anticipated operators were not as descriptive during the interviews and they did not have many opinions about the APC interfaces. But from the analysis (table 2.) can be concluded that operator UIs should kept simple with clear operating methods. The operators' interface should include supportive information related to APC control which helps the operators to define if control method change is feasible. This can be done through graphs from which relative information's history can be read. Also, most important measurements form the controlled process must be visible, so that operators don't have need to compare information between multiple pages. But from the interview is clear that operators don't need multiple similar looking interfaces which may repeat information.

In optimal case the interview research should have been conducted in the pulp mill's control room where the operators could have been monitored and interviewed throughout their shift. In future this flaw of this thesis will be corrected as the engineers will visit the plant in the project's control tuning phase. During those visits Valmet engineers can gather more information about the design choices made in this thesis and make corrections based on those opinions.

Theme	Representative sentence for the theme
Keep things simple	Operators are taught to follow certain measurements and graphs. Complex visualizations of process data are unnecessary as they are most likely not used or understood.
Multiple displays	Operators use multiple displays for one process area. Depending on pulp mill, process area view for APC display is unnecessary as the process is usually monitored through other pages.
Simple usage	Operators are taught to follow certain operating sequences in which APC interface is only used when control method is changed. Process is operated and process data is read through different interfaces.

Table 2. Thematic analysis of operator interviews

Summarized, the interview results gave support for initial thoughts and findings from preliminary study in which causticizing process was studied together with human factors in industrial environment. Also, interview results gave new insights on how engineers use these interfaces and what they need from them. The engineers also had extensive knowledge on the operator environment, and they had experiences on what operators usually want to see from the APC UIs which helped to gather preliminary information about operators' views.

9 RESULTS AND CONCLUSIONS

This thesis provides new APC UIs for causticizing which are utilized in Valmet's ongoing project. Designed UIs were done and validated with cooperation of project's stakeholders. The validation of designed UIs was done through heuristic evaluation.

The project's system is based on newest Valmet DNA system release which is operated through Valmet UI. The control room of the provided system consists of multiple operating stations which each has a large video wall, wide desktop displays and a tablet. The system is operable with keyboard and mouse or with touch through the tablet. For confidentiality reasons, details of the system and any realistic process data are not presented in this thesis.

New generation Valmet UI is so called high-performance human-machine interaction (HMI) system, which is based on contrast reducing design where page content is mostly in gray-scale. Gray scale improves users' attention span as users don't get distracted from their tasks so easily, and alarms are more noticeable from the UI.

In use, Valmet UI's background can be themed to be dark or light, which also automatically switches page's element colors to suit selected theme. Themeable interface improves user's ability to work efficiently in darker conditions e.g., in night shifts in a control room.

New generation UI also prevents situations where important information could be hidden behind other operating windows by removing last generation DNA Operate's movable monitoring windows. However, in Valmet UI there are no limitations on how many pages can be displayed in a screen, but the pages cannot be overlapped. User can select wanted pages from the hierarchy to the display area where pages are automatically scaled to fill the screen. Pages are adjustable by order and size by users. Valmet UI is a web-based system which is connected to the DNA distributed control system, from which process data is linked to the UI pages

In addition, former DNA Operate's interfaces were modernized by applying researched design methods to the older UIs.

9.1 Designed UIs

The design process started with a preliminary study on pulp mill recovery line focusing on causticizing process. Followed with Valmet's engineer and operator interviews. From the interviews, current best practices, and most important features of APCs were collected. Also, currently used UIs were reviewed with UI heuristics in mind. Main findings from current UIs were that they usually are clustered with measurements and colors are used widely which causes a lot of color contrasts in the pages, and overall experience of the UI pages felt quite overwhelming.

After interview research, it was clear that Valmet engineers and plant operators have completely different needs and use cases for the APC interfaces. Valmet engineers' usual use case of these interfaces is tuning of the control, and control room is not usually usable for them as it needed solely for operating the plant. Thus, they are limited to small laptop displays with a possibility of extra display, while they need extensive process data and trends visible. For this reason, I suggest that operator and tuning UIs are done separately. This eliminates confusing situations from operators and enables engineers to meet their requirements from the interface without making operating pages clustered.

9.1.1 Control Tuning Page

Control tuning page for causticizing APC was designed to be easily customizable by Valmet's engineers. The control tuning page is shown in figure 5. The page consists of process area view with most important measurements and process components. The control method change options are located to the sides of the page, near to approximate unit process areas they are optimizing. Aim for this design is to follow arching scan pattern so that most important elements for the APC control are located on strong optical focus areas while the process area view stays on area which is scanned less often. Because this page is not used by the operators, control tuning page design can be modified by the engineers as long as it stays intuitive for all Valmet's personnel. Also, control tuning operating example is shown in figure 6. without process data.

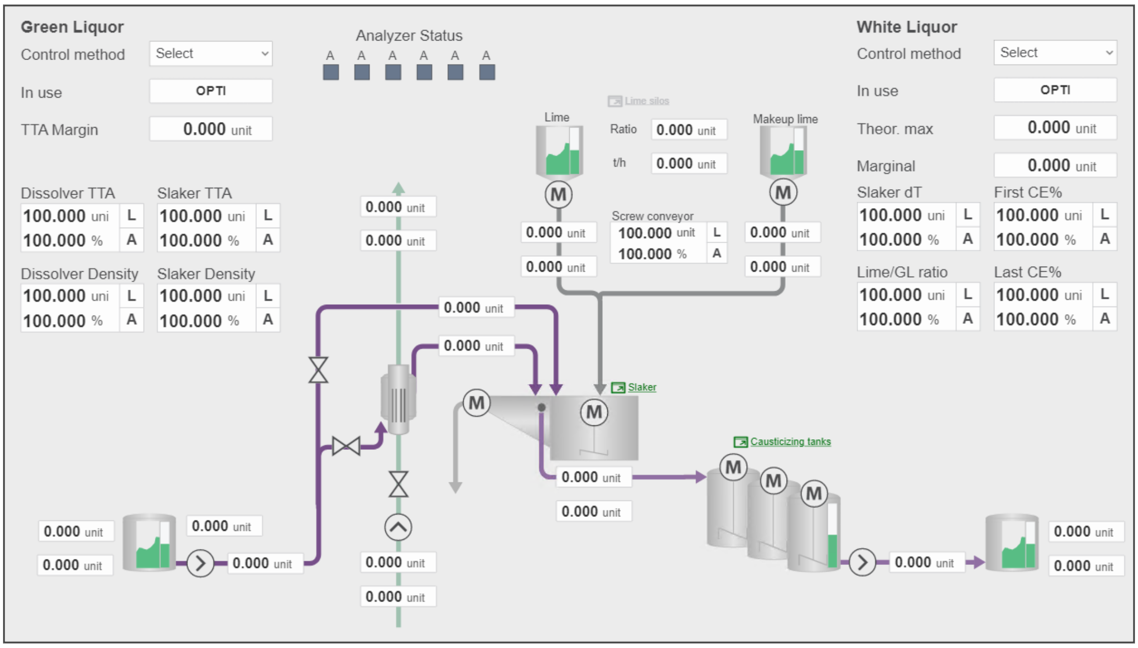

Figure 5. Designed tuning interface page for Valmet’s engineers

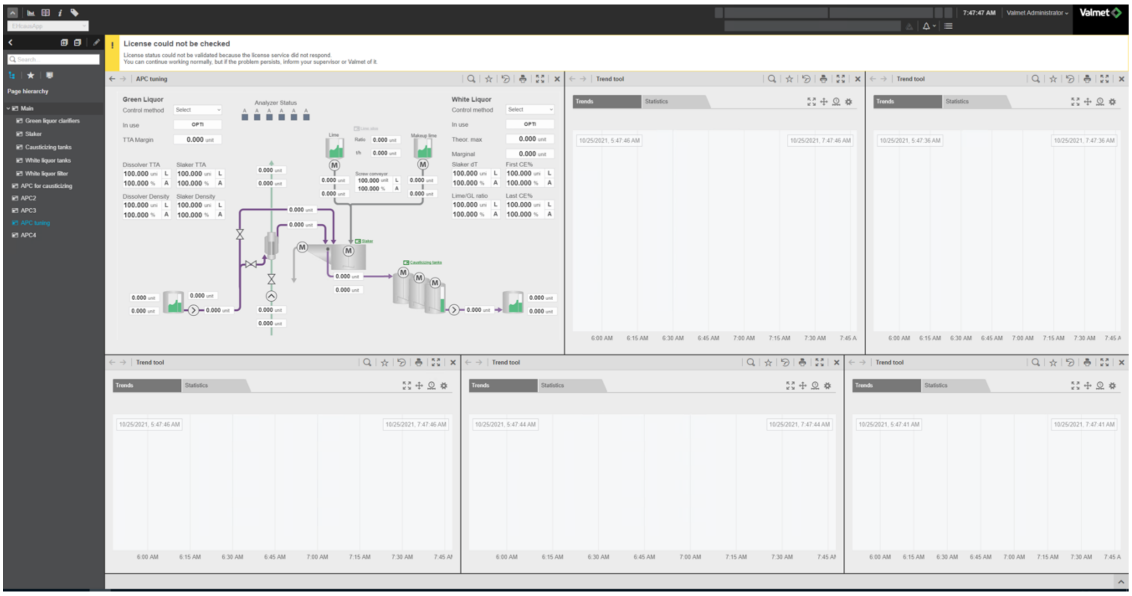

Figure 6. Tuning interface usage example with trend pages

9.1.2 Operator Page

In cases where pulp mill has good main process area interfaces, APC interface pages are only used by operators when the control method is changed. In this case, operators don't have the need for multiple measurements or visualization of process component states from the APC page. Thus, designed interface can be simple, consisting of only control method options and most important measurements. However, in cases where pulp mill lacks good main process area pages, APC pages are often used as such. Main display usage complicates the interface and makes it easily clustered. In this case, the page must be simplified, and only most important measurements and control faceplates should be shown.

Focus on operator interface design with Valmet UI is to operate it through well planned page hierarchy. There should be one main page for each process area which presents most important measurements and states of process components from the whole process with one glance. The main page should be supported with unit-process pages which give more detailed information from the processes and from these pages individual process components should be operable. When other pages of the process are well designed, the APC page can be simplified to include main control switches, measurements, and graphs of main measurements. This APC page design is shown in figure 7., and operating example is illustrated in figure 8, in which the main pages for causticizing are in the top display and the APC page is operable through tablet on the bottom.

The operator page design follows similar design principles as the control tuning page, but the process area view is replaced by graphs which includes most important measurements for causticizing process. Aim of the graphs is to support operators with their decision-making process as graphs provide easily readable information about the process history.

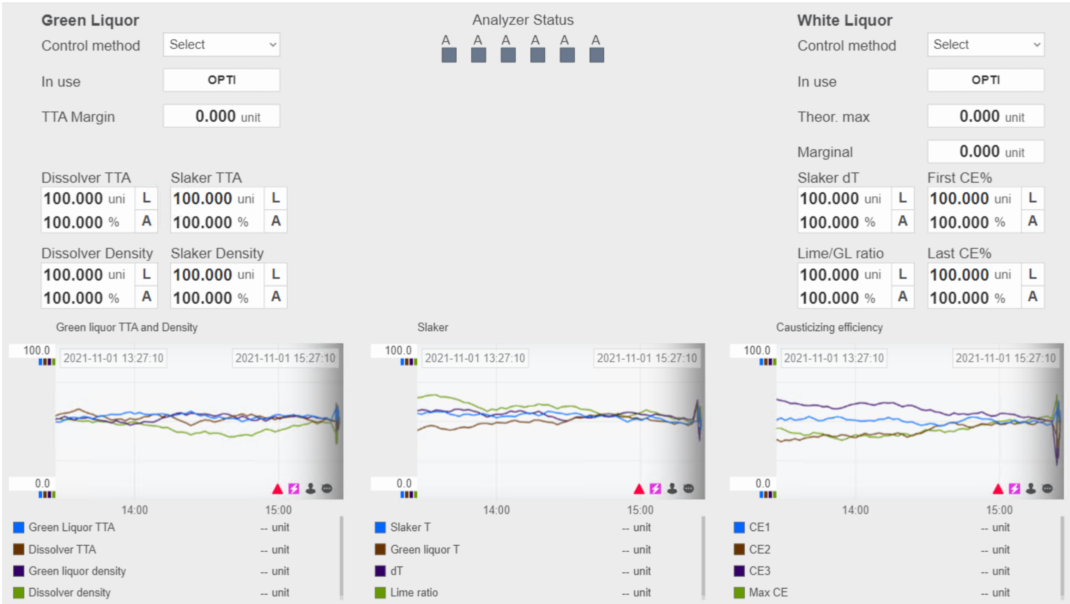

Figure 7. Causticizing APC interface page for operators

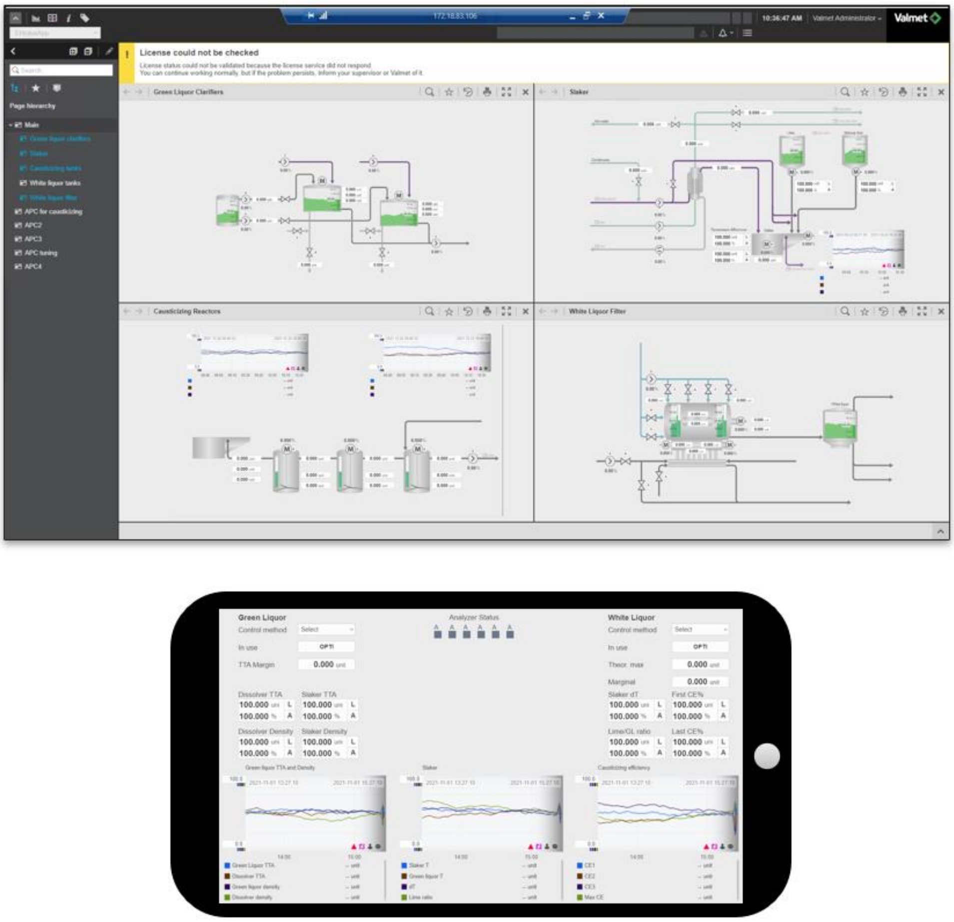

Figure 8. Example usage case of Valmet UI with designed APC page.

Figure 9 illustrates the whole operating concept of the Valmet UI. Main idea of the new system is to operate it through well planned hierarchy in which the content is divided in multiple stages, which are shown from different displays. From the first hierarchy stage, plant's overview can be seen with quickly readable KPI dashboards. The first stage would be shown from large displays which are located on the wall, over the operators' heads. The second stage would consist of process area views from which the unit processes can be monitored and possibly operated. The second stage would be displayed from desktop displays which are operable with keyboard and mouse. The third and fourth stage would be displayed and operated through tablet which can be taken along to process inspection rounds. From the third stage more detailed process view could be read and from which the process would be operated. The fourth stage would provide supportive and diagnostic information of individual process devices.

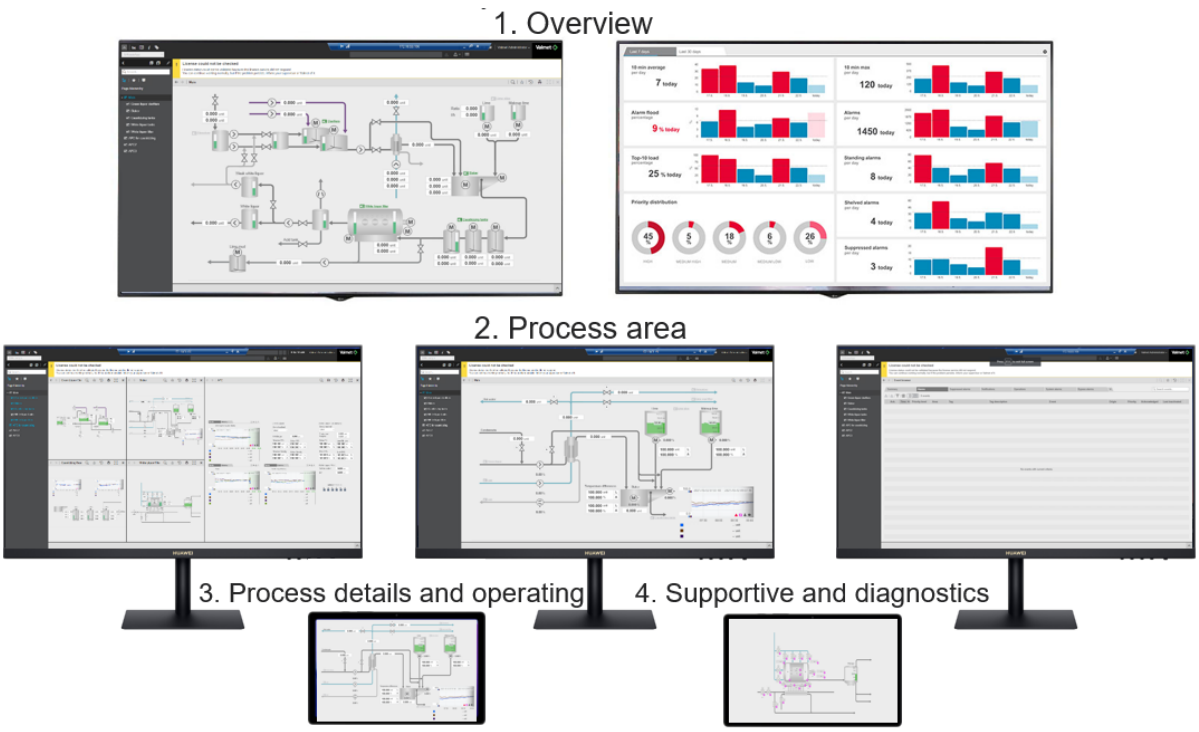

Figure 9. Example of a control room view for process area

9.1.3 DNA Operate

For DNA Operate, the prime focus was to make pages clearer for the users by applying design principles presented on this thesis. Challenge on this design was to include main process measurements and graphs in the same page with a main process view, as DNA Operate usage context is different from DNA UI and some plants with APC products don't have comprehensive main pages for the process areas. This interface simplifies currently used interfaces by providing clearer process area view with only most important measurements visible. Trends are also made clearer by reducing color contrasts. See figure 10.

In closing, it must be notified that if these designs are used as reference in future, the process area views must be modified to be similar with the customer's other process area views.

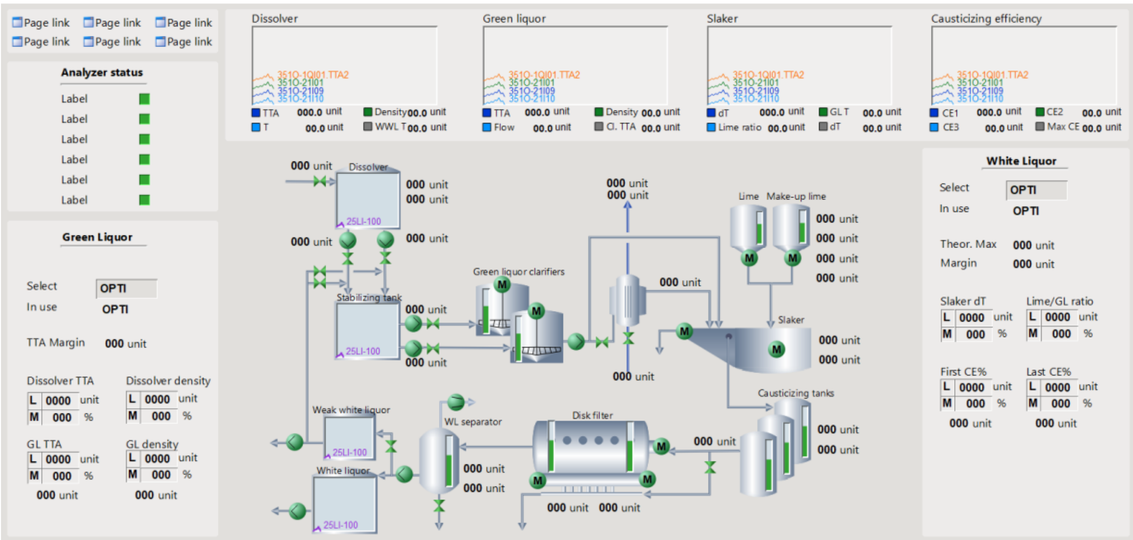

Figure 10. UI design for DNA Operate

10 SUMMARY

This thesis researched how interfaces should be designed for causticizing advanced process control system. The thesis explicated what user experience and user interfaces are and how they should be designed for the end user. The goal was to produce advanced process control interfaces for causticizing which would be used in Valmet's ongoing project.

The research built comprehensive theory around user interface and user experience design. The conducted interview research gave great insights on different usage cases of the two different user groups. Main findings from the interviews were that operators use advanced process control interfaces quite rarely and mostly when there is suitable moment to use optimizable controls. While the Valmet's engineers use the interfaces only when visiting the plant for control tuning. During those visits they need extensive information from the interface which needs to be usable from a laptop screen.

Based on theory and the interview research, new interfaces were designed for causticizing APC with cooperation of stakeholders of the project. The new interfaces are operable with Valmet UI which is a modern high-performance interface system. Main challenges on designing new interfaces were moving past of Valmet older system's operating practice, as the new Valmet UI reforms the operating practice by dividing the operation to multiple display levels which all have dedicated page hierarchies. Also, challenge was to fit the interface pages to be usable with mobile devices e.g., tablets. Compared to the old interfaces the new interfaces are more user friendly, more spacious, and they support the overall interface hierarchy better.

This thesis did not include end user usability tests but in future the designed interfaces will be refined with the operators when the engineers responsible for advanced process controls make plant visits during guarantee tests and control tuning.

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