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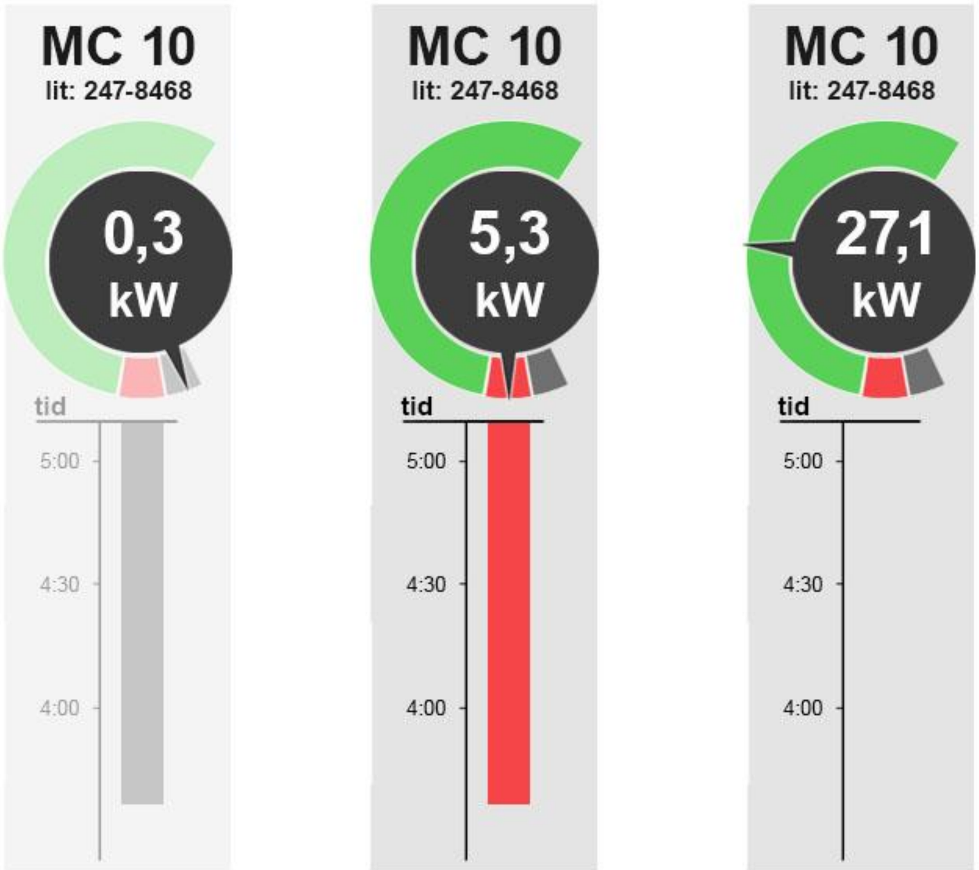

User Centered Design of a Monitoring Dashboard

For better energy performance

Master's thesis in Industrial Design Engineering

CARL CHRISTER-NILSSON

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

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Division of design and human factors
Department of Applied Information Technology
Chalmers University of Technology SE-412 96 Göteborg
Sweden
Telephone: +46 (0)31-772 10 00

Cover: A view of the dashboard when the machines are off.

Abstract

This report is the result of a master thesis project in the program Industrial Design Engineering at the department of Design & Human Factors, Chalmers University of Technology. The objective of the thesis is to produce visualization of production data in the form of a visually efficient dashboard for monitoring production on an assembly line. The aim is to influence the users' behavior, so that they act in an energy saving manner by regarding the visualization provided by the dashboard. A long term secondary effect is to make the end-users aware of the waste, and as a consequence feel encouraged to cut down on the unnecessary energy use. The theory behind the result is based in the field of Human Factors Engineering and Situation Awareness. The thesis project has been carried out in Volvo M1 facility at Lindholmen, Göteborg and at the MD 16 line, Volvo PowerTrain in Skövde.

Acknowledgement

I would like to thank my supervisors Lars-Ola Bligård and Per Hanarp for the support through the project. I would also like to thank my fellow master thesis student, Xuemin Deng for her contribution to the project.

I want to thank my family for putting up with me during my academic endeavors despite the circumstances and the knowledge that my services were needed elsewhere and also despite the unlikeliness of any success in a professional career.

Together with supervisor Per Hanarp Volvo Environmental R&T and Xuemin Deng master thesis student at Stockholm University this thesis was conducted at Volvo Trucks and Technology, M1 building at Lindholmen, Göteborg in the spring of 2013.

Innehåll

1 Introduction

In this chapter, the basis of this thesis project and the background to the problem with idling is described. The aim of the thesis project is defined and the objectives is stated. Also, what is not included in this thesis is described in the delimitations.

1.1 Background

The Volvo Group in general and Volvo Powertrain in particular, have a will to cut down unnecessary energy use in order to be more efficient and environmental friendly. In 2003 the Volvo Group's environmental objective included a goal to reduce energy consumption per produced unit by 50% during 2004-2008. In this case not only electricity but also heating, water use and other resources were accounted for in the total energy consumption. (Hanarp & Bengtsson 2008)

Typically, a continuous production line works as follows; material as in a part is loaded on to one end of the line and enters into a machine where it is being processed by some tooling equipment. The part is then transported to the next machine for more processing on a gantry or a track. This procedure continues until the part reaches the end of the production line where it is inspected and ready for delivery, or further processing somewhere else. (Hågeryd, Björklund & Lenner 2007)

Idling is seen as unnecessary use of energy, i.e. when the process equipment is turned on but it is not producing or is in standby mode. When production process equipment is idling, in a sense it is waiting until it is supposed to produce again. Idling in manufacturing and production is considered waste. On average, a third of the power outtake compared to full production is due to idling and the equipment is in idle mode nearly half the time *(figure 1).* (Hanarp & Bengtsson 2008)

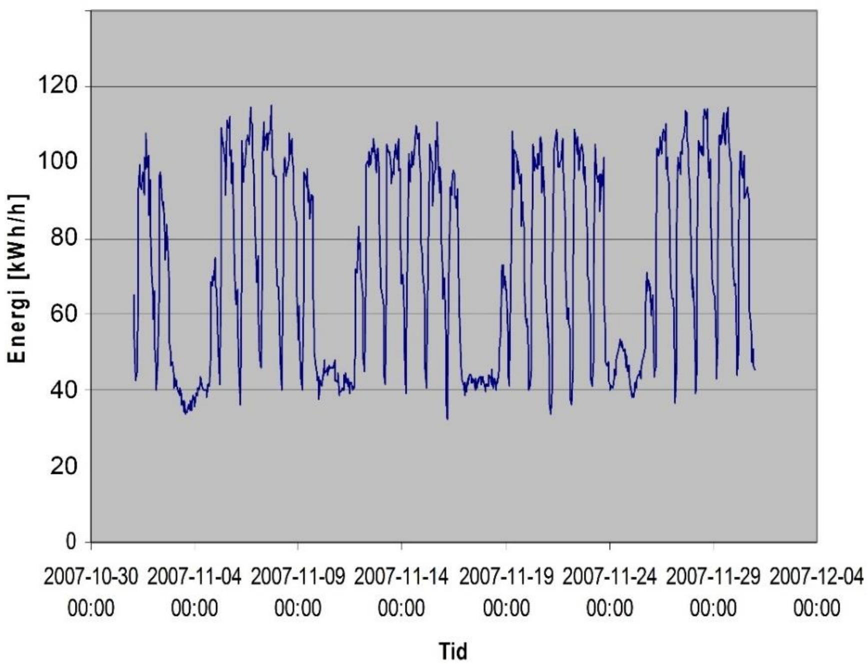


Figure 1.

Data stream of the power outtake over time. The graph is showing the idling situation over the line (energy/hour on y-axis and time on the x-axis).

The lowest energy level (at 2007-11-04-00:00) is due to idling, during weekend and at night, here roughly 40kWh/h.

(Volvo energy report, *Values are made up*)

Idling needs to be identified in order to address it and hence it needs to be separated from necessary energy use that contribute to production. Relevant information about the energy use can be measured and hence take the first steps towards identifying the idling in production. An Energy Measurement Systems (EMS) contributes in getting more detailed information about the energy use, such as individual machines' actual power usage in real-time. The detailed information and data can be analyzed, important issues followed up and further analysis can provide suggestions for energy saving actions in the future. Individual awareness of the energy use in relation to the total energy consumption can be spread amongst the personnel. The problem is to know when to save energy and lower the power outtake of the different machines and thereby influence the energy consumption in a positive way. Improved situation awareness is key for resolving the energy waste situation and satisfy the initial will that Volvo has, to consume less unnecessary energy. The identification and use of key performance indicators (KPIs) is a common method of performance measurement (Few 2006). In preparatory reports of the energy consumption situation it is suggested that in order to reduce idling, one must look into human behavior and make use of the right KPIs and also regard the equipment and production processes (Hanarp & Bengtsson 2008).

Information visualization is important when addressing the human behavior and transferring data into information that can be interpreted easily and quickly. Visualization is a tool for presentation of data and for the viewer to visually perceive the information. Visualization is one of many tools in Human-Machine System (HMS) and deals with human cognition and is a graphical representation of data (Porathe 2012).

1.2 The KAP project

The Volvo Group is a partner in a multi-company project named KAP and this thesis project is done parallel with the KAP-project's development. The KAP-project aims to develop a more sustainable manufacturing system than that of today. KAP stands for Knowledge, Awareness and Prediction and an introduction at the project's website states that "The KAP research project aims at increasing the transparency of sustainable manufacturing by combining Knowledge of past performance with Awareness of the present state to support Prediction of future outcomes" (KAP 2011a). Initially, a denotation of work packages was formed, a declaration of what needs to be done and in what order, and work package 4 is named "visualization" which is where this thesis project is involved.

1.3 The Aim

The aim for this thesis is to influence the energy saving behavior of the users by visualizing production data. The result should be visually efficient in order to make the users aware of the idle situation on the MD16 production line and as a consequence lower the unnecessary energy use. Visually efficient in this case means to show just enough data in order to achieve the goal. This means the data that is of interest for the viewer at any given time, neither more nor less, to be able to monitor production. The MD16 line is one of many production lines in VPT Skövde and it is the site for the implementation of the software outcome of this thesis. A subsequent goal is for the users to gain better situation awareness, make them more aware of the idle energy consumption and hence cut down on it.

Objective

To produce a dashboard that communicates production data in a visually efficient manner for the end-users.

1.4 Delimitations

The information that is not included in the data, i.e. information that is not able to be visualized is outside of scope. Other data sources besides the real-time power outtake, are not ready to be put in the visualization at this point in time and are hence not regarded in this thesis project. This includes information about how much is automated and what is done manually to the machines.

2 Theory

Theory in the field of human-machine interaction and data visualization that is relevant to the thesis project is presented in this chapter. The most important terms and vocabulary is explained in order to better understand the procedure and the development of the result.

2.1 Human-Machine Systems

Human Factors is a scientific discipline that describes the relations between "…humans and other elements of a system…" (International Ergonomic Society, IEA, 2006). It can be divided in many different subdivisions, such as user-centered design (UCD) and Human Machine System (HMS). Common to disciplines are the focus on making the human and the technology work well together. (Bligård 2011)

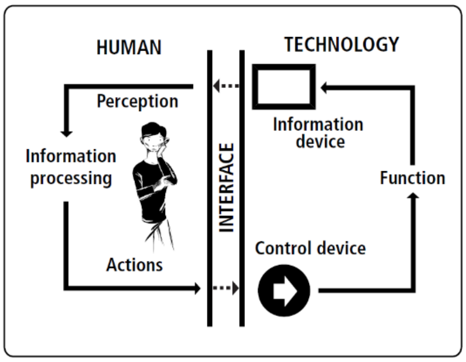


Figure 2.

Depiction of the Human-Machine system (Osvalder 2007)

Human-Machine System has its base in system theory and its approach is on the interaction between man and machine *(figure 2)*. The fundamental idea of system theory is holism which basically states that the whole is greater than the sum of its parts. The human and the machine are two subsystems which together are part of the greater system, which has other properties than either of its subsystems have. By defining a system description it is easier to see the entireness of the human-machine system. The aim of this is to identify the elements and the connections between them. A system contains several communicating elements in a specific environment, a context. One example of a system is Task-Activity-Human-Machine-Context where a task is supposed to be done by the involvement of human-machine interaction in a specific environment. The human and the machine collaborate within an environment in order to reach a specific system goal that the human cannot reach on its own. The system goal, also called the effect goal of the system is the expected outcome of the system.The goal for each system is to process or transform energy, information or matter over to a product or a result usable within the system or for the environment. (Bligård 2009)

User-centered design development is a process that revolves around usability and usefulness among others. This "philosophy" takes the perspective of the human use and the user's understanding in the center of the process. Usability is *"…the extent to which a product can be used with effectiveness, efficiency and satisfaction by specific users to achieve specific goals in a specific environment"* (ISO DIS 9241-11). This is an interactive attribute, an interactive property that is not tied to a specific product or tool, it is in the use situation. This property can be evaluated in usability testing. (Jordan 1998)

To have a holistic view is to identify the elements and the different factors that affects the system, to answer who is the user, what is going to be done, why is it done and where is this taking place? This is important to comprehend the interplay between these elements and factors in order to understand the entireness and the whole picture (Karlsson 2007).

2.2 User Interface

The user interface is the information barrier between the two subsystems, where data is transformed to suite the opposite subsystem. There are other interfaces besides the human-machine interface, such as human-environment; machine-environment to name a few. A graphical user interface (GUI) is one kind of user interface which usually contains graphical content, such as windows, icons and buttons. These should be representative and understandable to the user in order to control the input of data into the program. Graphical content can be arranged in different ways to communicate with the person who is interacting with the interface. For the viewer, the representation of something, like a graphic icon or similar, is called a mental model. It is a very individual and an internal picture of how something works. The viewer creates logic reasons of how something is built up and connects that to the expected result of an interaction; what is likely to happen if I do this? It is good to show an interface to a user that is close to the user's mental models in order to gain acceptance. (Cooper, Reimann & Cronin 2007)

The user's acceptance of something new (a product or an interface) is important in order to get as many users as possible to feel comfortable and willing to make use of a product (Osvalder et al. 2007). Acceptance is mainly about the ability to feel motivated to use the product or technology, or whatever that is novel in the situation. However, in many applications, good design is standardized design where the acceptance often is certain and not an issue. One example of standardized design is that "all" the web browsers have the URL search field at the same location of the screen.

A wireframe is a depiction of an interface that focuses on layout. Prioritization of the content and the functionalities and the intended behavior that it would bring about. Wireframes usually do not include any styling, color, or graphics. For the general shaping of an interface, wireframes are especially effective to evaluate the layout and the space of the graphical content. (Cooper et al., 2007)

When designing visual interfaces one should group elements and create a clear hierarchy. It is good to utilize standardized layout grids and create a logical path for the reader, i.e. from top to bottom and left to right, to provide visual structure and work flow. Furthermore to use cohesive and contextually appropriate imagery is also good design and also to avoid visual noise and clutter, which effects can be distraction and eye fatigue. Examples of visual noise or clutter are excessive use of pixels, e.g. colors, lines, graphics or other layout issues. (Cooper et al, 2007)

The visual attributes of the interface consists of data elements and functional elements. A data element is the actual content of the program and a functional element is what operation can be made to the data element. As an example, a data element in the software "Word" is the graphical representation of a rectangle where it says "times new roman" and the functional element is the drop-down menu that functions when it's clicked (Cooper et al, 2007).

2.3 Information Visualization

When using visualization as a tool, the goal is to make visualizations that are visually efficient, by using the knowledge about how perception works and translate it into rules for displaying data. If these rules are followed, an informative and important pattern could be recognized for the presented data. If the rules are discarded the data could become hard to interpret or in worst case misleading. (Ware, 2008)

The data which is going to be visualized is first collected somewhere and then the process of translating these data into something comprehensible begins, the data progresses from numbers into a visual form that suites the viewer *(figure3).* "Visual displays provide the highest bandwidth channel from the computer to the human. Improving cognitive systems often means tightening the loop between a person, computer-based tools, and other individuals" (Ware, 2008).

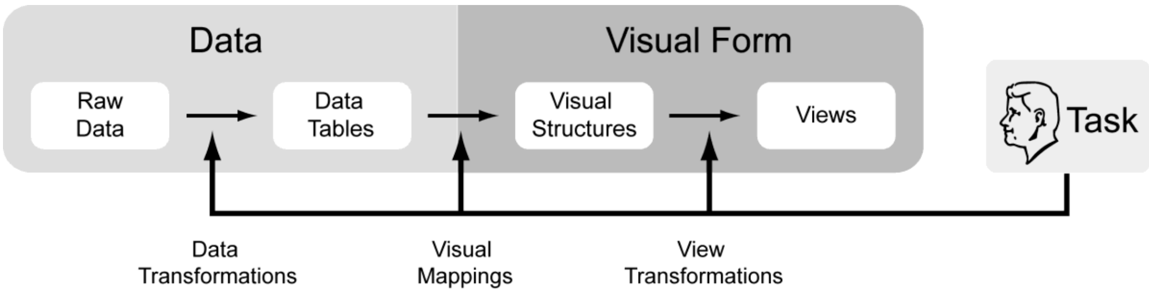


Figure 3. The process model of data transformation in Visualization (D4.1 visualization state of the art & cognitive task analysis)

In order to make use of visual displays the viewer must perceive the graphical content of the display, so how does perception work? Pre-attentive processing is an important cognitive mechanism to regard when it comes to perception. Visually, it has to do with the brain's ability to point out certain shapes or colors from their surroundings and occurs prior to the conscious attention. It is useful because of a shorter response time to identify vital information. Imagine a series of different numbers in the color grey except all the number 3's which are in the color red *(figure 4)*. The time to identify all the number 3's is much shorter than if all the numbers would have been in the same grey color. Pre-attentive processing is what the brain does immediately to pick out the red 3's in the total set of numbers. This can be considered as a visualization of the dataset of all numbers, where the task is to sort out the number three, 3. The same effect can be achieved through alteration in other visual attributes such as form, position and motion. (Ware, 2008)

Figure 4. In a set of numbers, it is easier to identify the colored set numbers and it happens without having to think about what to do. This is called pre-attentive processing. (Ware 2008)

2.3.1 Visualization tools

Utilizing a “Treemap” is a good way to show a lot of data at the same time and is very space efficient. It is a suitable visualization tool for data representation in more than one dimension, the user is viewing data categorized by size of area and color value *(figure 5)*. Alterations of treemaps have been developed over the last years, e.g. so called heatmaps. “Time searcher” is a software developed by Ben Shneiderman at the University of Maryland that enables the user to see the data flow over time and overlapped with comparative data, giving the advantage of zooming and highlighting certain bits of the flow that are of interest (Shneiderman 2011) *(figure 5)*. Parallel coordinates is a method of visualization where specific measures can be seen parallel to each other so that the viewer can get an overview of the situation and easily compare different entities and data (*figure 5). After all*, as Yau describes it – *“visualization is all about showing the data and to let the data tell the story”* (Yau, 2011).

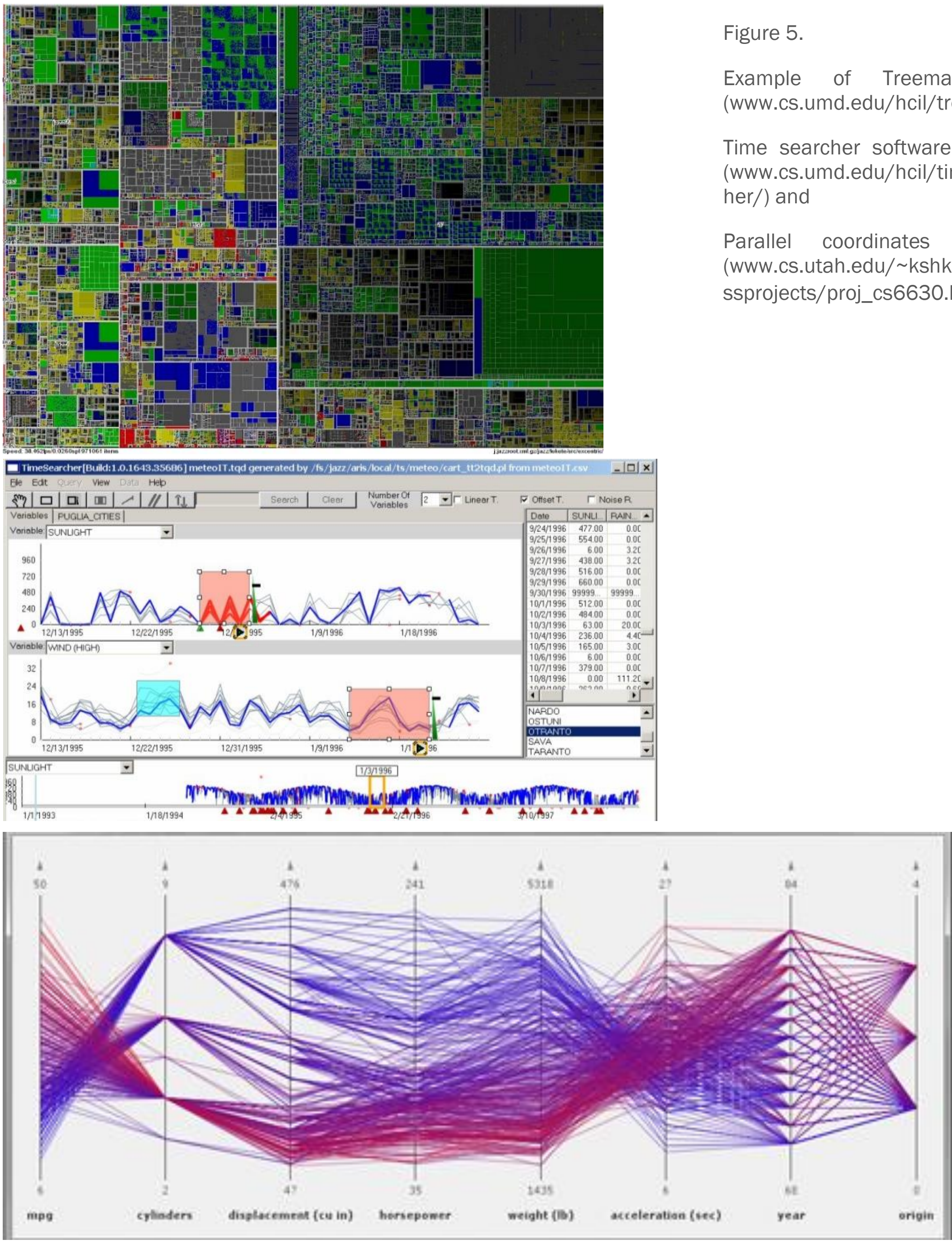


Figure 5.

Example of Treemap (top) (www.cs.umd.edu/hcil/treemap/)

Time searcher software (middle) (www.cs.umd.edu/hcil/timesearcher/) and

Parallel coordinates (bottom) (www.cs.utah.edu/~kshkurko/classprojects/proj_cs6630.html)

2.3.2 Dashboard design

There are many different opinions on what a dashboard is and what is should be. In this thesis the definition of a dashboard is “a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so the information can be monitored at a glance” (Few 2006). One of the challenges of dashboard design is to present a lot of data in a small space while maintaining clarity. This statement has a core aspect to it, to simplify. The trick is to simplify and not try to impress or entertain through visual means; it should be more about communication and keeping it clear. A rather famous way of expressing simplicity in data design is the data/ink ratio, a term introduced by Edward Tufte from the University of Yale, a pioneer in the field of data visualization. The pixel data vs. non-pixel data ratio can be seen as a trade-off between showing too much, making it cluttery and showing too little, to be inefficient (Few, 2006).

A common mistake when designing dashboards is to divide the data into different screens when it is not necessary. It is valuable for the viewer to see meaningful relationships between the data, (“data sense making”) through clear and effective visual design. Subtle colors are preferred to avoid eye fatigue and clutter. Saturated and intense colors are to be used carefully to support the data that needs to grab the viewer’s attention. Highlighting the important data is a key function for dashboards and enables the viewer to quickly interpret the data and see what stands out. (Few, 2006)

When two data elements show the same information in different ways, the two are redundant. Redundancy thus meaning that the already established information is repeated without adding any new information (Osvalder et al. 2007). An object display is an outlined, single graphical area in which many variables of data is displayed. The object displays works best if there’s a metaphorical relationship to the data being represented. When mapping many data variables onto a single object they will be read and processed together, in parallel. This can reduce visual clutter and make it easier for an operator to take in multiple sources of information. An example of this is a graphical representation of a cylinder in a GUI to metaphorically tie the relationship to a pressure tube in reality. The function is that many variables such as output, pressure, volume etc. is given a graphical and metaphorical representation attached to the data element of the GUI. (Ware, 2008)

2.4 Situation awareness

Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. There are four levels of which situation awareness is reached; perception, comprehension, projection and resolution. The theory about situation awareness does not only consider the information that the GUI is presenting, but also other secondary factors that depend on the context of the user, e.g. environmental, social and similar factors. (Osvalder, 2006)

The first level is about perception and to perceive the elements in the environment. It's about perceiving the information that is apparent and recognizing the status of the current state, if there are any distinguishing features of the present state. Answers the question; what are the current facts? (Osvalder, 2006)

The second level is to comprehend the current situation. It is about combining, interpret and to store and retrieve information in order to decide its relevance to the set goal. Answers the question; what is actually going on? (Osvalder, 2006)

The third level is projection of the future status. Given the previous two levels the next thing is about prediction of future events. The knowledge of the current situation and the dynamics of the process together with the ability to make judgments based on that knowledge leads to this level of situation awareness. Answers the question; what is most likely to happen if ….? (Osvalder, 2006)

The fourth level is to reach a resolution about what to do. It is acquired knowledge about what is best practice and procedure in the current situation. Answers the question; what exactly shall I do? (Osvalder, 2006)

3 Methods

The methods that were applied in order to reach the result are presented in this chapter. The different methods are sorted into different categories corresponding to in what phase of the project they were used.

3.1 Data gathering methods

Literature studies

Literature studies is to assimilate information that is transcribed into documents, presentations, papers, internet etc. This information is accessible in libraries, on the internet and sometimes through media and this makes these sources of information important to critically scrutinize. A systematical survey of information about a topic provides an overview of the existing domain in the field for the topic, what others have done and what methods and theories have been used and so on. It is common that researchers discover that the information reaches a greater extent than what was the intent from the beginning, and hence the need for delimitations. (Carlsson 1984)

Interview and mediating object

An interview is a good way to let a person explain in own words about the information that he or she possess. An interview can be conducted in a structured form with little or no room for follow-up questions or in an unstructured manner, with little or no prearranged questions. An open interview is informal to the character and the subject of the interview can express him- or herself in expressions and feelings that are personal and therefor explanatory. A group interview is when a group of people are interviewed at the same time and a version of the group interview is the focus group interview. (Karlsson 2007)

Mediating tools or objects can be used as stimulus in order to spark the discussion and enhance reflection about an issue. These objects should not be too detailed but serve as a framework for the discussion. An interviewer can probe deeper into the problem sources and try to elicit hidden needs or surprising needs that is hard for the subject of the interview to recall for itself. (Karlsson 2007)

Focus Group

A focus group can consist of about six to ten people and can be used to get different aspects of a specific issue from the assembled group’s internal experience. These participants are asked to talk about a topic of interest, which is predetermined by the moderator and the interviewers. The focus group interview constitutes of observing and taking notes and hence providing the interviewers with qualitative data. Collaboration within the group is important in order to get relevant data more in detail and gain from the method. The disadvantage of a focus group is that it is a method that is time consuming and very much dependent on the competence and experience of the moderator. (Karlsson 2007)

Field study

A field study is made at a location which has a link to what is of interest. It is to geographically locate yourself to the place of interest, to find out more at the spot. The benefits is that research is conducted in the relevant context and that observations can be made as first-hand information. (Bligård 2011)

3.2 Analysis methods

All the methods that were used to analyze the gathered information is presented here. Analysis is useful to break down information and sort it into categories or clarify course of events. Analysis of data generally helps to focus on the information which identify problems and leads the undertaken project forward.

System description and system goal

System description aims to identify the various sub-systems and elements in the human-machine system. The flow of information/energy and the communication between the involved parts that are active in achieving the system goal is important to describe, to get an overview of the system as a whole. (Bligård 2011)

To pinpoint what effect and what expected outcome the system produces for a specific task, a system goal is defined. The system description makes it is easier to see the entireness of the human-machine system and the correlations of the involved components and the system goal makes it easier to understand the purpose of the system. (Bligård 2011)

User Profile

A description of relevant information such as profession; competence; mental; physical and demographical data is typical characteristics in a user profile. If there are many operators in the human-machine system, the variation within the group of operators can be of interest. The internal relations between different users can in some cases be useful as a complement to a user profile. (Bligård 2011)

Use Case

A Use Case is a useful method when there's a need to get a general view of the situation and the functionality of the machine. A use case should provide an objective view of how the machine responds to interaction from a user with a specific goal. The method should declare the conditions of use, in what context the interaction takes place, what the system limits are and what circumstances are needed for the interaction to begin. After these are declared the sequence of interaction for the user in order to achieve the goal is described. The Use Case describes the performance and the limitations of the user in a given environment and performing a given task. (Bligård 2011)

User needs and requirements

The user needs describe what the user feels has to be fulfilled in order to accomplish good usability, not necessarily rendering good usability in itself. The use requirements are a further development of the user needs and more specified, often including some task related or function related formulation of the user needs. An important characteristic of a requirement is that it must expressed with disregard to possible solutions. It should only state what is required and not how to solve and fulfill that statement. (Bligård 2011)

The requirements can be divided into use requirements and functional requirements. They are part of the result of the task description and functionality definition. There are also usability requirements and esthetical requirements. The user needs can be divided into three categories; subjective; objective and contextual needs. Subjective user needs are based on information from the user, statements from the user that derive from knowledge and experience. Objective needs are based on information about the user, studies about the user. Contextual user needs are based on the use situation and the consequences of use. (Karlsson 2008)

Usability testing

To reach good usability in a situation, it is crucial to evaluate this attribute. Key to this evaluation is identifying measurable aspects, e.g. time, number of issues and number of failures. Also the appraisal measurements from the user is important, which can be measured on a rating scale. (Jordan 1998)

Tables and function listing

When dealing with different types of data, a good way to divide the information is to form tables and matrixes for building meaningful relationships between the information and get a clearer view of the entities. All the functions of the machine are listed and organized. The head functions are listed first and then the part functions and then the support functions that relates to the human-machine system goal. In this case the function listing and the definition of the design variables are closely linked. (Karlsson 2007)

3.3 Development and synthesis methods

Workshop

A workshop is the session when a set of persons, such as a project team, comes together and engages in an activity that aims to solve a specific problem or issue. The work is often characterized by creative problem solving and other methodologies. (http://en.wikipedia.org/wiki/Workshop_(disambiguation))

Brainstorm

This method is feasible when there's a need to come up with many ideas or solutions of an issue. It's important to create an open social atmosphere that can help people to feel confident in presenting ideas and be creative. For best effect, criticism is not allowed, quantity is the aim and crazy ideas is a good thing. (Karlsson 2007)

Design Variables

A design variable is something that has to be determined during the design development and construction. Much of the work in the development phase is to find the design variables which are necessary in order to fulfill the requirements and the goals. Design variables are continuously updated throughout the design development and refined as the process moves further on. Design variables are allowed to change during the development and are often dependent on each other, such as the weight of a machine is depending on how much capacity the battery is going to have. Some are more profound and builds the design early in the development process. (Bligård 2011)

Wireframes

The development of user interfaces does not always need to be in high detail, especially not in the early stages of the development phase. To save time and effort the concept of wireframing is often used to roughly sketch the layout of the screen and to explain the data element and function. (Few 2006)

4 Procedure

This chapter presents an overview of the thesis project structure and how the work was carried out in order to reach the objective *(figure 6)*. The supervisors for this master thesis have been Per Hanarp at Volvo and Lars-Ola Bligård at Chalmers. Besides me, the thesis project team included the supervisor (the team leader) and Atieh Hanna, Jenny Everbring and Xuemin Deng (Master Student at Stockholm University). The team has been situated at Volvo facilities in the M1 building at Lindholmen, Göteborg.

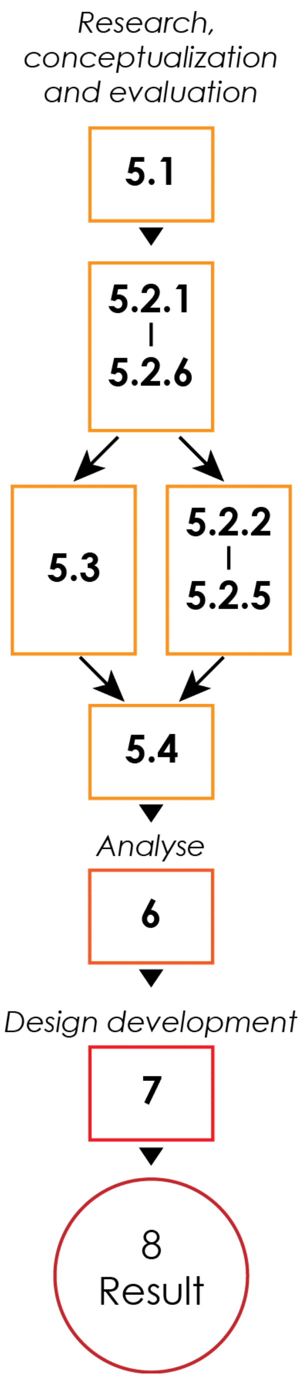


Figure 6. The procedure and progress of the master thesis project work is linked to the chapters. Research and development in the workshop sessions ran parallel most of the time in the project.

The team leader, Per Hanarp, conducted the work and the progress of the initial development. Two field studies were made and one focus group was assembled. The first field study was conducted at Volvo Penta factory in Vara were a data visualization tool already existed (*5.1*). The second field study was conducted at Volvo PowerTrain (VPT) factory in Skövde were the result, the monitoring dashboard was going to be implemented (*5.2.1*).

Two focus group interviews were conducted at the VPT factory site and the focus group consisted of different potential users out of the personnel at the factory *(5.2.6, 5.4.2)*. The purpose was to collaborate and pitch ideas together with the focus group to find the needs of the potential users and other important information.

A first workshop session was held together with an environmental project manager, in which a brief analyze of the initial prerequisites was done that formed the basis for the following five workshop sessions (*5.3.1, 5.3.2*). These were conducted together with the project team. Throughout the workshops the functions and features of the visualization were redefined and remodeled in order to sort out what was thought to be significant and beneficial for the users. A second and final visit to VPT Skövde for presentation and evaluation of the generated concepts *(5.4).* The concepts were evaluated by the focus group and functioned as mediating objects during the discussion that followed, where more information came to light.

Literature studies and analysis of visualization solutions of production data and of the solutions of the current situation in existing production factories was done parallel to the workshop sessions *(5.2.2 – 5.2.5).* The underlying work that had been carried out in the KAP project prior to the master thesis initiation was studied. A variety of techniques and approaches on visualization were found, some more interesting than others. This gathered information helped to form User Profile, a Use case, the system description and the system goal.

Analysis of the evaluation and all the previously found information in chapter 5, helped to unravel and pinpoint the needs and requirements *(6.1, 6.2)*. The requirements were categorized, ranked and listed and formed the basis of the development phase *(6.3).* This was followed by the clarification of the design variables (what to work with) and a more convergent way of working (*7.1).*More idea generation and sketches of possible novel designs characterized the design development and a few methods were utilized to synthesize all the previously acquired ideas and concepts *(7.2).* Finally, as much details as possible was put in to the final design, the result *(8.1, 8.2, 8.3, and 8.4).*

5 Research, conceptualization and evaluation

In this chapter, all the information that was retrieved during the data gathering phase is presented. Two field studies of the current situation at two different factories (Volvo Penta in Vara and Volvo PowerTrain in Skövde) is described. System theory is applied to present the human-machine interaction in this project in a holistic manner. This includes a user profile, where the different personnel in the factory are presented and a use case that concludes the actions that are needed to perform the task of saving energy. Concepts of data visualization and dashboards were created in workshop sessions. Finally the produced concepts were evaluated by a focus group.

5.1 The Volvo Penta factory, Vara

In this section, information from the first field study at Volvo Penta factory is presented. A look at their work with energy awareness issues by using visualization as a tool is declared.

5.1.1 Field study & interview with environmental coordinator & plant manager

The factory has a complete engine process factory which means that they make a product from scratch; from raw material to a ready functional Penta-engine. In 2005 the management in the Vara factory took the initiative to start their journey to become more aware of energy usage. 25 % of the total energy use was pure waste of energy at that time (idle processes and lights on during night time etc.). Since then, an energy program has been adopted and as a consequence they have reduced the total energy usage by 60% according to the environmental coordinator at the factory. The management on the Volvo Penta factory have not installed EMS on the machines but measure through other techniques which is not declared here. The team leader Per Hanarp has been in touch with the Volvo Penta factory since 2008 and they have made a huge progress and effort in avoiding unnecessary energy use through a visualization program. Today they include every energy consuming device in the whole factory in the visualization monitoring system which has been implemented and improved over time.

The plant manager gets the data every month for planning and follow-up activities. They have a very engaged environmental coordinator that has access to the data all the time and usually follows up on yesterday's performance in morning meetings together with the different personnel. This takes place before the start of the first shift of the day. Different responsibilities are delegated to different groups that each has a supervisor. There are checklists and instructions that states; "the following shall be turned off every night/at the end of the shifts". The routine is that the different personnel ends the shift and consults the checklist. The system will shut down automatically after 30 minutes if anything is missed in these checklists, and not turned off. The personnel in the Volvo Penta factory are continuously educated and they are aware of that environmental performance is an important issue. Both the plant manager and the environmental coordinator claim these cornerstones for "best effect" in achieving behavioral change amongst personnel:

- Simplicity
- Measure each department
- Immediate control
- Communication
- Driving spirits

5.1.2 The visualization at the Volvo Penta factory

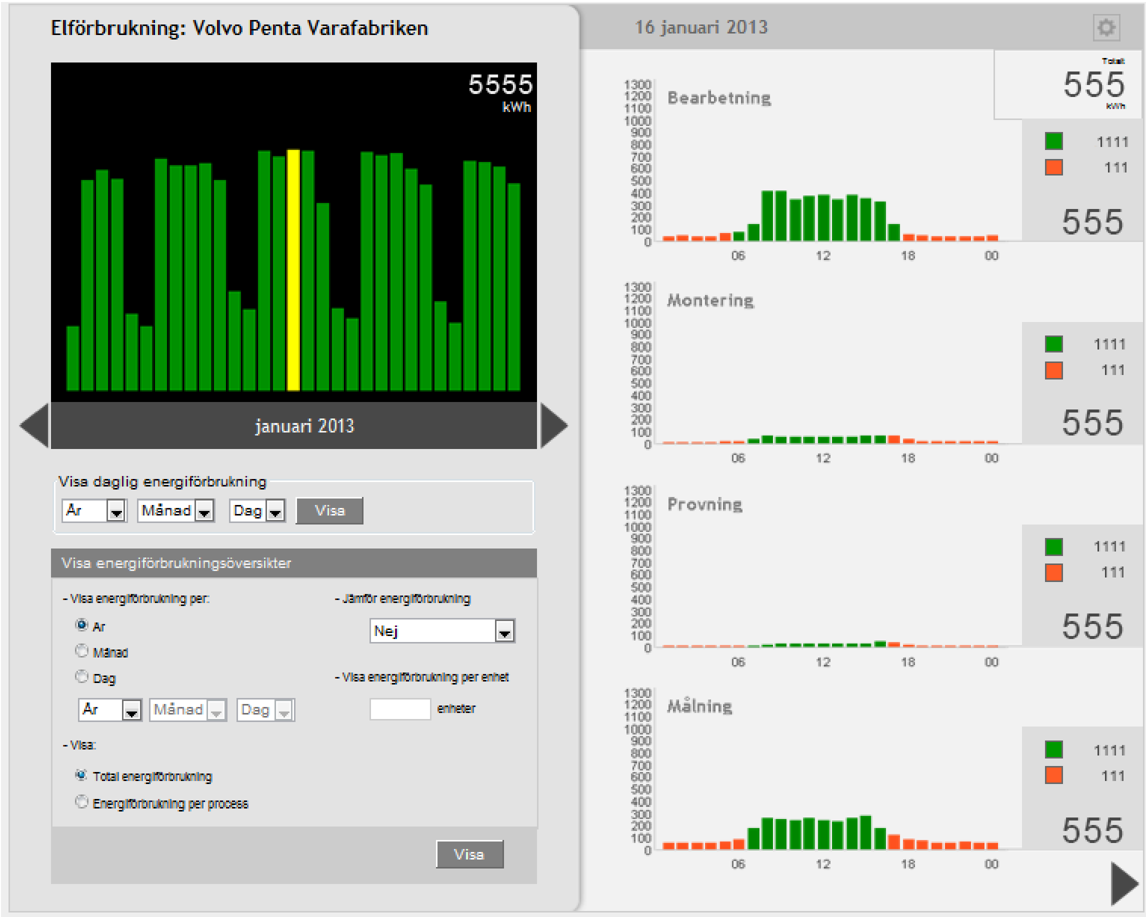


Figure 7. Visualization software used to follow up the environmental performance in the Volvo Penta factory. (Hanarp, 2008)

Figure 7 shows the analytical visualization in Volvo Penta factory in Vara, with interactive features. The diagram *(top left)* is showing bars that represents days in a specific month. The bars are interactive and if clicked, it turns yellow to indicate the selection (green is default color). The selected date is shown on the top bar *(right side)* and the departments underneath is detailed and is showing production hours versus non production hours over 24 hours. The visualization provides for different settings *(bottom left)* in time span and if you want to compare the data.

In the visualization, green is defined as "production" and this is when shifts are working– during these hours energy consumption is accepted. The red hours is defined as idling and that is when there are no shifts working in the factory, between 17.00 and 06.00 in the morning. A very high "green" consumption or a higher consumption than normal in the "red areas" are considered deviations and the deviations that raises suspicion and are followed up. The energy use of the different departments are registered and followed up through the visualization. The environmental coordinator says that the staff have gotten better awareness due to the visualization and the morning meetings and that the supervisors are happy that there are goals.

5.2 The Volvo Power Train (VPT) factory, Skövde

In this section, information from the field study and the first focus group interview at Volvo Powertrain (VPT) factory in Skövde is presented. The current situation on the MD16 production line and information about the personnel and the energy saving effort is described. A few of the personnel of the MD16 line were participants of a focus group that was involved with the development through meetings, interviews and discussion of ideas. Two of the personnel working with energy issues at the company, an energy consultant and an electrical engineer, guided the tour of the MD16 line during the field study in VPT Skövde.

5.2.1 The energy consumption and the factory layout of the MD16 line

The VPT factory is much bigger than the Volvo Penta factory in Vara, both when comparing the number of employees and the size of the plant. The MD16 line is a Volvo Production System and covers an area about 2500 m2 which holds 15 machines of seven different types. The machines are arranged in a series connection over the line and the department is producing cylinder heads for the engines. This involves different processes in a complex production setup that can produce different product variants. The line is provided with a tag'n'trace system for traceability, a general manufacturing monitoring system named DUGA (see 5.2.3) and T-alert which is a system that receives events from applications and provides functions for filtering, severity classification and distribution of the alert to personnel through one or more signal media. Recently, an Energy measurement systems (EMS) was installed on the first three machines on the line. The installations and investments concerns Complex Event Processing (CEP) and real-time data stream analysis. The CEP is a method used to track data. The CEP aims to reveal when certain events will happen and how to deal with it in a quick way. Combined with a real-time data stream the project will provide 'on-the-fly' KPIs generation to support real-time monitoring and situation awareness. (KAP 2011a)

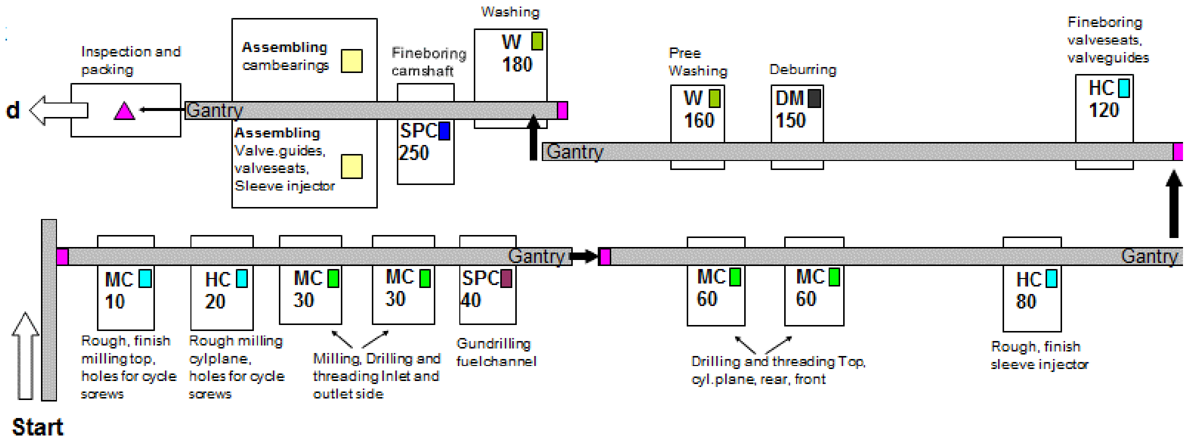


Figure 8. The factory layout of the physical location of the machines positions and arrangement, also what kind of machine it is (KAP energy group presentation, Volvo)

The factory layout view provides an overview of the line and is commonly used amongst the personnel in VPT Skövde *(figure 8)*. It's a generic map and outlines the machines and their operational number. There are different machines (e.g. Head charger *HC* and machining center machines *MC*) in different positions distributed over the line doing various machining operations to the work piece, or part. Different machines have different power outtake and independently consumes different amount of energy and hence some machines have a greater energy saving potential than others. The machines also have a littra-number that identifies a single unique machine which is not shown in this figure. There are four gantries on which the parts are moved between the machines. Each gantry demarks a station where the operators on the line work.

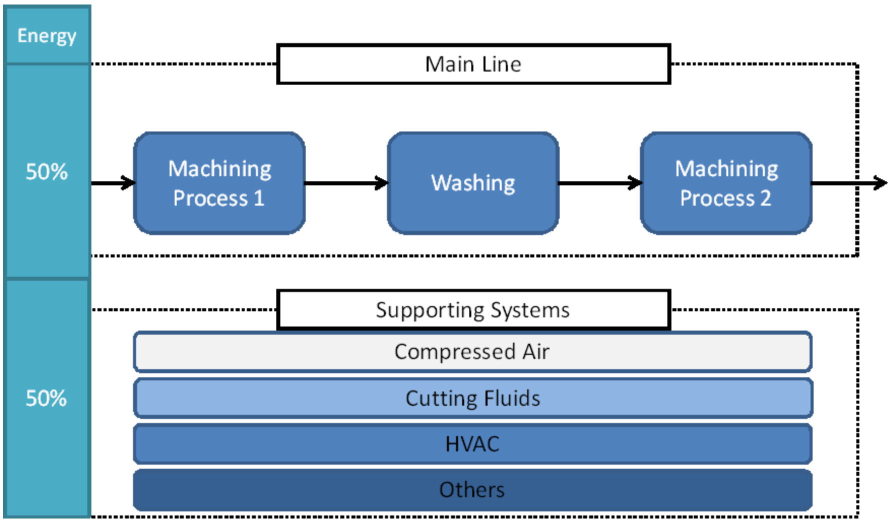


Figure 9.

The typical situation of energy consumption of all the items that consumes energy on the MD16 line.

(KAP 2011b)

Machine processes (such as cutting, drilling etc.) typically consumes about 50 % of the energy in the line (*figure 9*). The other 50% is contributed by auxiliary systems that run parallel to the machining processes, such as cutting fluid systems, compressed air, HVAC (heat, ventilation, air condition etc.) and others (KAP 2011b).

The power usages diverge in the production states compared to the non-production states for the different systems (auxiliary and others) on the MD16 line. One specific machine consumes negligible amount of energy when idling while others are consuming much more energy in the idle state. The ratio non-production/production is presented in table 1.

Table 1 Ratio energy consumption in production vs non-production.

Cooling	1
Compressed air	0,58
Washing	0,5
Assembly	0,5
Chargers	0,5
Ventilation	0,36
Machining	0,33
Cooling tower	0,25
Lighting	0,1
Paint shop	0,04
Sum	**0,36**

5.2.2 System description of the MD16 line

To get an overview of the daily routine of the personnel in production, a system description is depicted in figure 10. The human in this human-machine system is any potential user out of the personnel on the MD16 line (see 5.2.4). The system description shows the information flow and the interaction between the users (in this case the operators on their work stations) when monitoring production and the user interface to control the different machines in production in order to reach the system goal.

There are all together six different tool and monitoring screens plus a communication tool and a database screen. These are the run plan monitoring screen; three different OEE (Overall Equipment Efficiency) monitoring screens; energy saving potential screen; energy consumption monitoring screen and the screen linked to the database and the communication tool. The production process on the MD16 line is not completely automated, hence in order to reach the system goal (see Use Case) the screens needs the attention from the operators. The run plan needs to be attended because of numerous reasons, such as unexpected events and other problems. In the run plan for the line, each machine has a planned "turn on" time (e.g. machine nr 1 - turn on: 06.13) and a planned "shut down" time, e.g. at 14:55 for machine nr. 1 and perhaps 16:36 for machine nr. 8 on the line.

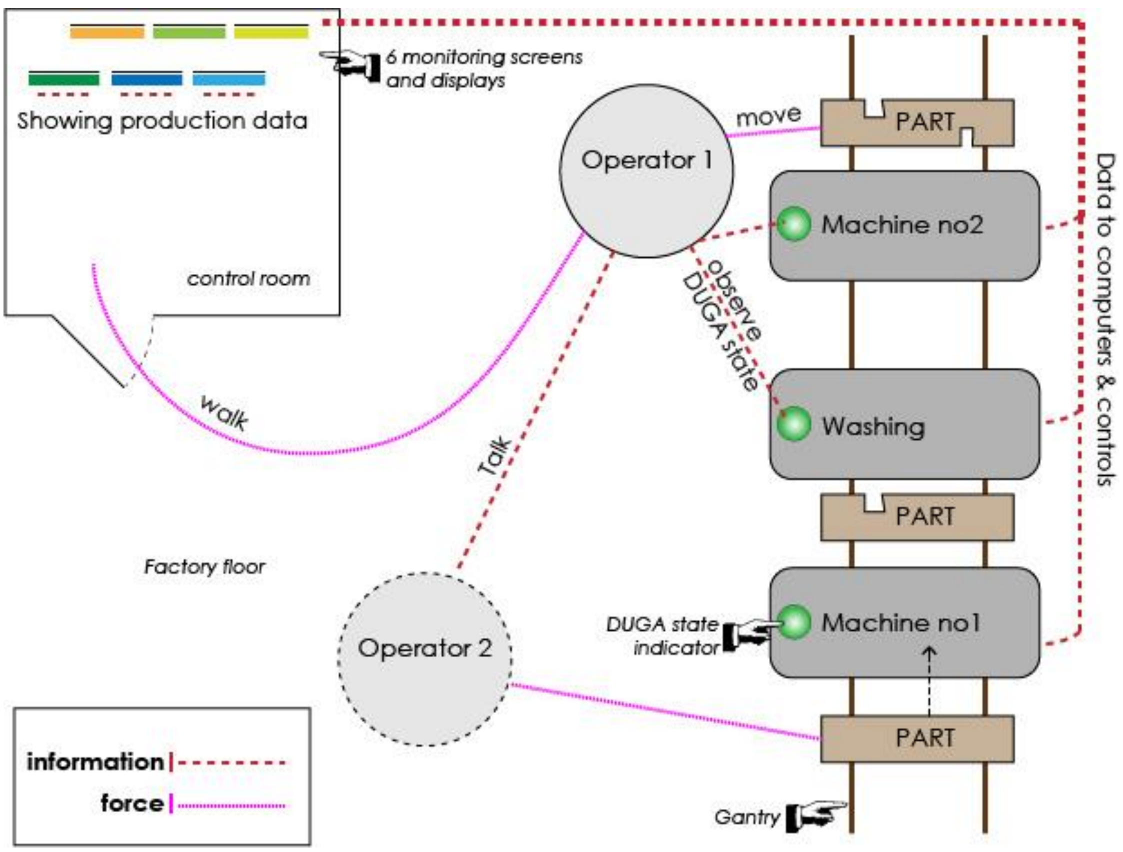


Figure 10.

A simplified system description of the human-machine system at the MD16 line.

User environment

The working environment at the worksite is quite noisy and the floor is marked with yellow fields that shows where to walk and where forklifts are running. The gantries are situated above the machines and are fixed in the ceiling. The parts move along the gantries from one machine to another. As mentioned in the user profile, the machines on the MD16 line are operating parts according to a run plan (established by the production planner and department manager). The machines continuously have to go through maintenance for multiple reasons and during that time they're not available for production.

System goal

The expected outcome of the system is the produced cylinder heads which are going to fulfil the demands of tolerances and pass inspection. A relevant sub-goal is to be environmentally aware of the energy use and cut down on the unnecessary use of energy which is declared in the Use Case. The ultimate goal of the system is to produce cylinder heads, economically optimized in any given situation for the company to grow in the long term.

5.2.3 DUGA software

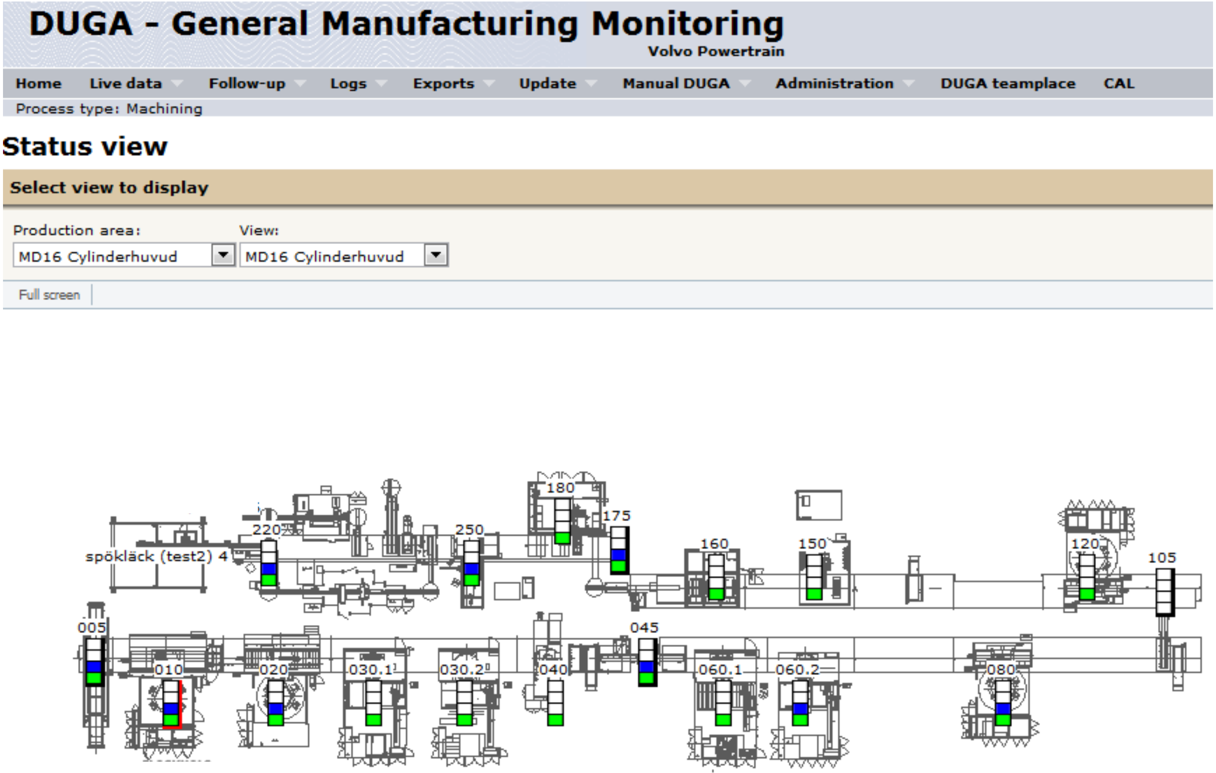


Figure 11. The web-based DUGA system that the personnel has access to. (Volvo DUGA-intranet screen dump.)

The DUGA system is a web-based manufacturing monitoring system that is in use today (*figure 11*). The system processes real-time data about the operations and the machines in the production system and their status and automatic follow-up operational interruption in production. The different personnel in the factory use DUGA for different purposes and it is not optimized for any particular user. The DUGA software provides about ten different kinds of states and they correspond to a sequence of light signals of the four light indicators. The four light indicators are placed in the factory on top of the machines. These can be seen by the personnel working on the floor and they have the knowledge of what different combinations of the lights mean. The entries of the gantries are also displaying state; they are identified here by 005, 045, 105 and 175.

5.2.4 User profile

In this section, a summary of the specific goals, knowledge and responsibilities of the personnel and potential users that work on the MD16 line is presented. This includes their whereabouts, what assist them in their daily routine and their correlations and collaboration in order to reach the system goal. Production of a part includes a few key roles of the personnel on the MD16 line, which makes up the sub-system “the human” *(figure 12)*.

The production planner participates in daily morning meeting to coordinate best possible planning. He has a view of all the factory‘s components including main process systems and sub systems. The main goal is to generate a run plan of what the factory is going to produce and also keeping track on the energy consumption of the plant. Input to the plan comes mainly from an old computer system that generates dump orders and the output is an excel sheet. Other systems used are DUGA, MES system and e-mail.

The production planner works together with the department manager whose main goal is to increase the OEE number (overall equipment efficiency) by influencing both maintenance and engineering through analysis of some KPIs. The department manager uses DUGA sometimes and is situated close to the shift leaders’, also called shift managers.

The shift managers are in charge of 15 operators in this department (MD16) and the main goal is to produce the correct amount of parts and moreover the quality and safety. The personnel work in four shifts, the first starts at 6.30. The shift leader is located in an office or on the factory floor. Shift leaders do not use much IT-systems besides from DUGA and outlook and the most important information comes from the morning meeting area where all important production data are traced. Other assigned tasks are to rearrange operators when needed, e.g. maintenance operators when some unplanned maintenance occurs.

The operators work close to the machines and are situated on the factory floor and in between the machines. They are handling the operative actions that are made to any of the machines and also attend the machines if any problem occurs.

The production engineer’s main goal is to monitor the production and how it follows the run plan and to physically attend the machines if any problems occur. The production engineers are situated either on the factory floor or in a control room. The production engineer mostly uses the monitoring system or their eyes to visually see the status of their work situation and to meet the goals.

A maintenance engineer’s goal is to maintain the machines manually. The maintenance can be both planned (i.e. preventive) or unplanned. Important tasks are to diagnose faults and to oversee time-critical repairs and checking the emergency work order database and DUGA.

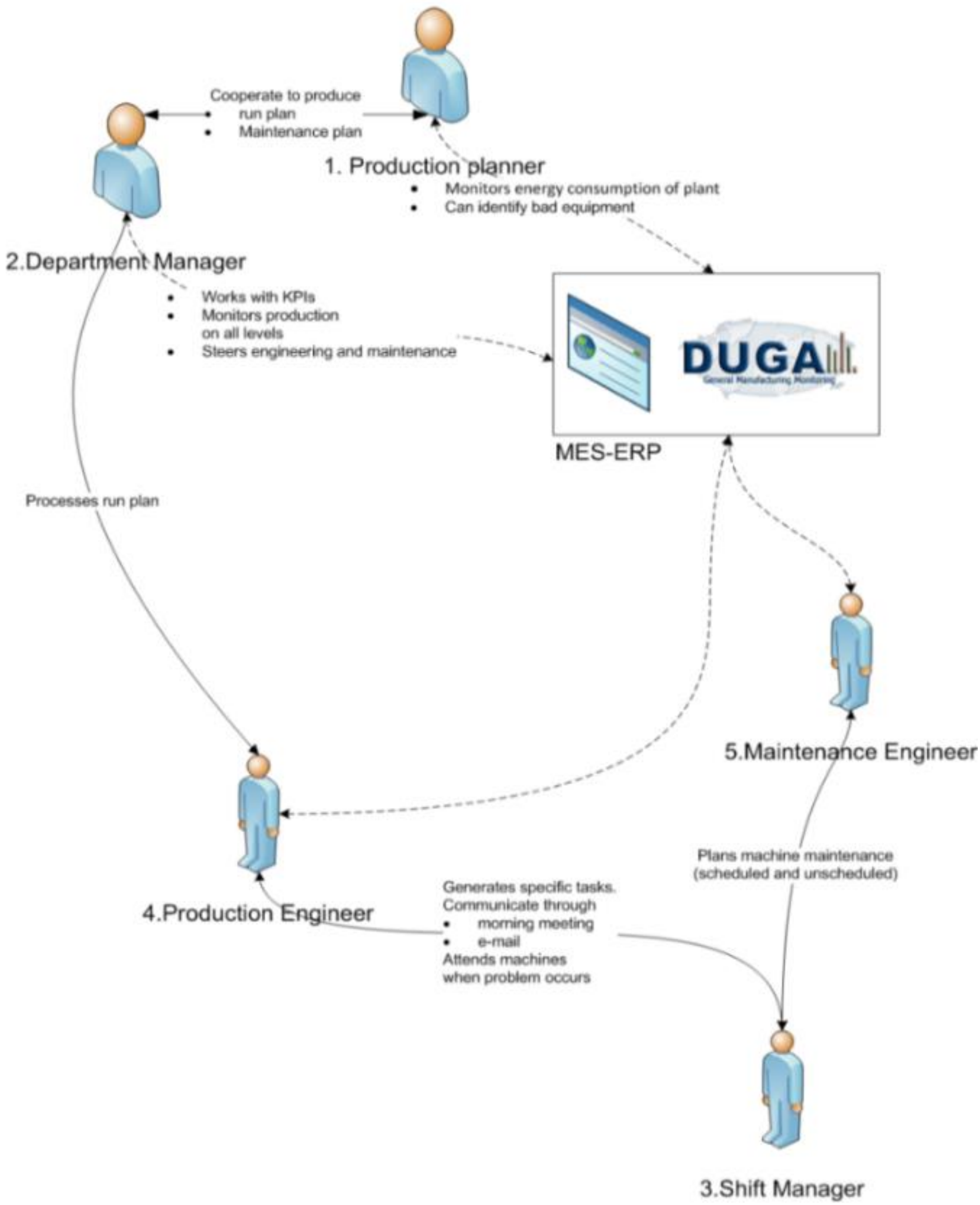


Figure 12. Interrelationships of the different personnel working on the MD16 line. (KAP 2011b)

5.2.5 Use Case

The potential users out of the personnel are the ones that attends the machines if any problems occur. These are the production engineer, the shift leaders and the operators (see 5.2.4). In figure 13 the use case is depicted and the colored lines represents different screens with production data (see 5.2.2). The task in this use case is "*investigate energy saving potential"*, in other words to engage in an energy saving activity is the task in this Use Case. The specific details of the different actions in the Use Case are not declared further (see 1.3 *delimitations*). (KAP 2011b)

1) Examine the run plan

2) Get machine *setup time* and other *time related data* for each machine.

3) For each machine with idle time, calculate and examine the *shutting down safety indicator* of shutting down idle machines. If there are any machines with shutting down potential – proceed to 4).

4) Calculate and examine *energy saving potential* and *cost saving potential* for the idle machines.

5) Select the potential machines and calculate the *shutting down time* and *turn on time* from the *setup time* and *current idle time.* Then change the *shutting down time* and *turn on time* for each machine.

6) Update the plan to the database.

7) Send to department manager.

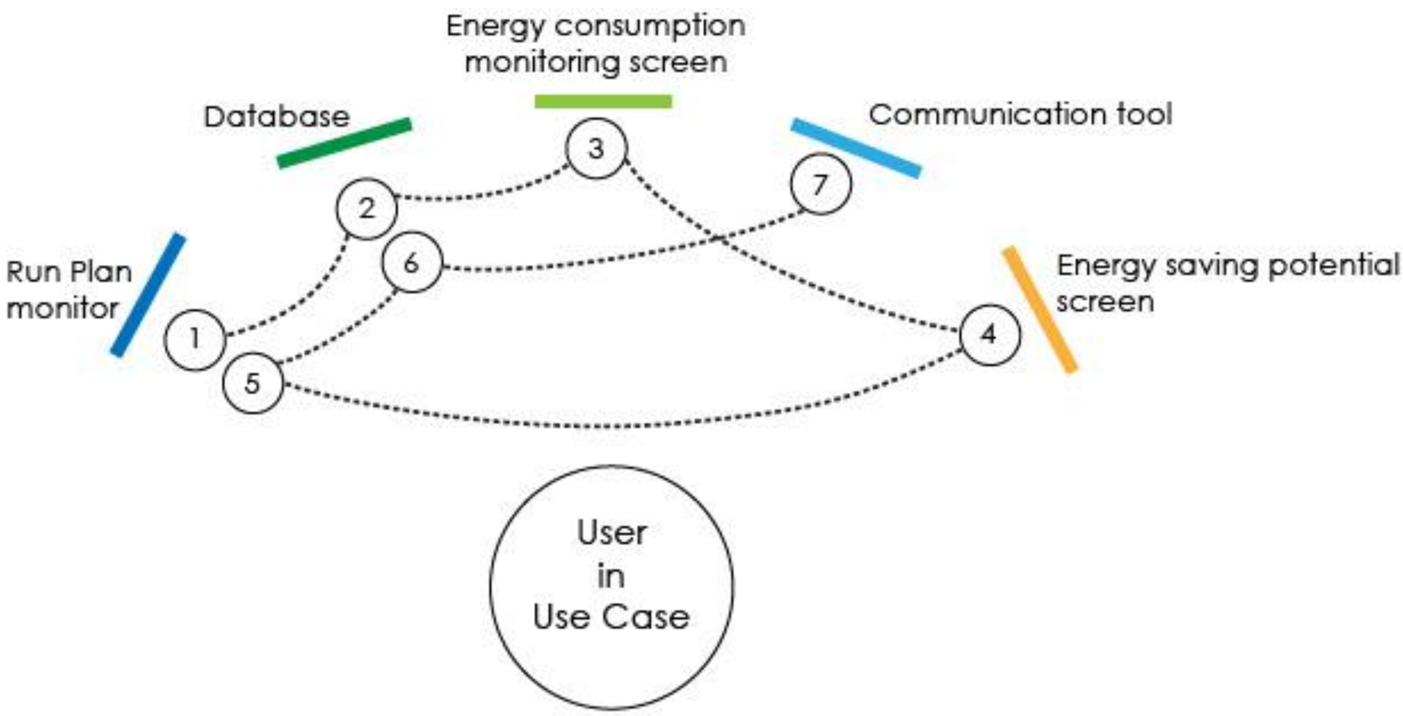


Figure 13.

Use Case schematically depicted: The task is to investigate energy saving potential. The figure shows the User has to read information from different screens to fulfil the task. The screens are marked with different colors.

5.2.6 First focus group interview, VPT Skövde.

The focus group interview started with a presentation of the master thesis project and was followed by a short interview session with the participants: an energy consultant; an electrical engineer and two Production Engineers. The focus group interview evoked some subjective needs and enlightened the work situation.

According to the production engineers, they have an interest in the energy waste situation and how much waste there is. The machines do not offer a quick and easy way to turn them off and on and the production engineers have noticed problems with the tolerances after the machines have been off, and then switched on. They are concerned that if the machines were switched off more often it would trigger more problems for the delivery output and quality of the produced parts. During night when there is no production, some support systems are running in the background for the machines, i.e. the machines are not completely off. When production starts in the morning, the machines need to warm up which causes a one hour start-up loss in efficiency and then the problem will fade away. This knowledge brings about a concern of the main issue, to lower the energy consumption by switching off machines as they goes into idling.

The operators and production engineers are moving around and doing other tasks during the day, rather than focusing on switching off machines. The machines on the line consume about 1 kW of power even though they are switched off, however this is much less than if they remain in the idle state.

Currently there is no software installed that shows energy data in real-time but the production engineers can look up production statistics, like minutes of break in production, waiting and idling on a computer at the factory. They have a lot of data in DUGA, they can see minutes in detail and they are comfortable in using that today although the data handling software, like analysis of production KPIs is for management only. The organization management has a need to measure where the energy losses are situated more precise than today, to pinpoint where most of the unnecessary energy is wasted. Management do not use the data to inform the operators about what is important to do in order to lower the energy consumption. The operators don’t have access to the analysis of the data themselves.

5.3 Workshops and concepts

In this section, the groundwork of the information organizing and the first development of visualization ideas into concepts are presented. First, an initial workshop is describing the construction of the prerequisites for the development of the data visualization. These paved the way for the process of producing the concepts in the following workshops, which are presented under the following heading.

5.3.1 The prerequisites for the workshops

The first workshop session was done together with an environmental project manager who had experience from the MD16 line in Skövde. He had detailed information about the daily routine of personnel working on the MD16 line and helped to form the prerequisites for the basis of the design development.

The users want an easy way to switch off the machines, including the auxiliary systems. In order to switch off the machines safely today, the users need to do a sequence of actions in the right order. There is also an emergency shutdown button or lever, a main switch that is not recommended for a safe shutdown sequence. The switch off sequence *(figure 14)* time t1 represents the time it takes to turn off a machine completely in a safe way. This sequence is divided into different levels of power that could be lowered and relates to one of the machine’s systems (including auxiliary), here represented by A, B and C. The start-up sequence t3 is the time it takes to turn on the machine in a safe way, to ensure good tolerances, minimal risk of error etc. The different parts of the machine’s subsystems power usage when turned on are illustrated, A’, B’ and C’.

Saving potential	*Little*	*Medium*	*Large*
1) OFF	A	A+B	A+B+C
2) ON	A’	B’+A’	C’+B’+A’

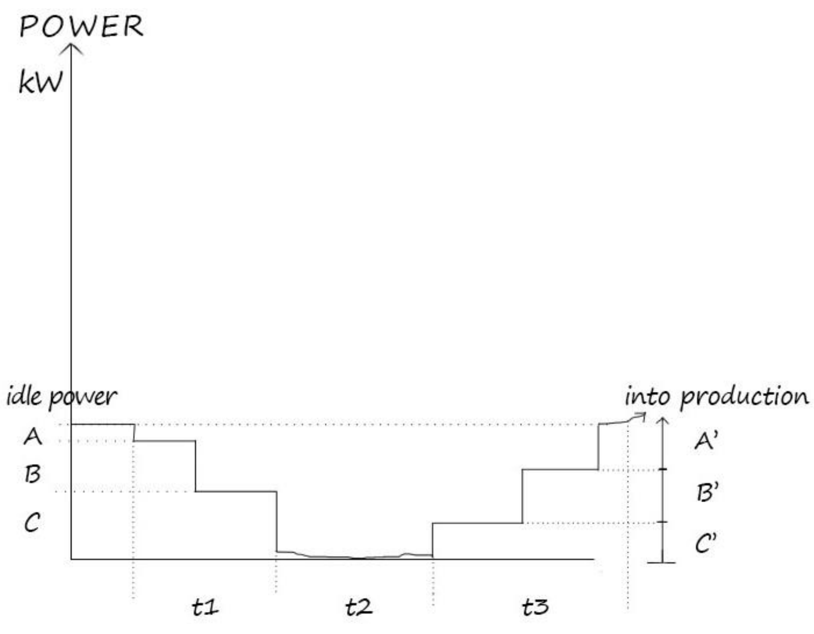


Figure 14.

A description of the power outtake over time in the shut-down sequence of a machine.

The time in between, t2 represents when the machine is totally off which is the most energy saving state. Today both t1 and t3 are calculated in order to get t2 and the energy saving potential.

A safe shutdown is important to secure the function of the machine and hence the quality of the machine operations when producing. Keeping the quality of the product is crucial when it comes to maintaining the delivery output and the tolerances of the produced part is the responsibility of the operators. If the produced parts cannot be used due to bad tolerances, this affects the number of parts produced, i.e. the delivery output.

Idle Seriousness

The following table presents reasons for a machine not being available for production:

Idle cause:	*According to run plan?*	*Time consumption:*
Changing tool	Yes	Small
Planned maintenance	Yes	Medium
Out of material	Yes/No	Variable
Unexpected error	No	Variable

Table 2 declares examples of the different origins of idling.

When working the shifts, the operators also care about the material supply, both for the whole line and for each machine. This means what is loaded on to the first gantry and also the material supply for each machine. They also care about what the tool-situation look like for each machine and the statistics of tool’s breakdown. The risk of machines breakdown is controlled through sound measurement and is something that the users care about. The operators are updated on what other operators in the shift-team are doing since a breakdown in one machine affects all the other machines on the line.

On a more conceptual level, the next generation of monitoring devices should have adopted the idea of the "safe switch off - button" including a timer and a way of selecting how much of the machine to shut down is preferred but hard to implement with today's technique. If something goes wrong, the dashboard could have a help function where one operator could call on other operators for help.

The operators should be able to follow up the data and read how they performed one day back, for example in the morning meetings. After some discussions, a list of data and a set of KPIs that were considered important for the users was concluded. These are listed here:

Data:

- Time
- Power
- Machine state in DUGA
- State from the power signal
- Predicted idle times
- Shift times
- Startup and shutdown time
- Error messages from the machines for maintenance
- Documentation of error
- Predicted maintenance
- Units

KPIs:

- Total energy consumption (last hour, last shift and last week)
- Cost of waste
- Energy per state of the machines performance
- Information messages or alarm messages for decision support
- Energy waste percentage of the total consumption

5.3.2 The workshop sessions and the concept generation

To simplify the situation, the switch off action was regarded as pressing an imaginable button which made the machines proceed through a safe and secure shutdown-sequence. Exactly what to do in order to switch off the machines was not considered further (see 1.3.2). Based on the prerequisites from the first workshop session, two main functions were determined: action functionality and performance functionality. The action functionality would be optimized for the operators to take action, i.e. to lower the energy consumption. The performance functionality would serve as follow up information on the energy consumption.

The development continued by taking a user oriented point of view. The requirements for the concepts emerged through discussions about what is needed to be visualized in order to set the machine into a state of lower energy consumption – to carry out and action. As a user, there is a need to know “do I have a problem with idling?” Throughout the workshops this was considered the most important requirement to show the user in order for him or her to do something about the idling problem. The next step for the user would be to investigate the root-cause of the problem. This rendered an idea of three screens, or views that the user could change between; a real-time view, a weekly view and a root-cause view. The purpose of the real-time view, which originated from the action functionality, was to present the real-time data and the machine state, i.e. an operational dashboard for monitoring and taking action upon visual stimuli. The weekly view was thought to be a summary of the ongoing environmental performance of the current week. The root-cause view would then provide information about what the problem of the current situation is, why the machine is idling or why it is waiting.

A set of sketches about visualization ideas and models were produced *(figure 15).* Many ideas were adaptations of existing visualization techniques, such as “treemap”, “time searcher” and “parallel coordinates” and combinations of other existing analytic software (see 2.3.1). These tools could work well to suite both the follow up functionality, for the environmental coordinators to see a pattern, and also for the real-time monitoring.

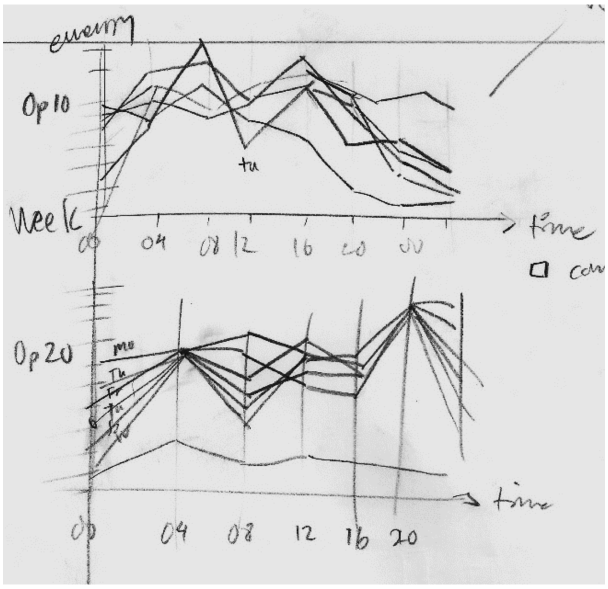
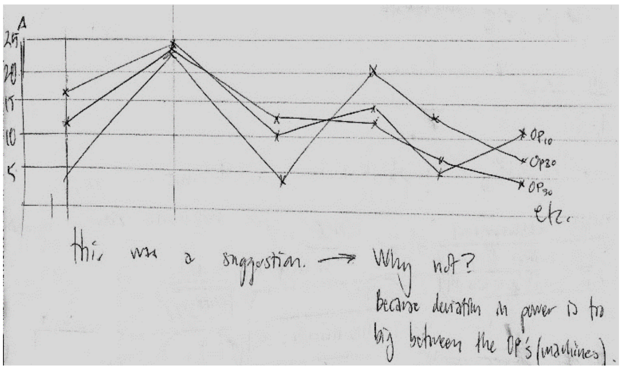


Figure 15.

Sketches of information visualization ideas from the workshops, here on the performance functionality.



More and more the focus was shifted toward developing the real-time view, i.e. the action functionality, into a monitoring dashboard. That is what is going to make the operators take action in a direct manner, in contrast to the follow-up function which in turn may build the sought after behavior, in the long term. The choice of colors to indicate the different states was not considered important during the workshops since conceptual design development is not detailed design. Some of the requirements that were listed during the workshops were “visibility from afar”, “call for attention” and “express seriousness of the situation”. The work was directed more and more into simple solutions for each function rather than having a holistic view of the situation and the problem. A lot of design variables were elaborated on in order to find solutions, such as conditional value of size and saturation and also flickering or growing animations in the graphics.

Concept 1

A navigational window that graphically represent the factory layout was made *(figure 16)*. The thought of this concepts was that it would be space efficient without creating visual noise. In this concept, the machines are represented by the boxes to the right which are highlighted in red, to signify the idling machines. The number of idling machines are show redundantly, by a big number and as seriousness on a scale of severity. The U-shaped factory layout is kept but slanted, for the user’s orientation and as a representation of the MD16 line.

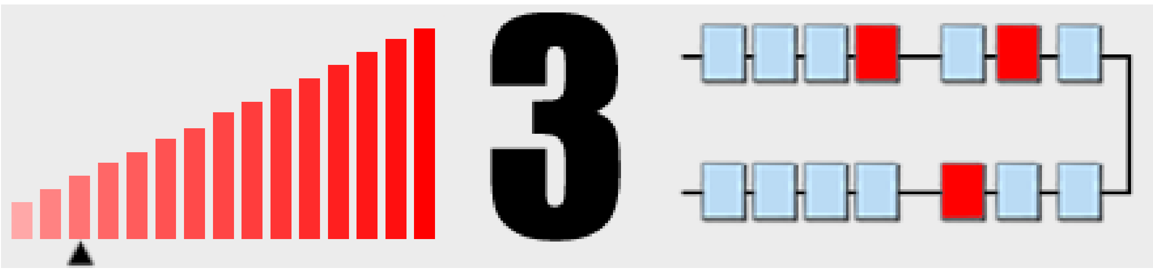


Figure 16.

The idea behind the navigational window was that the user could pay attention to seriousness of the current situation and the idling state of the machines, not all the states.

Concept 2

An adaptation of the treemap was developed which would serve the user by providing feedback of the idle situation *(figure 17)*. The viewer would very quick realize where the idling problem is big and where it is not so big. In this concept the area of the square represents one measure, e.g. an important KPI or other data, and the color intensity represents another measure. In this case the KPIs could be time in idle state, energy wasted, number of stops or similar. In this example the square called "op.120" is currently highly saturated with red color and that would imply that there is a need to look up what the situation is.

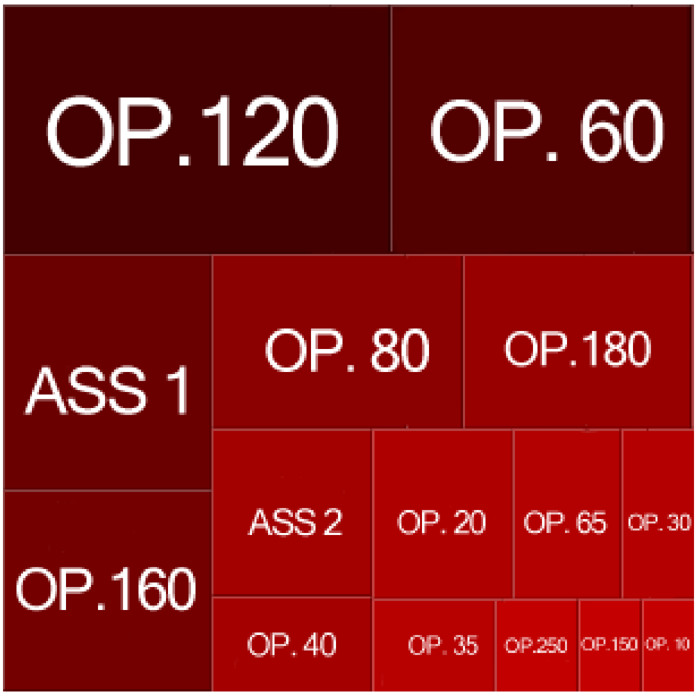


Figure 17.

Treemap of the idle situation on the MD16 line.

Color intensity (red) and area size are two variables in this concept.

Concept 3

The idea behind "the screen saver"-concept was to give the focusing on "when" there is a possibility to do something *(figure 18)*. The intention of this concepts was that it could run in the background as a screensaver and when any interaction (mouse, touch or whatever) occur, it would disappear and reveal a more declarative software, if there was a need for that. The screensaver concept satisfies the requirements "visible from afar", "call for attention" and "express seriousness". It is divided into power to the left and energy to the right.

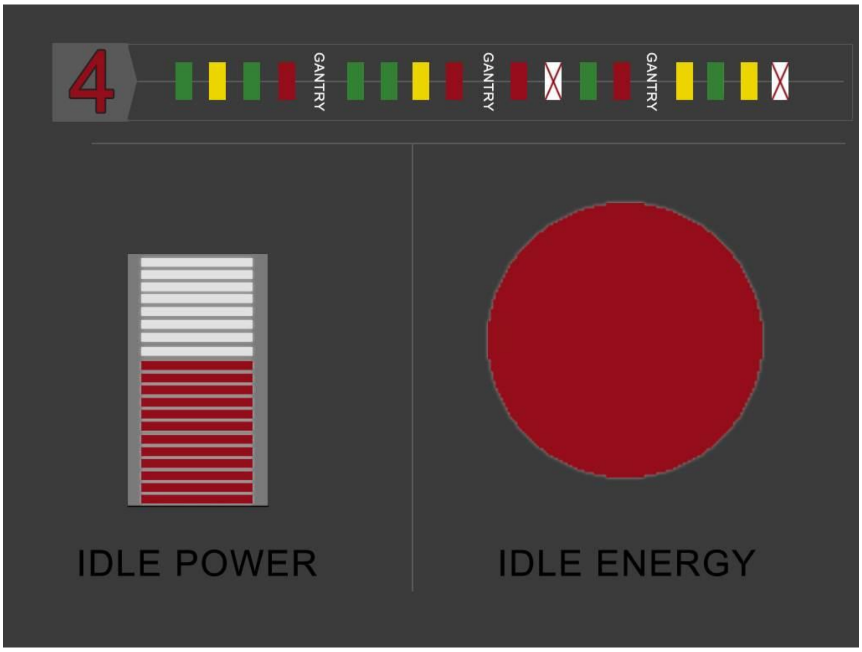


Figure 18

The "screen saver" concept which focuses on visualization of the idling situation only.

The idea behind "the screen saver" was that the user could know when there was an opportunity to do something, such as go further and investigate energy saving potential as described in the Use Case (see 5.2.5).

The power outtake is momentarily and the bar-meter to the left would indicate the proportion of idle power currently wasted out of the total power outtake, i.e. if every machine were idling the bar would show 100%. The red dot to the right would signify how much energy had been wasted since the first machine started idling.

For example, when any of the machines first switched into the idle state, the bar-meter to the left would show the corresponding proportion of idle power outtake and the red dot would be invisible, zero at first. The red dot would grow over time and this visual feedback would illustrate the seriousness of the current situation by the speed of which the red dot was growing.

These three concepts were brought to the focus group for evaluation and discussions for further information gathering about what requests they might have.

5.4 Evaluation and second focus group interview

The evaluation of the concepts and the second focus group interview is presented in this section.

5.4.1 Evaluation of the concepts

The production engineers think it is good to have the factory view in a U-shape because most lines are shaped like a U in reality *(figure 16)*. Even though they know the positions of the machines and the distribution over the line – it is good to show for others and to see the machines' distribution and corresponding positions. The comments on having big numbers that show how many machines are idling is seen as a good idea but they don't work with energy saving like that today. The treemap visualization (*figure 17)* was hard to comprehend and was seen as complicated.

The comments on the "screensaver" concept *(figure 18)* were that it was interesting but it would be hard to imagine such a solution in reality because today, none of the potential users amongst the personnel are switching off the machines when opportunity comes, according to the production engineers. To show the seriousness with the growing red dot was a good idea but it needs some reference. It would probably be hard to see the difference if there was nothing to compare to. A scale to measure if the dot was smaller or bigger than last time that the operator looked at the screen would be preferred.

5.4.2 Second focus group interview

The concepts functioned as mediating objects and helped to get the discussion going. After some discussions the focus group agreed on that one important data source to show is the idle energy, the waste. Other important issues were to *"highlight the machines that are idling and not the actual status because that can be seen in DUGA"* and *"…even more important is to highlight 'ok, now it's time to go and turn off the machine'… "* as the environmental coordinator commented.

For analysis of the data it is important to be able to see a pattern in the data, i.e. if there is a pattern. A follow up question would then be "is it the same for all machines?" They want to be able to choose to look at data from the entire department or to look at a single machine. Another important issue is the deviation and variance of the data statistics; to see if there are many small stops distributed over the day or few big stops in the machines. To be able to choose time span was also considered important in order to see a trend or pattern. A wish from the environmental coordinator was to have check boxes in order to choose what data to compare.

To motivate the end-users it would be a good idea to provide KPIs that are positive and motivating, exhibit something that assure the end-users that a small change can make a difference. That the recent action they made now works in favor of the environment. *"So maybe if we start to think about it we can actually shut them down and if we see that then we can work and improve ourselves but today they are meant to be waiting"* was a comment from one of the production engineers in the focus group. The supervisor Per Hanarp was very clear about what KPIs he wanted to see; a table showing saved energy, energy consumption/produced unit and total energy consumption all divided into the three main states; producing, waiting and idling.

Today, a breakdown or stop caused by an error will produce an alarm to handheld devices that displays an error message. The error message can be read and the user can attend the machine and try and fix the problem or call maintenance. In the event of breakdown, the machines situated after the troubled machine on the line are focused on. These machines are stopped or switched off, depending on the situation. It is not only visual information (like a monitoring screen) but also vocal communication that makes the operators take action towards lowering the energy consumption.

Today a routine is to keep the last machines of the line "waiting" (not to mix up with the state) in order to create a "suction" from the end of line. This means that the parts are taking less and less time to process as it proceeds on the production line so that the part does not obstruct the flow that is needed in continuous production, which is the case in MD16. Once a part is loaded to the gantry the aim is to have it processed without any pauses or delays.

5.5 Summary

The research in chapter 5 has given information which is going to be analyzed in the next chapter together with the suggestions on data visualization that was developed in the KAP-project prior to the thesis' initiation and the visualization used in Vara.

The two field studies gave valuable information of the current situation. The system description helps to get at better overview and context of the use situation. The prerequisites in the workshop sessions didn't encompass all the information of the current situation because the data gathering phase was progressing in the meantime. The data gathering and research was concurrent with the conceptualization during the workshops and the second focus group interview marked the end of this process.

6 Analyze

In this chapter the previously gathered information is analyzed. The aim is to clarifying what can be done about the idling issue and the energy saving behavior, given the information in chapter 5. First, the end-users actions is analyzed, taking a user centered design aspect of the idling issues. Then the visualizations are scrutinized from the same point of view. The analyze phase is characterized by sorting out significant information from the gathered data. One single problem can have various different causes, as well as many different problems can have the same cause. How these problems and different issues cohere is described and categorized into needs, requirements and functions.

6.1 The end-users' actions:

The two main divisions of data and functions are real-time data monitoring for operators, shift leaders and production engineers and the stored real-time data for follow-up reasons for other users, mainly the environmental coordinator. Looking at the Use Case, the only way to solve problems with idling machines is to complete the task. To address the users that can complete the task and perform the series of actions needed for that then seems reasonable. These are, once again, mainly the operators, shift leaders and production engineers and they are from now on called the end-users.

As can be seen in 5.2.2 and 5.2.5, the production system is not completely automated. End-users need to search for and analyze information in order to know if they can switch off any system of the machines. However, comments and discussions from the second focus group meeting suggests that they don't "*go around switching off machines*", and from the first focus group meeting that sometimes the hydraulics can be switched off.

The end-users don't actually know how much power the machine is consuming, they only have the state. During the EMS installation the power usage and the state were calibrated in order to know the effective output and what state that relates to. The state origins from the power usage data. The power usage vary in the "production"-state depending on operation that the machine is doing. The idling/waiting state is using the same, more or less constant power. When the machines are in an off-mode they drain power, which over time consumes a lot of energy in the long term. The different machines' amount of power and idle power are not equal, in fact they each vary a lot in between depending on what kind of machine it is and what kind of operations that it's doing.

Besides the power outtake there is a need to show the actual idling and not only the state, which can be seen in DUGA. This information indicates that the 10 different types of states in DUGA does not show whether a machine actually is idling or not, only the state. That means that DUGA must have another way of defining the state and that there is a need to see the real-time measurements. During the workshops, the seriousness was considered as a result of how many hours of idling. Rather than a result in terms of accumulated energy, the seriousness can be considered as a velocity of which the energy wasted in the current situation. The end-users could make judgments based on the real-time data to prioritize and select which machines idling that would render a "start investigating saving potentials", since they all have so different variations in energy consumption and power usage in the different states.

To check the material flow situation, error messages, predicted maintenance etc. are all tasks the production engineer has to do in their daily routine. To better support the notion of when to start investigating in energy saving potentials, not leaving it completely to the end-users' situation awareness - the function of the dashboard should be to show "now it is possible to start investigating energy saving potential" – like the environmental coordinator said *"It's even more important to highlight 'ok, now it's time to go and turn off the machine'.*

The end-users would benefit in reaching a high level of Situation Awareness (SA) when working on the MD16 line and therefore the end-users' SA should be better supported. There is a clear hierarchy in the different levels; *perception; comprehension; projection and resolution.* In order to reach the second level of SA a user must first have reached the first level, i.e. first you must perceive something in order to comprehend it. *Perception* and *comprehension* are linked to the interpretation of the graphical content of the user interface, which in this case is the visualization of the selected data and the dashboard that's going to be developed and implemented. SA and its relation to the end-users' needs are divided into categories; *if* there is an opportunity to do something and *when* there is an opportunity to do something. Other needs that are linked the *mental model* and attitude of the end-users and a positive effect in the short and long term, such as *acceptance* and *motivation.*

6.1.1 If, the perception - to attain and register the current situation

The workshop sessions worked around the question: "Do I have a problem with idling", which is what the end-users should ask themselves. The answer to *if* there is a problem depends on the current state of a machine and the power outtake, the material situation and so on. A machine that is in an idle state is not equivalent to a machine that is a candidate for switching off. It is depending on what kind of idling it is (see *"idle seriousness"* in 5.3.1) and for how long time a machine is going to be out of production. The machines on the MD 16 line are connected in a series line which means that problems in a specific machine will affect all the other machines, before and after which is why there is a need for a perspicuous view, an overview of the series flow over the whole line.

6.1.2 When, the comprehension - to realize the possible choices in the current situation

The next thing to consider is that it doesn't matter if a machine has been idling for several hours if it is supposed to be producing within the next minute. It is what is going to happened next that is important. To be able to know *when* is very much reliant on whether the machine is going to perform any task soon. This also depends on how the situation of all the machines on the line is, both before and after a specific machine, e.g. how the material situation looks like on the previous machines, if there are any maintenance jobs, cycle times etc. Any other data source than real-time data does not exist at the moment, therefore it will be hard to set up an imaginary "best practice"-scenario and delimitations on what data could be included for better decision support. The best situation would be if the machines shut down automatically and in that case there would be no need to visualize production data for operational use. Since this is not the case in the current situation, the data that is provided in the present is what is going to be visualized. The end-users should be able to realize that idling is currently happening and then go and get more information about how long it is going to be idling and follow the Use Case. In order to make a decision to switch off a machine the end-users still need to calculate as the Use Case suggests.

Visual feedback

As an end-user you need to know if your actions were right, if your actions resulted in less energy waste. Feedback of the end-users performance is useful to reassure the end-users in their decisions. This feedback can be given orally in the morning meetings but if it can be supported in the dashboard that is even better. To regard color blindness is important from a user centered design perspective. The dashboard should provide updated data and show visual feedback that reassures the end-user of the new energy saving status of the line. A visual message that from now on they are saving otherwise wasted energy.

6.1.3 Acceptance, motivation and knowledge

End-users acceptance level seems low and that has been expressed in several ways. In the evaluation and feedback meeting, the end-users could neither consider nor conceive another way of arranging the machines graphically on the line, than the traditional u-shaped disposition. They expressed a need to see a lot of data at machine level and to have comparison between all the machines on the line, which is similar to the DUGA system that already is in practice. The explanation could be that they always refer to the factory layout on screen and therefore has built a mental model of the arrangement, which perhaps functions as a map and signature of the MD16 line.

On the other hand they can't accept something that is too close to what they have today, then they claim, they would rather use DUGA instead. Exactly where the level of acceptance is for the end-users is hard to know but the similarities to DUGA is considered of low risk because the data inputs are so different.

There are many wishes from the end-users and from the project team of what should be visible on the screen to motivate and in different ways encourage the end-users to behave in an energy saving manner. This is also an organizational issue as Volvo Penta factory spends a lot of time to encourage the personnel to think of the energy waste. The problem in the MD16 line is not at this level because there is a need to be even more detailed in the power usage monitoring than the Volvo Penta factory. Some of the "green" production hours in the Volvo Penta visualization would be considered idling on the MD16 line.

The KPIs are not a part of the real-time data but is important for building knowledge amongst the end-users, which is one of the system goals and has to do with visualizing environmental performance. Examples of motivating KPIs or graphics could be "energy saved" or something that gives a more direct and immediate response to the end-user. There are two purposes for showing this, both to see that something has happened and that energy saving actions does make a difference, both directly and in the long term as an aggregated summary of total savings.

Morning meetings seems important in order to engage personnel in the energy consumption issues, as they do at the Volvo Penta factory in Vara. Another need that was elicited was the need to feel reassured by looking at statistics of what has been done and what the effects of those actions rendered, hopefully a positive result. The maintenance engineers' identifies the machines by the littra-number and the production engineer, shift leaders and the operators identifies the machines by the operational number.

6.1.4 The waiting state

The only difference between idling and waiting is time, where the state “waiting” automatically turns into “idling” after 5 minutes. To ensure that this limit is not just arbitrary preset, one could speculate in why the waiting state have been predetermined to 5 minutes. One reason could be to allow for the time it takes to transport the part from one machine to the next one. Another reason could be as a buffer time for the end-user, to avoid misinterpretation of the data that would have led the end-users to start calculating possible savings immediately when a machine has finished operating on a part.

Many machines’ processes are diverse and 5 minutes might be too much in some cases, or it might be too little. This waiting state data might obscure “true” data for the analyzer to set a statistical defined target for idling, a goal for the end-users to reach. Consider the case where a machine is supposed to be switched off. Here the 5 minutes is a waste of valuable time to have a potential to react, this is actually idle time and is not helpful to the end-user. Then it is 5 minutes of idle energy before realizing that it should be switched off. Since they have “suction” from the line, the limit for waiting is probably different for every machines. However, this suction is not an optimal solution but rather a way of solving the problem, as it looks like today.

6.2 The KAP visualization suggestions and the Vara visualization

In this section, the visualizations at Vara factory and a prototype that had been developed in the KAP project, as a deliverable from the work done prior to the start of this project are analyzed.

The visualization suggestion that was done in the KAP project was not dashboards. The suggestion is meant to be web applications for both analytical tasks and real-time monitoring *(figure 19)*. Besides from the real-time data, the developers also included the historical data which is placed under different tabs in the application. A navigation function where the user could choose how to view and monitor the production; the whole line, the stations or a single machine. Selection of view is done via mouse interaction on the computer.

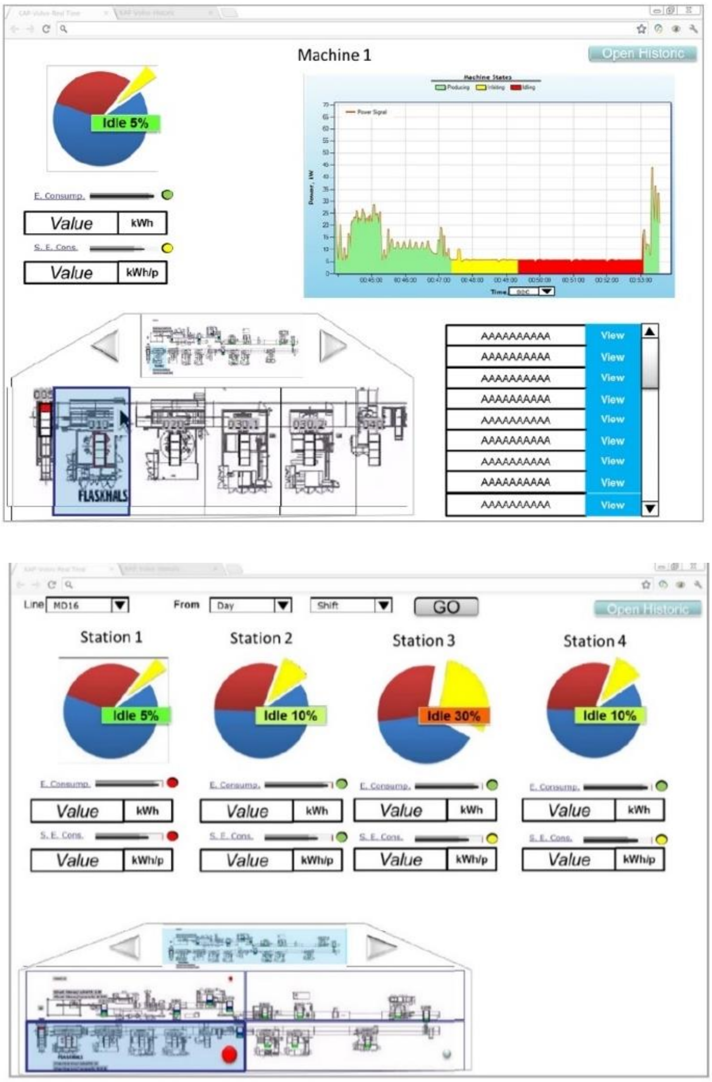


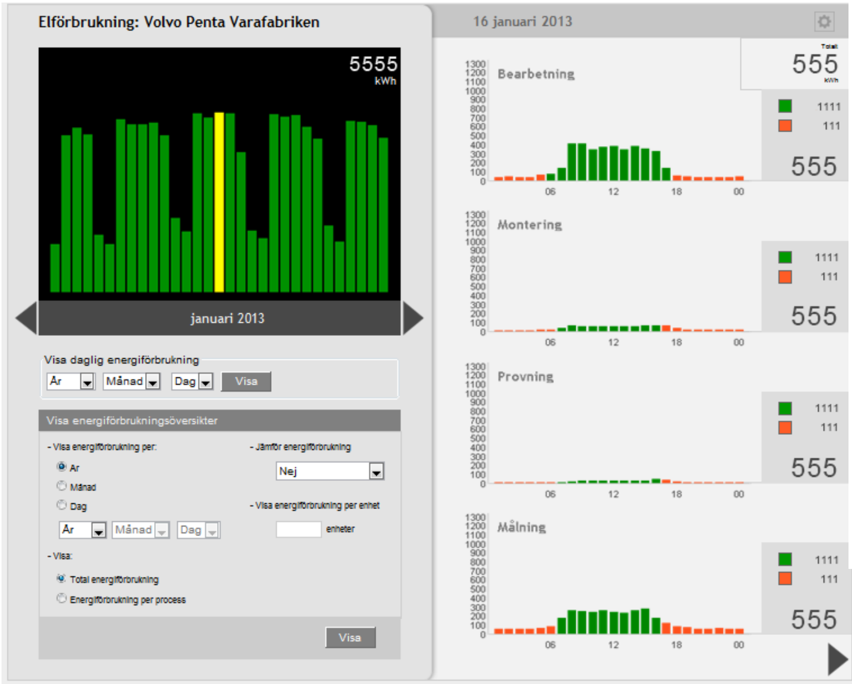
Figure 19.

The preceding work that had been done included interaction and allowed for zooming in and out of levels of showing data, i.e. machine, station or line level.

Three features are included and predominant in all views, the navigation window, KPIs of energy consumption and specific energy consumption (per produced part), and a pie chart of the energy consumption in the different states is showing the result of the day. The machine level provides a data stream of real-time data that is color-coded to represent the states of the machine and a message pane with a scroll function. The line level view is showing four pie charts, one for each station.

The visualization suggestion was not helpful to build further upon since it did not aim to show all the data in a single screen, it was never intended to serve as a dashboard and it seems that these visualization suggestions was not intended to be watched at a glance. The dashboard which is going to be developed builds upon other requirements and has more restrictions in terms of pixel area.

The Vara visualization does not provide for identification of idling state and does not have state detection (*figure 20)*. It is not possible to highlight the idling in real-time in the Vara visualization. During working hours, when all hours are green, they do not differentiate between idling, waiting and producing and consequently the different states of the machines are not visualized. It would be impossible for an operator to answer the question “do I have a problem with idling” if the Vara visualization would be installed and applied on the MD16 line, as it looks and functions today.



Figur 20.

The visualization at the Vara factory has another use than what is aimed for at the MD16 line.

6.3 Requirements

A list of requirements was compiled. Given the insights in this chapter, the levels of SA that are going to be addressed formed the categories of the different requirements. This is why the levels of SA are prioritized in hierarchical, ascending order. The requirements were abbreviated and given acronyms to facilitate further development.

Table of requirements

Category	Acronym	Requirement	Notes:
Perception *1st priority*	**P1**	Highlight the idling.	Know when a machine is idling, if there is an idling problem. Grab the attention of the viewer.
	P2	Show all data in one single screen	Allow for perception of the situation on the MD16 line, to be monitored at a glance. A perspicuous and more accessible view and hence tending to perceptional attributes.
	P3	Show data on machine level	More important than station level or line level.
	P4	Show real-time power outtake	Visualize the actual data
Comprehension *2nd priority*	**C1**	Rich visual feedback of the seriousness in the current situation	Be compatible to the other data sources in a good way and for reassurance and motivation.
	C2	Overview of the material flow over the line	To support knowledge of possible upcoming events and a perspicuous view for the personnel.
	C3	Afford comparison between the machines	Aim at decision support to select of the most crucial of the machines at a given time
Mental model and acceptance *3rd priority*	**M1**	Show the factory layout and the U-shape of the line	Good for acceptance of the visualization and suites the mental model of the end-users
	M2	Show the KPIs in a designated space.	Know about the environmental performance for motivation
	M3	Show littra-number and machine operative number	Helps the communication between personnel.

Table 3. The table lists the different requirements which will be used to build the dashboard upon.

For the new dashboard development, the human-dashboard sub-system's effect goal is for the users to discover idling. The end-users will be able to reach the goals through better situation awareness which is supported by the data visualization of the dashboard. This is going to help the end-users to initiate the energy saving potential task (see 5.2.5), by showing real-time production data in a clear and efficient manner, i.e. showing visually efficient data. The actual procedure is going to be the same, the same actions are needed to be performed in the use case.

Meeting the requirements in the table above will help the end-user to achieve the effect goal of the sub-system primarily by better perceiving and comprehending the current situation.

The effect goal (discovering idling) will have the following impact. An end-user will…

- …quicker realize that there is an idling problem
- …quicker find out if there is a potential to solve the idling problem (energy saving potential)
- …reduce time to perform the switch off action
- …build knowledge about the power usage and energy consumption
- …identify a pattern in idle consumption and see trends in the consumption of energy overall.

In other words; to work proactively by evaluating the situation, whether a machine is ready to produce or going into idling – all thanks to better situation awareness. They still need to do the calculations and all of that, but by evaluating the data on the dashboard they can plan their upcoming actions and activities easier.

As it is a dashboard for monitoring purposes the interface requires only data elements, no functional elements are needed because of the non-existing means of interaction through the screen. The interaction takes place elsewhere.

7 Design development

In this chapter the development, from ideas and concepts on to wireframes and further to the motivations for the choices that were made is presented. First, the design variables are described. These constitutes a variety of solutions and ideas that were determined by their functions and they affect each other through the detailed design process. In the convergent phase, the detailed design development is declared. This includes the reasons for, and purposes of the choices made.

7.1 Design variables

The layout of the data elements in the dashboard is presented in this section. The partitions of the total space of the layout are adjusted when determining the design variables. Therefore, these affect each other, one feature's allocated amount of pixels directly influences how many pixels that is left for the next feature or function. A highly ranked requirement, P2 is that every data that is visualized has to fit into a single screen. The different data elements and functions are the design variables with regard to the requirements in 6.3.

Highlight important data

The most important requirement is to *"highlight the idling"*, P1 is perhaps also the most important to do right. The highlighted visual feedback should be provided when it is needed and should not be exaggerated (Few, 2006). It is also, as Few states, key to use the highlighting economically, "*there is no need to tell the end-users that everything's fine*". The perception of the highlighted data is what is important and mainly the preattentive processing of the user when seeing the graphical content, to quicker perceive what stands out.

How "highlighted" should the important data be to be optimized for the perception and comprehension? Requirement C1, rich visual feedback should highlight information that support comprehension of what is going on at the moment and of the current situation. This refers to showing information that can work as an augmented information source to the DUGA and enhance that information. It is not good if it blocks out other information in the background or if it is not allocated enough space, then the highlighting function will be lost. The means of highlighting is a design variable in all these aspects, to balance the highlighting and keep it at a just right level.

Data element allocation

The layout of the data elements is a linchpin for the dashboard design. To keep the u-shape of the line is for the mental models of the end-users and is a requirement, M1. Figure 21 presents some examples of different ways of arranging the data elements in a U-shape of the MD16 line. All of the suggestions are dividing the MD16 line into the four stations. This grouping is according to the end-users mental model, because each shift is working on a single station and it is important to suite the factory layout and the requirement. The other requirement to see data on machine level, P3 is important and has to be combined with the requirement of M1. The different abstraction levels of the line, to see data for the whole line, for the stations or for every single machine is affecting the total space allocation of the data elements. The trade-off between the two requirements has been taken into consideration in respect to the layout as well.

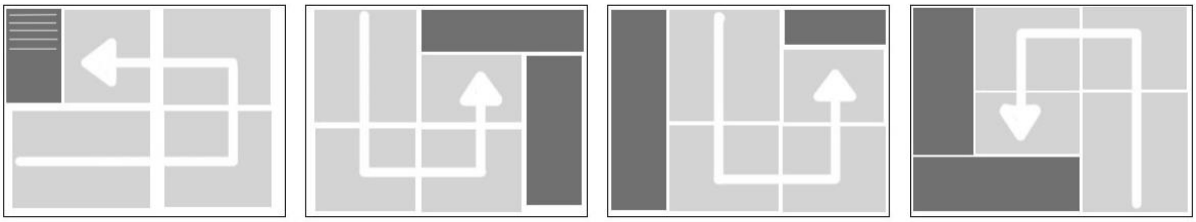


Figure 21.

Examples of data element allocation and different ways of arranging the layout of the data elements.

Power and state indicator

"Show real-time power outtake", P4 is one highly ranked requirement because it is the actual data that is going to be visualized. The amount of power, the state and a graphical representation of the power usage are three ways of showing if there is an opportunity to do something *(figure 22)*. These three indicators show the same data because they are based on the same dataset. They are therefore redundant which is good in order to perceive information quicker. On the other hand, a lot of information and colorful indicators may increase the level of clutter when displaying all three attributes.

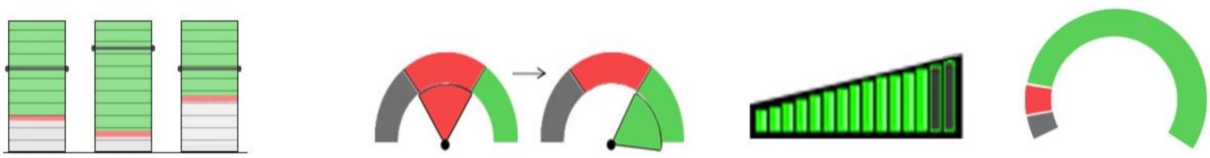


Figure 22. Different ways to show power usage and the state that comes with it.

The waiting state was considered to hide data and an "off-state" was never thought upon during the workshops. A new defined state, the *"off-state"* would bring about introducing a new color that would represent the state when an end-user had made a change. This would communicate the current performance and would signify "action taken". From that moment on, the line is actually saving energy, i.e. not consuming otherwise wasted energy. The off-state would be adequate in terms of visual feedback to support reassurance, that the action made a difference. The intension is that this will be motivating and positive as visual feedback for the end-users. The power is still important but the focus is on the total system and support functions.

KPI indicators

"Show the KPIs in a designated space" is a rather important requirement, M2 for the visualization. The arrangement and layout design variables requires a space to show KPIs and other motivating information. This data is not in real-time data but statistical data provided as a result rather than something to take action upon. Since the visualization should be presented in a single screen it will be included in the real-time view.

The whole point of the KPI dashboard is to improve the motivation and to provide for better energy knowledge, to effect of the energy saving actions and efforts that are made. Therefore the KPI information field could contain statistics and provide information for awareness about instant feedback that would instantly improve the motivating feeling.

7.2 Convergent design process

In this section, the way of representing the data and abiding to the requirements is determined. This is characterized by motivating advantages of different solutions which facilitates decision making.

To select what ideas to go further with at this stage of the design process had a lot to do with the acceptance from the end-users. The requirements for supporting the mental model (M1, M2, M3) of the end-users does not allow for too unorthodox design. Standardized design in this case would imply the Volvo VPT standard for this group of end-users.

The concepts that was developed in the workshops was based on already known visualization tools and only focused on the energy *(figure 23)*. The "treemap" and the "screensaver" were abandoned since they had no positive influence on the focus group. The navigational window represents the factory layout (the u-shape of the line) and the big numbers was seen as *"a good idea"*. To represent the situation on the line is most similar to the end-users mental model, because it is what they are used to in the current DUGA system, the factory layout of the MD16 line. This can be solved by arranging data elements as object displays, as graphical representation of the machines that will consume energy and display this kind of data.

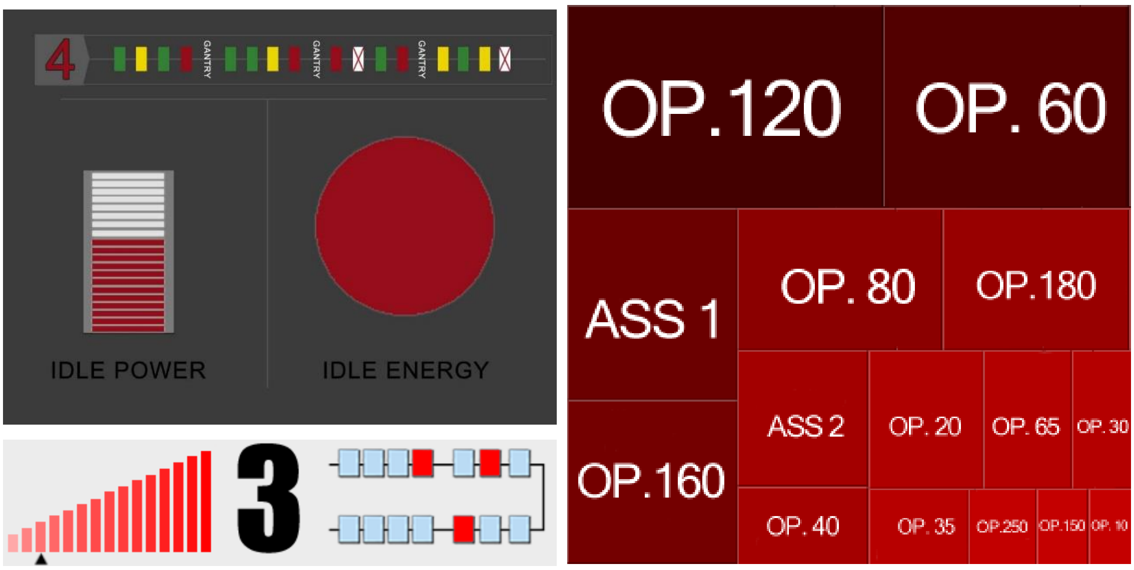


Figure 23. The three main concepts that was developed during the workshops. The screensaver concept (top left), the navigational window (bottom left) and the treemap (right).

Abstraction level

When regarding all the requirements (perception is first priority, followed by comprehension and mental model) the development of data elements that can serve as a machine representation seams more suitable. Regarding the layout of the data elements and their pixel allocation, the machine aspect is the least original but the most suitable way of representing the data. It is close to the end-users' mental model as it shares the machine abstract level in the same way as the DUGA software does, it would show a representation of the reality with gantry and machines. This starting point lead the development into a more real and substantial direction.

Data elements

The development started out with simple and non-detailed allocation of the data elements of the graphical user interface. When developing the machines representation and data in graphical form the idea was to create an object display for each machine on the line. Within the boundaries of the object display, i.e. the assigned pixel area, all the data and information about the machine is represented. The limits of these boundaries and the u-shaped factory layout are design variables that influence the size and shape of the object displays. In the first drafts, "data element allocation" design variable was elaborated on. Especially in the details of the layout, with the arrangement of the machines turned in another way *(figure 24)*.

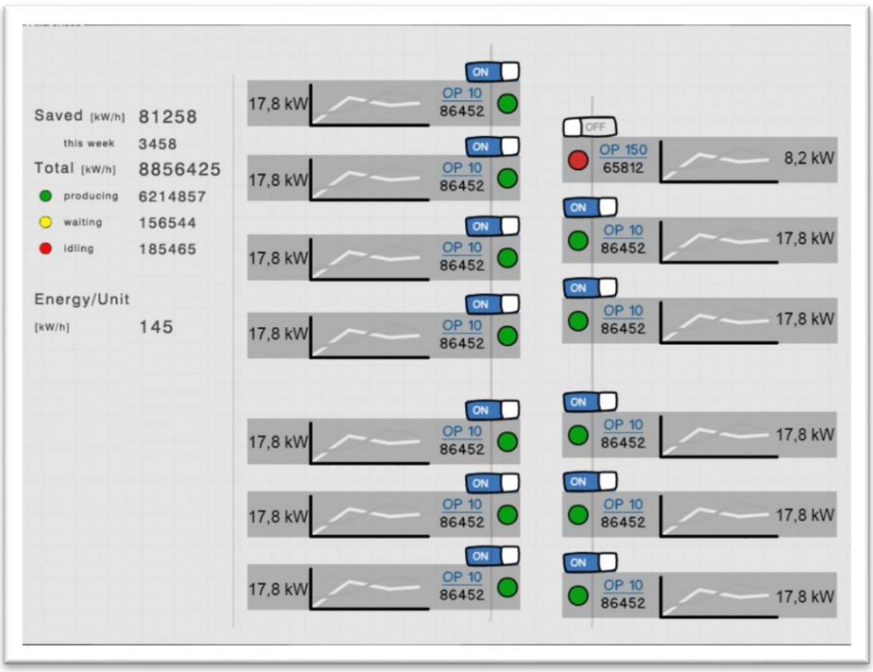


Figure 24.

The first wireframes tested the boundaries and features of the object display and its impact on the layout. The KPI dashboard is under development and featured to the left side of the visualization.

More drafts and wireframes were developed where the object display showed statistical data combined with real-time data on machine level *(figure 25)*. This was somewhat troublesome because the different machines have high variation in the power outtake, some machines have much higher peak of Watts during the cycles than others. The diversity would render big height differences in the power bars for the different machines and that would be hard to arrange in a good way. The other option would be to scale the power meter and the measurement, but scaling would be confusing when comparing the different machine's energy consumption and hard to distinguish between the machines. There is a balance between showing too much information and showing too little when visualizing data on machine level. The design variable is about finding that balance and having statistics under each machine always seemed to make everything cluttery and hard to distinguish and make out critical information.

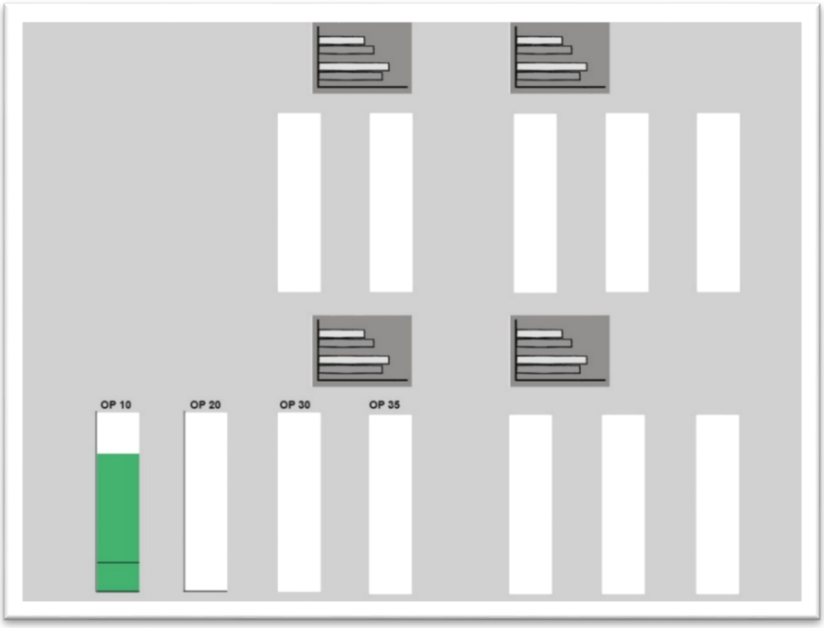


Figure 25.

Wireframes was made to elaborate with the features of the object displays and see how it influenced the design variables.

More and more the design variable leaned toward going with the circular shaped gauge meter. The gauge meter is an analog indicator of the power, the user reads the power outtake by the angle of the pointer in the gauge meter. This could be combined with a digital indicator in the middle to ensure a high precision measurement of the power outtake. The analog gauge would represent a symbol of a meter, for the feeling and look, to represent a measuring device.. The state color and a gauge can be merged, leaving a gauge with colored background that is showing both the state and the power usage, saving a lot of space and reducing clutter. Development of color codes was needed when the waiting state was discarded. The former yellow color for waiting is now included in the idling and all of it is red. A new color indicates "action taken", when the machine's energy consumption has been lowered. The new color can't be risked to be a source of confusion and therefore it must be unique. The color blue could refer to a mental model of a "cold" machine, but in DUGA the color blue indicate something completely different than "off". To avoid confusion this color must be avoided when expressing the "off"-state. The green and red color are consistent with the DUGA color code of the state. The layout was specified to how the machines are arranged in reality, it's a better logical path (from left to right) for the viewer and it match up better with the original factory layout.

More drafts were created *(figure 26)* where the gauge and state were combined in the object display. The gauge takes care of all the real-time data and hence the rest of the pixels in the object display can be utilized to give rich visual feedback, highlight important data such as idling or as in the draft in figure 26, show statistical data right on the object display.

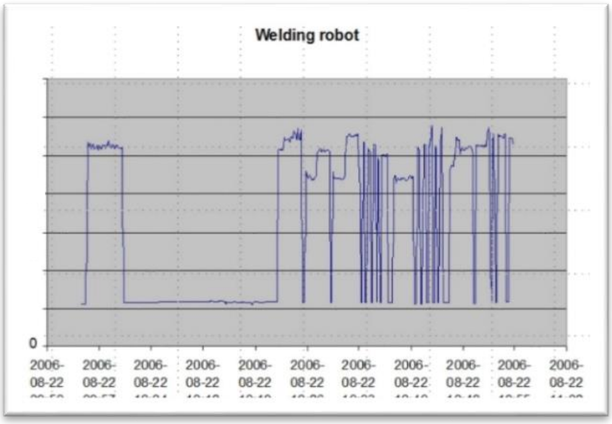
Figure 26.

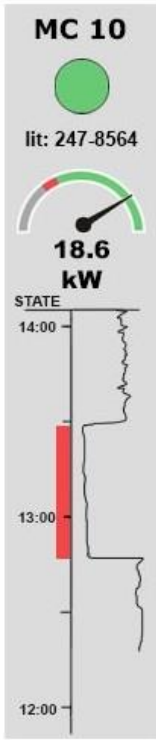
Layout and gauge design sketches (top) and wireframes (bottom).

Visual feedback - highlight important information

When highlighting the moment when there's a possibility to do something there are a few options to consider, most of which are linked to perception. But it's important to be careful about using flashing lights and sound that easily can be too much. Again, the idling is not equal to "switch off" and that's also a reason for not alarm the end-users too much. With regard to color blindness, the aspects of protanopia ("red blindness") and deuteranopia ("green blindness") needs to be considered when choosing means of illustrating the states and the visual feedback.

The Volvo standard of displaying real-time data is to show a data stream with power and time on the different axis *(figure 27).* The idea was to introduce a similar element, a time-frame that would keep track on any events of interest for the end-user. If an end-user could see the idle situation all over the production line, they could in advance be prepared for energy saving actions.





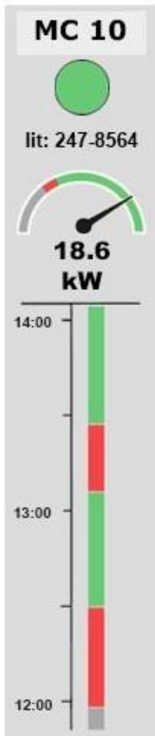


Figure 27.

Top:

The real-time data visualized as a data stream in a graph depicting time (x-axis) and power (y-axis).

Right:

The first versions of the object display that displays real-time data stream rotated 90 degrees and flowing downwards, with much clutter and vague distinction. The timeframe is showing too much information and highlighting "everything is fine"-issues.

The KPI dashboard

The requirement on showing KPIs for motivational reasons, M2 was developed parallel to the object display idea and secondary to the real-time data. The thought was to show the KPI statistics of the whole line instead of on machine level or station level, since the visualization represents the whole line even though the end-users work in teams based on stations. Every end-user is monitoring every machine through the visualization and these wireframes aimed to keep it simple and provide bar charts on a line level for environmental performance feedback. The first drafts of the KPI dashboard was comparing Value Adding energy (essential and necessary for production) to Non-Value Adding (idling, waiting and other) (*figure 28). Figure 21* shows the work in progress assigning a place for the KPI dashboard in relation to the other data elements of the dashboard. The relevant KPIs were considered and chosen together in the project team. Total energy consumption and today's energy consumption seemed sufficient KPIs for motivating the end-users.

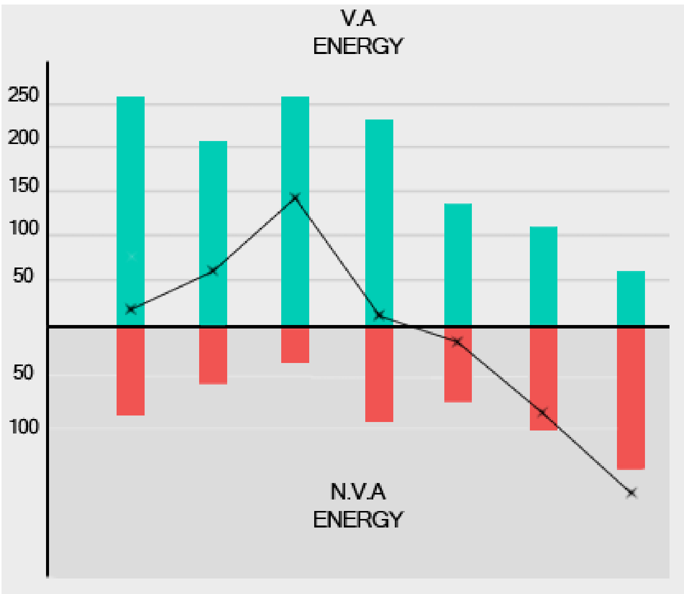


Figure 28.

The first design developments on how to visualize statistical data that are relevant for end-users.

8 Result

The final design of the dashboard is presented in this chapter. First a look at the dashboard's appearance to the users and then a more detailed description of the different features.

8.1 The object display

The object display was designed to be as big as possible and still suite the factory layout (the U-shaped line) and to fill the frame of the screen. A slightly asymmetrical power-meter to enhance the feeling of a greater value of the power usage as the meter turns and the digital number increase in value. The three states is visualized by the background color of the meter gauge where the arrow points. The states are "producing" in green, "idling" in red and "off" in grey. The machine is in the off state when it is using less electricity than if it remains in the idle state, i.e. if it has been switched off in any way.

The features are:

The machine's ID for end-users, corresponding to requirement M3.

Littra-number for maintenance and internal communication (M3).

Gauge that outlines the state and the power amount, which corresponds to requirement P4.

A precise power measure value, in redundancy with the gauge, P4.

A one and a half hour time-frame graph that is continuously updated to highlight the idling and show seriousness of past record. This is meeting the requirements P1, C1 and even C2 when looking at many object displays in a row.

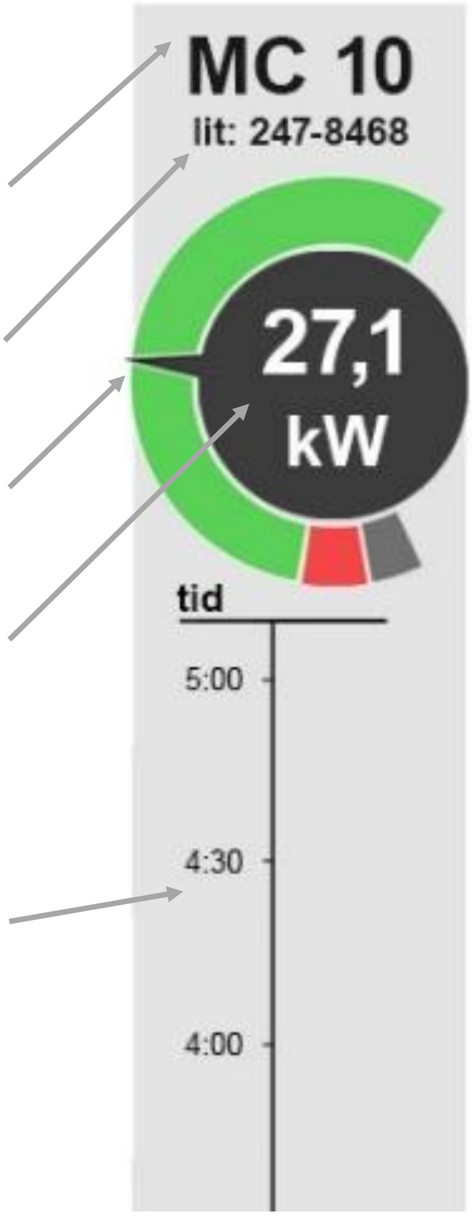


Figure 29. The appearance of the object display.

8.2 Visual feedback

To the right in figure 30, the first machine on the line (MC10) is shown. It is in the producing state and the power outtake is 27,1 kW. When the machine is in "producing" state the end-user should not do anything, the machine is using energy that is necessary for production. The object display is simply showing the value of the power usage, both in the angle of the arrow and in numbers, so called redundant information. The time-frame (5) is introduced for the purpose to highlight the important data. Instead of outlining a data stream of the real-time data the time-axis is "tilted" 90 degrees and "flowing" downwards continuously. In figure 30 the arrow is pointing downwards at the idle state, the red color is to inform about the idling situation. The power is shown by the value in the middle and as the machine goes into idling the energy (that is wasted) leaves a track in the time-frame graph. It's tracking the result of the idling situation as immediate follow-up information and also shows an illustration of the energy consumed (meeting requirement P1 and C1). The seriousness of the situation is thereby shown by the value of the power, 5,3 kW in the middle of the gauge and the end-user can figure out that 5,3 x 1,5 hours is the result of the energy waste for this machine's idling situation for the moment. The end-user can easily perceive and comprehend that idling is going on and that this machine has been idling for one and a half hours. In the off state the whole object display fades into white shade to illustrate that it is not able to produce at the moment, further providing visual feedback of "action taken" and meets the C1 requirement *(figure 30)*. The unlit appearance provides less clutter to the visualization and a clearer overview of the rest of the dashboard.

Figure 30.

Left: Producing state for the machine. The producing state is not highlighted in the timeframe.

Middle: Idling state for the machine, timeframe has recorded idling for 1½ hour.

Right: The off-state shows the machine with faded colors to illustrate inactivity.

8.3 The switch off/turn on sequence

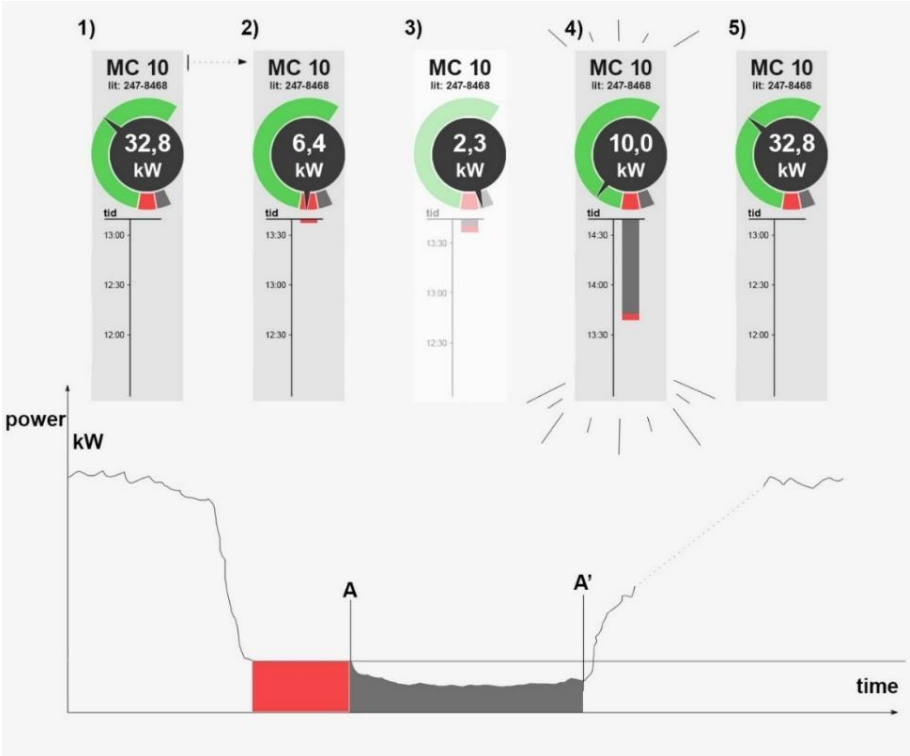


Figure 31.

The end-users' actions influence the object display, whose appearance changes as means of visual feedback for the end-users.

The way that the object display appears when looking at the dashboard during switch off and turn on sequence is described in *figure 31*, the different states is situated above the corresponding event in the power-time graph.

1. Machine MC 10 is producing, currently at 32,8 kW of power. This example shows the first machine on the line.
2. The machine has finished its cycle and is currently entering the idle state. The gauge drops downwards and the value decreases. The arrow is pointing downwards on the red idle state. The time-frame graph is highlighting and tracking the time of idling in red. Here, the end-user is realizing there's idling going on and has an opportunity to go and find out if there is any energy saving potential.
3. Evaluating the situation of the other machines over the line the end-user can proceed to check the run plan. The material feed situation is delayed (in this example) and the end-user makes a decision to switch off a few functions of the machine MC10. The arrow drops further down to the gray area which represents the off state and the value decreases. This shows the power usage which is lower than if continuing in the idle state. The object display is unlit and the gray color is tracked onto the time-frame graph.
4. After a while, the end-user receives information via the updated run plan about the new material situation and decides to turn on all of the machine's functions needed for production again. The object display is flashing slowly to communicate the warm up sequence and highlight this important information.
5. Up and running again (*see 1).*

The purpose of the time-frame graph is to leave out the excessive information and only focus on the important data, such as idling and when the machine is off – dedicated to the C1 requirement. The end-users react to the visual stimuli of idling and of the off-state, which signifies that the machine's energy consumption has been lowered and is "off". The flashing background of the object display when turned on is the only "flashing-feature" of the object display, minimizing the risk of eye fatigue. It only grabs the attention of the end-users in this manner. The idling and off states grabs the attention in a different manner, namely by the time-frame graphs growing track of red color, not flashing nor glowing – just growing over time.

8.3 The KPI dashboard

The KPI dashboard is a part of the dashboard where statistical data of the environmental performance is shown. This only contains data that is not real-time generated, it is like a score board of the end-users performance. The data is divided into the different states (including the off state) and is visualized in bar graphs. It shows the total energy consumption of the month and of the current day and also how much has been saved through the end-users' actions *(figure 32)*. Besides from total results, it also shows today's result in terms of energy consumptions per produced unit. The delivery output signifies how many parts that has been produced today.

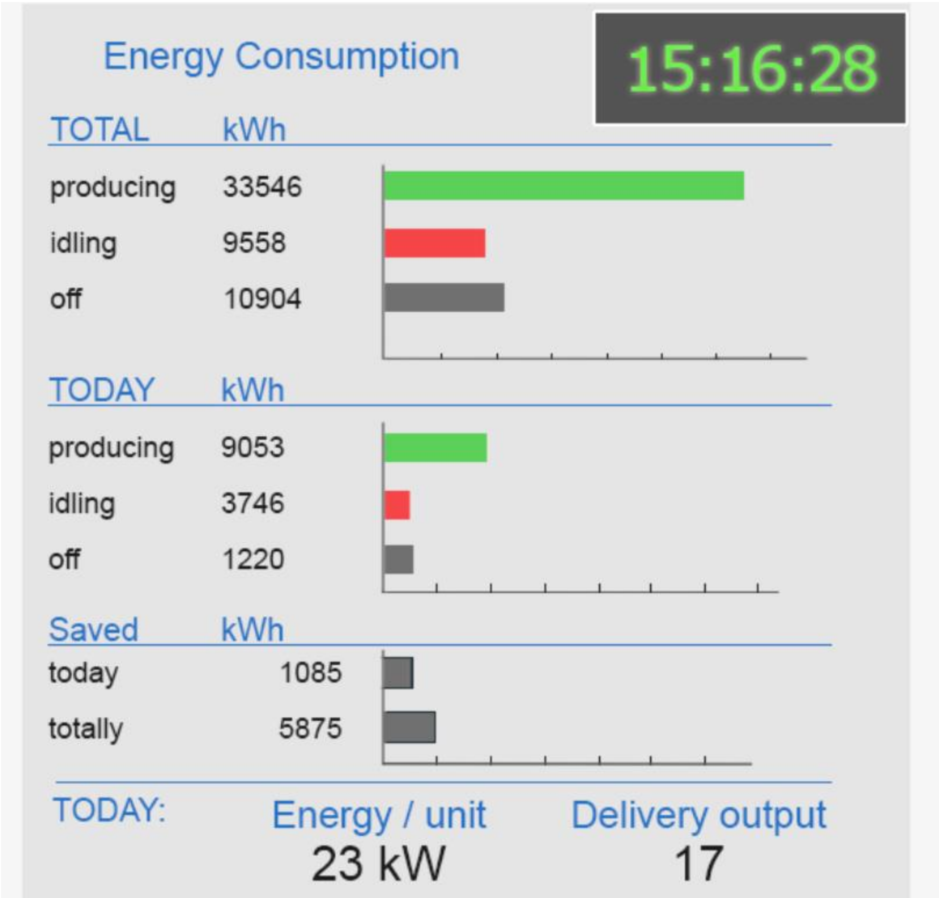


Figure 32. The KPI dashboard of the visualization is displaying environmental performance.

8.4 The Dashboard in total

The machines are represented as object displays and are arranged in the u-shaped factory layout, i.e. the same way as they are on the factory floor. A brown line helps to group the machines into four stations. This is fulfilling the requirement of the mental model for the user and is estimated to have higher acceptance value for the end-users. In figure 33, this “screen dump” shows the machines SPC250, W180, MC35 and SPC40 all in an the off-state. The MC30 machine is currently idling at 5,2 kW. Machine W160 is warming up after being switched off. All the machines on the line are visible so that the energy use in production can be monitored over the whole MD16 line at a glance, which is requirement P2. Since it is not divided and grouped into entities, the dashboard shows data of all the machines on machine level, which answers to requirement P3. As a bonus it provides an overview of the line.

When watching the machines over the line in a single screen, the end-users can compare the machines performance over time (req. C3). Perhaps the end-users will discover patterns in the generated tracks on the time-frame graphs. If end-users realize by monitoring the dashboard that a machine, positioned earlier on the line than the one they are operating, is idling then this will give an opportunity to investigate in upcoming energy saving potentials, which is corresponding to requirement C2 – overview of the material flow. These effects can support the decisions on when to go on to get more information from the run plan.

Figure 33.

When observing the visualization screen on the factory floor in the afternoon, this is what meets the eyes of the end-users.

The *figure 34* shows the dashboard's appearance when the end-users come to work in the morning is shown, if all the machines are switched off during night that is. The KPI dashboard is showing yesterday's results. This can be discussed between the operators and the shift leader and during the morning meeting before starting the first shift.

Figure 34. The appearance of the dashboard when every machine is turned off, at 05:16 in the morning in this image.

Figure 35 shows the dashboard as it would look like for a person with different types of color blindness. In both cases the distinction between the different states can be made, although the color selection works a little bit better for persons with protanoipa color blindness (“red” blindness) than for the people who are more sensitive to green colors, the deuteranopia deficiency.

Figur 35.

The appearance of the dashboard if regarded through the eyes of a person with protanopia deficiency (left) and deuteranopia (right).

9 Discussion

In this chapter, the result is discussed with regard to the aim and objective. The methods that were used and the procedure that the project underwent is commented.

The key problem and the main issue of this project has been to cut down the unnecessary use of energy in order to be more environmental friendly and at the same time more cost efficient. The unnecessary energy, called idling, was identified through measurement of the energy consumption in real time. This was made possible due to installation and configuration of energy measurement systems, EMS.

In order to address the idling, visualization of production data, provided by the EMS has been done and a dashboard has been produced. The dashboard can be regarded as visually efficient because it shows the power outtake and the corresponding state (out of which idling is one) of all the machines on the MD16 line in a single screen. The idling state is particularly distinguished by highlighting a part of the machines' outline during the time of idling. By highlighting the idle time of every machine on the production line in a single screen, the end-users can see when there is an opportunity to switch off a machine and proceed to further investigate this possibility. The dashboard communicates recent history of power use and energy waste and through KPIs, and it also presents perspicuous information in order for the end-users to gain better situation awareness.

The methods that have been used and the procedure this thesis has gone through is arguable, in retrospective it could have been executed better. Some methods were very poorly executed, such as the focus group interviews. Other things just did not work well, above all the communication within the project team and with the focus group. The subjective needs is not consistent with the objective needs. Also, the subjective information of the daily routine was different from the description in the KAP pre-studies. This was never discussed in the project team but is an important issue to regard. Contradictions and consequences are concerns of the personnel that cannot be disregarded. There are task descriptions on how to do to reach the system goal, which is to examine the run plan monitor, hence the organizational problem. The end-users have a delivery output to consider, which is jeopardized by switching off the machines in order to save the energy waste, hence the conflicting goals. When the machines are off the risk of bad tolerances on the upcoming parts increase, the consequence will affect the delivery output. The delivery output is the right amount that should be produced within the time frame of all the shifts or the whole day.

The field of human-factors is focusing much on goal oriented design solutions and holistic view of systems. Focus has been on the overall need to consume less energy, which has been set as the system goal of the initial system in this case. More issues were discovered concerning the system goal and how it could be reached which was left out due to the delimitations, one of them is the execution of energy saving actions. As a sequel in a series of steps towards achieving the system goal (identify the idling, visualize the energy consumption and show the idling) the result of the master thesis can be beneficial for the system goal. However, there was no possibilities to do usability testing to validate the design of the dashboard. The next step is to address issues regarding the "switching off"-action that the end-users has to make in order to lower the energy consumption.

To reach the original system goal even better, there must be more data sources included in the visualization, if it's going to work and function as something to make decisions and take action from. It is not enough by visualizing only the real-time measurement of power outtake and the idling, the visualization must include more functions. You cannot make judgments of a future status based on the current energy consumption. Therefore, it is irrelevant what the current energy consumption is if you don't know the upcoming events for the machine, especially when there are many different start-up times, cycle times and tolerances to consider. Therefore, the setup of the run plan is the most important information for knowing how much of a machine that can be shut down, but as stated many times this information is not known at the moment. The next generation of visualization could include more information, such as automatically performed calculations of possible savings and also the material flow situation and the available time for switch off action, if this action still is going to be made manually.

10 Conclusion

This chapter presents the reflections and insights that the whole thesis work it has given.

The aim of lowering the unnecessary energy use could be supported in many ways, one of which is by a monitoring dashboard. Even though the objective was achieved, the result has not been tested on the MD16 line and it has not been evaluated by the focus group. To meet the aim of the thesis I would have wanted to measure the effect of the result, to see if the dashboard gave rise to a change in the behavior of the different personnel of the MD16 line. There was no time to follow up on that in this project and it is uncertain whether this result or another result from the KAP-project is going to be installed on the MD16 line as the final result, the deliverable.

However, the conclusion that can be drawn from the thesis is that it is not possible to address all the actions needed for an end-user to perform with this type of raw data, hence there is a need to visualize more data, including data from the run plan and error messages to aid internal communication – if it is still going to be performed by a human.

11 References

Bligård, L.-O. (2009). *Cognitive ergonomics* [handouts]. Chalmers University of technology, Göteborg, Sweden.

Bligård, L.-O. (2011). *Utvecklingsprocessen ur ett människa-maskinperspektiv.* Institutionen för produkt- och produktionsutveckling [report]. Chalmers University of technology. Göteborg.

Carlsson B. (1984). *Grundläggande forskningsmetodik*. Stockholm, Sweden. Almqvist & Wiksell Förlag.

Cooper, A. Reimann, R. & Cronin, D. (2007). *About Face 3 - The Essentials of Interaction Design*. Indianapolis, USA. Wiley Publishing.

Few, S. (2006). *Information Dashboard Design – the effective visual communication of Data*. Sebastopol, USA. O'Reilly Media.

Hanarp, P. & Bengtsson, C. (2008). *Idling in production processes* [internal document]. VOLVO: ER-531018. Volvo.

Hanarp, P. & Bengtsson, C. & Persson, S. (2009). *Energy monitoring and control* [internal document]. VOLVO: ER-531042. Januari 2009. Volvo.

Hågeryd, L. Björklund, S. Lenner, M. (2007). *Modern produktions teknik; Del 1.* Stockholm, Sweden. Liber.

Jordan, P.W. (1998). *An introduction to Usability*. London, UK. Taylor & Francis Ltd.

Karlsson, M. (2007). *Lyssna till kundens röst - Att identifiera, analysera och kommunicera kunden och användarens krav på tekniska produkter och system.* Göteborg. Department of Product and Production Development, Chalmers

Karlsson, M. (2008). *Usability; Metoder och verktyg* [handouts]. Chalmers University of technology, Göteborg, Sweden, 2008.

Knowledge, awareness, and prediction of man, machine, material, and method in manufacturing (KAP) (2011a). *D1.1 Report of existing research and best practice in energy awareness* (KAP deliverables report). European Union: Seventh framework programme. http://www.kap-project.eu/index.php?id=607 [last retrieved 20150330]

KAP (2011b).*D4.1 - Visualization State of the Art & Cognitive Task Analysis* (KAP deliverables report) [access restricted]. European Union: Seventh framework programme.

KAP (2012). *D4.2 Visual design and Visualization framework architecture* (KAP deliverables report). European Union: Seventh framework programme. http://www.kap-project.eu/index.php?id=607 [last retrieved 20150330]

Osvalder, A.-L. (2006). *Ergonomi* [handouts]. Chalmers University of technology, Göteborg, Sweden.

Osvalder, A.-L. & Ulfvengren, P. (2007). *Work and technology on human terms Chapter 7; Human-technology systems*. Stockholm, Sweden. Prevent.

Porathe, T. (2012). *Information Visualization* [Power Point presentation]. Information Visualization, Chalmers University of technology, January 2012.

Ware, C. (2008). *Information Visualization – perception for design (second edition).* San Francisco, USA. Morgan Kaufmann Publishers.

Yau, N. (2011). *Visualize this, the flowing data guide to Design, Visualization, and Statistics*. Indianapolis, USA. Wiley Publishing.