# CHALMERS


# FACILITATING THE DRIVER INTERFACE OF MARINE VESSELS

*- Development of hardware and graphical user interface for an information device*

*Master of Science Thesis*

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2013

Department of Product and Production Development
Division of Design and Human Factors

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# ABSTRACT

This master thesis involved the development of a new interface device for leisure marine vessels, aimed at simplifying the driving experience. It was carried out at the department of Product and Production Development at Chalmers University of Technology and in collaboration with CPAC Systems AB.

Today the market is experiencing an influx of a new type of consumer with less traditional values and boating experience. The new consumers have higher demands for a visually appealing, understandable and ergonomical driving interface. In addition, the marine industry has experienced fewer advancements in technology and design compared to the car industry, which is mainly due to that sales volume of marine vessels do not allow the same level of investments in research and technology. And as the global economic downturn has lowered the perceived value of marine products, it is important to explore the possibility of improving the driving experience by implementing new technologies that can provide added user value at low costs.

The project involved a pre-study on boating, which showed that the driving experience is diverse and depends on many factors such as weather, lighting conditions and personal preferences. Moreover, it was discovered that the marine environment is harsh and affects the mechanics of the product as well as the human-machine-interaction. The final concept is a robust touchscreen device that displays engine and vessel information. It has been designed to withstand the marine environment and features a graphical user interface that is simple and easy to use.

*Keywords: marine, display, usability, interface device, product development*

# ACKNOWLEDGEMENTS

This report is the final examination for a Master of Science in Industrial Design Engineering at Chalmers University of Technology in Gothenburg, Sweden. During this project many people were involved and contributed to the outcome. We would like to thank everyone for their time and effort.

It has been very valuable to carry out the project at CPAC's head office. The close relations with all colleagues have helped progress the project and substantially raise its quality.

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Finally we want to thank our friends and family for supporting and encouraging us throughout the project.

David Carlson and Peter Forsaeus,
Gothenburg, 2013

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# 1. INTRODUCTION

*In this chapter an explanation of the background and scope of this master thesis is given. It contains the purpose and goal statements and the research questions that sets the basis for the project. A report outline in the end of the chapter gives an overview of the content of this report.*

## 1.1 Background

CPAC Systems AB (hereafter referred to as CPAC) belongs to the AB Volvo group and develops electronic control systems intended to provide intuitive driving of different kinds of vehicles. These vehicles operates in demanding environments and are boats, trucks and industrial and construction machines. The control systems include control and information devices, whose purpose is to provide the driver with engine and vehicle information as well as means to control the vehicle itself.

CPAC's main business area is the marine sector, for which they have developed Electronic Vessel Control system, or the EVC system. The marine industry has experienced fewer advancements in technology and design compared to the car industry, which is mainly due to that sales volume of marine vessels do not allow the same level of investments in research and technology. Despite this, CPAC are determined to cost-effectively develop the EVC system and provide a driving interface that further improves the driving experience.

A recent trend in the marine market is an influx of a new type of consumer with less traditional values and boating experience. The new consumers have higher demands for a visually appealing, understandable and ergonomical driving interface. Also, the global economic downturn has made the perceived value of marine vessels more sensitive. This has resulted in that new marine products need to provide additional customer value at competitive prices.

The current display lineup of the EVC system includes three displays, of which two are small sized. CPAC are interested in assessing the demands and requirements of this market segment and how a future concept could be design to align with these. Moreover, as the current displays are purchased from external suppliers, developing a display in-house would result in cost reductions and that CPAC would have the ability to faster react and resolve potential technical issues. This master thesis project constitutes the analysis of the current boat driving situation and the development of a conceptual device with focus on appearance, usability and construction.

## 1.2 Purpose and aim

The master thesis' purpose is to investigate demands and requirements regarding design, interaction, construction and assembly for information devices and to provide a conceptual solution that fulfills these.

The aim of the master thesis is to design a cost-effective information device that will simplify the boat driving by providing relevant information in an intuitive and clear manner. Thus, the device shall be robust in order to withstand a marine environment, be placed at driving positions and display information from the engine and metering devices in a way that is quickly understandable. The result of the thesis is an analysis of the current boating situation, regarding the boating experience, stakeholder demands and environmental influences, and a physical prototype intended to be used for further construction and evaluation of appearance, size and format, usability, manufacturing and cost.

## 1.3 Delimitations

The following delimitations were made:

- The user profiling is based solely on Swedish users. It may also represent users from other cultures as well, though this is not proven in the thesis.
- The entire interface was not designed and evaluated. Some views were designed in conceptual form and their contents were therefore not questioned.

## 1.4 Report outline

*Chapter 1 - Introduction:* In this chapter an explanation of the background and scope of this master thesis is given. It contains the purpose and goal statements and the research questions that sets the basis for the project.

*Chapter 2 - The EVC System:* In this chapter an introduction is given about the CPAC-developed Electronic Vessel Control (EVC) system, a fully electronic boat steering system that is a part of the context and poses requirements to and defines constraints around the interface device. Following is a detailed description of the reference products and at the end of the chapter are the stakeholders for the EVC system and their intricate relationships presented.

*Chapter 3 - Usability Theory*: This chapter contains the theoretical usability framework utilized in the thesis. Starting the chapter is Patrick W. Jordan's ISO definition of usability. The components of usability and users' characteristics on usability, as defined by Jordan, are then presented. In the end of the chapters are Jordan's ten principles of usable design described.

*Chapter 4 - Methods*: This chapter features theoretical descriptions of the used methods throughout the project. Each description also includes an explanation of how they were used in this specific project.

*Chapter 5 - Procedure*: This chapter will give a description of the model that the project has followed and relate the model to the outline of the report. Here the reader can learn which phases were implemented and why.

*Chapter 6 - Problem Definition:* This chapter will provide an understanding of the current problem situation and includes user and usage profiles, technical and use-related issues, market and life-cycle analyses. It ends with an initial requirements listing and a summary of the most important learnings.

*Chapter 7 - Use Situation Design*: This chapter will explain the intended use of the product, it frames this by describing the desired use situation and a scenario to illustrate the sought feeling and expression. After this a Design Format Analysis (DFA) of the Volvo Penta brand and a Mood board are presented to concretize, define and visualise the intended expression and direction of style. Ideas for new interaction and functions are presented towards the end of the chapter where they are also evaluated. Ending the chapter is a refined requirements listing and a summary.

*Chapter 8 - System Level Design*: This chapter introduces a hardware and a software architecture that are intended to solve the identified problems and achieve the desired use situation. These architectures result in a number of prerequisites that needs to be addressed when developing concepts, which are presented in the end of the chapter.

*Chapter 9 - Detailed Design and Construction:* This chapter gives a thorough description of both the hardware and the graphical user interface (GUI) development phases. The first part of the chapter contains the hardware development phase, which begins with the decision of an appropriate touch panel technology and continues with the construction of a hardware design around it, with the use of design variables. The second part of the chapter, which contains the GUI development phase, starts with the introduction of design concepts for the layout and interaction. These are evaluated and then further refined in a GUI concept with a graphic layer. Ending the chapter is a refined list of requirements, compiling the outcome of the phase.

*Chapter 10 - Final Concept:* This chapter will present the final concept. It is divided into a detailed description of the hardware - featuring construction, mounting and assembly - and the GUI - featuring usage and additional improvements. Lastly, both are treated with a final evaluation resulting in potential future improvements.

*Chapter 11 - Discussion:* The discussion starts with connecting back to the projects initial aim and relates it to the projects execution and result. A discussion is held on the identified uncertainties of the concept that need further evaluation and consideration. The next part handles process-related reflections and lastly a summary of our future recommendations is found.

*Chapter 12 - Conclusion:* The conclusions for this project empathises the importance of the thesis by referring back to the pre-study. It also synthesises the most important points from the results and puts the result in a larger perspective.

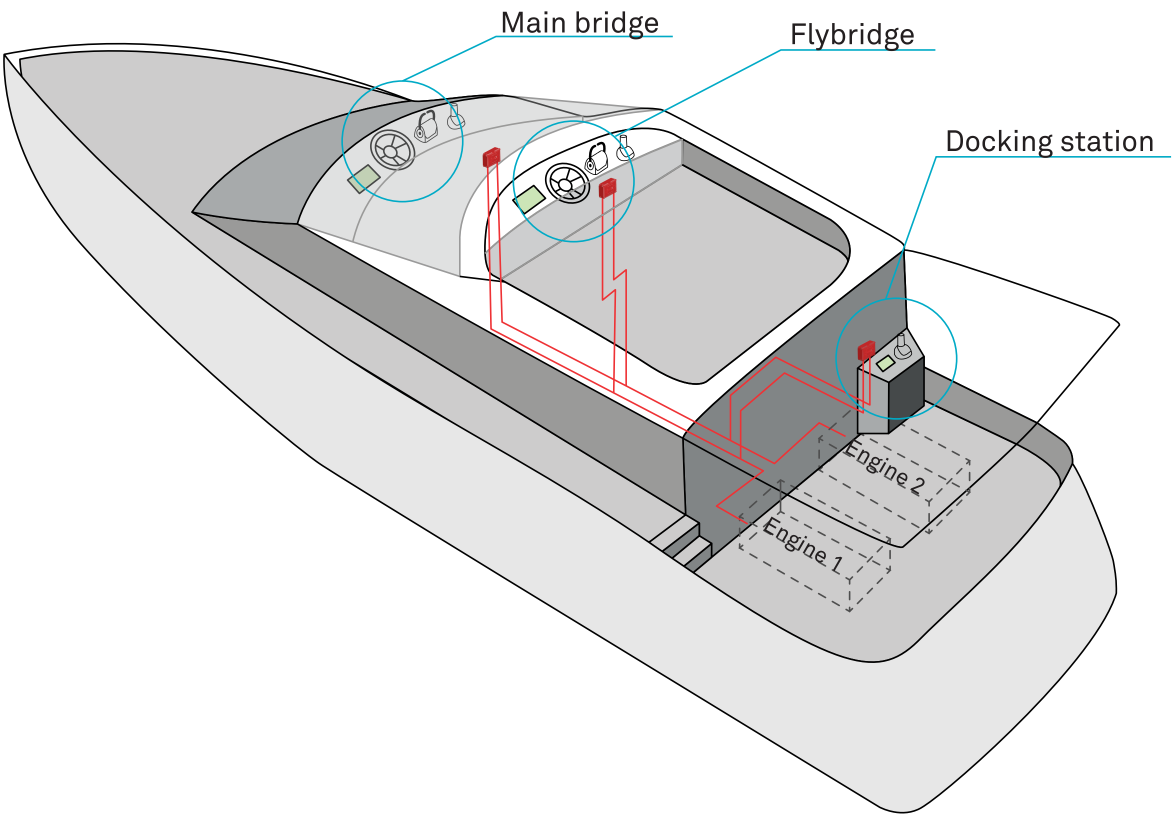


*Figure 1. A boat can contain several helms, all of which are connected to the EVC system.*


*Figure 2. Technical description of an example EVC system installation applied on a twin engine installation with a flybridge and a docking bridge.*

# 2. THE EVC SYSTEM

*In this chapter an introduction is given about the CPAC-developed Electronic Vessel Control (EVC) system, a fully electronic boat steering system that is a part of the context and poses requirements to and defines constraints around the interface device. Following is a detailed description of the reference products and at the end of the chapter are the stakeholders for the EVC system and their intricate relationships presented.*

## 2.1 The EVC system

The EVC system is a control system that is intended to allow a boat driver to govern a motorboat in an intuitive manner. The system transfers the drivers control actions from the boats driving positions, called helms, to the engine and displays the engine's response. It can also help the driver control the boat via automatic functions. The number of helms depends on the size and type of the boat and customer wants. However, there is always only one main helm station. The other helms can be located at various locations such as the flybridge or docking station, see Figure 1. The EVC system is designed for, and only used in, marine applications (Volvo Penta, 2013).

Boats can have single, twin, triple or quad engine installations and on each engine a computer called Engine Control Unit (ECU) is placed. This unit has direct control over the entire engine and steers fuel injection, engine speed, etc. Volvo Penta is responsible for this device.

CPAC develop the EVC system, see Figure 2 for a technical description. This system communicates with the Engine Control Unit (ECU) through a Powertrain Control Unit (PCU). The Powertrain Control Unit (PCU) is a computer controlling one driveline and is connected to the boat's driving positions, called helms.

For each helm-station, a Helm Control Unit (HCU) is placed. The Helm Control Unit (HCU) controls the specific helm station by receiving data from the controls and displays and sending it to the correct Powertrain Control Unit (PCU). The type of controls and displays installed depends on engine installation, boat size, boat type or customer requests. CPAC and Volvo Penta together develop several displays and controls for the different types of installations.

### *2.1.1 Displays*

CPAC have three types of displays in their product portfolio that are designed for the EVC system, see Figure 3. These are sized 2,5", 4" and 7" and are internally in the company named Flexi-display, G4 and 7" respectively. For convenience, these names will be used throughout the report.

The displays provide information about the EVC system and the engines, such as vessel speed, engine revolutions per minute (RPM), fuel level etc. The Flexi-display can also be used to activate or deactivate certain EVC functions and adjust their settings. The Cruise Control function is an example of this where the Flexi-display allows the driver to activate the function and to adjust the desired speed the vessel shall keep.

The three displays are aimed at different market segments and boat sizes. The Flexi-display is intended for smaller boats in the low-end segment and can handle information from one single driveline. The G4 display is intended for small-to-medium sized boats in the middle market segment. It can display information from up to two engines. High-end larger boats is the segment where 7" display is aimed at, which is why it is capable of handling information from up to four engines.


*Figure 3. From left to right: Flexi-display, G4 and 7"-displays. (Image source: Volvo Penta, 2013)*


*Figure 4. Analogue gauges are still common in the market today thanks to their low cost.*


*Figure 5. Chartplotters with large screens are available on the market, however, they cannot display all the information from the EVC system. (Image source: Garmin, 2013)*

Analogue gauges, see Figure 4, are still commonly used in many marine vessels, as they are cost-effective. However, in recent years digital instruments are becoming more common (Stigeberg, 2013, Bergström, 2013). There are also larger displays on the market, such as chartplotters, which can handle information from different sources, see Figure 5. However as these displays cannot display all the information from the EVC system, there must always be a dedicated EVC system display installed on a boat.

### 2.1.2 Controls

The EVC system has different controls for operating the boat, these are illustrated in Figure 6. All boats have at least one throttle control unit and a steering wheel placed at the main driving position. The type of installed throttle control depends on boat type, engine installation and customer wants. For the propulsion systems IPS, with two or three engines, and Aquamatic a joystick control can be implemented. This allows the boat driver to steer the boat in the same direction as the joystick is tilted.

Included in the EVC system is also an Electronic Key System. This consists of a panel and a portable RFID-key (Radio Frequency Identification) which is used to start the EVC system and the engines. The panel is placed at the main driving position.

### 2.1.3 Propulsion systems

Volvo Penta develop and sells three types of propulsion systems, called Inboard Performance System (IPS), Aquamatic and Inboard. The EVC system controls these systems through the controls and displays.

#### *Inboard Performance System (IPS)*


*Figure 6. The control devices of the EVC system, from left to right: joystick, Helm Control Unit (HCU), Electronic Key System. (Image source: Volvo Penta, 2013)*

In the Volvo Penta IPS, the propellers are forward facing in a pulling position, see Figure 7, contrary to the traditional pushing position. The system gives benefits in efficiency and maneuverability. The boat range for this system is between 30 to 100 feet (ca. 9-30 m), depending on engine size and number of IPS-systems.

### *Aquamatic*

The Aquamatic, also called Stern drive, system combines inboard and outboard advantages, where the engine(s) are placed inside the boat and the propeller(s) are placed as on a outboard engine system, see Figure 8. This system can be used with single or double propellers. It is commonly used for sport boats ranging between 20 to 45 feet (ca. 6-14 m), depending on engine size and number.

### *Inboard*

This is a traditional inboard engine, where the engine is centered in the boat and connected to the propeller via a straight shaft, see Figure 9. The system is used for various types of boats and sizes. Maneuverability is limited compared to the other installations.

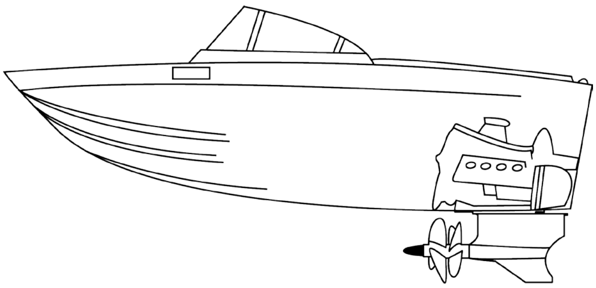

*Figure 7. The IPS system pulls the vessel forward with the forward facing propellers.*

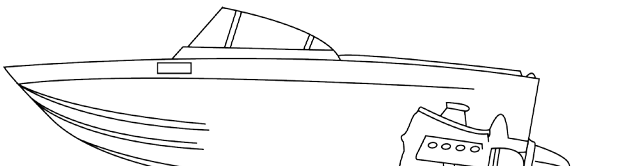

*Figure 8. In the Aquamatic propeller system the engine is directly connected to propeller, therefore minimizing the required space.*

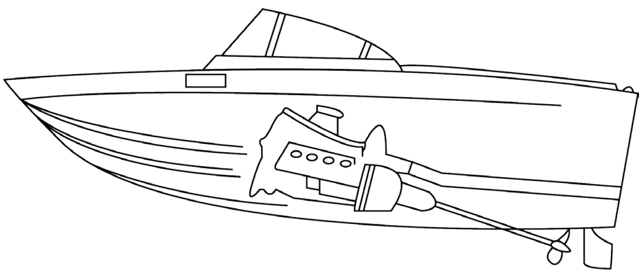

*Figure 9. The Straight shaft propulsion system contains a long straight shaft between the engine and the propeller.*

## 2.2 Reference displays

The Flexi-display and the G4 display, shown in Figure 10 are the small-screen segment of CPAC's display lineup. These are installed on boats sized above 16 feet (5 m) and they can both display all the information from the EVC system. The Flexi-display is the most commonly used display and is the simplest and most low-cost product in the EVC system. However, thanks to its small size and versatility it is also used in high-end boats. Figure 11 illustrates the wide range of boats the displays can be installed on.

The applications for the Flexi-display and the G4-display have both similarities and differences. Both displays can be used to display engine and vessel information, such as vessel speed, revolutions per minute (RPM) or fuel level. Both are also used to inform the driver about engine errors. If the EVC system detects an error, a sound will emanate and the screen will automatically display an alarm message. The alarm screen consists of two automatically alternating screens, one showing error information and code, and the other one showing a required action for risk reduction.

The displays are manufactured in relatively small volumes (8-10 000 units), which is why CPAC utilise the same hardware for different applications in order to gain economies of scale. This also means that development costs are reduced and that a greater focus can be kept on developing new software functions and applications.

### 2.2.1 Usage

The hardware buttons, found below the screen on each device, are used to navigate in the graphical user interface


*Figure 10. Front and rear of the Flexi-display (top) and G4 display (bottom).*

Figure 11. The displays can be found on smaller motorboats as well as on yachts with multiple helms. (Image source: Nimbus, 2013)

(GUI). In the more simple Flexi-display, each press on one of the two middle buttons changes one information flow, such as speed, water depth, engine oil pressure, water temperature etc., at a time. Figure 12 illustrates the GUI structure. The type and order of the information is pre-configured to display engine RPM, oil pressure, coolant temp and battery voltage. However, the driver can choose to display any other available information via a settings menu, which is found at the far right of the interface structure. In the settings view, the driver can also change engine settings such as: Drive mode, Toe angle, Trip etc. Here are also display specific settings located, such as contrast, brightness, beep level, etc.

On the G4 display the navigation works similarly, but with the differences that horizontal navigation changes views, which contain multiple information flows, see Figure 13. These views are called My View, Vessel View, Engine View, Fuel economy and Battery Management. In this interface, the settings view is found on the right end before a warnings manager, and here the user can make similar customisation as with the Flexi-display.

Both displays contain a warnings manager. Active alarms are displayed here and the user can read previously dismissed error messages. The messages also contain ID numbers used by service personnel.


Figure 12. The GUI for the Flexi-display is navigated by pressing on the two middle buttons, which changes one information flow per press. On the far right is the settings view. (Image source: Volvo Penta, 2013)


Figure 13. The GUI structure of the G4 display is horizontal and contains views with up to six informations flows shown simultaneously. (Image source: Volvo Penta, 2013)

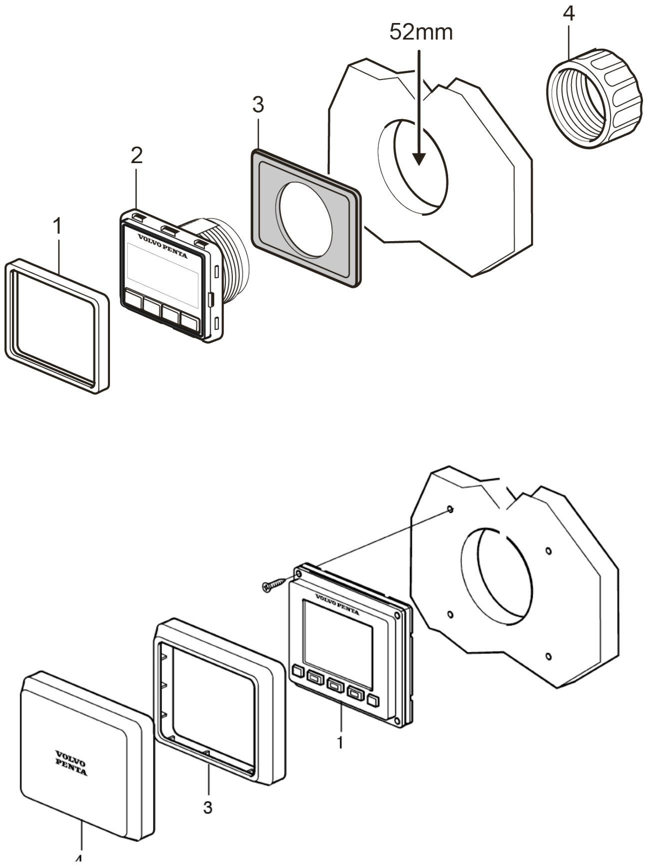


*Figure 14. Surface mount of Flexi-display (top) and G4 (bottom). (Image source: Volvo Penta, 2013)*

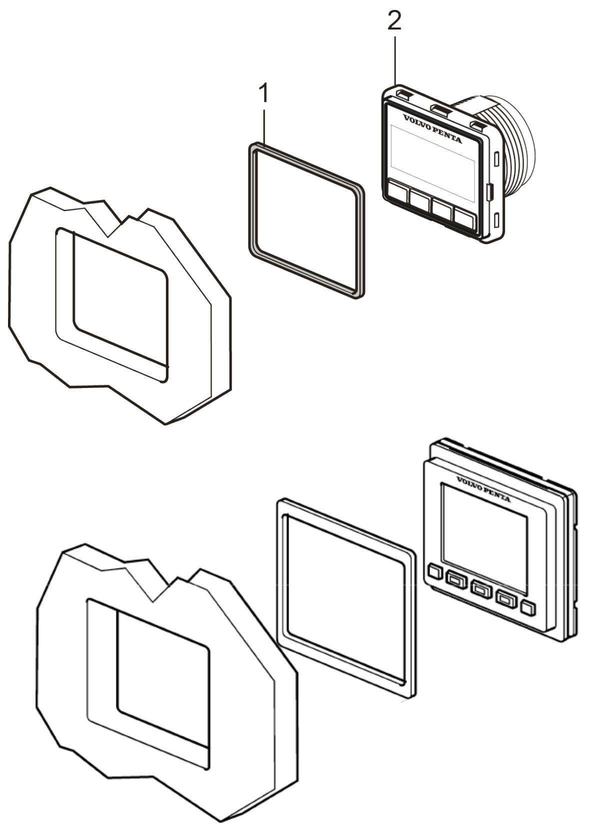


*Figure 15. Flush mount of Flexi-display (top) and G4 (bottom). (Image source: Volvo Penta, 2013)*

### 2.2.2 Mounting on helm

The reference displays can be mounted on the dashboard in two ways: surface mount or flush mount. Surface mount is when the device is mounted on the exterior surface of the dashboard, or other surfaces on the vessels such as a docking station. It is accomplished by drilling a circular hole of 52 mm or 85 mm size for the Flexi-display or G4 display respectively.

The Flexi-display is attached by hand-screwing a plastic bolt from the rear, also a sealing is placed between the display and dashboard to prevent water leakage. When installed, a plastic bezel is attached on the front of the display, see Figure 14. For the G4 display, it is mounted in a 85 mm hole and then attached to the dashboard by four 4.3 mm screws, here the sealing is already attached to the back of the display. Similarly to the Flexi-display, a plastic bezel is attached on the front of the display when installed. Surface mounting is generally used in low-end boats and when installing additional equipment on a finished dashboard, because of its simple installation.

Flush mounting is done by attaching the device from the rear of the dashboard, see Figure 15, so that the instrument is level with the exterior surface. For flush mounting, a square hole is sawn matching the outer dimensions of the display's front. The display is then attached from the inside of the dashboard with a gasket in between. The gasket ensures that the display is firmly installed on the dashboard frame. Flush mounting is generally used on high-end boats because it provides a more aesthetically appealing installation of instruments (Thorsson, 2013).

## 2.3 Stakeholders

The products that CPAC sell have many stakeholders that impose demands of different characters (these are described in *Chapter 6. Problem Definition*). As a result, it is crucial to consider all the stakeholders when developing a new interface device. Following is a description of the stakeholders and their relationships:

1. Consultant companies help CPAC develop and manufacture the hardware for some displays and controls.
2. CPAC then develops and delivers the hardwares and the control system EVC for Volvo Penta's engines to Volvo Penta
3. Volvo Penta combines and sells their engines together with CPAC's system to different boat manufacturers. The boat manufacturers can customize what kind ofequipment they want for each boat.

4. Volvo Penta also sell parts and accessories for the engine and control system directly to retailers.
5. Boat manufacturers sell their new boats either directly to a customer or through a boat retailer.
6. The boat retailers sell boats, new or second hand to customers.
7. The accessory retailers buy parts directly from Volvo Penta and then sell them to customers.

As can be understood from Figure 16, CPAC are distanced from the end-users. This makes it harder for them to gain direct customer input and most issues are brought to their attention through Volvo Penta or through boat manufacturers. CPAC have no contact with any retailers as they are not responsible for the product itself.

Furthermore, the products CPAC develop are entirely Volvo Penta branded. This makes customers believe that the entire control system is done by Volvo Penta, which makes the relation between Volvo Penta and CPAC very important as they both are dependant on the other party's performance.

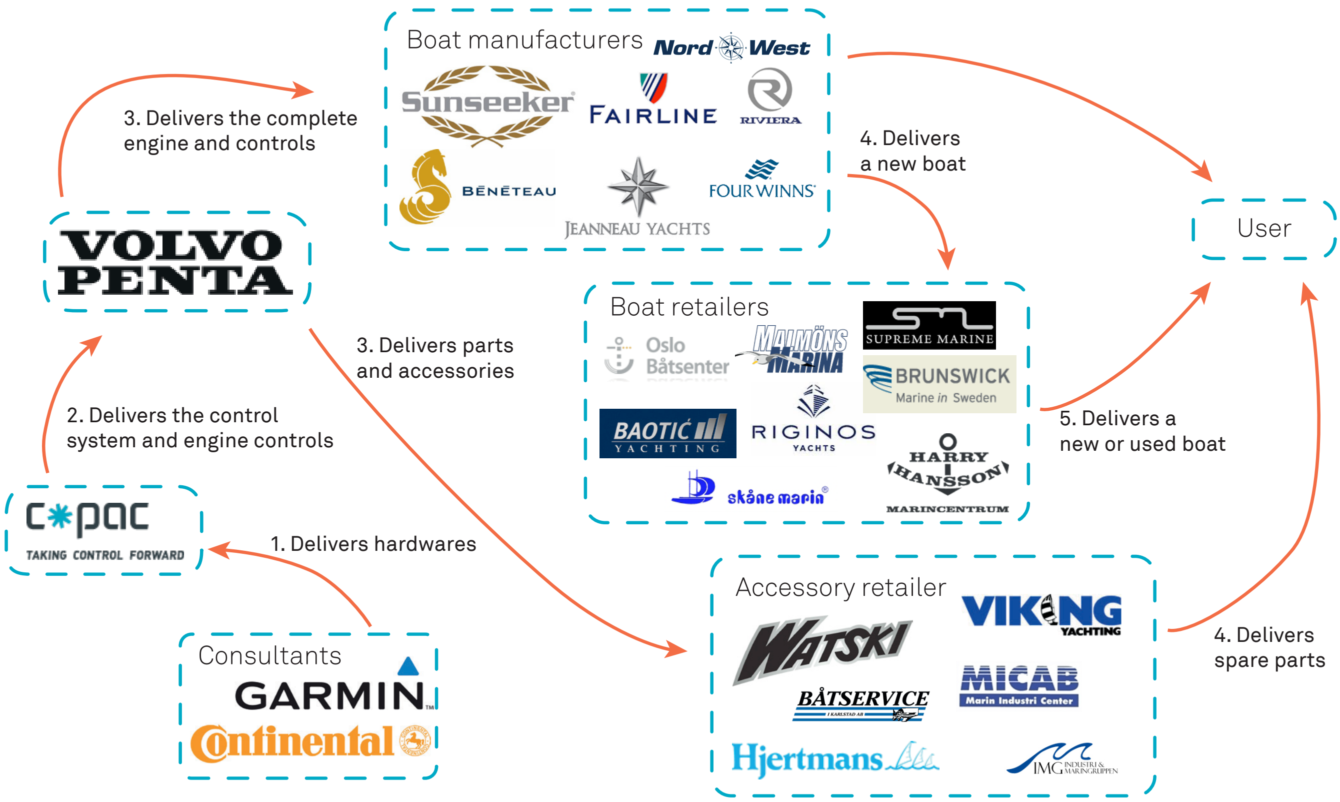


*Figure 16. The many involved stakeholders come into contact with the product at different phases, resulting in varying demands.*

# 3. USABILITY THEORY

*This chapter contains the theoretical usability framework utilized in the thesis. Starting the chapter is Patrick W. Jordan's ISO definition of usability. The components of usability and users' characteristics on usability, as defined by Jordan, are then presented. In the end of the chapters are Jordan's ten principles of usable design described.*

## 3.1 Definition of usability

Usability is a relevant aspect to consider when designing products since it affects the extent to which users of products perform tasks effectively, efficiently and with satisfaction (ISO 9241-11:1998). The usability of a product is dependent on characteristics of the user, the context of use, the task and the desired goal. Thus it is important to define requirements for usability by identifying who the "typical" user is, in what environment the usage happens, what the user wants to achieve and how this is achieved. The usability requirements will then provide a basis for verification of the new design.

The International Standards Organisation (ISO) defines usability as the "*extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*" (ISO 9241-11:1998). Jordan (1998) describes usability in more informal terms as something that refers to the "user-friendliness" of products. The definitions of the three components are (ISO 9241-11:1998):

- *Effectiveness - Accuracy and completeness with which users achieve specified goals.*
- *Efficiency - Resources expended in relation to the accuracy and completeness with which users achieve goals.*
- *Satisfaction - Freedom from discomfort, and positive attitudes towards the use.*

## 3.2 Components of usability

By repetitive use of a product, the performance of users is likely to develop over time (Jordan, 1998). A task that initially was difficult to perform might with exercise become easy. To address the change in level of task performance with repetition, Jordan (1998) developed a five component model of usability. It is important to note that each of the usability components refers to the performance of a specific task with a specific product, and not the product as a whole.

### 3.2.1 Guessability

Guessability is the effort required by the user to perform a task with the product for the first time. Depending on the use situation, guessability can be of more or less importance. For instance, products that are used once or seldom, such as a public information stands, benefit greatly from good guessability. In contrast, guessability can be less important for frequently used products, products with demonstration provided or products where accomplishing a task on the first try is not crucial. Examples of these are cars and professional software packages. However, even if a product is considered to benefit less from guessability, parts of the product can still benefit from it. In the case of software packages, having good guessability for rarely used features improves the product's usability, even though the often used features lack guessability. (Jordan, 1998)

### 3.2.2 Learnability

The usability component learnability addresses the effort with which a user can achieve a qualified level of performance with a task. The more memorable the way of performing a task is, the higher the degree of learnability the product has. For instance, if a user remembers how to send a text message on a smartphone after only one use, then the smartphone has good learnability regarding text messaging. Often the term intuitive is used as synonym for learnability.

Learnability is important in situations when training time is short or when users have to learn how to use a product by themselves. Contrary, learnability plays a less important role in situations where resources and training time are abundant. (Jordan, 1998)

### 3.2.3 Experienced user performance

Experienced user performance is the performance level to perform a task that a user can achieve after repeatedly using a product. It can be seen as the level of performance achieved when the skills of a user no longer improves significantly. Experienced user performance is important for situations where high-level performance is crucial and learning time is less important. As an example, computer-aided design (CAD) software applications benefit greatly from good experienced user performance because these are used by professionals. For situations where a product is used periodically or once, experienced user performance is a less important usability component. (Jordan, 1998)

### 3.2.4 System potential

System potential refers to the theoretical maximum level of achievable performance of a specific task with a certain product. Henceforth, it is equivalent to the upper limit of experienced user performance. Considering again a smartphone, the system potential of making a call to for instance a certain family member would be the minimum number of presses required to do so. If the user use the phone application instead of a suppositious shortcut from the lockscreen, their performance would not match the system potential.

System potential is an important usability component when the experienced user performance is limited by it. This can be a car with a top speed of only 45 km/h, which hinders an experienced driver from getting from one point to another at the fastest time possible when following traffic laws. When it is unlikely that system potential limits experienced user performance, then it can be considered an unimportant usability component. For instance, completing a novel is dependent on the time taken for the author to think and type rather than the speed with which the word-processing application interprets the input from the keyboard. (Jordan, 1998)

### 3.2.5 Re-usability

Re-usability is the reduction in user performance of a task over a relatively long period of time of not using a product. When there is a gap in repetitions of a task that is noticeably longer than what is expected, then the user performance can be considered a reflection of a system's re-usability. For example, Internet banking services such as paying the bills online are strongly dependent on re-usability as they are used intermittently. After the first time of use, a user has probably learned how to pay the bills and must after a month of not using the service remember how the system functions. If the service would have lack of re-usability, then the user would be forced to learn how the service functions again. Contrary, would it instead have good re-usability the user would be able to pay the bills with ease.

The deterioration of the level of performance is often dependent of the amount of time that has progressed since the last use of a product. However, there are tasks where the performance does not deteriorate, for instance riding a bike which is considered a skill that is not forgotten after being achieved. (Jordan, 1998)

## 3.3 User characteristics' effects on usability

People have different individual characteristics and therefore the usability of a product can be totally different between two individuals. Henceforth, designing for usability means designing for those who will use the product in question (Jordan, 1998). This means that knowledge about who the users of the product will be, is of the utmost importance. Jordan (1998) categorises user characteristics into five categories: *experience, domain knowledge, cultural background, disability, and age and gender*.

### 3.3.1 Experience

Past experience with the product itself, or with other products, is likely going to affect how easy or difficult it is to use. The more accustomed a user is to perform a task the easier it will become to perform that task in following attempts. The knowledge and skills gained from the said task will probably also make it easier to perform other tasks with the same product.

As there are many unusable products on the market, taking advantage of previous experiences with a product is necessarily not always the best solution. Instead, radical innovations may lead to better usability than relying on past ways of operating a product. (Jordan, 1998)

### 3.3.2 Domain knowledge

Jordan (1998) refers to domain knowledge as "*[...] knowledge relating to a task which is independent of the product being used to complete it*". In the context of boat driving, domain knowledge is the knowledge users have about the marine environment, engines, etc. rather than how to drive the vehicle itself.

### 3.3.3 Cultural background

The way users interact with a product is influenced by their cultural backgrounds. "Population stereotypes" affect our behaviour and method of interaction with products. For instance, in the USA and continental Europe light switches are usually flicked on upwards whereas in Britain they are flicked on downwards. Henceforth, population stereotypes are important to consider when designing a product for different markets. This is especially important for safety critical aspects of a product since users have to act instinctively in these situations. Furthermore, there are different physical characteristics that are related to race and nationality to consider. Scandinavian people a generally taller than people from Southeast Asia. (Jordan, 1998)

### 3.3.4 Disability

Disabled people have different needs than able-bodied people and this is an important fact to consider. By paying attention to the disabled users it is possible to give them greater opportunities and freedom. Designing with disabled users' needs in consideration can bring benefits to well-abled users as well. (Jordan, 1998)

### 3.3.5 Age and gender

Age and gender are two factors that affect how we interact with products. For instance, young males are usually stronger than females and elderly people. Therefore, a product that requires much strength can be usable for male users but unusable for female and elderly users.

Another characteristic that is affected by age and gender is attitudes. Females and males may be treated differently when they grow up. This can result in that male users pay more attention to technical aspects of a product while female users tend to focus on aesthetics. Similarly, young people are generally more accustomed to computers and other electronic products than older people are. This means that elderly people may be sensitive to the complexity of the product than their younger counterparts. (Jordan, 1998)

## 3.4 Principles of usable design

Jordan (1998) outlines design characteristics that are associated with usability. He describes ten principles of usable design that affect usability. These are presented in the following sections.

### 3.4.1 Consistency

Consistency is about designing a product in a way that similar tasks should performed in similar manners. The user can thus generalise on the experience gained by performing a certain task with a product to achieve another similar task. Consistency of a product can be exemplified with the tasks of attaching a picture or a contact in a text message. Both tasks are performed by opening the message application, then pressing the share button to the left of the text field and finally choosing either picture or contact.

### 3.4.2 Compatibility

Compatibility considers the extent to which a product complies with users' expectations based on their knowledge from the "outside world". This principle is important because people are inclined to generalise from one situation to another. Compatibility is similar to consistency with the difference that consistency refers to similarities of use within a product whereas compatibility refers to regularity between the product and external objects (be it a product or any other thing that users' may generalise from using it). An example of compatibility is the address book in smartphone, which refers to a physical address book. These contain similarities such as alphabetical categorisation of contacts.

### 3.4.3 Consideration of user resources

User resources refers to the ability of our cognition and physical body parts to interact with a product. For instance, while driving a car, we use our eyes to watch the road, our hands to steer the wheel and our feet to operate the pedals. It is important to consider the user's resources when designing a product in order to not overload them. This can lead to usability problems and errors.

### 3.4.4 Feedback

Providing clear feedback about performed actions to the user is an important principle of usability. Feedback is used to confirm that an action has been acknowledged and the results of it. It is also of important to consider the meaning the feedback has to the user. If, for instance, a sound is provided to the user after pressing a button, it can be designed to be either "happy" (indicating success) or "unhappy" (indicating error). The consequences of lack of feedback are user error and a sensation of uncertainty.

### 3.4.5 Error prevention and recovery

Error prevention and recovery is about minimising the likelihood of user error and making it as easy as possible for users to recover from mistakes that have been made. By designing a product where error recovery is high it is also possible to encourage an exploratory attitude, because users would not fear the consequences of making mistakes.

### 3.4.6 User control

Users should be given as much control as possible over the interaction with a product. They should be in control of the pacing and timing, and the system should not perform actions that are unexpected by the user. It is also important to include default settings so that the user can quickly and easily start using the product instead of putting effort into setting it up. Obviously, these settings should be adjustable. Thus, designing for adjustability is a way of providing user control.

### 3.4.7 Visual clarity

Visual clarity concerns how information is displayed to the user. The provided information should be presented in a way that it is quickly and easily interpreted without causing confusion. This is also relevant for feedback. To achieve good visual clarity, consideration should be take for aspects such as text size, the amount of information displayed, coding of colour and layout. For instance, providing much information at the same time means that the required depth of the menu structure will become decreased, which will decrease the risk of getting lost in the system. However, too much information can make the interface cluttered and difficult to interpret. Another aspect that must be taken into account is the distance that the user will be from the screen when interacting.

### 3.4.8 Prioritisation of functionality and information

When a product contains many functions or a great deal of information, it is necessary to prioritise them so that the user does not become overwhelmed. The prioritisation can be made on basis of many different aspects, for instance the function's frequency of use or its relative importance. Functions that are deemed most important should be given a prominent position in the user interface. By prioritising functions and information it is possible to prevent a cluttered user interface while at the same time allowing the user to quickly access often-used functions, thus upholding a certain level of system potential.

### 3.4.9 Appropriate transfer of technology

Appropriate transfer of technology is about applying technology developed for other applications to improve a product's usability. It is important that the transfer of technology is done with much thought or else problems might arise. For instance, the use of combustion engines in household appliances is not suitable due to the unhealthy exhausts they create, but the remote control has been a benefit for many products such as TVs, audio systems and lighting systems.

### 3.4.10 Explicitness

A product should be clearly understandable of how it should be used, because then user errors can be kept to a minimum and the satisfaction of use improved. By providing clear clues about how a product should be used, referred to as "affordances" by Norman (2002), the usability of such a product can be improved.

## 3.5 Chapter summary

- The ISO definition of usability is the *"extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."*
- Jordan has developed a five component model of usability that consists of: *Guessability, Learnability, Experienced user performance, System potential, and Re-usability.*
- The individual characteristics users have different effects on usability. Jordan categorises the characteristics into five categories: *Experience, Domain knowledge, Cultural background, Disability, and Age and Gender*.
- Jordan outlines ten principles of usable design: *Consistency, Compatibility, Consideration of user resources, Feedback, Error prevention and recovery, User control, Visual clarity, Prioritisation of functionality and information, Appropriate transfer of technology, Explicitness.*
- In this thesis focus was on using the ten design principles and assessing user characteristics' effect on usability. This does not mean that the components of usability were not considered because the are incorporated in the design principles.

# 4. METHODS

*This chapter features theoretical descriptions of the used methods throughout the project, the methods are divided into corresponding groups. Each method description also includes an explanation of how they were used in this specific project.*

## 4.1 Planning

This section describes the planning methods used throughout this project. The methods are different ways for bringing structure in an otherwise quite chaotic development project.

### 4.1.1 Gantt Chart

A Gantt-charts is a method used to create a timeplan over a project (Bligård, 2011). The chart is made up of a horizontal time line on which project activities are represented by horizontal bars with a length corresponding to the time frame for each activity. The end-sides of the bars indicates the activities' starting and end points. Furthermore, the Gantt-chart can also show interdependencies between activities and which activities that can be done in parallel.

In this project a Gantt chart was constructed in the planning phase of the project. However, as the accuracy of a Gantt chart should not be overestimated as the expected times in the beginning of a project are very uncertain, the chart was used more as a support than a strict plan.

### 4.1.2 Flowchart

A flowchart visualizes a project process, by showing its phases and their relations. It contains activities to be performed along the project and how each activity relates to others. The purpose of a flowchart is to illustrate the process and included activities. (Bligård, 2011)

During this project a flowchart was constructed as part of the planning phase. It was used to describe and illustrate the process. Together with the Gantt chart it worked as support throughout the project.

## 4.2 Data collection

This section describes the empirical data gathering methods used throughout this project. It consists of different methods for contact with relevant stakeholders and other important sources.

### 4.2.1 Interviews

Interviewing is a method where an investigator compiles a series of questions which are then posed directly to the participant(s). It can be structured as a unstructured, semi-structured or structured interview.

The interview structure is set depending on what kind of information is sought after. Unstructured interviews are used when the investigator wants to understand the participant, as they give the investigator a possibility to control the discussion and steer it towards issues which he finds interesting. A semi-structured interview is chosen when the investigator knows more about the relevant issues for the project. Here, the investigator has certain points which he wants the respondent opinions about. Finally, structured interviews are beneficial when confirming data in a later stage of development, to evaluate if drawn conclusions are accurate (Jordan, 1998).

For this project interviews were conducted in several stages, both unstructured and semi-structured. Unstructured interviews were mostly used for understanding the system and how the user interaction looked like. Semi-structured interviews were instead used for understanding more about specific issues or for testing ideas and acceptance.

### 4.2.2 Competitive research

For evaluating the current market diversity and to become familiar with related products, it is important to conduct competitive research. By researching competitive products an understanding for where a product can be differentiated from others is achieved; it can also provide ideas for the new product or the production of it. (Ulrich and Eppinger, 2012)

In this project competitor products were framed in a market analysis. This was used to identify possible points of differentiation and common solutions on other products.

## 4.3 Analysis

This section describes the analysis methods used throughout this project. Here are several methods which have worked to bring order and extract important conclusions from the data gathering.

### 4.3.1 User Profile

User Profiles describes abilities, characteristics and limitations among the users. This could include mental, physical and demographic data among the user population. Characteristics could include users' background, the usage and experience from using the product or other relevant aspects. It is important that a user profile shows the variation between different users (Bligård, 2011).

During this project, the user profile was used for gathering information about common characteristics of boat driver, especially drivers with a Volvo Penta engine system. It was also utilized to understand how the usage situation looks like and show how it depends on which application the device was programmed for.

### 4.3.2 Design Format Analysis

A Design Format Analysis (DFA) is used to identify the frequency of occurrence of styling features from a common design format (i.e. prominent styling features that represent a brand) on a product family (Warell & Nåbo, 2001). Furthermore, a DFA shows the extent to which each product of the product family conforms to the common design format. The aim of the DFA is to clarify the overall visual appearance of a brand and decide what styling features to consider in the design process.

For this project, a DFA was conducted on Volvo Penta's controls and displays, henceforth excluding the analogue gauges in their product lineup. As suggested by the theory, the aim was to find styling features that are typical for the Volvo Penta brand.

### 4.3.3 Life Cycle Assessment (LCA)

Life Cycle Assessment is a collection of methods used to assess a product's ecological footprint (Velpuri, 2009). The LCA gives a general picture of the product from cradle to grave. It is suitable to do a LCA in the product development process in order to identify in which phase and what aspects of the product's life where potential ecological improvements can be achieved.

The LCA in this project was done with an online tool named Product Ecology (found at productecologyonline.com). The tool was used to assess the reference product's life cycle and to identify opportunities for improvements.

### 4.3.4 List of requirements

A list of requirements contains stakeholders' demands and requirements of a product. The level of detail and abstraction of the requirements depend on how far the development process has progressed. Furthermore, the list can contain additional information such as the origin of the demands and their importance.

In this project multiple list of requirements were used, with different abstraction levels (in this project defined as needs, elaborated need and requirements). The requirements in the lists were refined to create the coming lists. This provided the project group with a structured way for concretising the identified needs and requirements and thus increasing the probability of fulfilling them.

### 4.3.5 Quality function deployment

Quality function deployment (QFD) Is a method for identifying critical customer attributes and to create a specific link between customer attributes and design parameters. Via a matrix information is organized and helps marketers and design engineers answer three primary questions: What attributes are critical to our customers? What design parameters are important in driving those customer attributes? What should the design parameter targets be for the new design? (Wheelwright & Clark, 1992)

In this project the latter part of the QFD methodology was utilized, namely the design parameters, their relations to each other and how each of them can be synthesized to achieve the best system performance. This was done in the hardware concept generation phase where design variables were compiled to different concepts.

## 4.4 Idea generation

One idea generation was used in the project, as the outcoming ideas were deemed satisfactory. Furthermore, the design process was iterative and henceforth ideas were further developed based on the previous ideas.

### 4.4.1 Brainstorming

Brainstorming is an idea generation method in which ideas are sketched or described in words, and then openly discussed in the project group. The idea is that the group members will elaborate on the discussed ideas and eventually new and improved ideas will emerge. During the brainstorming session all ideas are equally valued and critique is not allowed, as this can limit creativity. (Österlin, 2003)

The method was used in the initial stage of concept generation phase to create a great set of ideas with speed and little effort. It was deemed effective and relevant to use in the early phase because at that point there were few design constraints.

### 4.4.2 Usability heuristics

Usability heuristics are used to fulfill usability needs and goals. The heuristics are supporting principles that are important for the product development and cannot be be validated or verified. A heuristic evaluation is used to evaluate whether the usability goals have been fulfilled. (Bligård, 2011)

Jordan's ten design principles were used in this project as usability heuristics. These cover usability in a clear and understandable way, which is why they were used.

### 4.4.3 Mood board

A mood board is a collage of pictures that enables a designer to illustrate the intended direction of style and feel of a product. Mood boards are recommended to be used in design teams and with clients to ensure that all parties agree on the product concept's direction of style before making fixed decisions. It can also be used as a creative enhancer in brainstorming sessions. (Bear, 2013)

The project group used the mood board to internally define the direction of style and mood for the product concept. The mood board was also used to describe the expression that the product were sought to express.

### 4.4.4 Scenario

A scenario is a narrative form of describing a use situation. It contains a description of the usage, context and other aspects that influence the use situation. It is important to capture the user's thoughts and emotions as well as the mood of the use situation when writing a scenario. The aim is to convey the real use situation to developers and make it vivid. (Bligård, 2011)

In this project a scenario was written to describe the intended future use situation. As boating is diverse, there are many possible scenarios that can occur, which can be overwhelming to describe. Hence, only one scenario was written.

## 4.5 Evaluation

Designed ideas and concepts were evaluated throughout the duration of the project process. This was to ensure that the product concept was progressing in the right direction.

### 4.5.1 Audits with experts and stakeholders

Audits is a method with which stakeholders of the product review the design concepts. The stakeholders can be for instance users, marketeers, sales staff or technical developers. A benefit of audits is that they allow stakeholders to provide their inputs and needs. Audits can be done through interviews, focus groups or questionnaires. (Bligård, 2011)

For this project, audits were the main form of evaluation for all phases in the development process. Interviews and focus group session were conducted with boat manufacturers, CPAC and Volvo Penta employees, sales staff and a usability expert.

### 4.5.2 Mock-ups

Mock-ups are early, rudimentary prototypes that are used to acquire feedback about functionality/usability/understanding of design/etc. in the early stages of the product development process. Mock-ups are usually partly functional and focus often lie on quickly evaluating a concept and thereafter make modifications. (Soegaard, 2004)

Mock-ups were used differently for the hardware and GUI in the project. For the hardware, mock-ups were created to evaluate the size, format and design of the product concept. Instead for the GUI, the mock-ups (designed as wireframes) were used to assess usability aspects. For both, the mock-ups were used as mediating tools in audits and interviews.

### 4.5.3 Prototypes

A prototype is a functional representation of the product concept and is used to evaluate a solution, theories or performance of the product. Prototypes can contain different degrees of final functionality and can therefore be used to evaluate different concept aspects, such as design, specific functionalities, usability, etc.

In this project, a hardware prototype and screenshots of the GUI were designed. The hardware prototype was used to evaluate the final construction and as a mediating tool in interviews. The screenshots were used in a prototype board containing a screen with the same size, format and pixel density as the product concept. This allowed for an evaluation of design and certain usability aspects, such as visual clarity.

# 5. PROCEDURE

*This chapter will give a description of the model that the project has followed and relate the model to the outline of the report. Here the reader can learn which phases were implemented and why.*

## 5.1 Project process

The aim of the master thesis was to achieve an understanding for the complete use situation of the interface device and from there develop a concept that fulfills the identified needs and requirements of new and traditional boat drivers. Focus was on constructing a product that with an improved user experience will facilitate boat driving and henceforth become an integral part of the driving interface. In order to achieve this the product had to fulfill tough marine environmental requirements, have an appealing design, provide added user value through new functionality, be cost-effective and contain a graphical user interface that is usable and easy-to-use.

In order to achieve the set aim, a project process plan was created based on Bligård's model (2011). The model consists of four activities (planning, data collection, evaluation and documentation) that progress throughout the duration of the project and six sequential activities (needs identification, designing functions and tasks, general design, detailed design and construction, construction and deployment). This project process plan divides the project into seven sequential main phases: pre-study, problem definition, designing the use-situation, system-level design, detailed design and construction, final concept development, see Figure 17. The phases overlapped but a subsequent phase could not be finished before its former, as the result of each phase built on the forthcoming one. The on-going activities were followed as Bligård's (2011) model suggests.

### 5.1.1 The phases of the project

To complement the project plan, a GANTT-chart, see Appendix I, was constructed containing a time/resource-aspect and important deadlines. In addition to this, on-going weekly planning activities were created to explicitly specify the activities for each week.

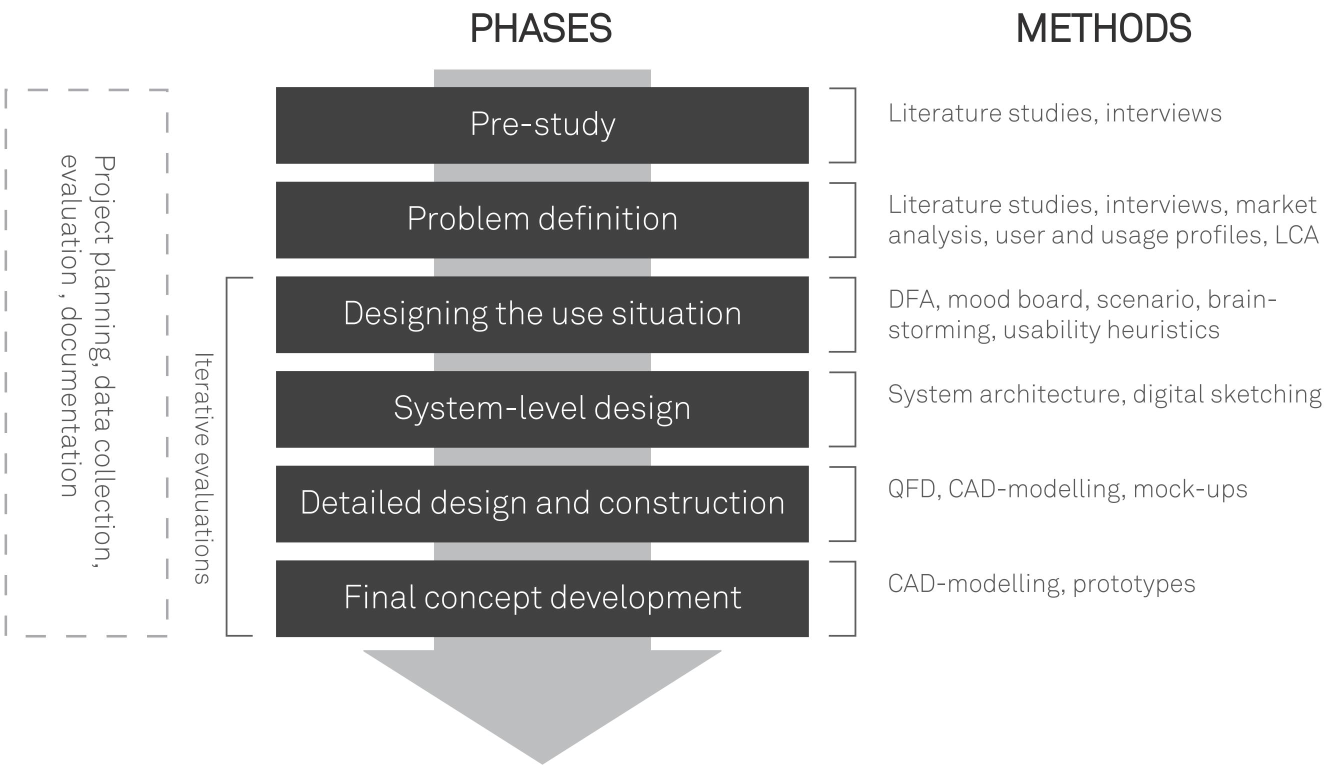


*Figure 17. The project process plan contains the sequential phases of the project and the methods used in each phase. In the design phases iterative evaluations were important in the design process.*

### *Pre-study*

After the planning phase, focus was to understand the EVC system. This was achieved by gathering information through literature research about the system and learning from CPAC and Volvo Penta employees. The information gathered from these sources was also used to assess quality and usability problems related to the reference products. By studying the EVC system, insights about the importance of usability issues were gained, thus a theoretical study about relevant guidelines was initiated. Theoretical principles were compiled into usability guidelines which then served as a framework for the entire development process.

As the purpose concerns meeting new market demands, it was important to relate the usability guidelines into value adding features for the intended target group. This was ensured by investigating user and usage characteristics and connect them to theory.

### *Problem definition*

This phase synthesized the theoretical study and current situation analysis into a conclusive definition of the entire problem situation. Here, requirements from relevant stakeholders was researched, the new and traditional users identified and an analysis of how the context affect usage and the product itself was executed.

Data was gathered by investigating challenges related to cost, technology, number of separate parts, reliability issues, design and appearance. Also, interviews with boat owners, resellers, manufacturers, test drivers, CPAC and Volvo Penta employees was used as input. Furthermore, recurrent visits to the Gothenburg Boat Show, Nimbus's head office och Volvo Penta's test center at Krossholmen in Gothenburg were conducted to gain direct, on-site insights.

By analysing the problem situation, initial needs were defined and ideas for how the problem situation could be solved emerged. The needs listing and the gathered problem definition served as a basis for what needs to fulfill and an aim to how a future use situation would be designed.

### *Designing the use situation*

In this phase the focus concerned how the user experience should be like. This was researched by compiling the usability theories, issues regarding the current situation, problem definition, needs listing and new research, a desired use situation could be created. From this target image additional analyses were conducted with the purpose of realizing the desired situation and create the intended behaviour. This work resulted in a more detailed and elaborated needs listing, which was supplemented by usability guidelines capturing the key elements for achieving the desired user experience.

### *System level design*

In this phase focus concerned the interface's design to facilitate the boat driving for the inexperienced user. From the elaborated needs listing and with the target situation in mind, architectural systems for both the hardware and the graphical user interface were created. The architectures were benchmarked from data in the current situation, with focus on maintaining the benefits in current products and solving the problems in accordance with the needs listing. Some parts of the systems were left unchanged and others completely redesigned, but the outcome was thoroughly elaborated with CPAC and Volvo Penta employees. This resulted in a set of decisions that were compiled and transferred to the Detailed design and construction phase.

### *Detailed design and construction*

The detailed design and construction phase contained a concept development process based on the previously created system architectures. The hardware concept was constructed by iteratively creating several digital and physical mock-ups. The mock-ups were used to evaluate several ideas and helped to diverge the solution space into a few design variables. The design variables were analysed for finding synergies between them and then composed into digitally presented concepts. The concepts were then evaluated in several steps towards personnel at CPAC, Volvo Penta and boat manufacturers. The outcome for the detailed hardware design phase was a new and refined requirements listing and a decided concept composition.

A similar process was adopted for the GUI development. From wireframes showing different compositions of the pre-decided information, a favourable combination of the most prominent design variables were constructed. After evaluation towards stakeholders, the graphical layer of the GUI was designed. The graphical layout was also evaluated regarding usability and the defined guidelines to identify the preferable design of each graphic element.

### *Final concept development*

This phase concerned the realisation of the made decisions in the detailed design and construction phase by constructing several prototypes. Here, a construction prototype made by rapid-prototyping, an interface prototype shown on a development board running Android OS and a digital CAD prototype made in CATIA were constructed. The prototypes had different technical functionality and were thus used for evaluation of its corresponding functionality. Together the prototypes were used to test the functionality described in the aim.

The physical prototypes were utilized for several evaluations of both the hardware and the GUI design. By evaluating the prototype together with as many relevant stakeholders as possible, the validity of the evaluation was increased. And performing evaluations with the use of a physical prototype in a situation close to a real end-user situation the degree of immersion was increased.

# 6. PROBLEM DEFINITION

*This chapter will provide an understanding of the current problem situation and includes user and usage profiles, technical and use-related issues, market and life-cycle analyses. It ends with an initial requirements listing and a summary of the most important learnings.*

## 6.1 Human-machine system

The human machine system consists of the user, the machine and the interaction between them, which in this case is handled by the information device. It describes important characteristics about the users and the usage situation. The primary users are the ones who most frequently come in contact with the product - these are also the final consumers. Thus, the user profile is based solely on this group.

### 6.1.1 User groups

During the lifetime of a boat many different types of users come in contact with the product. Each of these users have their own relation to the product, as can be seen in Table 1. The users are categorized into primary, secondary, side- and co-users, as suggested by Janhager (2005).

### 6.1.2 User profile

The purpose of creating a user profile was to understand the boat owners and drivers to find common user characteristics. The information that founded the user profile was gathered from Volvo Penta representatives, CPAC employees, boat resellers and manufacturers, boat owners and drivers, and statistics from Statistics Sweden (Statistiska Centralbyrån in Swedish) and Nordiska Ministeriet. Focus was on the use of leisure boats in Scandinavia and especially Sweden, thus excluding the commercial boat market, such as coast guard and fishing boats.

#### *Background*

Leisure boating has increased in Sweden by 8% between 2004 and 2010 (Statistiska Centralbyrån, 2013). In 2010, 18% of all Swedes owned a boat and about 2.5 million spent time in their own or someone elses leisure boat. The most popular type of boat in Sweden is a smaller motorboat without the possibility of overnight accommodation (49% of all boats). The second most common type is motorboats with possibility of overnight accommodation, responding for 22% of existing boats (Nordiska Ministeriet, 2009). The majority of boats with a Volvo Penta EVC system are included in this group.

#### *Statistical description of the user*

According to Nordiska Ministeriet (2009), boats owners in Sweden, Finland and Denmark can roughly be represented by two different types of owners. The first is an older male, who

*Table 1. The different types of users have different relationships to the product*

| **Type of user** | **Description** | **User** |
|---|---|---|
| Primary user | A person using the product as it is primarily intended | Boat drivers |
| Secondary user | A person using the product in another way than its primary purpose | CPAC developers, production personnel, assembly personnel, installation personnel |
| Side-user | A person not using the product but who is still influenced by it | Other boat passengers, Volvo Penta, boat manufacturers, boat accessory dealer |
| Co-user | A person interacting with primary users or secondary users, but not themselves using the product | Boat dealers, boat rentals |

owns a larger boat and is out at sea more than one month per season. This person is knowledgeable regarding his boat and conducts the majority of the maintenance by himself. He is not particularly concerned regarding environmental aspects and does not regard his own boating to have a significant effect on the environment. However, he is still willing to take responsibility and contribute to improving the environment, perhaps by primarily changing his way of driving the boat to make it more fuel efficient (Nordiska Ministeriet, 2009). This user most closely resembles the "typical" user of the reference product, as the EVC system is installed on larger motorboats.

The other type of boat owner is a younger person. This person uses their smaller motorboat for taking shorter day-trips, 10-20 days per season. They have a more evolved attitude towards environmental issues and this is reflected in their boating as well as their buying patterns (Nordiska Ministeriet, 2009).

Common for both user types are that they treasure freedom and nature. Both want to enjoy the archipelago and they consider everyone to have a responsibility to improve the marine environment. Also, weather, peace and quiet were rated as important by more than 85 % of the survey respondents. There is no age limitation or formal education required for propelling a boat, however two out of three boat owners have had some type of seamanship education (Statistiska Centralbyrån, 2013).

#### *Boat manufacturers' description of the user*

The Volvo Penta EVC system is mainly installed on larger motorboats (16 ft / 5 m length), thus owners of these are the most interesting ones for this project. On a visit to the 2013 annual Gothenburg Boat Show several boat manufacturers of larger motorboats were interviewed regarding their customers. The general opinion was that the boat business is conservative, where advancements take time. It was also stated that many boat owners prefer a motorboat thanks to its manageability and little need of maintenance. Owner of larger motorboat are often above 50 years of age and have owned other boats before. It is common to start with a smaller boat and then upgrade to a larger model, often within the same brand. Also, many boat manufacturers stated that their customers treasure the looks and appearance of the boat.

Concerning the dashboard layout, many owners are technically interested and want to monitor many flows in parallel. Thus it is often regarded as impressive with many different types of instruments on the dashboard, which often are analog gauges. Boat owners are also claimed to appreciate easy-to-read instruments as they tend to have diminished vision, which they often are unwilling to admit. (Windy, Nord West and Nimbus 2013)

In addition to this it was learned that a new type of customer is emerging. This type of customer is not as interested or knowledgeable in technical aspects and engine data and therefore rejects the traditional complex layout of a boat helm. Instead they expect "things to just work", similarly to their expectations of a new car or other home electronics. Thus, they look for a simple and easy-to-understand helm station. The situation could even be that a potential customer is afraid of buying a larger motorboat, because they are afraid of being unable to control it properly. (Thorsson, 2013)

#### *Conclusion*

Motorboat owners appreciate their boats for being simple and easy to steer - they also enjoy nature and freedom. Also, it is common for owners to stick with one brand and upgrade their boat size successively. This can make owners of larger motorboats feel attached to "their brand" of boats, which makes them faithful customers.

It was also found that the entire boat business is conservative, some customers look for traditionally designed boats with many analogue gauges. However, it was learned that this was about to change, as new types of customers emerge with new requirements. As technology evolves, people become accustomed to other types of interaction, thus they might not have the same requirements as today's customers.

### 6.1.3 Usage profile

Boats with the EVC system are used in many different applications; these can be divided in leisure and professional applications. Within both of these, there can be several driving positions and thus different equipment at each helm station. However, both of them follow different usage patterns and focus is on leisure use.

Leisure usage is defined as recreational use by a private person. It is a seasonal activity, at least in the northern regions. However, even at places where the boat can be used throughout the year, the common user only uses their boat occasionally. This motivates a high re-usability in interaction with the instruments, as it is important for users to quickly remember how they used the instrument last season.

#### *Context of use*

The helm station of a boat is often compiled of different instruments and equipment from several different companies. This results in dashboards at helms being cluttered with various instruments. Thus, a helm environment can be perceived as confusing and overpowering at first sight. Figure 18 illustrates this, in which the driving position contains a wide range of displays and controls. The perceived confusion of a complex helm was also confirmed by interviewed boat manufacturers, who empathized the importance of the driver understanding how to control their boat. (Nord West, 2013).

Boat manufacturers also appreciated the fact that all displays could be both flush and surface mountable, as this provides them with extra freedom when designing the dashboard layout. They and Volvo Penta also requested that a new device would use a Volvo standard hole pattern for mounting. (Nimbus, Nord West and Volvo Penta 2013)

Depending on the helm location, the marine environment has a different impact on the reference display. On the flybridge and docking station, controls and displays are exposed to long periods of sunrays, harsh rain and wind, sea water splashes and high and summer temperatures. This can lead to moist damage to electronic components and create fog on the protective glass cover. Furthermore, for all outdoor driving positions daily temperature fluctuations occur, influencing the mechanical characteristics of the plastic materials.

From boat drivers it was also learned that different types of information are important depending on boat speed (Pihl, 2013, Thorsson, 2013, Christensson, 2013). For instance in lower speeds, current depth, speed, rudder angle are interesting to monitor. But in higher speeds some of these are not interesting. As speed increases the boat will start to sway, especially if the wind is strong. This requires the driver to focus more on the surrounding sea and propelling the boat, thus higher demands are placed on the drivers cognitive capacity. Also, as the boat rocks heavily the driver needs to hold on and limits their physical capabilities. Regardless of vessel speed, it was found that it is uncommon that users make settings frequently.

### 6.1.4 Conclusions

The information differed between the sources as boat retailers and manufacturers had noticed a shift towards more, inexperienced customers entering the market; this shift was not reflected in the statistical research. Instead, the statistics described boat owner as older and younger. Based on the similarities and differences of the sources, the most important conclusions for the user and usage profile are compiled in the list below:

- There exists several different types of boat owners and drivers.
- Some users are knowledgeable about their own boat and perform much maintenance by themselves. They use their boat frequently and are technically interested.
- Some users are less knowledgeable about their own boat, they expect everything to work and want a hassle-free boating experience. They do not drive boats frequently.
- Users are willing to take responsibility for environmental consequences of their boating in terms of fuel consumption.
- Many boat owners appreciate their motorboats for being simple and easy to steer.
- Boat users like the freedom of boating and enjoy being out in the nature and at sea.
- Boat owners with a EVC system are rarely first-time boat owners.
- There are conservative boat owners that enjoy analogue gauges.
- During boat driving the physical and cognitive capabilities of the driver are heavily loaded.


*Figure 18. The wide plethora of controls and displays creates a cluttered driving interface that risks intimidating inexperienced drivers.*

## 6.2 Problems

This section describes technical and use-related issues regarding the current interface devices. The issues described are mainly focused on the reference product Flexi-display, as data for the G4 was not available.


*Figure 19. The joint between the screen cover and the upper housing has caused water leakage, which has been mitigated by gluing as method of attachment.*

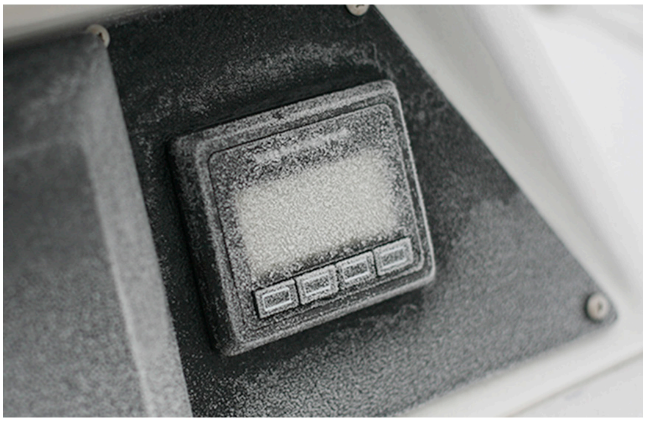

*Figure 20. When frozen, the buttons of the Flexi-display may lose their functionality.*

### 6.2.1 Technical problems

The current hardware construction of the Flexi-display has been the source of many quality related issues. According to a quality supervisor at Volvo Penta, the 2,5" display is the second largest source of hardware issues among all of their products. (Skoglund, 2013)

#### *Water leakage*

The Flexi-display has previously had many problems concerning the joint between the screen cover and the upper housing, see Figure 19. This joint was initially made by tape, but the tape was substandard and caused water leakage. Today this joint is glued, which has lead to a significant decrease in problems (Skoglund, 2013).

However, the Flexi-display also suffers from other hardware problems. When visiting Volvo Penta representatives at their testing facility at Krossholmen and at their booth in the Gothenburg Boat Show, both withheld that water can seep in behind the buttons, this was also experienced first-hand by the project group. When temperature drops, the water freezes and the buttons become unusable, see Figure 20. Another reason for buttons becoming unusable is that the salt from evaporated salt water accumulates behind the buttons, jamming their function (Volvo Penta, 2013). To mitigate this, the Flexi-display must to withstand great variations in temperature. For storage, these are specified as -30 °C to +85 °C (CPAC, 2009).

According to CPAC and Volvo Penta, the reason behind the button problems is located within the very construction of the buttons and the design of the silicone gasket, which works as a container for the leaked water. Attempts have been made to solve these issues by adding new silicone gaskets around the button holes, however it still has not completely solved the problem.

The Flexi-display is classified as IPX6, from the front. From the backside it does not have any classification. Although, as the majority of water leakage problems herein from the front it can be questioned whether IPX6 is a sufficient

*Table 2. IP Classification (SP, 2013)*

| Level | Test | Details |
|---|---|---|
| IPX6 | The enclosure is subjected to a jet of water from a 12,5 mm diameter nozzle at a distance of 2,5 - 3 m from the item under test. | Test duration: minimum 3 minutes<br>Water volume: 100 l/min<br>Pressure: 100 kPa at distance of 3 m |
| IPX7 | The test is made by completely immersing the enclosure in water in its service position. | Test duration: 30 minutes<br>Immersion at depth of at least 1 m measured at bottom of device, and at least 15 cm measured at top of device. |

classification. For more information about IP classification see Table 2.

### *Weather-related problems*

The Flexi-display is frequently placed outside on the boat's flybridge, docking station or other helms, thus it needs to withstand all types of weather conditions while still fulfilling its intended function. This includes when the display is placed at a flybridge during a hot summer day and the sun is blazing down. This puts high requirements on readability, temperature and reflexivity.

A general problem with the displays was that they sometimes are installed on horizontal surfaces. On a visit to a customer, one of the representative had noticed that a horizontally installed 7" display had water amassed on the screen, due to it having a higher border around the screen which created a "bowl-shaped" design (Volvo Penta, 2013).

### *Installation problems*

Boat manufacturers and Penta also stressed the importance of the display taking up as little space as possible. The dashboard space is very limited and boat manufacturers struggle to make use of every centimeter, which is why they suggested that cabling behind the dashboards must be made slimmer. As space is limited on a boat and much information should be presented to the user simultaneously, outer dimensions of every device are important. As a Nimbus seller explained "We install the 4" display on dashboards with limited space, since that model displays considerably more information than the 2,5" display in relation to the space it requires". (Nimbus, Volvo Penta, 2013)

Another issue with the installation of devices are that dashboards, or parts of dashboards, are sometimes curved and this can result in two problems. Firstly, attaching the instruments against a curved dashboard will flex the instrument and create tension in the body and display. This may lead to the cracking of the glass that covers the display. Secondly, the sealing between the dashboard and the instrument will not be as strong because the sealing force at the edges of the sealed area will be decreased.

## 6.2.2 Use-related problems

Boat manufacturers, boat magazine reviews and Penta claimed that it is hard to see the information on the existing Flexi display, due to low lightning, small screen and numbers and low contrast. Many customers are above their 50's and may have diminished vision. Thus, good readability in all conditions (including blazing sunlight and night-time) is a crucial requirement (Volvo Penta, Nord West, CPAC, 2013). As the boat magazine "Vi Båtägare" wrote in a review regarding the placement of a info-display "the instrument displays are pathetically small, poorly located and thus unreadable" (Vi Båtägare, 2013)

According to a boat owner (Christensson, 2013), boat driving should be as easy as possible because while driving, the visual and haptic senses are nearly fully engaged. Boat driving can therefore be compared to car driving; the visual sense is mostly focused on the surroundings while the hands are used to steer the vessel. Therefore there is little time to read or interact with instruments. The boat owner expressed that the visual sense is even more engaged when the windshield of the boat is covered by dried saltwater and further stressed the importance of good readability. Furthermore, a boat salesman from Nimbus (Bergström, 2013) explained that it can be problematic for the user to interact with the instruments at sea, since there is a risk that the boat sways because of waves. This makes it difficult for the user to interact with the screen with precision. Reading and interacting with the instrument should, thus, take away as little attention as possible from the actual driving and require limited input precision.

For the boat owner (Christensson, 2013), analog gauges provided sufficient information to have full control over the engine state. Christensson stated that digital instruments do not bring added value. However, Christersson emphasised that he was knowledgeable about boat driving and that less knowledgeable users would likely need more assistance. From his experience, the inexperienced user is increasingly more common on the sea. Therefore he could see a benefit with digital instrument as it has the possibility of providing more dynamic information.

The cognitive ergonomics of the instruments is also an important issue. According to a Nordwest salesman there are many functions to learn for the new customer and it takes time to learn them, thus good usability is of importance. (Nord West, 2013)

From several boat manufacturers and retailers it was also learned that the overall look of the dashboard is important for customers. "When buying boats of a certain standard, looks play an important role" (Gillholms Marina, 2013). This was explained as one of the reasons for why the boat manufacturer Nimbus flush mounts all of their Volvo Penta displays "The dashboard is supposed to look good" (Nimbus, 2013). However, during a visit to the Gothenburg Boat Show 2013 it was only found that one of the manufacturers flush mounted their displays. This indicates that the thickness of the display plays an important role in the aesthetics of the dashboard. This could herein from the consumer electronics market, where products become thinner and more advanced.

The above statements was also confirmed by CPAC and Volvo Penta, who argued that the existing Flexi-display looks outdated and somewhat misplaced on the dashboard of new boats. (CPAC, Skoglund, 2013)

### 6.2.3 Conclusions

The following conclusions were drawn from the issues-related problems:

- Aftermarket problems are costly, therefore it is important to have a high quality.
- The risk of water penetration needs to be mitigated.
- The new interface device shall withstand all weather conditions and provide good readability in different lighting conditions.
- Vibrations and shakings from hitting the waves while driving affect the durability of displays.
- The interface device should take up as little space on the dashboard as possible.
- Displays are often used together with many different instruments, which all can display different information.
- The appearance of the display is an important factor.
- The display needs to have good usability.

## 6.3 Sustainability

A Life Cycle Assessment was done on the reference product Flexi-display. It was conducted to identify potential areas of sustainability improvements.

### 6.3.1 Life Cycle Assessment

In order to perform a life cycle assessment, the materials of a product must be identified. For the Flexi-display, these are:

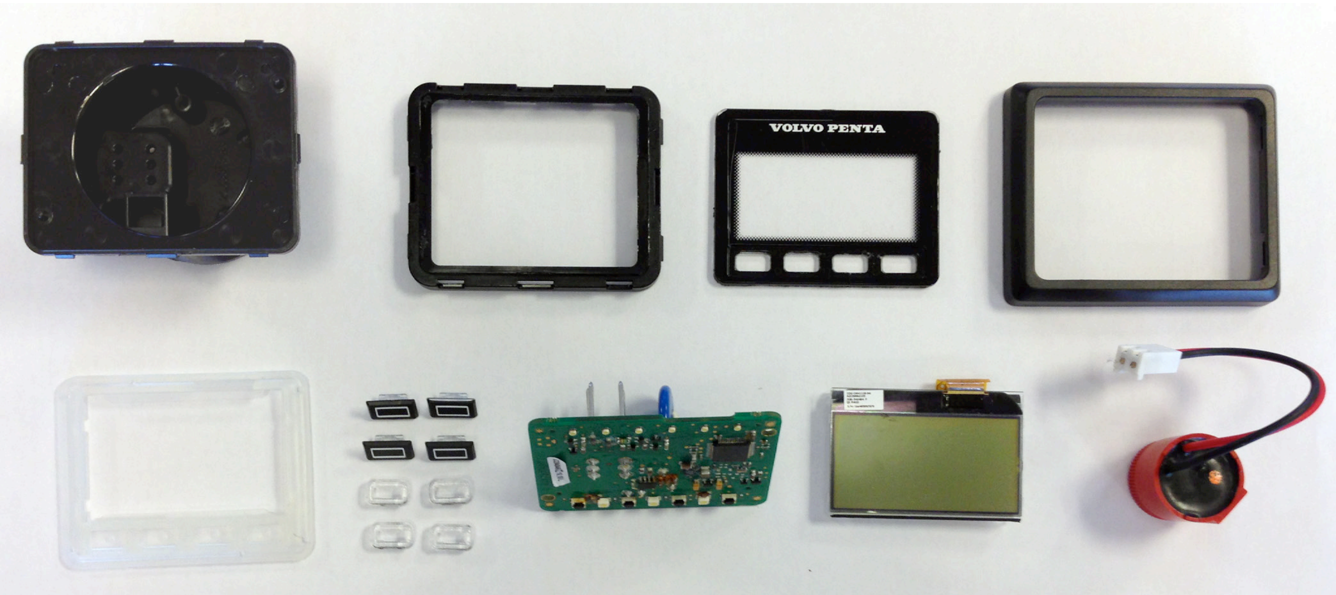


*Figure 21. The Flexi-display contains many different components such as plastic parts and electronics.*

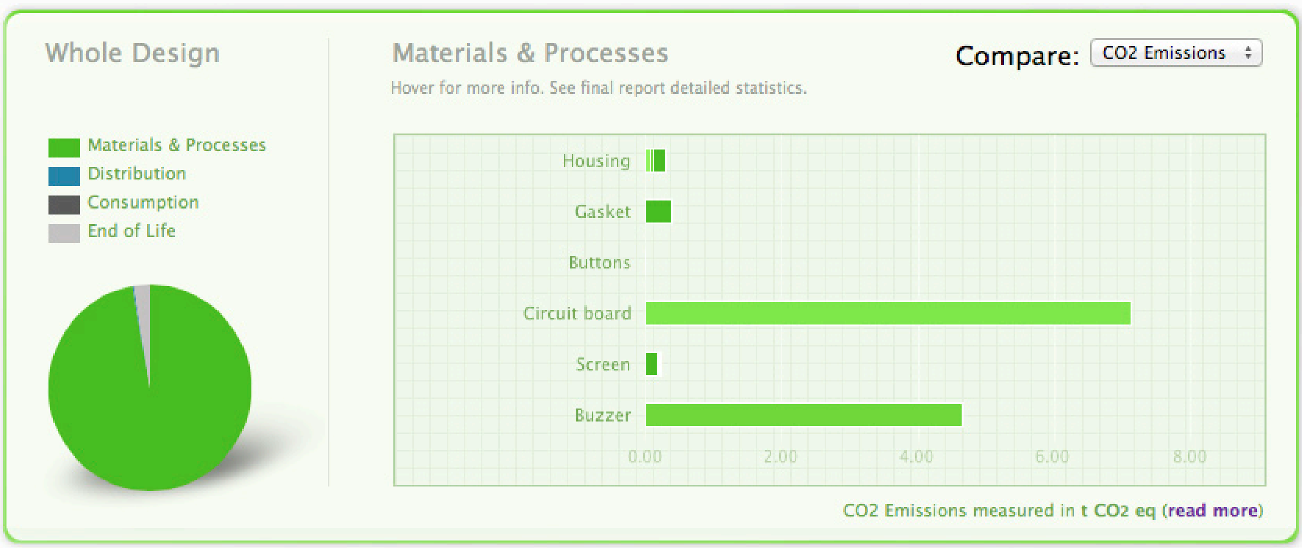


*Figure 22. Life Cycle Assessment, CO2 emissions. (Product Ecology Online, 2013)*

- Lower housing made from Polycarbonate and including flame retardant
- Upper housing made from Polycarbonate and including flame retardant
- Internal sealing made from silicone
- Four buttons and four button steering parts all made of Polycarbonate
- Screen cover made from Polymethylmethacrylate (PMMA)
- Bezel made from Polycarbonate
- Circuit board made from silicon (electronic component, unspecified materials)
- Monochrome, 2,5", backlit, LCD display (LCD display, unspecified materials)
- Buzzer (electronic component, unspecified materials)

The components of the Flexi-display are shown in Figure 21.

The life cycle overview of the current display shows that its main emissions herein from where the materials and their processes are manufactured, see Figure 22. This is the same case for CO2 emissions, water usage and waste output. From the analysis it can also be noted that the components that contribute the most to the emissions are the circuit board and the buzzer. These parts together stand for more than 90% of the product's total environmental effect. The complete analysis can be read in Appendix II.

However, there are also several other issues affecting the product's environmental aspects. One important aspect is the assembly process. The existing product consists of 16 parts (counting the circuit board as one part) where all of the parts need to be connected to each other. The upper and lower housing as well as the button's connection to their steering part are made by snap fittings, which do not require any other material for mounting. However there are glued connections, such as the one between the screen cover and the upper housing. Using glue in an assembly process may increase the risk of rejected products, as the glue can be misplaced and attach the wrong parts. However, as found in the study, gluing is essential to ensure a functioning sealing.

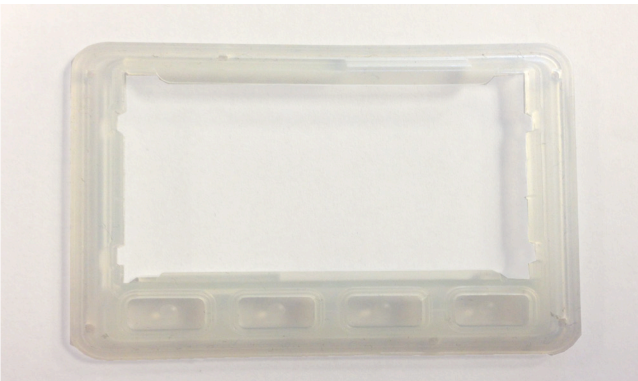

*Figure 23. The complex construction of the silicone seal makes the assembly and production complicated.*

Furthermore, the silicone seal, see Figure 23, is a very complex construction and completely encloses the button's steerage inner-part. This makes assembling the silicone seal very complicated and requires special tools. It also makes the production of the silicone seal more complex as the mould needs to have an equally complex structure. The high complexity of the construction has consequences in the environmental aspects.

### 6.3.2 Opportunities for improvement

The Life Cycle Assessment showed that the circuit board together with the buzzer account for more than 90 % of the Flexi-display's environmental effect, meaning that the two components provide the greatest opportunity to improve the sustainability aspect of the product. However, as these are electronical components which are complex in their construction and material composition, and because electronic product development is outside the project scope, they were not considered for sustainability improvements. Similarly, the LCD display was also not considered.

Two opportunities for sustainability improvement were deemed feasible for this project; to design for better assembly and to look at how the display can help the driver propel the boat in a more sustainable way.

## 6.4 Market Analysis

A basic market analysis was conducted to acquire general knowledge about competing products, see Figure 24. The aim was to roughly describe the market and consequently to identify and formulate market needs and demands related to: form factor, IP classification and back thread diameter. Furthermore, the market analysis also served to provide differentiation opportunities for the future product. The criteria included in the analysis were meant to assess form factor.

There is a wide plethora of instrument displays on the market, which is why the conducted market analysis had to be limited. Henceforth, only displays from major manufacturers were included and only digital information displays were regarded (as the new product will be digital and not analog). This excluded chartplotters, fishfinders, etc. as they provide other functionality than the Flexi-display. A limitation above 5" was also done, this prevented including instruments that would be intended for other market segments. A few of the products do not have complete data due to that it is not publicly available.

### 6.4.1 Results from analysis

The market analysis shows there are commonalities, patterns and differentiations between the analysed products. It is notable that all the instruments are fairly similar. They

| BRAND/MODEL | Raymarine<br><br>i40 | <br>i50 | <br>i70 | <br>ST40 | <br>ST60+ | Nexus<br><br>NX2 | Mercury Marine<br><br>Vessel View |
|---|---|---|---|---|---|---|---|
| HW FOR DIFFERENT APPLICATIONS | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| OUTER DIMENSIONS (MM) | 128x72 | 110x115 | 110X115 | 126x70 | 110x115 | 113x113 | 198x132,5 |
| SCREEN SIZE | 3,7” | 4” | 4” | 3,5” | 3,6 ” | ? | 5” |
| COLOUR | B/W | B/W | C | B/W | B/W | B/W | C |
| TYPE OF DISPLAY | Alphanumeric | Alphanumeric | Graphic | Alphanumeric | Alphanumeric | Alphanumeric | Graphic |
| MODE OF INPUT | Buttons | Buttons | Buttons | Buttons | Buttons | Buttons | Buttons |
| IP CLASS | IPX6 | IPX6 | IPX6 | IPX6 | IPX6 | ? | ? |
| PROTECTIVE COVER | Yes | Yes | Yes | Yes | Yes | ? | ? |
| BACK THREAD DIAMETER (MM) | 55 | 90 | 90 | 52 | 52 | 63 | No circular cutout |

| BRAND/MODEL | Furuno<br><br>FI-503/504 | <br>FI-507 | Garmin<br><br>GMI 10 | GeoNav<br><br>MID 110 | Simrad<br><br>IS20 | <br>IS40 |
|---|---|---|---|---|---|---|
| HW FOR DIFFERENT APPLICATIONS | Yes | Yes | Yes | Yes | Yes | Yes |
| OUTER DIMENSIONS (MM) | 110x115 | 175x115 | 109x111 | 112x112 | 114x114 | 118x115 |
| SCREEN SIZE | ? | ? | 4” | 3,5” | 5” | 4,1” |
| COLOUR | B/W | B/W | C | C | B/W | C |
| TYPE OF DISPLAY | Alphanumeric | Alphanumeric | Graphic | Graphic | Graphic | Graphic |
| MODE OF INPUT | Buttons | Buttons | Buttons | Buttons | Buttons | Buttons |
| IP CLASS | IP56 | IP56 | IPX7 | IP67 | IP56 | IPX7 |
| PROTECTIVE COVER | ? | ? | Yes | ? | ? | ? |
| BACK THREAD DIAMETER (MM) | 89 | 89 | 89 | No circular cutout | 88 | 85 |

*Figure 24. Market analysis of digital instrument displays, focused around their mechanical characteristics.*

all make use of buttons as the mode of input; the outer dimensions for the majority of the instruments differ only a few millimeters; the same hardware is utilised for different applications, such as speed or depth instrumentation. There are however also differences. For instance, the GeoNav MID 110 instrument is the only instrument that makes use of a wheel for interface navigation. Furthermore, Raymarine's i40 and ST40, Furuno's FI-507 and Mercury Marine's Vessel View instruments are rectangularly shaped, which contrasts the more common squared form factor of the market. This indicates that there is not an explicit demand for a specific form factor.

The analysis also shows that monochrome and alphanumeric displays are more common than colour and graphic displays. This is especially evident for smaller screen sizes. Mainly, this is due to market segmentation. There is a great demand for small inexpensive screens (Nimbus, CPAC, Volvo Penta, 2013), which is why the majority of manufacturers make small monochrome displays. Coloured displays are instead targeted towards a less price-sensitive target group.

Because marine instruments are used outdoors in a marine environment, IP classification is an important feature. None of the assessed instruments have a lower classification than IPX6. Only Garmin GMI 10, GeoNav MID 110 and Simrad IS40 are classified for IPX7, indicating that IPX7 is a differentiating feature.

The market screening also shows that several manufacturers make use of protective covers, including the CPAC displays. These are attached on instruments that are not in use and cover them from sunlight or water. This solution was deemed interesting and was henceforth included in the market analysis.

Manufacturers have slightly different back thread diameter on their instruments. The dimensions are related to the size of the instrument unit. Small instruments have smaller thread diameter while large instruments have larger thread diameters. The cutouts, in which the back threaded part is fit into, are made from standard tools with a set diameter. This indicates that there is a certain degree of freedom for the length of the back thread diameter. Also, Mercury Marine's Vessel View and GeoNav's MID 110 are not installed with circular cutouts, instead a rectangular hole is made for them to fit into. Henceforth, there are different manners for instrument installations, though the most common one is by circular cutouts.

### 6.4.2 Market opportunities

As buttons were the only mode of input for the analysed information screen products, there is a possibility to introduce a product with a new mode of input, such as touch or voice control, that will strongly differentiate it from competitors. A new mode of input that eliminates physical buttons will not only make the product stand out from its competitors, it has also the potential to improve usability.

The market analysis also indicates the opportunity to better position the new product in terms of IP classification. Improving the classification from IP66 to IP67 would mean that it would be positioned above the majority of competing instrument displays and thus provide yet another competitive advantage.

## 6.5 Chapter summary

The new display will be used on motorboats sized above 16ft (5m). The people who buy these boats appreciate simplicity and easy maneuverability, therefore the new device should build on this.

- Since users commonly remain faithful to a certain brand it is important that the new device will capture the Volvo Penta brand and being considered as modern and appealing.
- The user profile is diverse. Both highly experienced and knowledgeable, as well as completely inexperienced and novice, boat drivers exist. These two groups have different demands on the dashboard layout.
- The diversity is also represented in the different contexts where the devices are placed, such as an indoor driving position or outdoor flybridge. Also, the technical quality is very important as a device needs to withstand the harsh marine environment.
- A conflict between minimizing the outer dimensions of a display and provide enough information for the driver was identified. This will be evaluated further and decided whether added functionality in the display can indemnify an increase in dimensions and whether the added functionality risks cluttering a smaller display interface.
- From the LCA it was found that it is hard to improve the materials but that the new display could guide the driver into propelling the boat in a more environmentally friendly way. It was also concluded that there is opportunity to simplify the assembly and disassembly processes.
- The market analysis resulted in an identified opportunity for introducing other types of interaction as a means of differentiation.

## 6.6 List of needs

The findings and learnings from the studies are framed in the list of needs, see Table 3, to give a broad overview of the issues that need consideration in the further development. The next chapter will explain how the issues will be handled in order to design an improved product.

*Table 3. List of needs identified from the pre-study.*

| List of Needs | Origin (Chapter) |
|---|---|
| **Basic functionality** | |
| Contain the same functionality as Flexi-display. | Purpose and Aim |
| Should be used on boats above 16ft | Reference displays |
| Be directed towards leisure use | Usage profile |
| Contain differentiating attribute | Market analysis |
| **Aesthetics** | |
| Comply with the Volvo Penta brand | Human Machine system |
| Provide a visually appealing and modern look | Human Machine system |
| **Construction** | |
| Withstand placing under the same circumstances as current devices. | Technical issues |
| Have at least IP class 66 | Technical issues |
| Be both flush and surface mountable | Usage profile |
| Use a standard hole pattern for surface mounting | Usage profile |
| Hinder accumulation of water on screen | Technical issues |
| Minimize outer dimensions | Use situation issues |
| Ensure functionality within temperatures -30 to +85 °C | Technical issues |
| Reduce cost | Purpose and aim |
| Allow mounting of sun-cover | Market analysis |
| **Usability** | |
| Facilitate boat driving | User profile, Use sit. issue |
| Have a simple interface | User profile, Usage profile |
| Warn the driver of engine malfunctions | Usage profile |
| Provide good readability in sunlight | Use situation issues |
| Provide good readability during low-light conditions | Use situation issues |
| Provide good readability for vision impaired driver | Use situation issues |
| Provide good re-usability for seasonal usage | Use situation issues |
| Allow imprecise interaction | Use situation issues |
| Provide appropriate information for both experienced and inexperienced drivers | User profile |
| **Sustainability** | |
| Contain functions for guiding the driver to propel the boat in a more sustainable way. | LCA |
| Improve product assembly and disassembly | LCA |

# 7. USE SITUATION DESIGN

*This chapter will explain the intended use of the product, it frames this by describing the desired use situation and a scenario to illustrate the sought feeling and expression. After this a Design Format Analysis (DFA) of the Volvo Penta brand and a Mood board are presented to concretize, define and visualise the intended expression and direction of style. Ideas for new interaction and functions are presented towards the end of the chapter where they are also evaluated. Ending the chapter is a refined requirements listing and a summary.*

## 7.1 Intended use situation

In order to capture the problems identified in *Chapter 6. Problem Definition,* a description of the intended use situation follows below:

Users recognizes and looks for the Volvo Penta products. Therefore this new interface device will further enhance the visual brand image. Furthermore, the interface shall be differentiated from competing products and become a factor in the purchase decision of a new leisure boat. It shall be something that the buyer will especially look and ask for.

This behaviour shall be noticed by the boat manufacturers who will give the device a more prominent position on the dashboard. The new interface device shall be considered modern and high-tech and fit well with medium to high-end boats as it shall reflect the boats' performance. In addition, it shall help the driver propel the boat in a environmentally good way.

When users interact with the device they shall find it easy-to-use, intuitive and directly help them remember how they did during the last usage, even if they are not technically inclined. The interface should also require little precision from the user and be used with ease on a swaying flybridge during hard wind. Users shall also find the display to be bright and clear, even when the sun is shining on a hot summer day. The screen brightness shall also be easily adjustable when the evening approaches, as a bright display can cause glare.

Moreover, the device shall have a long life, no problems with water penetration or other quality issues. It shall be mounted in the same way as the current device and fulfill the same technical requirements.

The above situation is reflected in the scenario below.

### 7.1.1 Scenario: The one-day family trip

A family of four is going on a one-day trip from Gothenburg to Marstrand on a lovely summer's day. The parents have been looking forward to spend a day on the sea with their young children and have a day off from their hectic work.

The day starts with the family getting settled into their boat. As the weather is nice, the father decides to drive from the flybridge. Since they use the boat only a few times every summer the father (who is basically the sole driver) feel insecure about the state of the engines. He goes down to the engine room and does a routine check of oil level, eventual leakages, etc. Today everything seems to be working fine, but he still feels insecure whether he has done a proper check. When he starts the ignition, the new interface device displays information about the engines, which confirms his check and this makes him feel more confident. The information tells him whether he needs to perform service on the engines, or if he should fill up with extra engine oil before driving off.

After the start-up message is shown to the father, he is provided with the most relevant information that is needed for leaving the dock and driving in low speeds (about 7-10 knots). The family slowly drive to more open water where the father accelerates to higher speeds (about 23-25 knots) in order to level the boat.

Due to the high speed, the ride is bumpy and the father must keep full attention on the surroundings. The new interface device will therefore dynamically alter the information it displays to suit the new driving conditions. Now the father can with a quick glance see the desired information, even if the sun is blazing on the display, and continue focusing on the driving.

As the trip progresses, the wind picks up and sea water starts to splash on the helm. Even though the interface device gets covered with water, the father has no problem interacting with it or read the information. And thanks to the excellent sealing ability, the father does not even consider that something can go wrong with the device.

After about one hour the family arrives to Marstrand where they dock the boat. The new interface device will now automatically go back to its initial, low-speed state. With this information the father can dock the boat as easily as he could leave the dock from the start of the trip.

The family enjoys a tasty lunch in the sun at an open-air restaurant. They spend a few hours in town and then decide to drive back home. On the way back there is a sudden increase in engine temperature, the new interface device notifies the father of this by showing a temperature icon and a graphic of the engine. He is advised to drive home in low speed in order to reduce engine load. The device also gives him recommendations to contact the nearest Volvo Penta dealer.

The father becomes a bit nervous, but since the family only have a short trip back to their dock he drives the boat back on a low RPM. The interface device switches back to the low-speed view, which also allows the father to interact with it. During the drive back the father shows his wife how easy the boat is to drive and the device is to interact with. The wife becomes curious and also wants to test drive the boat, she appreciates how interacting with the display resembles using her mobile phone.

When approaching the dock, the father contacts his local workshop, they advise him to control the cooling water intake. When doing so the father notices a plastic bag blocking the intake, it is easily removed and the boat functions well again

## 7.2 The Volvo Penta brand

As motorboat owners often are faithful and loyal to their brands it is important that users will recognize the new interface device as a Volvo Penta product. Therefore a brand analysis and a Design Format Analysis (DFA) was conducted to capture the most important aspects of the Volvo Penta brand. Volvo Penta and its brand is part of Volvo Group. Their corporate identity, core values and visual brand identity originate from this bond (Volvo Group, 2013).

### 7.2.1 Core Values

Stated on their website, Volvo Penta's core values are: quality, safety and care for the environment (Volvo Penta, 2011). These core values are shared by all Volvo brands belonging to Volvo Group.

*Quality*

Quality for Volvo Penta means both to deliver products with high performance and craftsmanship, it is also about caring for customer needs during the product's lifespan (Volvo Penta, 2011).

VOLVO PENTA

*Safety*

Safety is a core value originating from the Volvo corporation, it refers both to protect the operator and to assure the functionality of their products in all contexts (Volvo Penta, 2011). Volvo Penta states that reliability is closely related to the notion of safety and that their engine applications should never fail when cruising at sea or in emergency situations.

*Care for the environment*

Care for the environment is a part of Volvo Penta's commitment to customers and end-users, employees and the community and is incorporated in the company's development processes (Volvo Penta, 2011). Volvo Penta's diesel and gasoline engines have an impact on the environment and this is something that the company is aware of. As such, they state that they have a responsibility to reduce the environmental impact from their products; from production to end-of-life.

### 7.2.2 Design Format Analysis

The DFA, see Figure 25, illustrates the common design format, i.e. the most common design features of the Volvo Penta brand, and how strongly their products conform with the format. The vertical columns represent the occurrence of design features while the horizontal rows show the extent to which the products employs the features.

From the DFA, it can be concluded that the product family is consistent since all products scored fairly high. Furthermore, the products with the lowest scores lack only weak design features (Volvo black colour, metallic parts, curved forms and glossy plastic), except for the HCU which has a black logo in contrast to the commonly white one. The weak design features can be attributed to the difference in purpose of use for the products. The display units carry the design features of glossy Volvo black plastic, while the steering units make use of metal and curved body forms. Henceforth, the common design format for the display units and control units are stronger within the respective applications, but differs slightly between them.

Excluding the design features that are exclusive or strong within the two applications, the DFA shows that the common design features are strongly represented throughout the product lineup. These features are:

- Volvo Grey Colour
- White text or icon on buttons
- Distinct chamfers
- White Volvo Penta logo
- Matte plastic
- Rectangular-shaped buttons

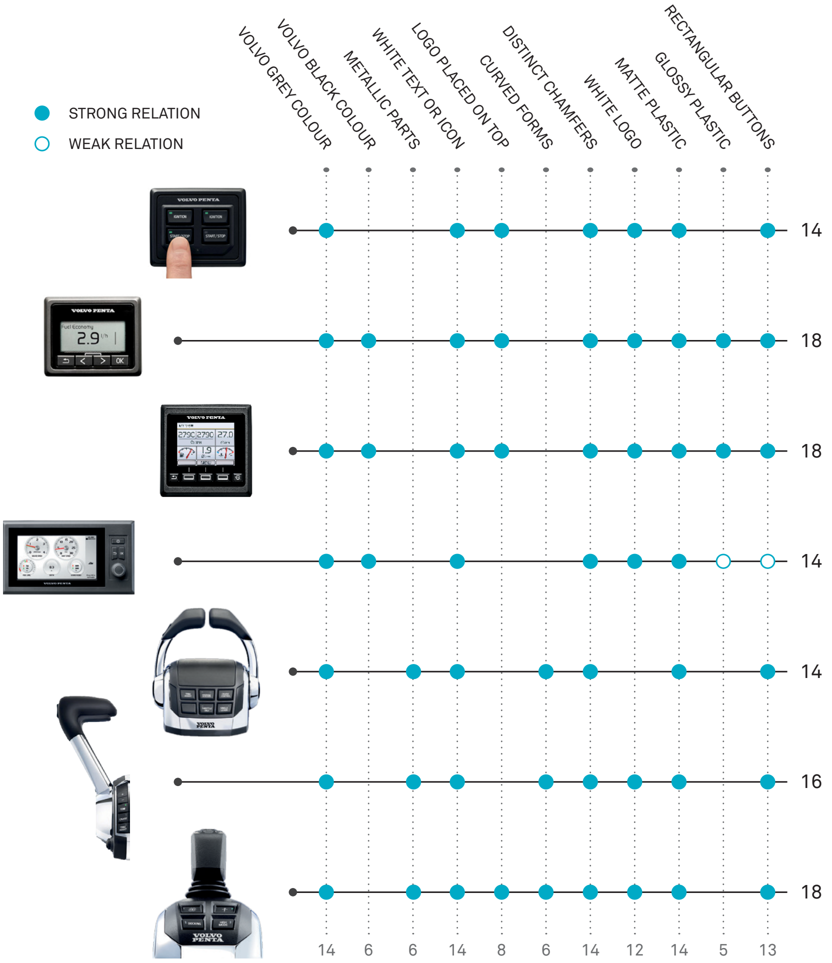


*Figure 25. Design Format Analysis illustrating the common design format of the Volvo Penta Brand. (Image sources: Volvo Penta, 2011)*

*Figure 26. The mood board illustrates the expressions and the direction of style. (Image sources: Jardin Lapin, Volvo Cars, Matomeno, Nest, wallls.com, Nord West 2013)*

## 7.3 Mood board

A Mood board was created to define and illustrate the direction of the style for the new interface device, see Figure 26. The moodboard depicts the desired expressions *sleek, reliable, accurate, simple, professional and modern*. These expressions derive from the problem definition, an interpretation of Volvo Penta's brand values and the intention of designing a product positioned at the avant-garde of the marine display market. The strive was also to create a look that better fit with the well-designed marine vessels of today.

The pictures, from top left to bottom right, describe the following ideas, design elements and expressions:

- Lamp - distinct chamfers, material matteness and form elements. Expresses modern, sleek and simple.
- Volvo V40 dashboard interface - simple and easily understandable information. Expresses accuracy and professionalism.
- Clock - display the most important information. Expresses simplicity and accuracy.
- Nest thermostat - simple exterior, advanced interior. Expresses modern and simple.
- Cogwheels - accurate performance. Expresses reliable, accurate and professional.
- Boat hull - describes the dynamic marine context. Expresses sleek.

## 7.4 Ideas for new interaction

The interface device can potentially utilize several different ways of interaction. Regarding information transfer, the device will have a display and a buzzer. However, regarding the devices control methods several possibilities exist, the most relevant ones include:

- Physical buttons - A number of buttons placed in relation to the display, similar to the existing reference displays.
- Touch - A touch panel could be placed above the display surface. This would make interaction with the device similar to a mobile phone or tablet.
- Voice control - A voice sensor could be placed inside the device, which reacts to certain voice commands. This allows the display to be interacted with from afar.
- Motion control - A motion-capturing camera could overview the driver and respond to certain movements, similar to the Xbox Kinect.

### 7.4.1 Comparison of ideas

When considering the context that the interface device is to be placed within, it becomes clear that interaction with the device using some of the interaction methods will be hard. When, for example, driving the boat from the flybridge in high speeds, there are a lot of sounds from engine(s), wind etc., limiting voice control functionality. Thus, voice control was excluded.

As for motion control, the technology requires several advanced cameras that range in costs from about $800 and above (Meta Motion, 2013). This would significantly increase the price of the device. In addition, motion control is not a particularly common way of interaction, thereby it could even make the interaction less intuitive for the driver.

This leaves physical buttons and direct touch as the two most feasible techniques of interaction, as they demand similar user resources. These two are evaluated towards each other in the following chapter.

### 7.4.2 Touch vs. buttons

Touch and physical buttons have differences in how the interaction is designed, technology maturity, flexibility, construction, cost, etc. To evaluate whether touch or physical buttons was the preferable solution for this device several factors needed consideration. All of CPAC's existing devices use physical buttons as their means of control. Thus, physical buttons are a proven technology and customers are used to interact with them. On the other hand, devices using touch technology have become increasingly common during the last years, smart-phones, tablets etc. By using touch technology the user-interaction can be similar to other devices, the size of the product can be decreased and it allows for more flexibility. Furthermore, implementing the touch technology can be used as a differentiating attribute. In order to make a fair comparison between the two, differences in key attributes were identified and compiled in Table 4.

### 7.4.3 Conclusion

When comparing the two technologies it is clear that the touch technology has several uncertain areas. However, if those areas are solved then the touch technology could add extra value to the device and provide the driver with a more intuitive interface. Also, as no other products on the market use touch technology (for the aimed market segment) it can be a very strong differentiating attribute. This was also acknowledged by several CPAC and Volvo Penta employees.

Based on these attributes and discussions with CPAC and Volvo Penta, the touch technology was chosen as the prefered technology. The uncertainties will be evaluated in the continuation of the project.

## 7.5 Evaluation of touch technology acceptance in a marine context

In order to evaluate whether customers would be receptive towards using touch technology in their boats, a broad screening was conducted. This screening included stakeholders from the Gothenburg Boat Show, Volvo Penta, Nimbus and boat users.

The opinions regarding touch technology were diverse. At the Gothenburg Boat Show, some boat manufacturers were sceptical about the use of touch-screens due to the lack of haptic feedback and precision issues. Others were very positive, claiming that touch is the future and should definitely be implemented into the device.

A sales representative from Nord West explained that good usability for the driving interface is very important for many customers. When asked about using touchscreens as the medium of interaction, the sales person saw both advantages and disadvantages. When the boat sways out at sea, he thought touchscreens would be unsuitable. However, he uttered that touchscreen development has progressed and that touchscreens are certainly something that customers will demand and expect in a near future. (Nord West, 2013)

The sales person from Honda considered touchscreens to be suitable in marine environments. He stated that

*Table 4. Comparison between touch technology and physical buttons.*

| | Touch technology | Physical buttons |
|---|---|---|
| **Technology assessment** | New type of technology, used somewhat in chartplotters but none as an information display. Possibility of differentiation. | Well tested technology, proven functionality within marine environments. |
| **Versatility** | Interaction can be designed in numerous ways. High versatility and flexibility. | Interaction is limited to number and placement of buttons. |
| **Haptic feedback** | No haptic feedback can be provided from the device. As the device is stationary, vibration cannot be included. | Buttons are easily felt, thus the driver does not need to look directly at the display when interacting. |
| **Water and glove sensitivity** | Sensitivity is uncertain on standard screens. Screens exist that work with water and gloves. | No problem. |
| **Construction** | No buttons allows for simpler construction. | Buttons require sealing and are a quality risk. Requires more parts to assemble. |
| **Size** | Outer dimension relative screen estate is minimized. Improved readability. | Buttons require additional room besides the display. Low screen estate. |
| **Obstruction** | Interaction can obstruct the screen and leave fingerprints. | Interaction can be done without obstructing the screen and does not leave any marks. |
| **Cost** | More expensive components, more simple construction | Less expensive components, more advanced construction. |
| **Future development** | Allows for addition of future functions. In line with the overall development of technology. | Has limited development possibilities. |
| **Customer responsiveness** | Uncertain, needs further evaluation. | Todays customers accept the technology. Customers of tomorrow are uncertain. |

their customers are used to touchscreen devices such as smartphones and tablets and that they enjoy having the same technology on their boats (referring to touch-chartplotters). Questioning the reliability of touchscreens, the sales person responded that he had not received or heard complaints regarding water leakage or usability issues. (Honda, 2013)

Representatives from Volvo Penta were also asked about touch technology and their opinions regarding it. Sales personnel from Volvo Penta responded that they were positive towards the concept of using touchscreens. Martin Pettersson (2013), Systems Architect at Volvo Penta was also interviewed. He was positive towards integrating touch technology among Volvo Penta's product lineup. Of course there would be some problems to overcome but he was certain that they could be solved.

Nimbus sales representative Erik Hanson (2013) was in general positive towards touchscreens since they are considered modern and have more screen estate for displaying information. However, he was still skeptical to the idea of using them as information displays and mentioned that it will be problematic for the user to interact with the screen at sea, since there is a risk that the boat sways because of waves and thus making it difficult for the user to interact with precision. However, he thought touchscreens would be usable in calm contexts, such as docks.

Contacts with Nimbus were continued at their head office, where a meeting was held with quality supervisor Rickard Thorsson, head of sales Peter Bergström and head of technology Mats Jakobsson. The three agreed on that there are several challenges to overcome in order to be able to implement the technology. However, if it could be successfully implemented, the technology could provide the driver with many additional benefits and greatly simplify the interaction for the driver.

### 7.5.1 Acceptance conclusion

Overall, opinions about using the touch technology were positive during the screening. Many boat manufacturers and other stakeholders claim that it is not a question about if, but when the touch technology will be commonplace in marine applications. It was made clear that for the technology to succeed, quality and reliability are important factors. The loss of haptic feedback and the required precision for interacting with a touch panel needs to be managed in a good way to allow success. Could the potential issues be solved by a cleverly designed interface, a touch display would provide users with improved interaction in a modern product with a large screen estate.

## 7.6 Usability consideration

The following section describes how Jordan's design principles will be considered when developing concepts for a touch screen based GUI. These are intended for helping achieve the desired use situation and scenario.

### 7.6.1 Consistency

Because boat driving is seasonal, it is therefore important to aim for strong consistency. Accessing functions that are similar to each other should be performed in a similar manner and navigation through the interface should be consistent. By designing with consistency in mind users will be able to learn the GUI faster.

### 7.6.2 Compatibility

As the device will feature touch as means of interaction, inspiration should be taken from GUI:s of existing smartphone and tablet operating systems, such as Google's Android and Apple's iOS. This will make use of the experience users have gained from using their smartphones and create a recognisable user experience. Furthermore, relevant interface elements and architecture from existing Volvo Penta displays and devices shall be considered or directly transferred to the new GUI, meaning that users will be able draw upon their past experiences with these products.

### 7.6.3 Consideration of user resources

Driving a marine vessel imposes strain to both the physical and cognitive resources of a driver. The level of strain depends on the vessel's speed. Driving in high speed results in users having to focus nearly all their cognitive and physical resources on driving the vessel, resembling to driving a car at high speeds. Thus, consideration of user resources for different driving speeds shall be taken when designing the GUI.

### 7.6.4 Feedback

Feedback should be addressed in two ways: provide visual confirmation of the user's touch inputs, and inform the user about status changes and potential engine malfunctions and help the user solve them. Since the users' domain knowledge about engines vary greatly, feedback should support inexperienced drivers but at the same time provide explicit information to knowledgeable drivers.

### 7.6.5 Error prevention and recovery

As driving a marine vessel strains both physical and cognitive resources, error prevention and recovery will be considered. The amount of errors should be minimized by partitioning certain functions and limit the required precision when interacting with the display.

### 7.6.6 User control

In conformance with current devices, users with varying domain knowledge should be able to adjust what information to display. However as users strain both physical and cognitive resources while driving, user control should be limited in these aspects.

### 7.6.7 Visual clarity

As the display will be placed outdoors and exposed to different light conditions, such direct sunlight and low light during the night, and that the user's cognitive resources are limited while driving, visual clarity will be considered. A solution that presents clear and easily interpreted information should therefore be designed. Also, many users have reduced vision that further emphasise the importance of visual clarity. Visual clarity will be achieved by considering text and object sizes, the amount of information displayed, contrasts, colour coding and layout.

### 7.6.8 Prioritisation of functionality and information

The EVC system contains vast amounts of information and therefore information and functionality will be prioritised. Furthermore, as the driver's mental capacity is strained the amount of information shown to the user should be limited. Thus, the GUI should provide the right amount of information that is sufficient but not overwhelming.

### 7.6.9 Appropriate transfer of technology

This design principle was regarded when choosing touch as the mode of input. However, the appropriate type of touch technology should also be chosen as to represent the pursued type of interaction.

### 7.6.10 Explicitness

In terms of explicitness, the device should give clues (affordances) to the user in order to help them interact with the product, understand that touch is the mean of interaction and make them understand how to navigate through the interface. This will also increase the guessability and thus provide benefits for seasonal usage patterns.

## 7.7 Ideas for new functionality

From internal brainstorming sessions, discussions and interviews with boat manufacturers, boat drivers, boat dealers etc. several ideas for how an interaction that will help create the desired use situation emerged. With help from the usability principles, the ideas were elaborated by the project group.

### 7.7.1 Description of ideas

*Idea 1: Drive view*

When propelling the boat, the driver is often occupied with steering the boat and keeping attention to the surroundings, thus user resources are strained. Therefore it is important for drivers to gain a good overview of the boat's total status by simply glancing over the instruments. Here, a Drive view would be suitable. This view will be directed more towards inexperienced users and focus on high visual clarity and simplicity. Thus, it will only show the most important flows that the driver requires in order to propel the boat.

*Idea 2: Easily accessible detailed information*

As the Drive view is directed towards novice users, expert users who request more extensive information about a certain flow they can easily access it by pressing on the gauge of the flow, which will activate a pop-up. This pop-up could present additional details about the flow, such as its change over time or relate it to other factors of interest.

*Idea 3: High-speed view*

Driving in high speeds is extremely bumpy and requires the driver and passengers to firmly hold themselves onto the vessel in order to not fall overboard. Therefore the driver's physical and cognitive resources are highly loaded. This idea introduces a new High-Speed view that only displays the most relevant engine and vessel information in a clear way. Hence, the driver is able to quickly read the information thanks to good visual clarity. The view is automatically displayed when the vessel speed exceeds about 20 knots, which means that the driver can continue to focus on the driving and keep a firm grip on the steering wheel. To discourage users from interacting with the new interface device while driving fast, the High-speed view will deactivate the touch input functionality. Another intention is that this security feature will further enhance the "safety" core value of the Volvo Penta brand.

*Idea 4: Start-up view*

To aid novice boat drivers in understanding the state of their boat's engine(s) a Start-up view is displayed shortly after the engines have been started. It provides the driver with relevant information regarding engine status and service intervals. This information could help the driver plan their intended trip distance and route and to help avoid unexpected engine problems. The Start-up view would automatically disappear after 5-10 seconds and be replaced by the Drive view.

*Idea 5: Quick settings view*

In order to maintain a high visual clarity under the varying lighting conditions that the display will be exposed to, brightness settings are important to be easily reachable. This is also recognized among current products, as many have a specific button for altering screen brightness. To facilitate these settings, the new device could include a Quick settings view. This view will be easily accessible from all other views and consistent in its accessibility.

#### Idea 6: Notification system for engine and EVC errors

Experienced boat drivers appreciate the ability to read several engine information flows in parallel to detect trends and changes in engine status. This information helps them predict engine problems before they occur and, hopefully, remedy them. For instance, an increased coolant temperature could result in engine overheating or a decreased engine oil-pressure could cause engine malfunction. For inexperienced drivers, raw and untranslated engine information has little or no meaning. Therefore, the new interface device could instead present engine status information when the system notices a negative engine trend. The idea is to present the engine information and its consequences in way that is understandable to an inexperienced user and thus decrease the sensation of incertitude. In addition to notifying the driver of a potential engine malfunction, the interface could present direct actions that the driver should make in order to avoid the malfunction, or to contact service personnel.

#### Idea 7: Eco guidance system

According to Nimbus boat manufacturers, there is a demand from inexperienced drivers for a guidance system helping them to propel their boat in a more environmental and economical way (Thorsson, 2013). This idea introduces such a guidance system, which would help the driver find the correct planning speed and adjust the trim angles accordingly. The results would be lower fuel consumption and a smoother ride for the driver and passengers. This information could be presented in the Drive view, as both are directed towards the same target group.

#### Idea 8: Windshield wipers integration

Nimbus boat manufacturer appreciated when several functions were integrated within one controller (Thorsson, 2013). For instance, it was requested to include the windshield wipers in the EVC system. This would allow the boat manufacturers to discard a controller only for this function from another supplier and, if integrated to the new interface device, gain additional space on the dashboard. The same type of integration could also include other functions such as; lightning, active bilges etc. Thus additional space could be gained on the dashboard and allow room for a bigger and more versatile display controller.

#### Idea 9: Showing data from two engines

CPAC and Volvo Penta expressed the wish of letting the display show data from two engines simultaneously (Stigeberg, 2013, Arvidsson, 2013). This would increase the potential market share of the display relative to the Flexi-display, as it would also include double installations.

### 7.7.2 Evaluation of ideas

The presented ideas were evaluated in cooperation with CPAC and Volvo Penta employees during several meetings. It is important to note that the ideas were not evaluated and directly compared against each other. As such, the purpose of the evaluation was not to decide on a single solution to further develop.

*Idea 1: Drive view* was discussed on several occasions and it was deemed as an interesting feature that would be beneficial for novice drivers to understand the most important information about their boat. Though the idea needs further evaluation regarding which information is the most crucial to display. Consequently it was decided to further investigate and develop this idea.

*Idea 2: Easily accessible detailed information*, was decided to be discarded due to that the EVC-system does not contain the additional information that was sought to display. Also, by having additional virtual buttons on the screen, the precision requirements increase. Thus resulting in an increased risk of use errors. However, in future applications this idea could be interesting as it resembles interaction with other touch-screen devices.

The idea to dynamically change to a high speed view, *Idea 3: High speed view*, was positively received by CPAC and Volvo Penta (Monzani, 2013, Arvidsson, 2013). It was thought to be highly feasible and to have the potential to noticeably benefit the driver in high speeds. There were, however, concerns about how much the view would differ from the low-speed view and if the automatic transition would confuse the driver and limit user control in a negative manner. Conclusively, it was decided to further investigate and develop this idea.

The *Idea 4: Start-up view* was also found interesting to explore further. This idea helps the driver to monitor their engine(s), similar to the engine monitoring system of a car, which informs the driver whether there are issues to attend. The similarity to the car system was found very positive as it was something that future customers was believed to be expecting from a new boat. Therefore the idea was deemed interesting for further development.

Considering that all existing CPAC devices have the screen brightness setting easily accessible, the idea to include those controls in a *Quick settings view* was positively accepted during evaluations. It was also evaluated that in order for it to be "easily accessible" it should not require more than one action from the user, similar to existing devices.

Similarly, *Idea 6: Notification system for engine and EVC errors* was deemed interesting by CPAC (Stigeberg, 2013, Monzani, 2013) to develop further. As many boat owners (especially future boat owners) lack knowledge about their boat's engine system, a new and improved notification system would potentially lead to fewer engine damages and hence increased customer satisfaction.

All parties (Monzani, 2013, Arvidsson 2013) found *Idea 7: Eco guidance system* to be visionary but too complex to implement directly. The problem with the idea of helping the driver to find the correct planning speed is that there are many dynamic factors influencing this function (engine size, propulsion system, hull design, cargo, weather or marine growth). In order to implement a eco guidance system the EVC system would have to know for every boat made the form of the hull, the type of engine, the current sea condition, the weight of the cargo etc. As a result, the idea had to be discarded and re-developed.

*Idea 8: Windshield wipers integration* was deemed interesting, but not enough for the project as it did not bring the desired added value to the driver. Even though this idea would be feasible to implement in the near future, it was deemed that focus should be put on the other ideas.

The final *Idea 9: Showing data from two engines* would allow the display to be a potential replacement of also the G4 display. If the new display could feature this function it would have the same functionality as the G4, and as the G4 display is bought entirely from Garmin, CPAC would benefit financially from losing an intermediary company. Thus this idea was deemed interesting to explore further on (Stigeberg, 2013).

## 7.8 Chapter summary

In this chapter a new use situation and how a product could be designed in order to realize this vision were suggested. The described desired use situation and scenario explained a device that will simplify the driving experience and provide the driver with a dynamic display, which will present the right information at the right time.This target scenario will be achieved by accomplishing the following:

- Incorporate the Volvo Penta brand and follow the direction of the mood board.
- Incorporate a touch panel as means of interaction. The uncertainties regarding the applicability of using touch in a marine environment will be further evaluated by the development of a prototype.
- Consider and design after the defined usability principles, which are compiled under Usability guidelines (found below).
- Feature the ideas that are approved for further evaluation. These are: Drive view, High-speed view, Start-up view, Quick settings view, Notification system and displaying information from two engines simultaneously.

By including the above, it was also learned that the functionality provided by the new device could potentially replace not only the Flexi-display but also the G4 display. This became very interesting as one new product could replace two current ones and, henceforth, lead to greater economies of scale for the new display.

### 7.8.1 Usability guidelines

A set of general usability guidelines, originating from the consideration of the usability principles, were defined and compiled to aid in the GUI development and help generate new requirements. The guidelines are:

- Similar functions shall be accessed in similar ways.
- Users shall be able to draw upon past experiences with other touch devices and CPAC's current displays.
- Users' physical and cognitive resources in different driving speeds shall be considered.
- The GUI shall provide visual confirmation of the users touch inputs and inform the user about status changes, potential engine malfunctions and help the user solve them.
- Critical functionality in the GUI shall be restricted for the user.
- Users shall themselves be able to alter certain aspects of the GUI to fit with their explicit needs.
- Visually clear and easily interpreted information shall be presented by considering text and object sizes, the amount of information displayed, contrasts, colour coding and layout.
- The GUI shall provide sufficient but not overwhelming amounts of information.
- The pursued type of interaction shall be achieved by the appropriate type of touch technology.
- The user shall understand that touch is the mean of interaction and affordances shall inform how to navigate through the interface.

## 7.9 List of elaborated needs

The initial list of needs was elaborated with the aim of defining the intended use situation more explicitly and to capture the newly emerged data. The elaborated needs are compiled in Table 5. Similarly to the original needs, the elaborated ones were weighted from 1-3, where 1 equals a wish and 3 equals a requirement.

*Table 5. List of elaborated needs that describe the intended use situation.*

| Need | Elaborated need |
|---|---|
| **Basic functionality** | |
| Contain the same functionality as the current devices | Contain the same functionality as flexi-display. |
| | Contain the same functionality as G4 display. |
| Should be used on boats above 16ft | |
| Be directed towards leisure use | |
| Contain differentiating attribute | Use touch technology as means of interaction. |
| **Aesthetics** | |
| Comply with the Volvo Penta brand | Incorporate Volvo "Black" colour |
| | Incorporate Volvo "Grey" colour |
| | Use Volvo instrument font |
| | Use Volvo Penta logo |
| | Make use of distinct chamfers |
| Provide a visually appealing and modern look | Allow a smooth surface mounting |
| | Minimize bezel around screen |
| | Incorporate a colour display |
| | Express sleek, reliable, accu, simple, profes and modern. |
| **Construction** | |
| Withstand placement under the same circumstances as the current CPAC devices. | Withstand placement under the same circumstances as the current flexi- and G4 displays |
| Have at least IP class 66 | |
| Be both flush and surface mountable | |
| Use a standard hole pattern for surface mounting | |
| Hinder accumulation of water on screen | |
| Minimize outer dimensions | |
| Ensure functionality within temperatures -30 to +85 ∘c | |
| Reduce cost | Be built from standard components |
| Allow mounting of sun-cover | |
| **Usability** | |
| Facilitate boat driving | Feature a High-speed view. |
| | Feature a Start-up view. |
| | Feature a Quick-settings view |
| | Feature a Drive view |
| | Feature a notification system for warnings and changes . |
| Have a simple interface | Allow the driver to gain a good overview of the engine status by simply glancing over the display. |
| Warn the driver of engine malfunctions | Feature a Volvo Penta standard buzzer. |
| Provide good readability in sunlight | Feature screen brightness controls |
| | Feature a bright screen display |
| Provide good readability during low-light conditions | Feature screen brightness controls |
| | Feature a bright screen display |
| Provide good readability for vision impaired driver | Increase screen size |
| Provide good re-usability for seasonal usage | |
| Allow imprecise interaction | |
| Provide appropriate information for both experienced and inexperienced drivers | |
| **Sustainability** | |
| Improve product assembly and disassembly | |

# 8. SYSTEM-LEVEL DESIGN

*This chapter introduces a hardware and a software architecture that are intended to solve the identified problems and achieve the desired use situation. These architectures result in a number of prerequisites that needs to be addressed when developing concepts, which are presented in the end of the chapter.*

## 8.1 Hardware system architecture

The connections and components of the hardware concept is illustrated in the cross section-view of the hardware architecture in Figure 27. The display and touch panel are bonded together and then mounted on the bezel and housing. Inside the housing are electronics placed in order for them to be protected from the outside environment. The housing also has a Controller Area Network (CAN) interface bus for connecting it to the EVC system. The architecture was developed with support from display retailer, mechanical designer, quality engineer and electronics engineer at CPAC.

### 8.1.1 Display and touch panel

The touch panel should function with sea water and withstand environmental conditions such as strong sunlight and low and high temperatures. It should withstand these factors in both short and long time periods.

The display should have good visibility during all light conditions. It needs to have a high enough screen brightness to be readable in strong sunlight and a low enough brightness to not cause glare while driving in night time. The sunlight should neither have any affect on the performance of the display. Also, the viewing angle should be satisfactory as the final position of the display cannot be controlled and the driver needs to be able to scan information from it at all times.

The screen dimensions for the display and touch panel need to be large enough to contain the intended information, but small enough to not take up too much space on the dashboard. Furthermore, the pixel density of the components shall provide readability from a viewing distance while being seated (about 1-1,5 m).

### 8.1.2 Housing

The housing will enclose and protect the components inside from the surrounding environment. It needs to have a large enough room for required electrical components and allow for a failsafe mounting. The intention of the housing is that the electronics should fit in the lower cylindrical part of the housing and not be positioned directly underneath the display. This will lower the devices height above the dashboard thus allowing a thinner construction and a more modern design. The outside of the housing should have a CAN interface, for allowing connection with the EVC system. It should also have a connection for Volvo Penta's standard buzzer.

The housing together with the bezel should allow both flush and surface mounting on a helm. The surface mounting should be done with a Volvo standard dimension (52mm or 85mm). This means that the back part will have a cylindrical dimension of either value.

### 8.1.3 Bezel

The bezel is placed around the screen. It should feature a Volvo Penta inspired profile design, prevent water from accumulating on the screen, and together with the housing allow both surface and flush mounting. The bezel should neither take up more space than necessary on the dashboard, as a big bezel will lower the screen estate of the device thus give it an impression of being bulky and outdated. Also, a big bezel would take up extra place on the dashboard.

### 8.1.4 Cost aspects

Cost aspects that need consideration are manufacturing costs, component costs and their lifespan. As the production volume of the display will not be enough to economically justify a completely customized display and touch panel, standard off-the-shelf components should be sought.

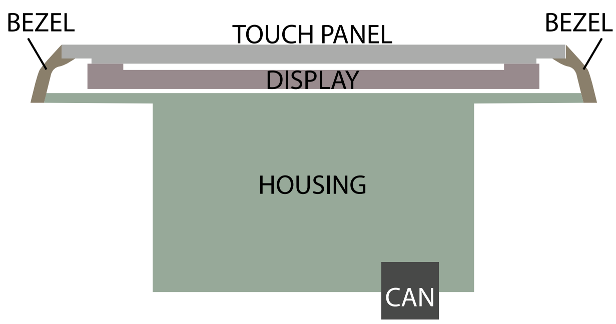


*Figure 27. The cross-section illustrates the hardware architecture, which consists of parts providing user interaction, electronics enclosure and connection to the EVC system.*

This means that the display and touch panel components need to be available on the market for at least 5-10 years. Furthermore, the display and touch panel must fulfill Volvo Penta's requirements on temperature functionality and EMC levels.

The touch panel, display and electronics will be the cost-driving components of the concept. Due to the price-sensitive consumers of today, it is important to find components that can provide noticeable added user value at limited costs. This will prospectively increase the perceived value and consequently justify an increased price-point for the end-user.

## 8.2 Graphical User Interface (GUI) system architecture

The system architecture for the GUI, illustrated in Figure 28, was benchmarked from the Flexi-display and the G4 display. These GUI's contain information and functionality that must be incorporated into the new interface device. Consideration was also taken for the wide range of interactions such as single press, swipe (with one or multiple fingers), long press and pinching that touch technology permits. In addition, the diverse user characteristics of boat drivers were taken into consideration, as they play an important part of the understanding for the interface. Lastly, Jordan's ten design principles and the set usability guidelines were considered and used as and evaluation guidelines. The concept for the system architecture resulted in following structure:

- When the user starts the engines, the interface device starts up and display a *Start-up view*. The view contains information about the current status of the engine(s).
- A main view, called *Drive view*, is the default driving view. This is where the most important engine information for driving is displayed.
- *Detailed information views*, which are accessed through horizontal swipes and contain the same information as the view found in the G4 display. The views are also named in the same way: *Engine, Fuel Economy and Vessel.*
- A *Settings view* is found at the right end of the horizontal structure. Here is also the Warning Manager found.
- A shortcut to brightness settings is located "above" each view and is accessed through a vertical drag from the screen's top center. This view is named *Quick Settings.*
- *Warning notifications* (not illustrated in Figure 28) pop-up when urgent engine malfunctions are at risk of occurring.

### 8.2.1 Interaction and content of views

The five major views (*Drive view, Engine view, Fuel Economy view, Vessel view, Settings*) are accessed through horizontal swipes, either to the right or to the left. This horizontal structure resembles the G4 and 7" displays' navigational structure, henceforth, users of the those devices can make use of past knowledge. Being able to interact with low precision is beneficial when using the new interface device in a swaying driving condition.

By structuring the detailed information views similar to the G4 display, the concept is compatible with Volvo Penta's current interface devices. Hence, users who are accustomed to Volvo Penta's products will be able to utilise their past experiences and will better recognise themselves and find the information they seek. The views can display up to six information flows simultaneously, as a greater amount of flows would negatively affect visual clarity (Alpsten, 2012).

As the device will mainly be used to read information, presentation of information has been prioritised. Therefore, the information views are the most easily accessible in the GUI. A further strive towards prioritisation of information and functionality is that virtual buttons will be avoided in the information views. This will provide more screen estate for the actual information, thus increasing the prospect of visual clarity.

#### *Start-up View*

The Start-up view shall provide the driver with easy-to-understand information about the current state of the engine(s) and when next service is due. Therefore the Start-up View shall contain the following information:

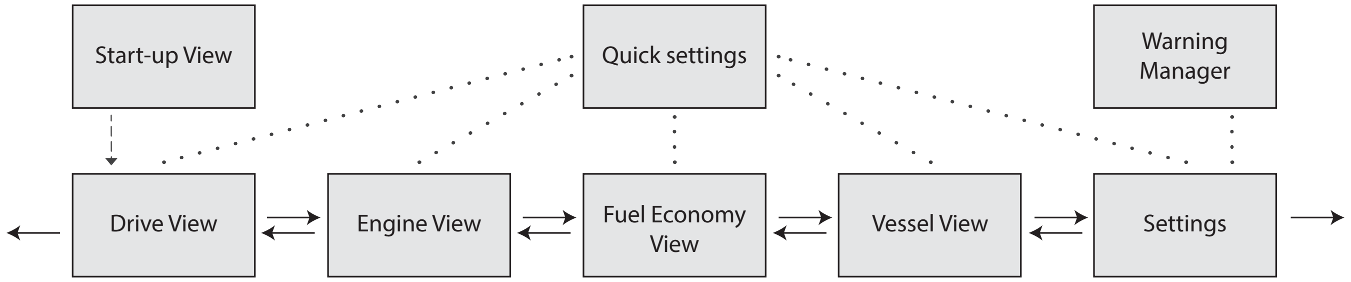


*Figure 28. The system consists of five majors views that are accessed through horizontal swipes, a quick settings view and a warning manager that is found in the settings view.*

- General indication of engine(s) status
- Hours until next service [h]
- Hours until next oil filter change [h]

### *Drive view*

The Drive view is intended to be the default view when driving. To create a balance between visual clarity and amount of information, and considering the cognitive workload while driving, the view shall provide only the most relevant information that is needed for satisfactory driving. Based on interviews with CPAC and Volvo employees, sales representatives from the Gothenburg Boat Show and an experienced boat driver, the Drive view shall contain the following information:

- Vessel speed [knots]
- Engine speed [RPM]
- Fuel level [%]
- Sea water depth [m]

Except for engine speed, information flows that shall be shown are dependent on extra equipment, such as a log for vessel speed or sonar for water depth. Therefore, the Drive view shall be designed for modularity, meaning that the view shall be adaptable to display fewer than four information flow simultaneously or display other information.

The speed of the vessel can be assessed by perception, however it is crucial to provide the driver with the true speed. This is especially important in situations where the driver has speed blindness or when driving in waterways with speed limits. As such, speed information was included in the view and it shall be highly prioritised.

Engine revolutions per minute (RPM) is, together with vessel speed, the most important information. It provides the driver with information about engine load and many drivers today use RPM for many other purposes as well. For instance, RPM can function as support to know when the boat levels and certain boat owners use RPM together with vessel speed to examine the state of the boat. Such a case is if the vessel speed is low compared to RPM, which is probably due to marine growth on the hull and/or propeller.

The decision to include a percentual amount of available fuel was based on two conclusions: users need to quickly and approximately assess the distance they can drive and displaying proportional fuel tank level is conventional in most vehicles, such as cars. Furthermore, users tend to learn the fuel consumption of their boats and are therefore better evaluators of the distance they can go than an instrument, as it is not able to take into consideration the great deal of variables that influence fuel consumption.

Water depth is included in the view as it is important to know the distance to the bottom in order to avoid running aground. Water depth is usually specified in chartplotters but the accuracy of the GPSs of today is insufficient. Reading physical charts is also too inaccurate, especially in close proximity to land.

Since the Drive view contains only four instruments, it was deemed that a High-speed view would be redundant. The limited benefits of having a High-speed view, introduced in *Chapter 7.7 Ideas for new functionality*, would henceforth not justify the potential confusion of the automatic transition between the views.

### *Engine View*

The Engine view shall contain the following information, which is based on the information the G4 displays:

- Engine speed [RPM]
- Power trim angle [°]
- Coolant temperature [°C]
- Battery voltage [V]
- Engine oil pressure [bar]

### *Fuel Economy View*

The Fuel Economy view shall contain the following information, which is based on the information the G4 displays:

- Current and average fuel rate [l/h]
- Current and average fuel economy [l/nm]
- Fuel remaining [l]
- Distance to empty [nm]
- Time to empty [h]

### *Vessel View*

The Vessel view shall contain the following information, which is based on the information the G4 displays:

- Vessel speed [knots]
- Fresh water tank [%]
- Seawater temperature [°C]
- Fuel level [%]
- Seawater depth [m]
- Rudder angle [°]

### *Settings*

A Settings view is found at the far right of the menu structure. This view contains the same settings functionality as the G4 display. An additional function is that settings for altering information in the detailed views are performed here.

### *Quick Settings*

As lighting conditions can change many times during a day, an easily accessible Quick Settings view is included in the concept in which users can change brightness settings in order to compensate for the lighting variations. Included in the view is also the ability to change between pre-configured view modes that are suited for day or night use. The Quick Settings view is accessible through any view with a vertical drag from the top of the screen to the bottom.

### *Warning notifications*

The Warnings notification system displays warnings about the EVC system and the engines. When the EVC systems detects an engine malfunction or a loss of communication between EVC components, it informs the driver about this error. Warnings have the highest priority and therefore a pop-up screen takes over the screen. The intention with the warning pop-ups is to get the driver's full attention and inform about the problem and provide the appropriate action to perform. This will help the driver to act and potentially decrease their stress level.

### *Warning manager*

The Warning manager contains all the accepted but yet unresolved warning messages. Users shall therefore have the possibility to dismiss a warning pop-up message and re-read it later, or gain additional information. This could, for instance, happen when a driver manages to get their boat to safety after having followed the instructions of a warning message and dismissed it.

## 8.3 Chapter summary

This chapter suggested a conceptual architecture for both the hardware and the GUI. The architecture was developed in cooperation with CPAC employees, with benchmarking from existing products and from knowledge gained from previous phases. The below decisions were used as inputs into the List of requirements (found in *Chapter 9.6 List of requirements*) and served as input into the next phase.

Regarding the hardware architecture, the following decisions were taken:

- The device shall be surface mountable using a Volvo standard dimension (52mm or 85mm)
- Screen dimensions of the device shall be large enough to contain the intended information, but small enough to not take up too much space on the dashboard.
- The display shall be of a standard model that will be available for 5-10 years
- The touch panel shall be of a standard model that will be available for 5-10 years
- The housing shall have a Volvo standard CAN interface.
- The bezel shall have minimal outer dimensions.

Regarding the GUI architecture the following decisions were taken:

- Architecture shall be benchmarked from G4 and 7" display.
- Changing between views shall be done by horizontal swipes.
- The use of virtual buttons shall be minimized.
- The High-speed view shall be removed.
- The Start-up view, shall contain; Engine status, Next service, Next oil filter change.
- The Drive view shall contain; Vessel speed, Engine RPM, Fuel level, Sea water depth.
- The Engine view shall contain; Engine RPM, Power trim angle, Coolant temperature, Voltage, Engine oil pressure.
- The Fuel Economy view shall contain; Current and average fuel rate, Current and average fuel economy, Fuel remaining, Distance to empty, Time to empty.
- The Vessel view will contain; Vessel speed, Fresh water level, Sea water temperature, Fuel level, Seawater depth, Rudder angle.
- The Settings view shall be placed at the far right end of the architecture it should contain the same functionality as the G4 display.
- The Quick Settings view shal be accessed from all screens and contain screen brightness settings and view mode selection.
- Warning messages shall pop-up and take over the screen and provide the driver with explicit and relevant information about the warning and suggest actions.

# 9. DETAILED DESIGN AND CONSTRUCTION

*This chapter describes the hardware and the graphical user interface (GUI) development phases. The first part is the hardware development, which begins with the decision of a touch technology and continues with the construction of a hardware design around it. The second part of the chapter, is the GUI development, starts with design concepts for the layout and interaction. These are evaluated and further refined in a GUI concept with a graphic layer. Ending the chapter is a refined list of requirements, compiling the outcome of the phase.*

## 9.1 Touch panel technologies

In order to evaluate different touch panel technologies and research which technology would be the most feasible alternative in this application, a technology screening was conducted. In this chapter, the four most common touch technologies (Pakula, 2008) are presented. Their advantages and disadvantages are discussed, compared and then evaluated in the end of the chapter.

### 9.1.1 Resistive

Figure 29 illustrates resistive touch technology, which consists of a number of flexible sheets that are coated with resistive and conductive material. The conductive material is usually made of Indium Tin Oxide (ITO), since this oxide has two properties that are suitable for touch panels: it is electrically conductive and optically transparent in thin layers (Umicore, 2013). When touch is applied on the screen, the top surface is pressed downwards and the two layers meet. This causes an alteration in the electrical current and by measuring the resistance level between the layers the coordinates of the touch position can be identified. (HowStuffWorks, 2013, Ockenden, 2010)

Since the touch input event is dependent on pressing together the conductive and resistive sheets, any stimuli can be used to interact with the touch panel, be it a finger or a hard object such as a stylus. However, this means that the top layer of the screen must be flexible and thus the screen cannot be covered by a hard material, for instance glass.

### 9.1.2 Capacitive

A capacitive touch panel, illustrated in Figure 30, consist of an insulator, such as glass, coated with a transparent conductive layer. Similarly to the resistive touch technology this layer is often made of Indium Tin Oxide (ITO). When a conductor, such as the human finger, touches the surface a change to the capacitance of the electrostatic field of the ITO layer is detected. There are different technologies to determine the location of the touch input (MIT Engineering, 2011, Ockenden, 2010).

#### *Surface capacitance*

A small voltage is applied to the corners of the ITO layer, which provides a uniform electrostatic field on the conductive surface. When a finger touches the surface, it attracts a very small amount of electrical current. The location of the touch input is measured from the change in capacitance from the four corners of the surface. One resolvable touch point is supported, which means the screen detects only one touch point simultaneously. (3M, 2012, Ockenden, 2010)

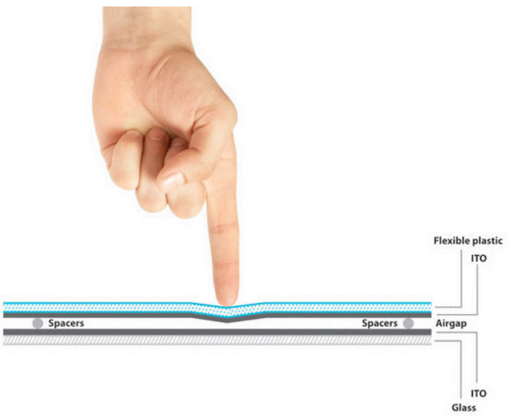


*Figure 29. The touch input is registered when a number flexible resistive and conductive layers are pressed together by a press. (Image source: PCPro, 2010)*

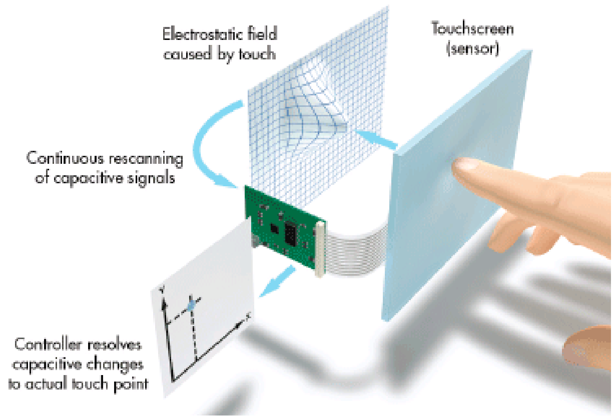


*Figure 30. Capacitive touch technology functions in a way that when a finger touches the surface it changes the capacitance of an electrostatic field and the touch input is detected by a controller. (Image source: Telecom Circle, 2010)*

### *Projected capacitance*

There are two types of Projected capacitance: self capacitance and mutual capacitance. Both types make use of a X-Y grid on which touch input can be detected at every intersection of the grid. For self capacitance, the grid is located on a single layer, which means that a single input can be detected simultaneously. Mutual capacitance instead makes use of two conductive layers: one with vertical lines and one with horizontal lines. This allows for multi-touch to be detected. Mutual capacitance is for instance used on Apple's iPhone. (Lorex, 2012)

## 9.1.3 Infrared grid

Touch panels made with infrared grid technology make use of a frame, on which LED's and photoreceptors are placed, that is attached to a display. The LED's create a grid of infrared light beams, which are detected by the sensors on the opposite side of the frame. When the beams are interrupted, for example by a finger, the location is identified by the photosensors in terms of X and Y coordinates. Figure 31 illustrates how the technology works. (TouchScreen Solutions, 2008)

## 9.1.4 Surface Acoustic Wave (SAW)

Surface Acoustic Wave touch technology, shown in Figure 32, uses transducers that send ultrasonic sound waves, which are reflected across the glass surface of the panel. The sound waves are then received by sensors. When a finger interrupts the sound waves it absorbs the acoustic energy. The change in amplitude is measured to identify the location of the touch input. (HowStuffWorks, 2013).

## 9.1.5 Comparison of presented touch panel technologies

As the presented touch panels function in different ways, this results in differences regarding screen clarity, touch input capabilities, durability against climate and environment, and cost. In Table 6 the differences are described in terms of advantages and disadvantages.

It is evident that the Sound Acoustic Wave (SAW) technology is not suitable in a marine environment. Although it has excellent image clarity and good durability, it cannot be completely sealed due to that the transducers sending the ultrasound and their corresponding receiving sensors must be placed above the touch surface. In addition, this fact also limits the construction of the casing and makes it impossible to, for instance, design a bezel that is part of the touchscreen.

The same arguments mentioned above are valid for the infrared technology, since also the LED's and sensors must be placed above the touch surface. Furthermore, dust particles and water can interfere with the touch input. Conclusively, SAW and infrared technologies are not considered for the development of the new interface device.

Table 7 presents a comparison between capacitive and resistive technologies. Since there are different capacitive technologies, the one compared is projected mutual capacitance. This technology provides the greatest benefit for usability thanks to its support of multi-touch. Also, projected mutual capacitive touch panels are the most common because of their popularity in modern smartphones.

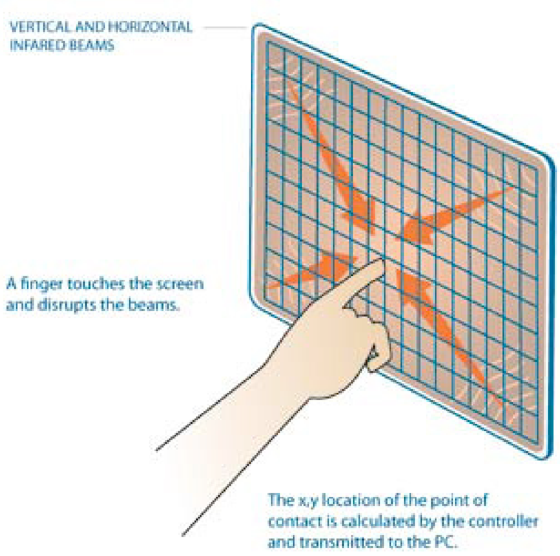


*Figure 31. When the infrared beams are interrupted, the touch input is located. (Image source: Tech Global, 2012)*

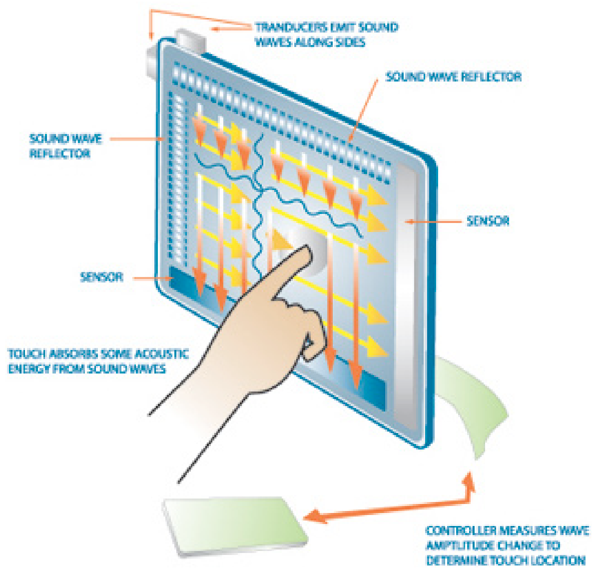


*Figure 32. When the sound waves are absorbed by an object, for instance a finger, the touch input is located. (Image source: Tech Global, 2012)*

*Table 6. Different advantages and disadvantages show that the touch panel technologies are suitable for different applications. (Sources: TouchScreen Solutions, Lorex, Display Elektronik)*

| | Resistive | Capacitive | Infrared grid | SAW |
|---|---|---|---|---|
| Advantages | Touch input from gloves and other objects is possible<br><br>Usable in all climate conditions<br><br>Cost effective | Supports multi-touch<br><br>High touch sensitivity<br><br>Up to 90% optical transparency (i.e. high clarity) | High screen clarity<br><br>High sealability from dust and liquids<br><br>Touch can be activated by any object<br><br>High durability | High optical transparency, provides good screen clarity<br><br>High durability<br><br>Functions in environments with static moisture and liquids |
| Disadvantages | Multitouch not possible<br><br>Screen is easily scratchable<br><br>Requires periodic calibration of touch input<br><br>Performance deteriorates over time<br><br>Demands pressure for touch input<br><br>75% optical transparency, lowers screen clarity | Sensitive to cracking of glass<br><br>Limited supply of touch panels that allow input from other modes than human fingers<br><br>Uncertainty about performance in different weather conditions<br><br>Does not work with artificial replacements (of arm, hand, finger)<br><br>Expensive | Big outline dimensions<br><br>Sensitive in environments with dynamic moisture<br><br>Dust particles or liquids can interfere with the IR light beams<br><br>Very expensive | Only operable with fingers or sound-absorbing stylus<br><br>Usage in wet environments is not possible<br><br>Cannot be sealed<br><br>Dynamic moisture or dust can cause malfunction<br><br>Limited detection accuracy<br><br>Very expensive |

*Table 7. The touch technology comparison between resistive and capacitive touch technologies shows that the capacitive technology provides the greatest benefits overall.*

| Requirements | Resistive | Capacitive |
|---|---|---|
| Resistance against physical impact | ★ | ★★ |
| Screen clarity | ★ | ★★★ |
| Sealability | ★ | ★★★ |
| Touch accuracy | ★★ | ★★★ |
| Protection against sunlight | ★★ | ★★★ |
| Ease of use | ★ | ★★★ |
| Cost (high score equals low cost) | ★★★ | ★ |
| Hinder accumulation of water | ★ | ★★★ |
| Function with water on screen | ★★★ | ★ |
| Touch input with gloves | ★★★ | ★ |
| | / 18 | / 23 |

The comparison shows that neither of the two touch panel technologies completely satisfy all aspects related to the requirements. However, the capacitive touch panel scored the highest (23 points versus 18 points for the resistive technology) indicating that it is the most suitable touch technology for the application of the future interface device. It does provide a greater opportunity to create a more intuitive interaction than the resistive technology thanks to its multi-touch support and the soft touch input. An example of this is the pinch-to-zoom gesture which provides an intuitive way of zooming. Furthermore, the capacitive technology has better screen clarity, thus it has better readability under sunlight.

Another advantage of the capacitive screen technology is that the touch surface can be made of durable glass, in contrast to the resistive technology which requires a flexible surface. This has two implications: the surface of the capacitive touch panel is more durable against scratches and the glass material provides a qualitative expression. In addition, resistive touch panels deteriorate over time, especially when exposed to harmful sunrays, something that the capacitive screens do not. Resistive touch panels also require periodic calibration.

The resistive touch panel technology has two important benefits: it is an inexpensive technology and it can detect touch input from gloves and other non-conductive objects (such as stylus, nails etc.). However, new capacitive touch panel technologies have been released that makes it possible to use gloves or fingernails when operating them (Hollister, 2012). The low cost of the resistive technology is the major factor why it is still a widely used technology (XpaV, 2012). However for this project, cost is secondary to usability and thus not a strongly decisive factor.

In conclusion, projected mutual capacitive touch panel technology is the technology of choice for this project.

## 9.2 Hardware concept generation

Based on using a capacitive touch panel as the means of interaction, a hardware construction was built around a touch panel. When establishing the construction particular focus concerned:

- Minimizing the outer dimensions
- Minimizing the thickness
- Allow for both surface and flush mounting
- Allow a similar mounting mechanism as todays products
- Maintain Volvo standard measurements

### 9.2.1 Choice of touch panel and display

When choosing an appropriate screen dimension for the display and touch panel, both the above factors and the list of elaborated needs together with the conclusions from the latest phase were considered. For expert knowledge a close contact with the display retailer Arrow was established. Contact with other retailers, Martinsson Elektronik, and directly with manufacturers, Mitsubishi Electronics was also established.

Considering the requirements and with the assistance from Arrow, the decision to increase screen size to 4,3" was taken. This was due to that the market of displays and touchscreens below is very uncertain and products are seldom available for more than a few years. 4,3" is the smallest standard dimension that have a satisfying range of models and manufacturers. It was also deemed that in order to be able to fulfill the requirements regarding visual clarity, user resources, feedback and explicitness a screen size of 4.3" would be appropriate.

A 4,3" touch panel from TouchNetix "Brilliance family" was chosen as the most cost-effective solution. It fulfills the requirements regarding EMC, temperature endurance, viewing angles and durability to a satisfactory level, and has the potential to be competitively priced. A 4,3" colour TFT-LCD display from AUO was chosen for the same reasons as the touch panel. The components are shown in Figure 33. The touch panel and display will be bonded together before

*Figure 33. The chosen 4,3" capacitive touch panel and TFT-LCD display.*

*Figure 34. Mock-ups used to evaluate size and format of concept.*

assembling with the rest if the product. The actual cost of the components can only be assessed by negotiations with the manufacturer, which is not part of the project scope. This is why the end-prices of the touch panel and the display are not specified in this report.

### 9.2.2 Evaluation of screen size/format

Due to the significant increase in size compared to the existing Flexi-display, the size and format was evaluated in relation to existing products and possible cannibalisation. This was done by building three example mock-up frames, from wooden frames in plywood and dummy touch panels and displays from plastic cut outs, see Figure 34.

The mock-up frames were shown to Nimbus and employees from CPAC and Volvo Penta, including product planners, design engineers and sales managers. The general opinion was positive towards the format. It was considered to be an attractive size thanks it the greater possibilities it provides, albeit not occupying too much space on the dashboard. Nimbus representatives claimed that if the interface device added extra value to the customer, they would definitely be willing to pay the potential extra cost for it.

A risk of market-cannibalisation was identified as the screen size is increased above the G4 display that CPAC currently distributes. However, this could also be seen as an advantage since the G4 display is bought from Garmin and thus has to be sold with lower margins for CPAC. Furthermore, it was noted by the project group that the screen format would better differentiate the concept from the Flexi-display than the G4 display does today. This would potentially make the concept more appealing for manufacturers who want to install a mid-sized display on their boats. According to the product planner at CPAC, the new display could be a viable and potential replacement for both the Flexi- and the G4 display thanks to its format. This would mean that better economies of scale could be gained thanks to higher production volumes.

### 9.2.3 Design variables

The following design variables were compiled to achieve a structured approach and handle all limitations when designing the hardware. These were then further analysed in relation to functionality and related variables, to come up with the most favorable combinations and combine them into concepts. The process resembles the Quality function deployment methodology.

#### *Placement of splices*

As there are several components and all of them need to be assembled, a splice needs to be placed somewhere in the construction. However, splices are a considerable source of quality issues and therefore the goal shall be to minimize the number of them.

#### *Sealing the splice*

The splices needs to be sealed using some type of fastener and gasket. This fastener can be screws, snap fittings, glue, tape or of another type. For maintenance purposes the splice should be separable. However as a separable splice is more vulnerable to leakage it should also have a satisfactory sealing. If the product will contain more than one splice, others should be permanently sealed.

#### *Integrated/removable bezel*

All of CPAC's existing products have a removable bezel. A removable bezel allows for a similar flush mounting to the existing product, which is proven to work. It also gives a possibility to brand the product by changing the bezel.

If a product should be designed without a loose bezel it would require one less part, resulting in a cost reduction. By not having a loose bezel it could be designed to minimize the splice between the touchscreen and bezel. However by integrating the bezel in the body, there is no possibility of branding the bezel and flush mounting is made more difficult.

#### *Bezel profile*

The surrounding bezel should have a profile which allows it to blend in on any dashboard and reduce the risk of water accumulation on the upper edge. It should also help to reduce the perceived size and to brand the product.

#### *Back-cylinder size of housing*

As the product should have a minimized height above the dashboard during surface mount, the circuit board should not be placed directly underneath the display. Instead the circuit board should be placed in the back-cylinder part of the housing.

The size of the back cylinder should be of a Volvo Penta standard dimension, meaning either 55mm or 85mm in diameter. The back-cylinder should neither protrude more than necessary behind the dashboard, as space here is also limited.

### 9.2.4 Combined construction concepts from design variables

The previously mentioned design variables were combined into three concepts. Each of them incorporate synergy effects from combining certain variables. Not all variables are represented in the concepts as some of them were determined to have too many disadvantages compared to their counterparts.

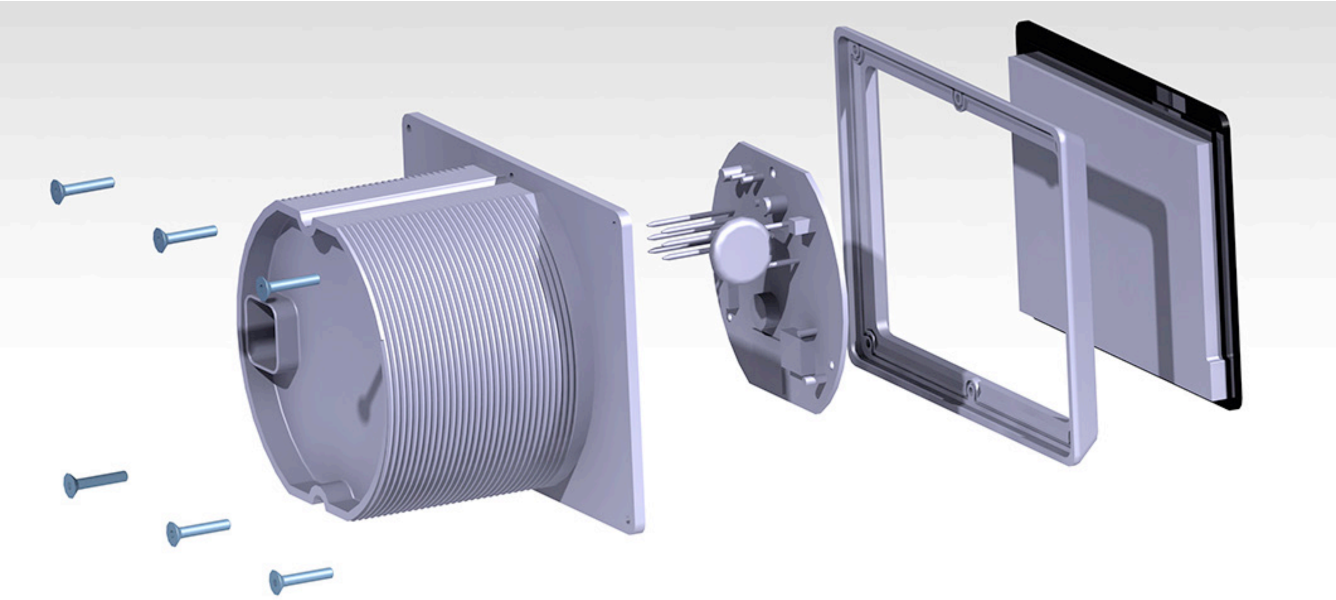

*Figure 35. Rear view of the assembly principle for the Traditional concept. Six screws are used to attach the back housing with the integrated bezel. Inside the circuit board is placed.*

*Figure 37. The Onepiece concept has one main body in which the other components are attached to.*

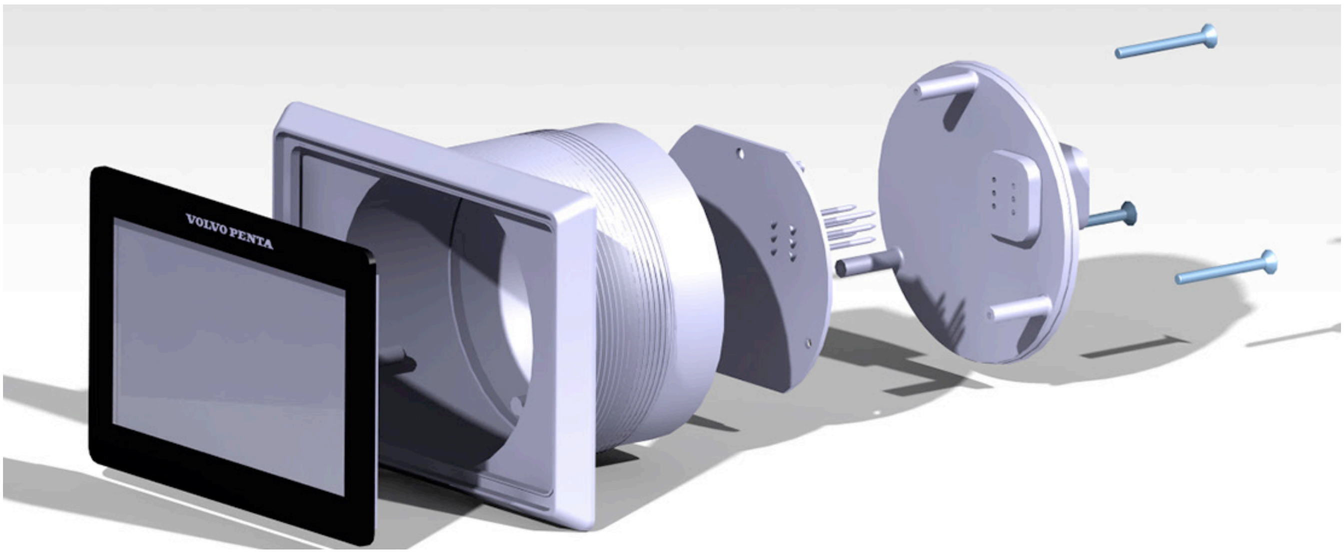

*Figure 38. The Back Opened concept has the separable splice on the rear side, from which the circuit board is mounted. The display together with the touch panel are attached from the front, creating a waterproof solution.*

### *Traditional concept*

In this concept the construction is similar to the existing solution, with a body consisting of a housing and a bezel attached with screws, see Figure 35. The concept has two splices, one between the touch panel and upper body, and the other between the upper and lower body parts. The first splice will be glued or taped depending on the available fastening area. The other splice can be separable by unscrewing the six screws, it is sealed with a rubber gasket between the parts.

The housing can be produced with a thread on the 85mm cylindrical part. This will allow the product to be surface mounted using the same type of plastic nut as existing Volvo Penta products, thus simplifying for boat manufacturers.

Flush mounting the display needs to be solved in a new way. Because the loose bezel is integrated in the upper body, the idea is to achieve flush mounting by milling the inverse profile in the dashboard-frame, see Figure 36.

### *Onepiece concept*

In this concept, illustrated in Figure 37, one splice has been eliminated, which removes a part and reduces the risk of water leakage. Only one plastic part is required for the housing of the concept. However, this concept cannot be disassembled and therefore no repairs can be done inside the product. The circuit board is mounted from the top and then the bonded display and touch panel are glued or taped to the body. Surface and flush mount is solved in the same way as the traditional concept.

### *Back Opened concept*

In this concept the separable splice is moved to the rear of the product, which places it underneath the dashboard. As the underside of the dashboard is less exposed to water this splice will not be as vulnerable as in the *Traditional concept.* It is sealed using three screws and a rubber gasket, see Figure 38. Assembly is done from two ways, first the display and touch panel are attached using tape or glue from above. Then the circuit board and back lid are mounted from the back and attached via screws. Surface and flush mounting are done in the same way as the other two concepts.9.2.5 Concept evaluation of design variables

Several meetings and discussions were held with CPAC mechanical, quality, software and electronics engineers concerning the hardware construction, quality, expression and electronic construction. Each of the design variables were evaluated and the below conclusions were drawn.

### *Placement and sealing of splices*

The three concepts have all splices placed at different places. The most advantageous would be the "Onepiece" concept with only one splice. However, this feature was evaluated to be unfeasible as it would make the assembly impossible. Furthermore, no repairs could be conducted on the product due to its glued splice, instead the whole product would have to be replaced. Of the "Traditional" and "Back Opened" concepts the "Back Opened" was preferred as it moves the exposed splice underneath the dashboard. Also the "Traditional concept" forces a thicker frame due to screws needing to have sufficient material for the threads. Conclusively, the "Back Opened" concept's splice placement was chosen for further evaluation.

### *Back cylinder size*

Together with CPAC electronics designer and a Arrow seller it was evaluated that the necessary electrical components would fit within the housings 85 mm cylinder. If additional connectors or other equipment were required two boards could be stacked together, resulting in doubled space. The 55 mm cylinder could also have been used, however the smaller sized electrical components that would be required would significantly increase product cost. Thus the 85 mm opening was chosen thanks to its cost advantages.

### *Integrated/removable bezel*

Initially it was found more advantageous to have an integrated bezel and therefore all concepts were equipped with it. However, when evaluating the solution towards design engineers at CPAC it was learned that the construction would result in too great variations in material thickness, which would result in draughts on the surfaces. A more advanced tool could be designed to solve this, however this would greatly increase the production cost, more than the cost of adding another part.

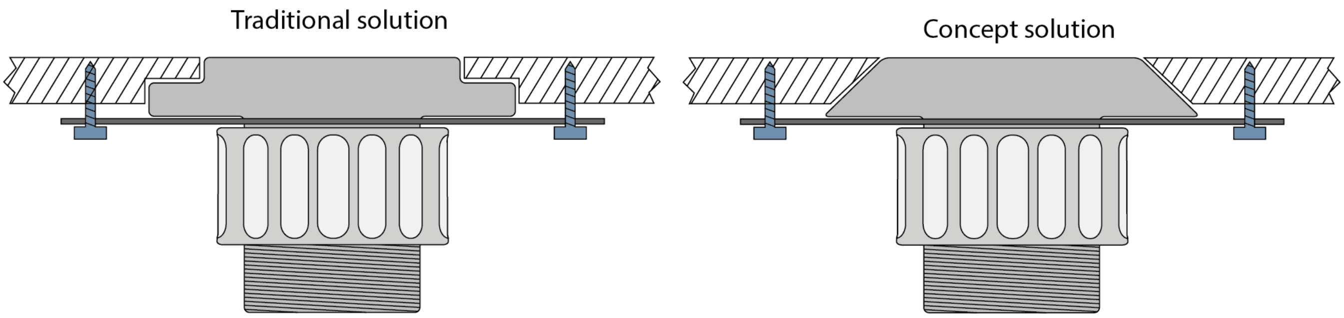


*Figure 36. An angled milling process is required for the flush mounting of the concept, in contrast to the traditional solution that requires L-shaped milling. The concept solution was evaluated among the design variables.*

Also, when evaluating the new flush mounting procedure, with the help of a mock-up as shown in Figure 39, against a boat manufacturer it was learned that it would require much more effort from them compared to their existing mounting procedures. Based on the two strong opinions, the integrated bezel solution was discarded in favour of a removable one.

#### *Bezel profile*

Different bezel profiles were evaluated in the CAD-concepts, as well as in the wooden frames. A bezel that could minimize the perceived size but still capture the Volvo Penta brand was sought after. After the evaluation, a profile with a distinct chamfer was chosen, much similar to the bezels of CPAC's existing products. The bezel should also smoothly enclose the touch panel and prevent water from accumulating on the screen.

#### *Back cylinder thread*

Manufacturing problems emerged when evaluating the construction properties of the back cylinder thread. As the construction needs to have an even thickness, a channel has to be molded from underneath. This channel needs a mold tool coming from underneath the structure and this means that the threads on the back cylinder are impossible to mold as they require tools from each side. A solution could be to postprocess the threads in a lathe, however this would significantly increase product cost. Instead, an idea of surface mounting in the same way as the G4 display is mounted emerged, see *Chapter 2.2 Reference displays*. This idea was found feasible to implement, especially in combination with a removable bezel and was thus decided upon. The thread on the back cylinder was removed due to production cost and the surface mounting solution benchmarked from the G4 was implemented.

*Figure 39. The mock-up shows that flush mounting of the concept is possible, however it was deemed to require too much effort from a boat manufacturer.*

### 9.2.6 Conclusion

From the evaluation the following decisions were taken:

- The concept shall feature a separable splice in the housing underneath the dashboard similar to the "Back Opened" concept.
- The housing's cylindrical part should have a dimension of 85mm.
- The device shall have a removable bezel and feature a similar surface and flush mounting as the G4 display.
- The removable bezel should have a distinct chamfer with a similar angle as current devices.
- No thread will be added to the cylindrical part of the housing.

In the next chapter the above decisions will be implemented into a final concept design.

## 9.3 Graphical User Interface (GUI) concept

As the screen size and ratio were set, wireframes for the GUI were designed. The wireframe sketches were used to set up a basic layout, which was later evaluated. In addition, the wireframes were used for evaluating text size, icons, comprehension of GUI elements and to a certain extent graphic design.

### 9.3.1 Description of views

#### *Drive view*

Out of several paper sketches, six concepts for the Drive view were chosen for computer illustration, see Figure 40. These concepts were deemed to have the highest visual clarity and best explicitness among the drawn concepts.

In all concepts, vessel speed and engine speed (RPM) were given the most prominent positions and sizes, as these have the highest value to the driver. Because vessel speed does not provide the user with indications about engine status trends or other relations, it is presented in absolute values in all concepts. Variations in text size and unit have been designed to explore and find a satisfactory readability from 1-1,5 meters distance, which is equivalent to the viewing distance at an average helm station.

Contrary to vessel speed, engine speed (RPM) is presented with an analog gauge. The gauge is normalised, where the normalised state is the center of interval (at 2000 RPM) and the values are multiples of one thousand. This allows the driver to quickly scan the instrument and easily assess the engine load. The gauge is also supplemented with a colour coded part of the value interval that indicates abnormally high values. It is aimed mainly towards inexperienced drivers who do not have knowledge about when the engine load is too high.

By presenting vessel speed digitally and engine speed analogically, higher visual clarity is acquired as these are noticeably differentiated from each other. Henceforth, the driver is able to quickly glance at the center of the screen and assess both the speed of the vessel and the engine load at the same time. Drive view 6 departs from the idea of presenting engine and vessel speed together in the center of the screen by separating these information flows and instead placing engine speed (RPM) on the left side. The aim of this idea is to further improve visual clarity.

The concepts also include a fuel level meter, which is presented in different variations. The common characteristic among the variations is that the fuel tank meter is designed to show proportional fuel levels and not the exact amount. It is intended that this concept will comply with users' mental model, because it tells the user whether there is plenty, adequate or scarce amounts of fuel. The design of the fuel level meter is influenced by fuel level meters found in cars, as most people are accustomed to them.

Water depth is presented digitally and either with an icon or with text. As there is limited screen estate, the final concept shall include only text or only an icon.

A bright red/orange warning sign has been included and positioned at different locations in the wireframes. The warning sign shows the driver that there are faults in the EVC system or the engines and is visible when there are active warnings.

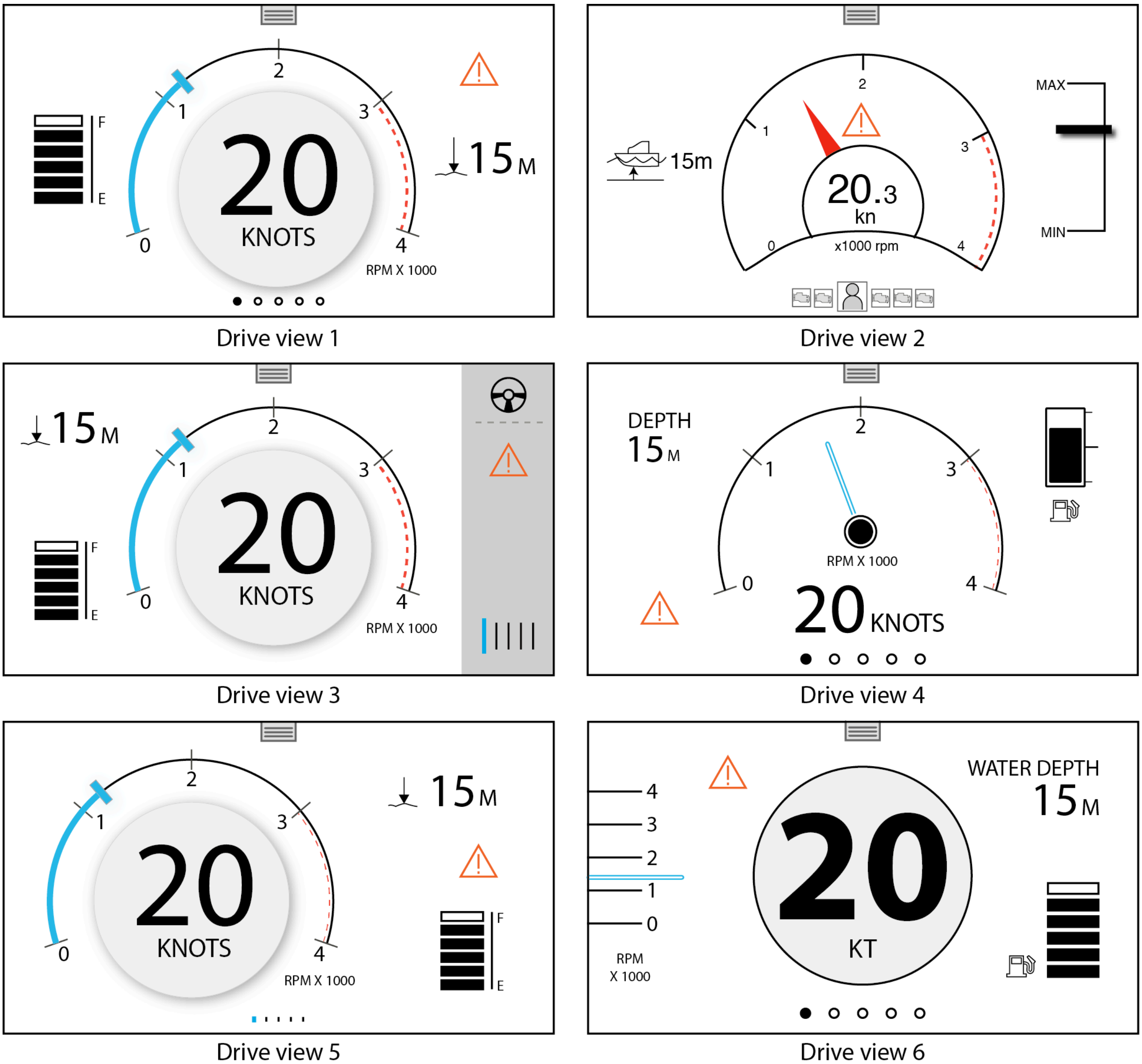


*Figure 40. The concepts illustrate variations in layout, type of information displayed and presentation of information.*

In Drive view 3, a permanent bar has been placed on the screen's right side. The bar contains information about which screen is active, the warning sign as well as the GUI location indicator. The idea is that the bar will be fixed and visible in all views and therefore a natural place to look at when seeking information besides engine data.

To emphasize that swiping horizontally is the input method, a location indicator is included in every screen. This indicator is illustrated in different ways, and shows the user's current location and the locations of the other available views. The indicator is also present in the other main views and shall in the final concept be placed at the same location in the views.

### *Detailed information views*

The detailed information views, Engine view, Fuel Economy view and Vessel view shall contain the same information as the one displayed in the G4. As such, these views were only designed with a graphical layer and are presented later in the report.

### *Settings*

This view will contain the same settings functionality as the G4 display. Due to the screen's widescreen format, the view is horizontally divided into two parts: the left side contains menu categories and the right side is where the settings are made, see Figure 41. The idea is that users will find themselves

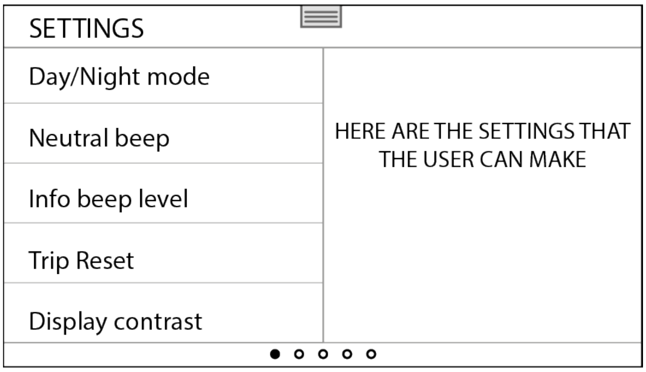


*Figure 41. The settings view consists of a left-side menu and the adjustable settings on the right-hand side.*

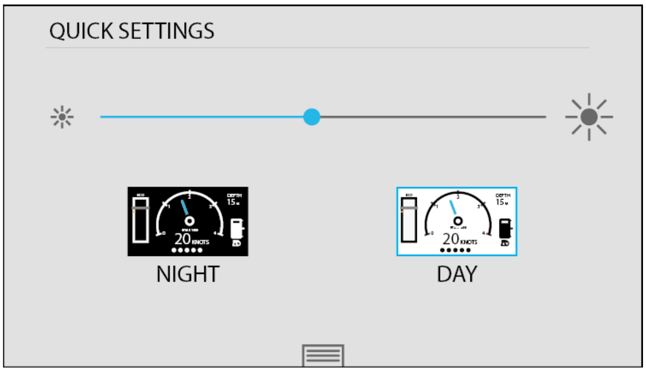


*Figure 42. The Quick Settings view is accessed by dragging down the curtain button. It contains brightness settings and view mode selection.*

familiar with this system because the layout resembles the way settings are made on modern tablets.

### *Quick Settings*

The quick settings menu can be accessed at every view by dragging down a curtain, see Figure 42. This works in a similar manner to the way notifications are accessed in Apple's iOS and Google's Android operating systems. In the concept a small knob is located at the top middle part of the screen and functions as an affordance of the curtains presence (this affordance does not exist in iOS or Android). The decision to include this affordance was based on the fact that the usage of the new interface device will be seasonal/sporadic, and therefore the driver is more likely to forget that there are views "outside" the screen.

At the top of the Quick Settings view is a brightness slider, where the brightness scale goes from left (low brightness) to right (full brightness). The user changes the brightness by sliding one finger to the right or to the left. Below the slider two view modes can be chosen: black-on-white or white-on-black. These two are intended for day and night use. A black text on white background is beneficial for day use as many pixels in the display are lit and give extra brightness, thus a better visual clarity in bright conditions, and vice versa for white text on black background. (Monzani, 2013)

### *Warning notifications*

The idea for the warning notifications is to design the pop-up screen and formulate the error message in a way that it is comprehensible and provides the driver with concise actions for recovery and prevention of potential engine damage. The driver should, thus, be able to perform the actions without hesitation and have a basic understanding of what the error may lead to. A concept for the warning notification is presented in *Chapter 9.4 GUI with graphic layer*.

## 9.3.2 Evaluation

The wireframe concepts were evaluated against the set design principles and were also discussed with CPAC and


*Figure 43. The tank meter in Drive view 1, 3, 5 and 6 resembles the tank meter on the 2013 Volvo V40, which further strengthens the Volvo brand recognition.*

Volvo Penta employees. A prototype board with a resistive touch panel was used to show the wireframes in their true size. Focus of the evaluation was on the Drive view. The goal was to further define the requirements for the GUI.

The way engine speed (RPM) and vessel speed are presented together in Drive views 1, 3, and 4 was deemed to be the best solution. Both are easily readable even though they are in close proximity of each other. This was concluded to be a result of that they are differentiated in their forms. Also, the round meter is easier to read than the vertical meter in Drive View 6. Henceforth, there is potential to achieve visual clarity and prioritise information as intended. Furthermore, it was considered that the text size for "RPM x 1000" was small, but that it was rather something positive as it takes up little space. Users will nevertheless learn quickly that the meter shows multiples of a thousand.

For water depth, the icons designed were perceived as insufficient regarding explicitness. Because there is no established icon for water depth, it was decided that water depth should be labeled with text. It was also decided that this approach should be taken throughout the GUI.

The fuel level meter was evaluated for its ability to show the proportional level of fuel. The meter in Drive views 1, 3, 5 and 6 was found to be doing this to the best, thanks to the division of the bars. This design is similar to the meter found in the new Volvo S40 interface, see Figure 43, which was deemed another strength as it further strengthens the Volvo brand. Furthermore, it was deemed that an icon as the one in Drive View 6 was sufficient for showing that the instrument represents fuel level.

The location indicator was received in a positive manner, because it helps the user navigate through the system. The simple form found in Drive views 1, 4 and 6 were the most appreciated, as they are simple and look similar to the location indicator found in Apple's iOS and some versions of Google's Android smartphone operating systems. However, its exact location, form and size was difficult to determine since the graphic elements did not exist in the wireframes. Consequently, a general guideline was set that that the location indicator shall take up little screen estate, be placed at the same location on every screen and be designed in a way that is understandable to the user.

Similar to assessing the placement of the location indicator, the warning signal icon was evaluated in general terms. The conclusion of the evaluation is that the signal icon must be large enough and placed correctly to be visible, but at the same time its location should not disturb the harmony of the screen.

The chrome bar on the right side on Drive view 3 was thought to take up too much screen estate in relation to its contents. Thus, the idea was discarded.

The curtain knob for the Quick Settings view was received with different opinions. As an idea of an affordance for the curtain it was considered good. However, a Volvo Penta employee considered it too vague and that the knob should be labeled, suggesting the word "tools". On the other hand, that was the only negative source. In order to strive for good visual clarity, the simple knob illustrated in the concepts was deemed sufficient as an affordance as users will find the Quick Settings view by exploring the GUI.

The contents of the Quick Settings view were considered appropriate, as brightness settings and view modes are the most frequently used settings. They way of setting the brightness was deemed clear, partly because it complies with the way it is done in current smartphones. The specific view modes that should be available as options did not need to be specified in this project. It was suggested that the view could contain more settings as it has much unused space.

Because the content of the Settings view is not part of the project scope, only its layout was evaluated. All the interviewed people had positive reactions, much thanks to that the widescreen format is utilised. The benefit that was seen as positive was that the user would no longer need to go back and forth in a menu structure.

### 9.3.3 Conclusion

The following decisions were taken based on the evaluation:

- Text size for the Drive view shall be clearly visible for visually impaired users from 1-1,5 m distance.
- The most important information shall be enhanced via a higher contrast against the background, compared to less important information that shall have a lower contrast.
- Vessel speed and engine (RPM) shall have the highest priority. They shall be visually differentiated from each other.
- Vessel speed and water depth shall be presented digitally. The former shall be more detailed and presented with one decimal precision. The latter shall be labeled with text.
- Engine speed (RPM) shall be visualised with an analogue gauge. The values shall range from 0 to 4 thousand RPM, of which the range 3 to 4 thousand RPM shall be marked as harmful.
- The location indicator shall be placed at the same location on every screen and shall be designed to take little attention from the other GUI elements. Furthermore, its screen estate claim shall be minimised.
- The detailed information views shall contain the same information as the G4 display. Text as headlines shall be used as default and not icons. The user shall have the option to change the headlines to icons in the Settings view.

- The warning icon shall be clearly visible from 1-1,5 m distance. It shall be placed in a central location that does not claim much screen estate.
- The Settings view shall consist of two parts that equally divide the view horizontally: the left part contains the menu structure and the right side contains the adjustable settings.
- The Quick Settings view shall contain a variable brightness settings and the option to change between view modes.
- The Quick Settings “knob” shall take up as little screen estate as possible but at the same time be easily used.

## 9.4 GUI with graphic layer

With the layout decided, graphic design concepts were designed. The concepts were developed in accordance to Jordan’s design principles and were aimed to conform with Volvo Penta’s visual brand identity. Furthermore, the strive was to enhance visual clarity and design graphics that arouse interest from the user.

The graphic profile is to a great extent based on Volvo Penta’s coming GUIs, which are not pictured in this report due to confidentiality. A darker grey serves as background colour with full white text as information. The graphics are also intended to express sleek, accurate, simple, professional and reliable - i.e. the intended expressions from the mood board.

### 9.4.1 Start-up screen

The first screen presented to the driver when the system is started contains information about the engine’s general state, see Figure 44. This is indicated by a light that glows green to indicate that engine status is ok; yellow if the system has detected minor errors or red if the engine has grave malfunctions. The errors can then be reviewed in the warnings manager. Furthermore, the driver is notified about how many driving hours remain until service or when oil filter change is due. In short, the Start-up screen’s purpose is to support the driver in keeping check of the engines and to inform whether the driver needs to perform any extra service actions before start-up, or if a workshop service should be done before the coming itinerary.

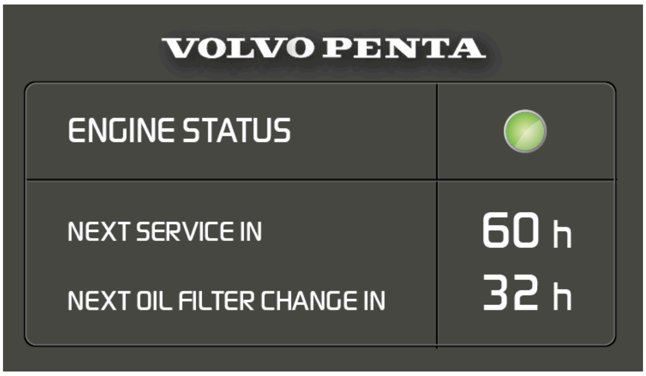


*Figure 44. When the ignition has been started the driver is presented with a general status of the engines.*

### 9.4.2 Drive view

As previously stated, the Drive view is the view that is intended to be used most frequently. Three variants have been designed that illustrate different ways of presenting the Drive view, see Figure 45. Focus has been on designing concepts with high visual clarity and relevant prioritisation of information.

The main GUI elements, vessel speed and engine speed (RPM), have been given the most prominent position and size, in accordance to the decisions made after the former evaluation. Vessel speed is shown with a large font size, with decreasing size for the decimal and unit. Furthermore, the unit abbreviation (KT) is coloured with a light grey colour to blend in with the environment, which will provide a greater attraction to the actual speed value. The idea is that the user will quickly learn the unit and then ignore it. This concept

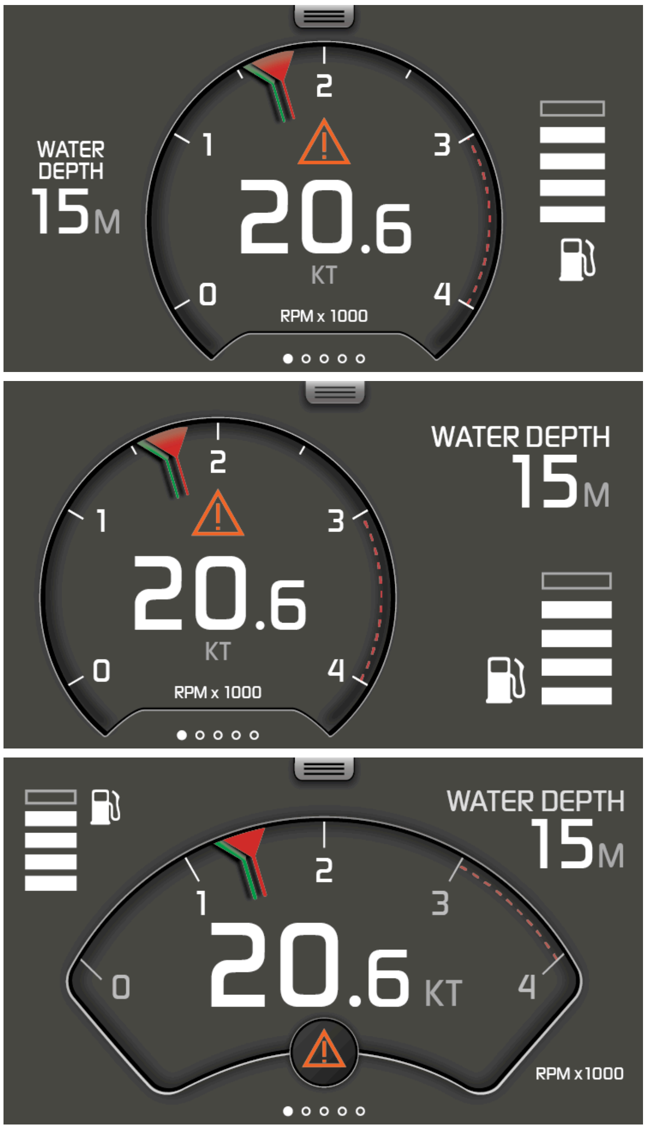


*Figure 45. Three variants for the Drive View, from top to bottom: Variant A, B and C.*

has been utilised for all units in the GUI, which is seen on the water depth indicator.

RPM is visualised with two variants of a representation of an analog gauge - a circular gauge and a curved shaped gauge. Both gauges includes two pointers that show the engine load for the port and starboard engines. The pointers are colour coded in accordance to the conventions of the marine industry.

The advantage of the circular gauge is that it resembles physical analogue instruments such as ones found in cars or boats with older instruments and henceforth it complies with users' mental model. Users will know that the latter part of the scale (above 3 000 RPM) means that the engine is overloaded, just as conventional analogue gauges work. To further emphasise engine overload, the critical region in the scale is marked with a red coloured dashed curve. Variant C has been designed with a curved RPM meter to make good use of the display's widescreen format. This feature will hopefully make reading the RPM easier as the driver needs to scan a shorter span compared to the circular gauge.

The two other information flows, water depth and fuel level, have secondary prioritisation. As such, they have been placed on either side of the RPM gauge (in Variant C they are both placed on the right side) and been designed as more simplistic graphic elements. This is also to differentiate them from the large gauge and to create an affinity between them. They are sized and placed with the goal of achieving readability from 1-1,5 m distance for visually impaired users. Furthermore, the simple design of the fuel level meter is intended to be easily and quickly understandable.

The navigation elements, i.e. the Quick Settings "knob" and the location indicator, have been designed to be discrete and informative. The "knob" has been designed to resemble a handle, which will inform the driver that the view can be dragged downwards. The location indicator has been placed in close proximity to the gauges, thus blending in with the harmony of the view. With similar reason, the warnings symbol has been placed in the analogue gauge - its location is also intended to minimise clutter, but also to gain attention from the driver.

### 9.4.3 Detailed information views

The detailed information views, shown in Figure 46, are designed with modularity in mind. This means that up to six information flows can be shown simultaneously, which is represented in Vessel view where the flows are equally separated. With fewer information flows the size dedicated to the flows increases in the order from the top to the bottom. This is illustrated in Engine view and Fuel Economy view, where the top two flows have more dedicated space as the views contain five flows. The amount of information flows is dependent on the equipment of the specific marine vessel, and as previously stated the design concepts illustrate the same amount of information as the G4 display as default. The content shown in the information views can be fully customized in the Settings view.

The information flows are framed and divided by thin lines, thus making it easier to distinguish the flows. The lines also create a subtle depth that is intended to make the views

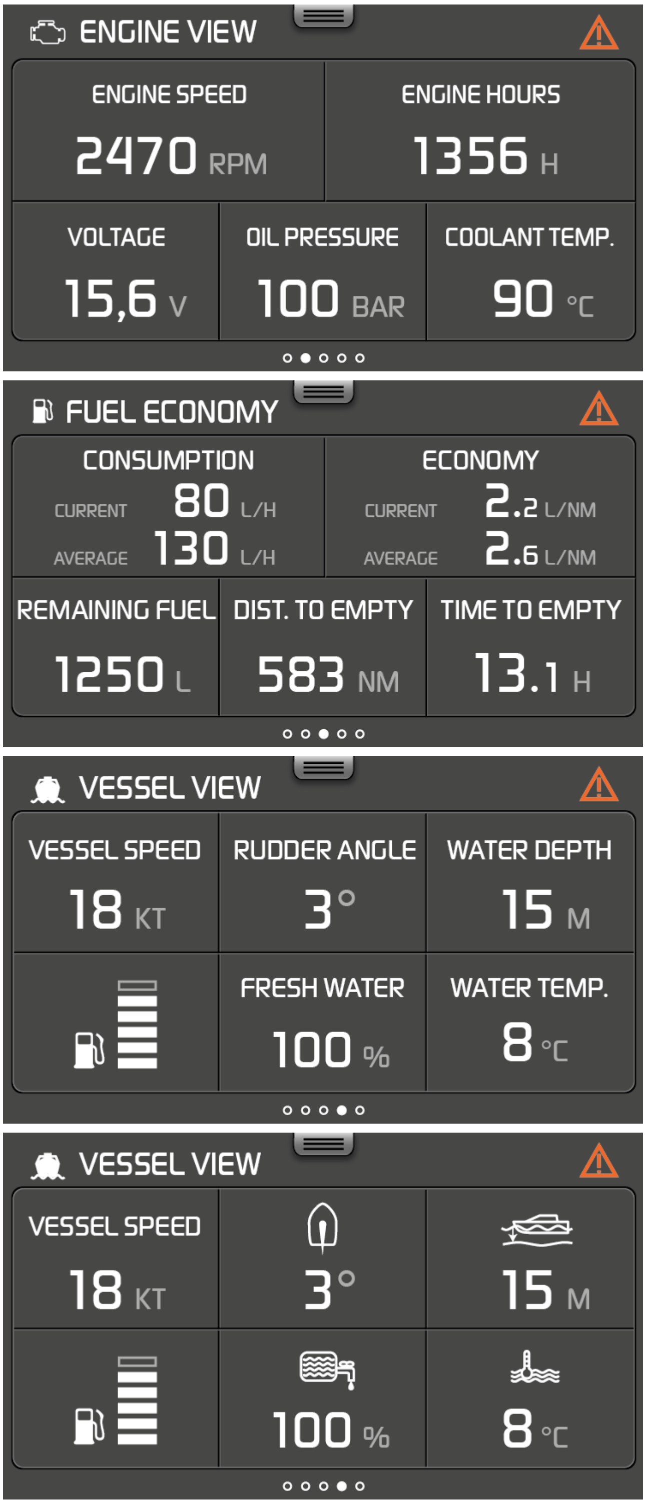


*Figure 46. The three detailed information views. Vessel View is also shown with icons as labels.*

visually interesting. Furthermore, the appearance of the views has been designed to be noticeably simplistic and thus clutter has been avoided. The simplicity also means that the information does not compete with, for instance, complex graphics. Similarly to the Drive view, the units are dimmed to further highlight the values.

Each information flow is labeled with text as default, as this is more explicit and understandable than icons in the early learning stage of a GUI (Wiedenbeck, 1999). However, as the value of text labels retracts with time, the user has the option to have icons as labels, illustrated in Figure 46. The reason for wanting to show icons is that they are more quickly perceived than text when they are learned and they claim less screen estate.

At the top left of each view is the name of the view together with a corresponding icon. Showing the name of the view clearly informs the user what view is active and what the

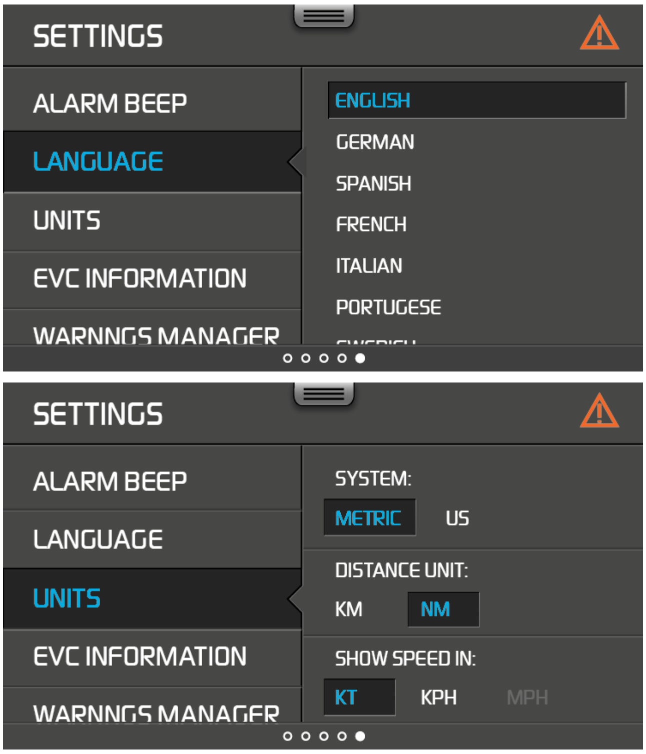


*Figure 47. The Settings view consists of a left-side menu and settings on the right side.*

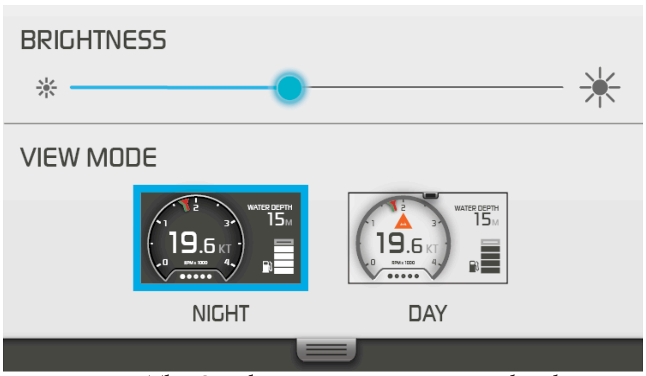


*Figure 48. The Quick settings view contains brightness settings and view mode selection.*

information regards: the engine, the fuel economy or the vessel. On the left side of the top is the warnings symbol located, thus creating symmetry. The bottom of the view contains the location indicator. This has been placed at the same location as in the Drive views with the indicator centered, as changing its location would potentially confuse users.

### 9.4.4 Settings

The structure of the Settings view consists of two equally large halves, as defined by the decision made in the former chapter: a menu on the left part containing the categories that are adjustable and a right part where the settings are made, see Figure 47. The category and settings that are active are recessed and their text is coloured with a vivid blue colour. This design is aimed at explicitly emphasising the choices the user has made. In addition, a subtle recessed area further emphasises the active category. Also, the last option visible in each list is partly hidden and this will prospectively work as a affordance that more information can be seen by scrolling downwards. The location indicator and the warnings signal are placed in accordance with the other views.

### 9.4.5 Quick settings

By dragging down the Quick settings curtain the user can quickly change brightness or view mode in the Quick settings view, see Figure 48. The view is colour inverted, hence the background is white and text and other graphic elements are dark grey. Changing view modes, which are shown as thumbnails, is done with a simple touch. The thumbnails

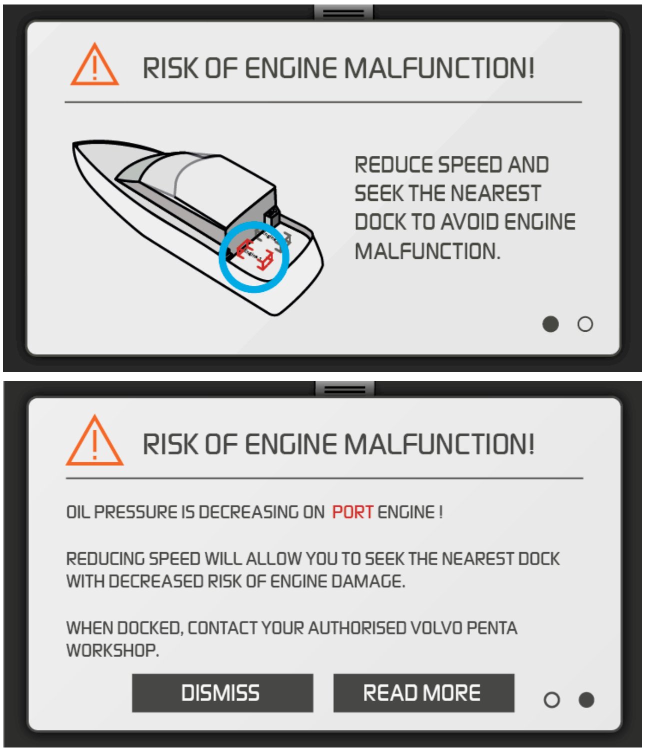


*Figure 49. The warning message consists of two screens - the first one contains a short and explicit prompt, while the second contains more information.*

are small replicas of how the views will look like, thus users will know in advance how the GUI will appear. A blue frame around the thumbnail informs the user of the active view mode. Setting the brightness is done, as previously explained, by sliding one finger on the slider bar.

### 9.4.6 Warning messages

When the EVC system detects a negative engine trend, a warning message pops up and takes over the screen, see Figure 49. The first screen that is shown to the user contains a brief prompt of what the user shall do. It also contains a visual explanation of which engine is affected. This short message is intended to relief cognitive load in the stressful situation and provide the user with only the most necessary information. If the user desires more information or to dismiss the message, a slide with one finger to the left brings forward the second screen. This screen contains more details about the problem, a button to dismiss the message and a "Read more" button that takes the user to a new screen with more explicit information. This information is directly based on an instruction manual that follows the purchase of a boat with Volvo Penta engine(s).

### 9.4.7 Evaluation

The GUI with a graphic layer was evaluated with a Chalmers doctor with expert knowledge in the field of usability, a Volvo Penta employee, a quality manager from Nimbus and several CPAC employees with boating experience. Similar to the evaluation of the wireframes, a prototype board was used to show the views. The evaluation of the GUI at this stage was focused on detailed aspects.

#### *Aesthetics*

All interviewed persons found the GUI to be aesthetically appealing and complying with Volvo Penta's visual brand. A simplistic design language was considered positive, as it enhances visual clarity by reducing clutter. However, the project group found the contrasts to not be sufficient, which is something that must be improved for the final concept.

#### *Start-up view*

The Start-up view was considered a good idea and the amount of information was deemed well-balanced for the intended inexperienced user. However, it was noted by CPAC that it is more interesting to know the engine oil levels than when next oil filter change is due. A suggestion was to display this with a bar. Conclusively, engine oil levels shall be displayed instead of next oil filter change for the final concept.

#### *Drive View*

The three variants of the Drive view were equally received in a positive way. The evaluators found positive aspects with all of them, however there was no consensus on which one would be most suitable. For instance, the variant with the gauge on the left side and the other flows on the right side was seen as easy to read and understand as the information is distinctively divided. On the other hand, the two other variants were liked because the gauges, which contain the most important information, are placed in the center of the screen. This ambivalence regarded also the preferred type of RPM gauge, as the evaluators had different opinions and likings. The round gauge was liked for its conventional design and similarity to current physical gauges. On the other hand, the curved gauge was considered to be easily readable and visually interesting. Furthermore, the curved gauge makes good use of the widescreen format, as noted by the usability expert.

The location indicator as an affordance was deemed to be insufficient by the usability expert. In the concepts with a round gauge there is a risk that the indicator is connected to the meter itself. Furthermore, as it is located in the concepts the indicator takes up valuable screen estate, especially in the detailed information views where the bottom part becomes unusable. A suggestion was therefore to move it to the top of the screen.

In conclusion, it was decided that the Drive view variant with the curved gauge will be used in the final concept, thanks to its way of showing RPM in a clear way and making good use of the screen estate. Furthermore, the location indicator will be moved to a location on the top of the screen in order to clear up screen estate.

#### *Detailed information views*

Text sizes in the detailed information views were deemed by the usability expert as readable from an arms length (i.e. the equivalent of the actual viewing distance), even when shaking the display to imitate boating in a swaying sea. Furthermore, it was found positive that the units are darker as emphasis should be on the information values. The usability expert suggested two change regarding text for the views: to also fade the labels and reduce their text size, and to increase the size of the value numbers, as these changes would bring even more focus to the values. In addition, it was also suggested to make use of only text or only icons in the views, and thus make an icon for the "Vessel speed" label and to show fuel level with a number in the Vessel view.

Based on the feedback from the usability expert, it was concluded that there was potential to improve visual clarity by greying the labels and decrease their text size, and to increase the text size of the values.

#### *Settings*

The text size on the left side of the Settings view was deemed as readable and the recessed areas that show the active choices were found to be explicit. However, the usability expert considered the text size for the options on the right side to be too small as it would demand far too high precision from the user. Therefore, increasing text size would be a design improvement for the final concept.

*Quick settings*

The Quick settings was considered to be easy to understand and contain relevant settings. It was deemed by the project group to have room for one more setting. However, during the evaluation it was not found which setting to add to the view. It was decided that finding the correct setting would be time consuming and therefore this was excluded from the project. Hence, this view needs to be further developed.

*Warning messages*

According to the usability expert, the warning message should be dismissible already on the first screen, and that being provided more information should be an option and not something that the driver is forced upon. Otherwise, there is a great risk of irritation for experienced driver as they have to go through an extra step.

The project group considered that the headline of the error message should be more descriptive. Also, the label "*Read more*" was deemed as not fully explicit, because it refers to text reading. Instead, "*More info*" would be a clearer label, as it communicates to the user that more information is provided by pressing the button.

### 9.4.8 Conclusions

Based on the feedback, the following decision were made:

- Improve contrast.
- The Start-up view shall contain information about: general engine status (via a green/yellow/red lamp icon), next service (in hours), and engine oil levels (as a bar).
- The Drive view variant with the curved gauge shall be used in the final concept.
- The location indicator shall be moved to the top of the screen.
- The detailed information views shall have text labels sized maximum 3,0 mm (height) and be darker than the value text. It shall be slightly decreased.
- Minimum height for value text shall be 5,6 mm. The current size shall be increased.
- Text labels shall be default. The option to display only icons shall be available and be done in the Settings view.
- Text size on the right part of the Settings view shall be increased.
- The Quick settings view shall contain brightness settings (altered via a slider) and two view modes (white text on black background and black text on white background) selection.
- Warning messages shall consist of one pop-up view and contain a message about what actions the driver should take. Furthermore, there shall be two buttons that allow the driver to either dismiss the message or gain more information.
- The headline shall better describe the origin of the error message

## 9.5 Chapter summary

In this chapter detailed design concepts for the interface device's hardware and GUI were introduced. The chapter started with a touch panel technology screening. The screening resulted in the choice of capacitive touch technology as it was deemed to provide the most satisfactory interaction. A specific touch panel was chosen together with a 4.3" widescreen display. Design variables were introduced that describe the design challenges that were faced during the concept generation process. Three concepts with different construction principles were developed and introduced. These were evaluated and the best solutions from the concepts were decided to be incorporated in the final concept.

After the hardware concepts were presented, a concept for the GUI was introduced. The concept consisted of wireframe sketches illustrating specific views. The concept was evaluated and certain decision were taken aimed at improving the interface. Following was a concept for the GUI with graphic layer introduced, which included graphic elements and a visual appearance that will be close to the final concept. This refined GUI concept was similarly evaluated and ending the section were conclusions about aspects to work further on.

## 9.6 List of requirements

| Need | Elaborated need | Requirement |
|---|---|---|
| **Basic functionality** | | |
| Contain the same functionality as the current Flexi-display and G4 display | Feature detailed views for fuel, engine, vessel and settings | Engine view shall contain; Engine speed (RPM), Power trim angle, Coolant temperature, Voltage, Engine oil pressure |
| | | Fuel Economy view shall contain; Current and average fuel rate, Current and average fuel economy, Fuel remaining, Distance to empty, Time to empty |
| | | Vessel view shall contain; Speedometer, Fresh water level, Sea water temperature, Fuel level, Seawater depth, Rudder angle |
| | | Settings view shall contain relevant settings for all views and be placed at the far right in the architecture |
| | | Text labels shall be sized maximum 3,0 mm (height) and be darker than the value text |
| | Architecture shall follow from the G4 and the 7" display (Fulfilled by other requirements) | |
| Be used on boats above 16ft (Fulfilled by other requirements) | | |
| Be directed towards leisure use (Fulfilled by other requirements) | | |
| Contain differentiating attribute | Use touch technology as means of interaction. | Feature a 4,3" touch screen from TouchNetix "Brilliance family |

| Need | Elaborated need | Requirement |
|---|---|---|
| **Aesthetics** | | |
| Comply with the Volvo Penta brand | Incorporate Volvo "Black" colour | Hardware should have Volvo "Black" colour |
| | Incorporate Volvo "Grey" colour | GUI should have Volvo "Grey" colour as background |
| | Use Volvo instrument font | GUI should contain Volvo instrument font |
| | Use Volvo Penta logo | Feature a Volvo Penta logo centered on top of the screeen |
| | Make use of distinct chamfers | Feature a bezel with a Volvo distinct chamfer |
| Provide a visually appealing and modern look | Allow a smooth surface mounting (Fulfilled by other requirements) | |
| | Minimize bezel around screen | Use 3mm metal screws, with 5mm head to attach the device in dashboard. |
| | Incorporate a colour display | Feature a AUO 4,3" colour TFT-LCD display |
| | Express sleek, reliable, accurate, simple, professional and modern (Fulfilled by other requirements) | |

| Need | Elaborated need | Requirement |
|---|---|---|
| **Construction** | | |
| Allow placement under the same circumstances as the current CPAC devices. | Allow placement under same circumstances as Flexi- and G4 displays (Fulfilled by other requirements) | |
| Compatible with the EVC system | | Feature a CAN interface |
| Have at least IP class 66 | | Feature a separable splice underneath the dashboard. |
| | | Feature a glued joint between PCAP and housing |
| | | Rubber gasket placed between device and dashboard. |
| Be both flush and surface mountable | | Apply same mounting system for surface and flush as current G4 display utilize |
| | | Feature a removable bezel |
| Use a standard hole pattern for surface mounting | | Housings back cylinder should have a diameter of 85mm |
| Hinder accumulation of water on screen | | Have a smooth enclosing bezel that is not higher than the screen. |
| Minimize outer dimensions (Fulfilled by other requirements) | | |
| Ensure functionality within temperatures -30 to +85 c (Fulfilled by other requirements) | | |
| Reduce cost | Be built from standard components(Fulfilled by other requirements) | |
| | | Only contain plastic parts that can be manufactured by a two-tool mould |
| Allow mounting of sun-cover | | Feature a sun-cover covering the entire screen |

| Need | Elaborated need | Requirement |
|---|---|---|
| **Usability** | | |
| Facilitate boat driving | Feature a Start-up view. | The Start-up view shall contain information about: general engine status, next service, and engine oil levels |
| | | General engine status shall be presented as a green / yellow / red light icon, depending on status. |
| | | Next service interval shall be presented in hours left |
| | | Oil level shall be presented as a bar |
| | Feature a Quick-settings view | The Quick-settings view shall contain: screen brightness settings and view mode. |
| | | Quick Settings view shall be accessed in the same way from all screens |
| | | The Quick Settings "knob" shall take up as little screen estate as possible. |
| | Feature a Drive view | Feature a Drive view containing: Speed, Engine RPM, Fuel level, Sea water depth. |
| | | Text size for Drive View shall be clearly visible for visually impaired users from 1-1,5 m distance. |
| | | Vessel speed and RPM shall have the highest priority. They shall be visually differentiated from each other. |
| | | Vessel speed and water depth shall be presented digital. Speed shall be presented with one decimal. Water depth shall be labeled with text. |
| | | RPM shall be visualised with an analogue curved gauge. |
| | | The RPM values shall have markings on the harmful values. |
| Have a simple interface | Allow the driver to gain a good overview of the engine status by simply glancing over the display. | The most important information shall have a higher contrast against the background, compared to less important information that shall have a lower contrast |
| | | Minimum height for value text shall be 5,6 mm. |
| | | Text labels for detailed views shall be default, icons shall be optional and changed in the Settings view |
| Warn the driver of engine malfunctions | Feature a notification system for warnings and changes in the system. | Warning messages shall pop-up and take over the screen. |
| | | The warning icon shall be clearly visible from 1-1,5 m distance. It shall be placed in a central location that does not claim much screen estate. |
| | | Warning messages shall contain a message about what actions the driver should take. |
| | | Warning messages shall have a button for acknowledging the alarm. Labeled "Dismiss" |
| | | Warning messages shall have a button for gaining more information about the warning. Labeled "More info" |
| | Feature a Volvo Penta standard buzzer (Not adressed in the project) | |
| Provide good readability in sunlight | Feature screen brightness controls (Fulfilled by other requirements) | |
| | Feature a bright screen display (Fulfilled by other requirements) | |
| Provide good readability during low-light conditions | Feature screen brightness controls (Fulfilled by other requirements) | |
| | Feature a night mode on display (Fulfilled by other requirements) | |
| Provide good readability for vision impaired driver | Increase screen size (Fulfilled by other requirements) | |
| Provide good re-usability for seasonal usage | | The location indicator shall show where the user is in the system. |
| | | The location indicator shall be placed in the top right corner of the screen, it shall have this postition on every screen. |
| Allow imprecise interaction | | Changing between views shall be done by horizontal swipes. |
| | | The GUI shall minimize the use of virtual buttons. |
| Provide appropriate information for both experienced and inexperienced drivers (Fulfilled by other requirements) | | |
| Allow 100% reliability of start/stop engine function (No longer considered) | | |

| Need | Elaborated need | Requirement |
|---|---|---|
| Sustainability | | |
| Contain functions for guiding the driver to propel the boat in a more sustainable way. (No longer considered) | | |
| Improve product assembly and disassembly (Fulfilled by other requirements) | | |


*Figure 50. The final concept is a robust touchscreen interface device.*

*Figure 51. The final concept blends in well with the interior of a modern boat interface. It is placed in close proximity to the drivers position, in order to simplify interaction. (Image source: Nimbus, 2013)*

# 10. FINAL CONCEPT

*This chapter will present the final concept. It is divided into a detailed description of the hardware - featuring construction, mounting and assembly - and the GUI - featuring usage and additional improvements. Lastly, both are treated with a final evaluation resulting in potential future improvements.*

The final concept is a touchscreen interface device aimed at facilitating boat driving by providing information in a clear way and feature an easy-to-use interface, see Figure 50. It has a robust construction that shall withstand a marine environment and is adapted for marine vessels with limited dashboard space. Figure 51 displays the concept installed in a realistic context.

## 10.1 Hardware

From the evaluation in the previous chapter the hardware was further developed. The final hardware concept is based around the architecture of the "Back Opened" concept, it features a removable bezel and has a solution benchmarked from the G4 for surface mounting.

The concept consists of three injection molded plastic parts: a bezel, housing and back lid. The parts can be manufactured using two-tool injection moulding. This is a cost-effective and simple manufacturing method because it common and it does not require any moving tools. The assembly process is intended as follows; the bonded touch panel and display

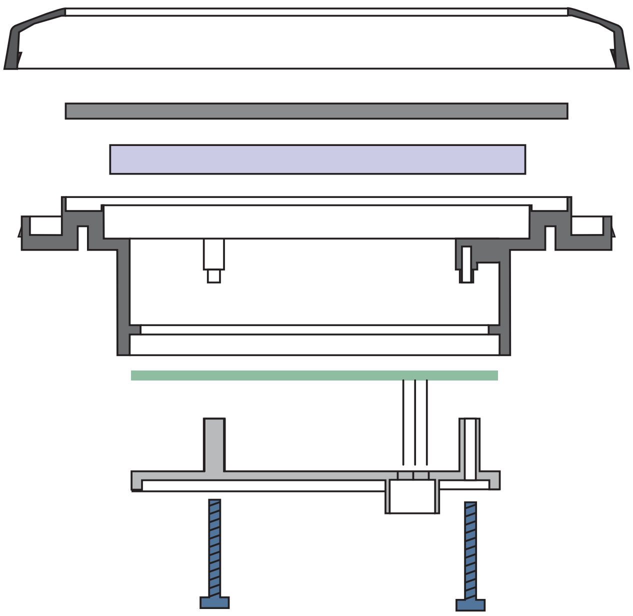

*Figure 52. The touch panel and display are glued from the front of the housing. The circuit board and back lid are mounted from the back and attached with screws.*

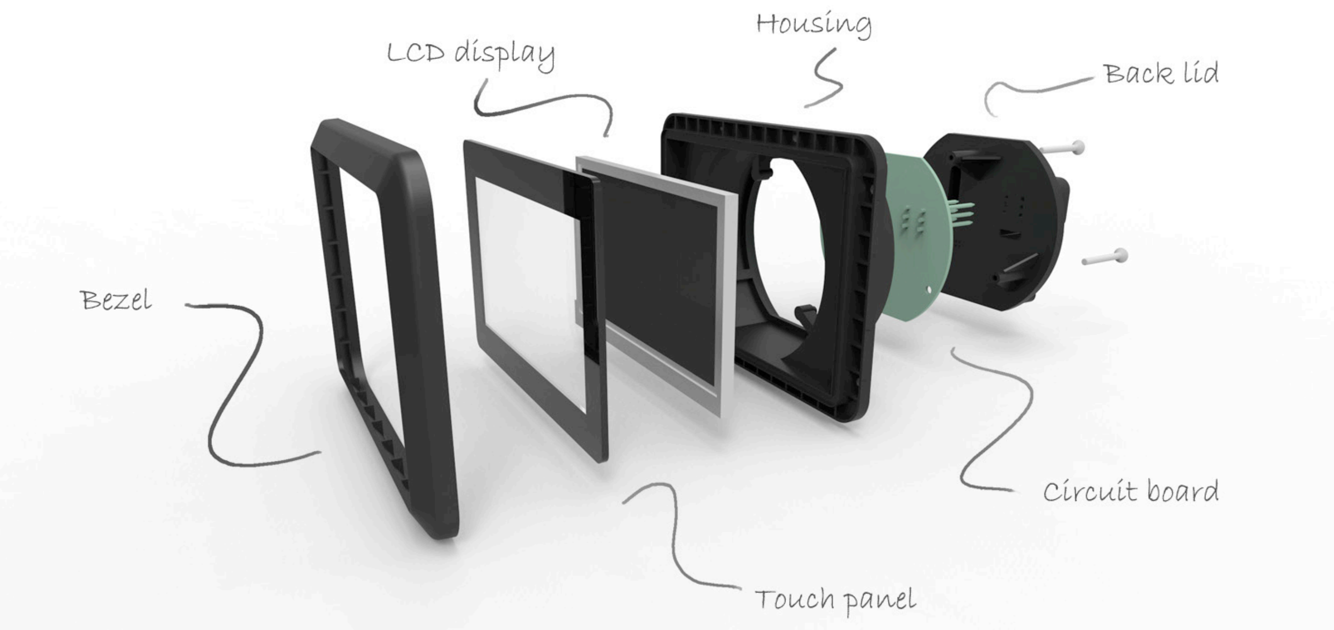


*Figure 53. The final concept have a well thought out construction with only allows each part to be placed in one way.*

are glued to the housing. Afterwards the circuit board is mounted from the back and connected to the touch panel and display; the position of the circuit board is limited by the hole positions and thus only allows it to be placed in one position. Finally the back lid and a rubber gasket are mounted using three M3-threaded screws. The loose bezel is attached via snap fittings and allows for CPAC to use different bezels and brand the product towards different customers. The included parts and the method of assembly are illustrated in Figure 52 and 53.

The rear of the display, shown in Figure 54, contains a CAN interface, which the EVC system uses for communication. The display is connected to the CAN bus after it has been firmly attached to the dashboard. When the cable has been attached it creates a waterproof seal. Furthermore, the rear includes a Gore-Tex membrane, which allows moisture to from inside the housing.

### *Mounting*

The new touch display can be both flush and surface mounted, see Figure 55 and 56, similar to the existing panels. Flush mounting is solved by milling a L-shaped profile around a square hole with the same dimensions as the touch panel and mounting the device from underneath; this allows the edge of the display to rest on the L-profile. In order to hold the display in place, a large washer is mounted around the back cylinder. The washer is manufactured by the boat company and is especially designed by each boat manufacturer to fit with their dashboards. It can be held in place with screws from the bezel and into the dashboard. This procedure is similar to existing mounting procedures of the Flexi-display.

The surface mount is achieved by drilling a 85mm hole in the dashboard, lower the display and gasket into the hole and then use 3mm metal screws in the holes around the frame to fasten it in the dashboard. Finally the bezel is attached over the display. This construction allows maintenance of the display without having to reach underneath the dashboard to unmount it. The mounting procedure resembles the one used for the G4 display.

### *Construction aspects*

For allowing the parts to be injection moulded using only two tool halves, an even material thickness throughout the model is crucial. This resulted in the addition of a channel on the rear of the housing, see Figure 54. The channel will also provide additional sealing benefits when the device is mounted on a slightly curved dashboard. As it works as a deformation zone, it allows the edge to bent and thus providing a tight sealing towards a curved dashboard, without putting too much tension on the more sensitive touch panel surface, see Figure 57.

The splice between the touch panel and the housing will be glued together, this requires a robot in the production, thus creating additional cost. However, glueing the joint was found to be most beneficial method, in oppose to taping which was also considered. According to quality engineers at CPAC, their products that made use of tape between screen and housing had suffered from extensive quality problems, thus adding to the cost that was gained from using tape initially. This made CPAC start glueing these splices as well.


*Figure 54. The rear contains CAN interface for communication with the EVC system and a Gore-Tex membrane to allow condensation to exit. The illustration also shows the mounting holes behind the bezel and the channel for relieving tension.*

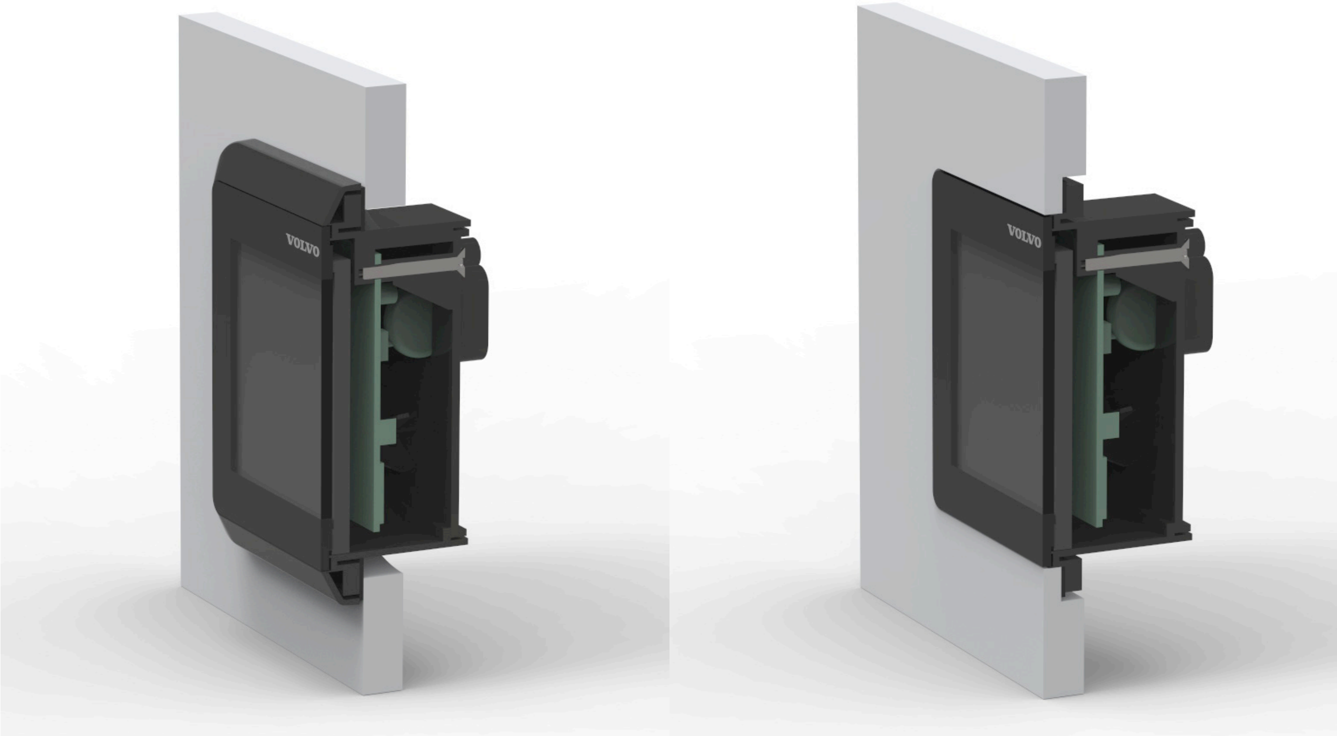


*Figure 55. When surface mounted the device is installed with the bezel on top to cover the screw holes (left). In flush mount, the device is mounted without the bezel (right).*

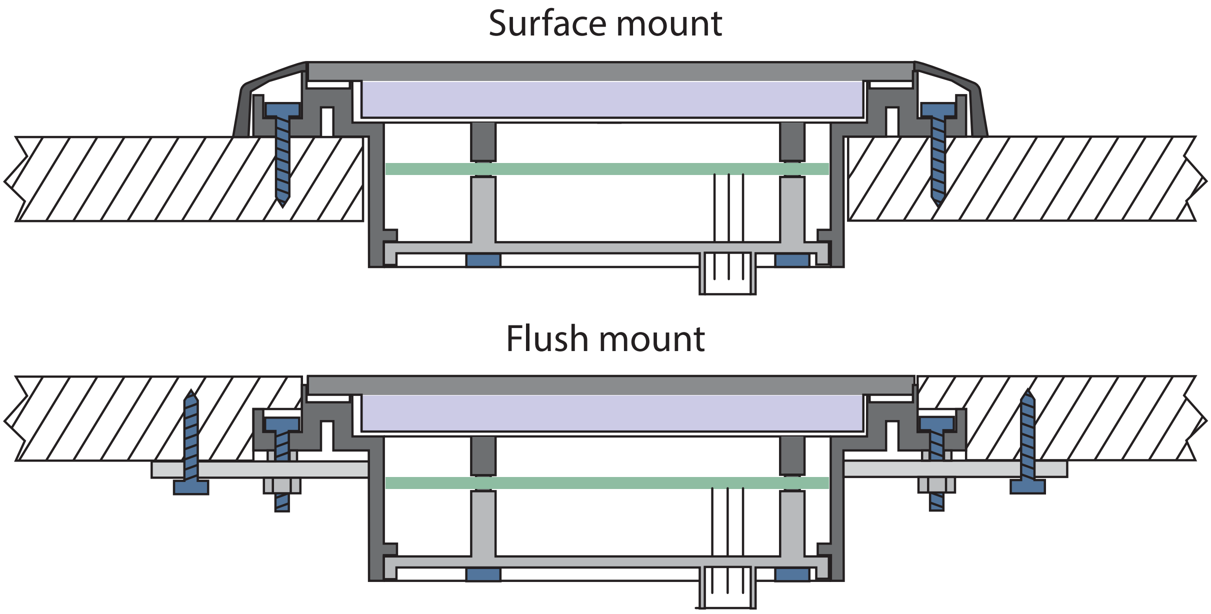


*Figure 56. Mounting the device in surface mode is achieved by drilling a circular hole. The device is then lowered into the hole and attached using screws in the holes around the edge. Finally the bezel is attached with snap fittings. Flush mounting is achieved by milling out a L-shaped profile in a square hole in the dashboard and mounting the device from underneath.*

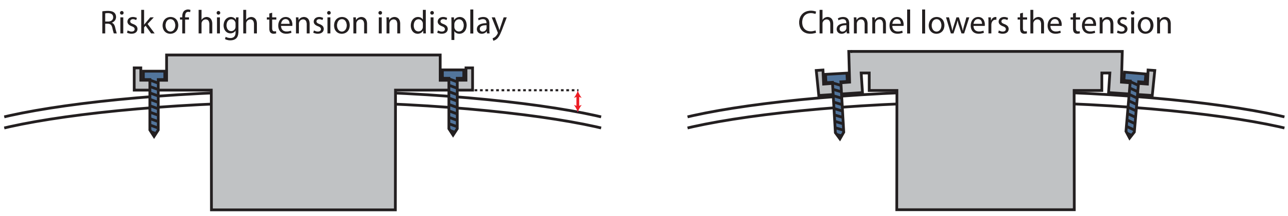


*Figure 57. The channel allows the device to be mounted on slightly curved dashboards whilst still providing a tight sealing (exaggerated curvature).*

The separable splices between housing and back piece and the splice created between the device and dashboard after mounting also needs a tight sealing. To achieve a tight and safe sealing between these parts, a rubber material used on other CPAC devices should be utilized. This material has been tested and evaluated towards other products and it is approved by Volvo and CPAC for usage in their marine applications.

## 10.2 GUI

The final GUI (Figure 58) is a further development of the concept presented in the previous chapter. This section contains a general description of the concept, how it is used and improvements that were made based on the feedback from the evaluation in the detailed design and constructions phase. Detailed descriptions of the GUI are found in *Chapter 8.2 Graphical User Interface (GUI) system architecture* and *Chapter 9.4 GUI with graphical layer.*

The general idea with the GUI is that is shall be useful for both experienced and inexperienced drivers and recognised as a Volvo Penta product. Therefore modularity and adjustability are key aspects that have been considered in the design process. Furthermore, being able to read the information while driving (and with different lighting conditions such as strong sunlight) is crucial, which is why the design principles visual clarity and prioritisation of information and functionality were strongly focused on. This is evident from the amount of information displayed on each view, which is based on the context of use. The simplistic design is also a result of providing information in a clear way.

### 10.2.1 Usage

The main form of navigation is made with swipes. To change between information views and the Settings view, the user can swipe either to the right or to the left - the same manner with which we navigate between homescreens on Android and iOS. As the main view structure is a closed loop, the user can swipe in one direction and return to the original screen.

Accessing the Quick Settings view is done via a vertical drag downwards, which brings down a curtain. The view contains brightness settings and view modes selection. By dragging the “knob” upwards, the user can return to the screen that was covered by the curtain.

All settings (except the ones found in the Quick Settings view) are performed in the Settings view. Here the user can for instance set the language or adjust the content of the information views. The intention with restricting adjustability to only two views is that it simplifies the GUI and errors can be prevented because the user cannot press any “wrong” button in the other views.

### 10.2.2 Improvements

From the evaluation of the detailed designed GUI concept it emerged that the GUI had a solid ground and only minor improves needed to be done in order to achieve a satisfactory level of usability. The improvements aimed at creating views with better layout (and henceforth visual clarity) and to some extent provide more relevant information. The improvement are as follows, see Figure 58:

- Background colour is now darker to create better contrast and further improve the visual appearance.
- The Start-up screen now displays engine(s) oil level, visualised with a bar.
- The Drive view contains a curve-shaped gauge. The RPM pointers in the gauge have been redesigned so that they are both shown when two engines are equally loaded.
- The location indicator is now placed in the upper right corner and is thus better adapted to the information views. This means that screen estate has been gained.
- Values are more highlighted in the detailed information views. This is thanks to an improved size and colour ratio between the labels and values, which makes the values “pop out” more.
- In the Settings view, text size on the right side has been enlarged and is now the same size as the text on the left part. However, headlines on the right side are slightly smaller, which is intended to emphasise the available settings.
- Pop-up warning messages are now simplified and consist of one screen. The cause of the warning is now shown and the driver can with one touch dismiss the message or be provided with more information.

## 10.3 Hardware evaluation

In order to evaluate the construction of the hardware a prototype built from SLS (Selective Laser Sintering) was constructed, see Figure 59. The prototype was compatible with the chosen display and touch panel. However, no circuit board or other electronics were installed as these could not be prototyped. Henceforth, the prototype was solely used for evaluating quality risks, construction, assembly, mounting, size and format of the concept.

Evaluation meetings were held at CPAC with representatives from departments for quality, electronic construction, mechanic construction product planning. During these meetings, potential issues regarding mounting, water penetration, vibrations and assembly risks emerged. However, the evaluators considered the issues to be minor and feasible to solve. Thus, all representatives agreed that the concept was realistic and could be a potential product from a hardware perspective.

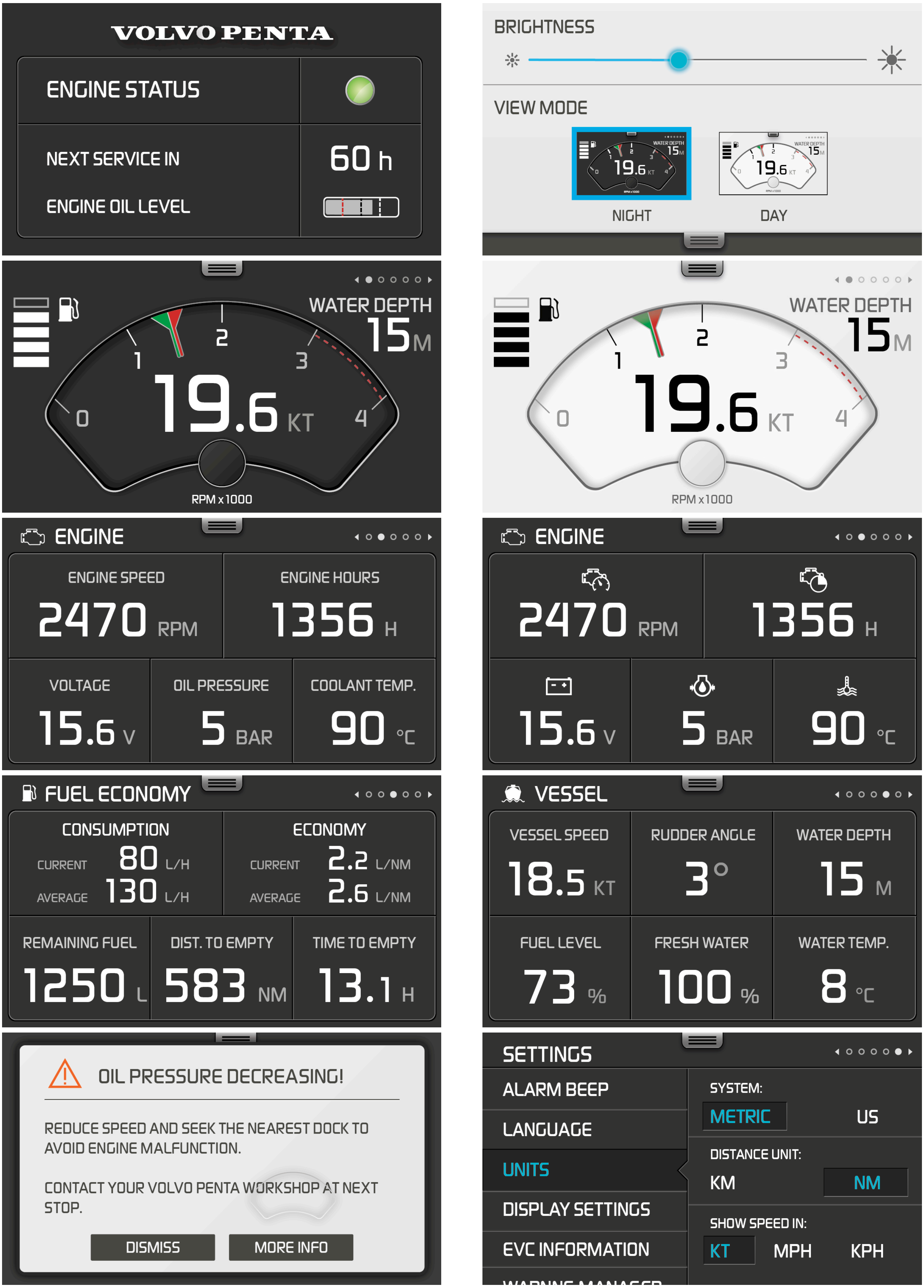


*Figure 58. The entire GUI structure. A white version of the GUI is illustrated by the white Drive view. The Engine view illustrates when icons are used as labels.*

### 10.3.1 Quality risks

Regarding potential construction issues, a risk could be that the intended 3mm metal screws that will hold the device in place during surface mounting do not withstand long-term vibrations. It would be beneficial to assess how strong vibrations the device is exposed to during driving and then evaluate whether the channel underneath the housing will moderate these vibrations or if the device will loosen and cause water penetration behind the dashboard. A tensile test on the intended metal screws attached to a fiberglass board (which is a common dashboard material) would give a good indication whether the screws would be enough to withstand the forces.

Slightly curved dashboards may impede the sealing between the device and dashboard and expose the flat device to strong forces, see *Chapter 6.2 Problems* . On CPAC's existing products this has resulted in several quality issues, where displays have cracked due to uneven tension. The risk of cracking is high for surface mounted displays that have attachments around their edges, which is the case for the new device. It is still uncertain whether the channel would

*Figure 59. Final SLS-prototype with installed touch panel and display (top two pictures). Bottom picture shows the dissassembled parts*

be enough to counter this. However, several other solutions exists to mitigate this, such as using a thicker rubber gasket material or extending legs underneath each corner on the housing. The conclusion would be to test only using the channel and a standard rubber gasket. If that is not enough to withstand the tension, additional solutions can be applied.

### 10.3.2 Assembly risks

It is important to make the assembly procedure as simple, safe and faulty-proof as possible. An important aspect is to design asymmetric parts that only can be mounted in one position. This is why the housing was designed with three screws and a noncircular cross-section. However, the asymmetric principle was not applied to the way the display and touch panel are mounted in the housing. Therefore there is a risk of mounting the display upside down in the housing.

To solve this, the display should steer the assembly into the housing, since it has an asymmetrical shape. Stiffeners could be added in the housing to steer the display in its correct position, and prevent a 180 degree misassembly. And since the touch panel and display will already be bonded together, the stiffeners for steering the touchscreen needs to have higher tolerances.

### 10.3.3 Water performance risks

The performance of the touch panel when exposed to water is also an important aspect. The performance depends on what type of touch technology is applied, but also how its software is configured. For the concept, a capacitive touch technology was chosen, and touch panels of this technology can be software enhanced to reduce performance deterioration due to water. Since a touch panel was already defined for the project, water tests were conducted on the screen to evaluate:

- How much water can the touch panel withstand and still allow precise interaction?
- Are there differences between salt/fresh water?
- Is the touch technology reliable enough for controlling the critical functionalities?

The complete test and evaluation can be found in Appendix III.The results show that when using the initial settings on the display it has a low response with fresh water and a very poor response with salt water. This means that with the initial settings of the display, interaction with wet hands is not possible. However, with the correct settings and further testing the display should be able to mitigate some performance reduction.

Performance reduction can be solved by defining a certain range of input that the screen will interpret as touch input and the number of simultaneous inputs can be limited to counter unintentional inputs. If these actions are insufficient, the panel could also be instructed to suppress inputs that are outside of a dry human finger, meaning that the driver will need to ensure that both his finger and the screen are dry in order to interact. This will prevent unintentional inputs caused by water, but might limit the interaction. Therefore a compromise between these two is recommended.

### 10.3.4 Conclusion

Based on suggestions during evaluations, the project group suggests the following:

- Conduct tensile tests on the 3 mm metal screws intended for surface mounting.
- Test the sealing capacity of the device on curved dashboards, with different gasket thicknesses.
- Design steering stiffeners for faulty-proof mounting of the display in the housing.
- Trim the touch input settings to counter unintentional touch input caused by water.

## 10.4 GUI evaluation

The GUI was evaluated with the same prototype board, see Figure 60, used for the previous evaluations As the concept was iteratively evaluated from idea to final concept, the evaluation served as a final verification. Focus was on mainly evaluating the GUI on a general level. Two CPAC employees (Pihl, 2013 & Monzani, 2013) and one boat manufacturer (Thorsson, 2013) were evaluators at individual sessions.

The design and overall structure of the GUI was found easy-to-understand and appealing by the CPAC employees. They thought boat drivers would be able to quickly learn how to navigate since GUI system is not complex. Furthermore, they considered the design to be visually appealing and perceived as a Volvo product. The boat manufacturer's view on the visual appearance corresponded with the CPAC employees, however he questioned the whole structure of the GUI and asked if horizontal swiping between information views is the optimal interaction. Instead, he suggested that there should be the Drive view, and from that view the user should be able to acquire more information by dragging the curtain knob, in the concept used for the quick settings, downward. In his opinion, this would be much simpler.

One common issue that emerged from all evaluators was the detail level of the fuel level meter in the Drive view. It was deemed easy to understand, however all evaluators thought that it should display the fuel level more exactly. The boat manufacturer explained that their previous boats were sold with a fuel level meter with 6-8 steps, and that their customers complained that it was far too inexact. One of the CPAC suggested to show the last 20 % of fuel in more detail, because the last amounts can determine if a destination can be reached or not.

The boat manufacturer pointed out that there is a risk that the Start-up view may encourage boat drivers to believe that they no longer need to visually inspect the engine(s). He stated that they encourage all their customers to visually inspect the engine room and check the engine(s) before driving off, because there are aspects that the system will not be able to monitor. However, he also suggested that the device could solve this by informing the driver to visually inspect the engine(s). And, as the device contained a high-resolution display, it could display some kind of visualization to aid the driver inspecting the engine status.

Another suggestion from the boat manufacturer was that there should be a light sensor that automatically adjust the brightness according to the lighting conditions. He stated that in the majority of cases, users are unwilling to put effort into manually changing brightness while at sea. However, he still thought it was good to provide users with the possibility of a manual override for adjusting brightness.

### 10.4.1 Conclusion

Based on the comments and suggestions from the evaluators, the project group suggests the following:

- Show fuel level with a more detailed meter.
- Incorporate a light sensor into the hardware and make the system adjust brightness automatically in accordance to the lighting conditions.
- Evaluate the possible risk of discouragement from checking the engine(s) in the engine room created by the Start-up view.
- Further evaluate the GUI structure.


*Figure 60. A prototype board was used in the evaluation of the concept. Its size, format and pixel density match the display recommended from Arrow. However it does not have the same screen brightness and viewing angles.*

# 11. DISCUSSION

*The discussion starts with connecting back to the project's initial aim and relates it to the project's execution and result. A discussion is held on the identified uncertainties of the concept that need further evaluation and consideration. The next part handles process-related reflections and lastly a summary of our future recommendations is found.*

## 11.1 Fulfillment of project aim

The initial aim of the project was very limited and only comprised the development of a replacement product for the Flexi-display. However, as the project progressed and we incorporated the touch technology, CPAC representatives and others saw more and more potential in the product. This drove us into redirecting the aim and steer the project towards developing a generic and robust small touchscreen that could also be sold to customers in other businesses. If CPAC could sell the product in other applications as well, then the yearly production would increase, thus resulting in economies of scale. The device's symmetrical shape, which allows both landscape and portrait mounting, is an additional strength of the concept as it provides additional freedom. For instance, it can be used as a fish finder device or in other non-marine applications.

The project contains two main insecurities: the first one is that no thorough cost evaluation of the product was done. The other one is that no first-hand information from inexperienced users was gained.

Regarding cost, we wanted to evaluate and give an estimate or a cost approximation. However, as cost-driving parts such as the PCB-components, display, touch panel and the total production volume were still undecided, it was deemed too uncertain to make a realistic cost estimation. Another argument for not estimating cost was that the majority of the product cost will come from its electrical components and their production volume, therefore it is important to not lock oneself with one specific component in order to leave room for open negotiations.

Regarding the lack of inexperienced users, we tried several different channels for contacting suitable interviewees (i.e. inexperienced boat drivers with boats equipped with Volvo Penta engines) without results. Henceforth, the research of inexperienced drivers was based on secondary sources such as experienced boat drivers putting themselves in the position of a inexperienced ones. Secondary information about inexperienced users also came from representatives at Volvo Penta, CPAC, Nimbus and sales persons at the Gothenburg Boat Show. These sources provided a consistent picture of who the inexperienced driver was and how they use their boats, though the reliability of the data can still be questioned. Most of all, the lack of test persons hindered the project group from fully empathising for the user.

### 11.1.1 Technical uncertainty

There are still uncertainties about the performance of touch panels in a marine environment. Also, quality problems with IP-classification, condensation, interaction with water, salt, sunlight visibility, EMC, vibrations etc. could not be realistically evaluated. Even though the construction of the concept was evaluated towards several mechanical engineers, it has still been solely a theoretical evaluation. Thus it needs to be tested in realistic surroundings.

All of these uncertainties need a functional prototype to be properly evaluated, which is why the prototype needs to have working electronics and a connection with the EVC system. Thus, this is our recommendation for future evaluations. A functional prototype could also be used for further evaluating interaction with water on the screen in a moving boat.

We intended to build a semi-functional prototype, which would have the correct touch panel and display installed and functioning, but with some limitations in colour representation and interaction. However, the construction of this prototype was dependent on others and due to time constraints this prototype was not finished.

### 11.1.2 Usage uncertainties

As the previously mentioned semi-functional prototype could not be finished, neither could the correct display's visibility in strong sunlight be evaluated. This is something that needs further evaluation via a prototype that has the correct display installed and can display the GUI.

As the device incorporates touch as interaction, this also creates some questions regarding the interaction. In contrast to a button, a touch panel does not give any haptic feedback. Thus, it can be questionable whether this has an affect on the interaction or not. Since many of today's users are accustomed to interacting with touchscreens without any haptic feedback, we believe that they will apply the same mental model when interacting with the new device. However, this assumption requires further testing via a functional prototype installed in a boat to be thoroughly evaluated.

Another problem with interacting with a touch panel is that by touching it users transfer grease from their fingers to the screen's surface. The grease stains may cause the screen to become less readable.

The size of the bezel around the screen was larger than the original design intent. Our intention was to minimize the bezel around the screen to create a modern and slim look, however, due to construction and cost constraints the bezel of the final concept had to be enlarged. We believe that users expect the product to look similar to a tablet or smartphone and do not care about the technical limitations. It is therefore recommended to explore other solutions for attachments to reduce the black frame of the touch panel.

## 11.2 Project process and implementation

The methodology adopted for the project worked very well as it brought structure to the work. By continuously working in small iterations where new new material was analysed and evaluated before it was incorporated in the product, a certainty of the products feasibility was achieved. The updated requirements specification and continuous planning, data gathering and documentation gave a good support along the progress. However, as the data gathering progressed during an extensive part of the project and as the new information was not structured in a thorough way, the new input sometimes resulted in problems gaining a good overview of the situation. A solution to this is to have a designated place where all new input can be gathered and clustered in its corresponding field. By having all information clustered in one place, a better overview could have been achieved, thus contradicting and reinforcing information would be easier to identify.

### 11.2.1 Division of focus between interface and hardware

The project initially focused around the development of the hardware. However, as a touch based information device is very closely linked to its interface, it was also part of the project scope. Designing the interface with the same level of depth as the hardware proved to be overwhelming. This resulted in that the interface design could not be as elaborated and critically examined as the hardware, including the existence of some contents, the overall structure, the form of information representation and the dynamic behaviours that a touch technology allows.

Considering CPAC's perspective, a more critically examined and explored interface that can provide further functionality would perhaps have been more valuable. However, the hardware served very well to provide validity to the concept and in combination with the interface it gave a realistic feeling to the entire concept.

## 11.3 Learnings

During the project, we had the possibility to work at CPAC's headquarters in Gothenburg. This was a great advantage for the project work as it provided us access to CPAC's employees and henceforth we could have ad-hoc or planned meetings to receive direct feedback on the ideas and concepts we created. Moreover, it also meant that we had access to CPAC's test lab, where their current products are tested, and to their discarded products. We could therefore benchmark the construction and interface of their products and combine the best ideas from each device. Working at CPAC also meant that we were able to meet many people from Volvo Penta. They provided valuable information from another perpective than CPAC's.

Another important learning was prototyping and its benefits. After we decided to use a specific touch panel for the prototype, we built mock-ups that we used to get an impression for the size of the product. We also used the mock-ups to discuss with the different stakeholders and were surprised about their effectiveness as mediating object. When the people we talked to could see the concept taking form, they provided us with valuable feedback and suggestions. It also convinced them about the legitimacy of the product concept. The prototypes (physical and software) functioned even better as mediating tools and provided us with more detailed information. Thus, using prototypes early and extensively is definitely something that we will bring along in future projects.

Lastly, we also learned much about the technical and cost related compromises that are required to develop a concept that shall satisfy all relevant stakeholders. Issues regarding manufacturing, construction, design and functionality all need to be balanced towards every stakeholder. These are all important learnings that are useful in a future career as a product developer.

## 11.4 Future recommendations

Based on the discussion in this chapter, we suggest the following recommendations to CPAC for further development of the concept:

- Conduct a cost investigation to assess whether the product is commercially viable.
- Explore other applications for the product concept. If the product can be sold to more consumers it will increase its commercial viability.
- Conduct a thorough touch panel screening and find a panel with a smaller black bezel that provides a satisfactory sealing.
- As the concept has not been evaluated with inexperienced drivers, find suitable test subjects and conduct a concept test and a usability test.
- Build a functional prototype and evaluate technical aspects such as software improvements for touch panel, vibration, condensation, etc., and the suggestions made in the hardware evaluation, in the real usage environment.
- Use the functional prototype to incorporate the changes suggested in the final GUI evaluation and use it in the suggested usability test.

# 12. CONCLUSION

*The conclusion for this project emphasises the importance of the thesis by referring back to the pre-study. It also synthesises the most important points from the results and puts the result in a larger perspective.*

The results from the pre-study clearly indicate that there is a need to improve the driving interface of marine vessels in order to create an easy driving experience. There are many inexperienced consumers buying boats who want and expect things to work without constant supervision. With today's technology, this is not yet possible and therefore it is important to provide the driver with engine and vessel information in an understandable and explicit way to help them keep track of their boat's state. The information provided must also facilitate boat driving and support the inexperienced driver.

Furthermore, the study also shows that the harsh marine environment puts tough requirements on devices placed on boats. They have to withstand large temperature fluctuations, seawater, sunrays etc. Fulfilling these requirements implies incorporating more expensive components, and due to the price-sensitive consumers of today, this limits the solution space for new marine products.

The outcome of this thesis is a concept for a new, touch-based interface device for leisure boats. The device includes a 4,3" widescreen touch display that can display information from CPAC's EVC system. Its graphical user interface is designed to be easy to read and simple to use. Henceforth, the main mode of interaction is swiping that demands little precision and facilitates interaction in swaying conditions. Also, swiping does not occupy any screen estate. The intention has been to create a product that is useful to both experienced and inexperienced drivers. Therefore the interface is modular and can display a varying amount of information.

The construction of the product concept has been designed to withstand the harsh marine environment and be easy to produce, assemble and install on dashboards. It can be constructed with few production tools and includes several standard components. The simple construction also allows the product to be used in other applications. In theory, every system that needs to display information to a user can be a potential application. This is an important strength to consider as it makes the product more commercially viable.

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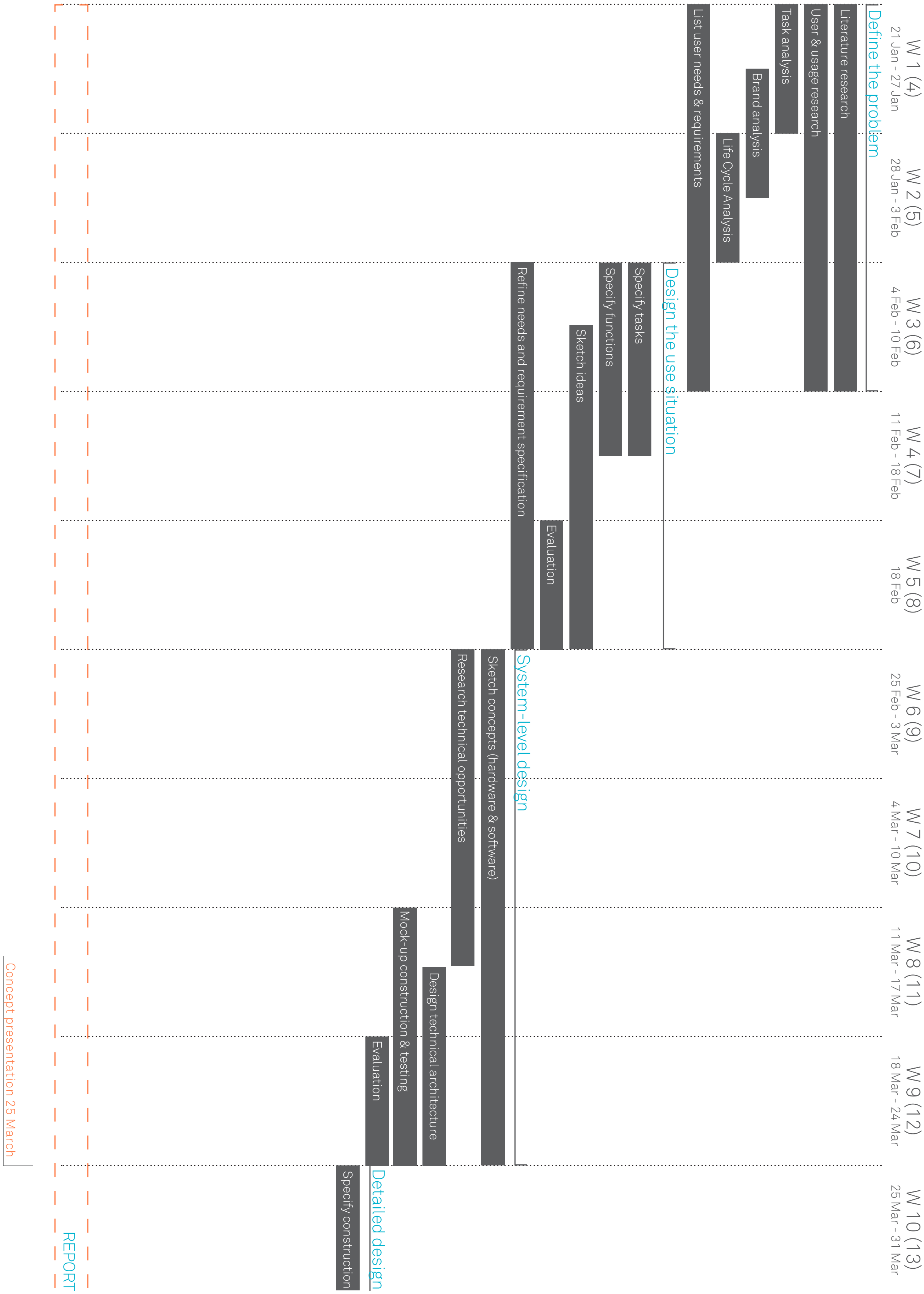
# APPENDIX

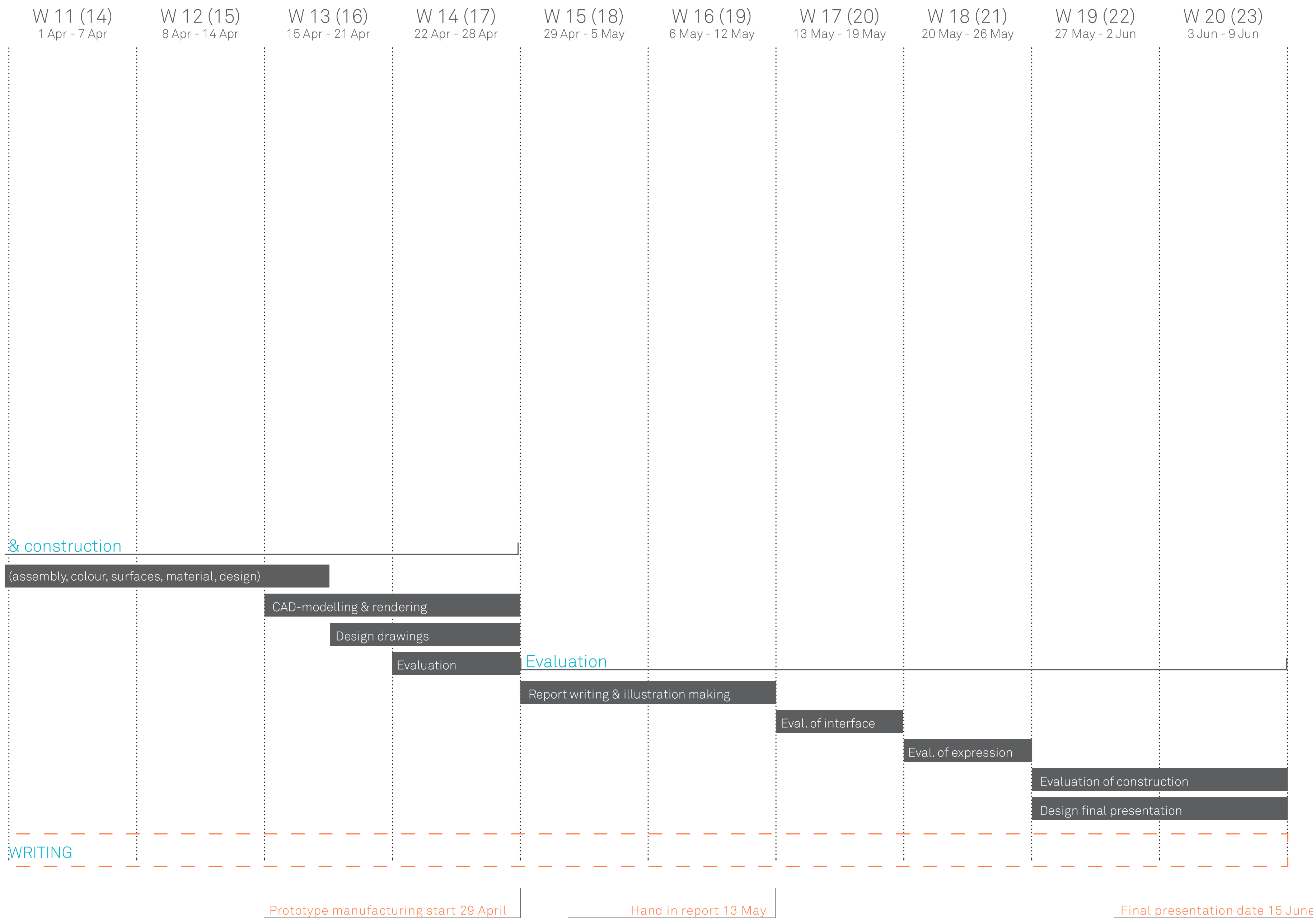
Appendix I - GANTT chart

Appendix II - LCA

Appendix III - Touch Panel Water Performance

# Appendix I - GANTT chart




W 11 (14)
1 Apr - 7 Apr
W 12 (15)
8 Apr - 14 Apr
W 13 (16)
15 Apr - 21 Apr
W 14 (17)
22 Apr - 28 Apr
W 15 (18)
29 Apr - 5 May
W 16 (19)
6 May - 12 May
W 17 (20)
13 May - 19 May
W 18 (21)
20 May - 26 May
W 19 (22)
27 May - 2 Jun
W 20 (23)
3 Jun - 9 Jun
& construction
(assembly, colour, surfaces, material, design)
CAD-modelling & rendering
Design drawings
Evaluation
Evaluation
Report writing & illustration making
Eval. of interface
Eval. of expression
Evaluation of construction
Design final presentation
WRITING
Prototype manufacturing start 29 April
Hand in report 13 May
Final presentation date 15 June

# Appendix II - Life Cycle Analysis

produced with product ecology™

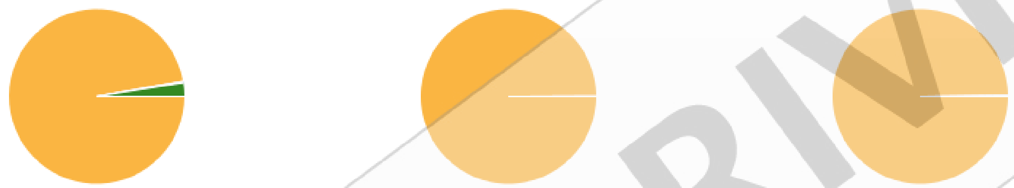
## Summary

| | |
|---|---|
| **Design** | **Original product** |
| **Product** | **Flexi-display** |

## Product image


## Design Impacts

| CO2 Emissions | Water Use | Waste Output |
|---|---|---|



| | CO2 Emissions (t $CO_2$ eq) | Water Use (m3) | Waste Output (kg waste) |
|---|---|---|---|
| Materials & Processes | 1.292e-2 | 1.438e+1 | 1.485e-1 |
| Distribution | 3.690e-5 | 4.406e-3 | 1.653e-4 |
| Consumption | 0.000e+0 | 0.000e+0 | 0.000e+0 |
| End Of Life | 3.324e-4 | 4.902e-3 | 1.371e-4 |

## Lifecycle Overview

**Product Breakdown and EoL Destination**

| Component | Part | Material | Process | Amount | EoL Destination |
|---|---|---|---|---|---|
| Housing | | | | | |
| | Lower housing | polycarbonate, at plant | | 0.025 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| | Upper housing | polycarbonate, at plant | | 0.005 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| | Screen cover | polymethyl methacrylate, beads, at plant | | 0.009 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| | Bezel | polymethyl methacrylate, beads, at plant | | 0.008 kg | disposal, plastic, industr. electronics, 15.3% water, to municipal incineration |

| | | | | | |
|---|---|---|---|---|---|
| | Hand bolt | polybutadiene, at plant | | 0.022 kg | |
| Gasket | | | | | |
| | Silicone gasket | silicon, multi-Si, casted, at plant | | 0.006 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| Buttons | | | | | |
| | 4x Push buttons | | | 0.001 | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| | 4x Button steerings | polycarbonate, at plant | | 0.001 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| Circuit board | | | | | |
| | Board | electronic component, unspecified, at plant | | 0.026 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| Screen | | | | | |
| | Back part | backlight, LCD screen, at plant | | 0.003 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| | LCD-screen | assembly, LCD screen | | 0.009 kg | disposal, plastic, industr. electronics, 15.3% water, to municipal incineration |
| Buzzer | | | | | |
| | Buzzer | electronic component, unspecified, at plant | | 0.017 kg | disposal, plastic, consumer electronics, 15.3% water, to municipal incineration |
| Packaging | | | | | |
| | Cardboard box | solid unbleached board, SUB, at plant | | 0.046 kg | |
| | Packaging plastics | fleece, polyethylene, at plant | | 0.005 kg | |
| | Instruction manual | paper, woodcontaining, LWC, at plant | | 0.022 kg | |

## End of Life Overview

| Description | Process | Amount |
|---|---|---|

## Distribution Overview

| Description | Transport Mode | Distance |
|---|---|---|
| From factoyr to Gothenburg | transport, lorry >16t, fleet average | 1600 km |

# Appedix III - Touch Panel Water Performance

Water tests were conducted to assess the performance of the touch panel provided by TouchNetix. For each test, a specific amount of liquid was applied on the touch panel's surface and a spiral was drawn using TouchNetix's evaluation software TNxTouchHub. The amount of the liquid applied on the screen ranged from 0,5 ml (equivalent to moist fingers) to 2,5 ml (equivalent to very wet fingers) for the two amount extremities. Freshwater from the tap and saltwater with 4 % salinity were tested. The tested saltwater was of higher salinity than the oceans', which ranges between 3,3% and 3,8 % (Encyclopædia Britannica Online, 2013). This was to ensure that the tested saltwater would represent at the very least the most extreme marine condition.

The test results, as shown in Table 1, indicates that the TouchNetix PCAP's performance strongly differed between freshwater and saltwater. It performed poorly for all amounts of saltwater that were applied on it while it functioned fairly well for 1 ml of freshwater and well for 0,5 ml and less. Due to the lacklustre results with saltwater, tests with amounts greater than 1,5 ml were not conducted.

Further evidence of the touch panel's performance with water on it's surface is shown in Figure 1 and Figure 2. The line drawings are supposed to represent a uniform black coloured spiral. Since the touch panel has support for 10 simultaneous touch inputs, other colours than black represent a new touch input.

At 1,5 ml of freshwater, the performance of the touch panel is affected, which is shown by the gap of the spiral and the brown coloured part in Figure 1. The result is due to that the touch panel stops detecting touch input and then detects a secondary touch input, which is the brown coloured part of the spiral. When more amount of water is added, the touch panel does not longer detect a single touch input. Instead, it detects multiple erratic touch inputs and touch locations.

With saltwater applied on the panel, the performance was much inferior than with freshwater. As shown in Figure 2, the panel's performance was acceptable only for water amount less than 0,5 ml. For greater amount of water, the panel could not detect the proper touch input and instead multiple erratic touch inputs were detected.

The results of the freshwater and saltwater tests indicate that the performance of the touch panel with water on it's surface is unsatisfactory. It means that usage with wet hands is not possible, thus limiting the usefulness of the interface device. However, there are software improvement that can be made to improve the performance and henceforth the possibility to use the touch panel with moist fingers.

*Table 1. Test results show a clear difference in performance depending on amount of liquid and salinity.*

| Amount (ml) | Freshwater | Saltwater (4% salinity) |
|---|---|---|
| < 0,5 | Not tested | Bad |
| 0,5 | Good | Bad |
| 1 | Good/Average | Bad |
| 1,5 | Average/Bad (mostly bad) | Bad |
| 2 | Bad | Not tested |
| 2,5 | Bad | Not tested |

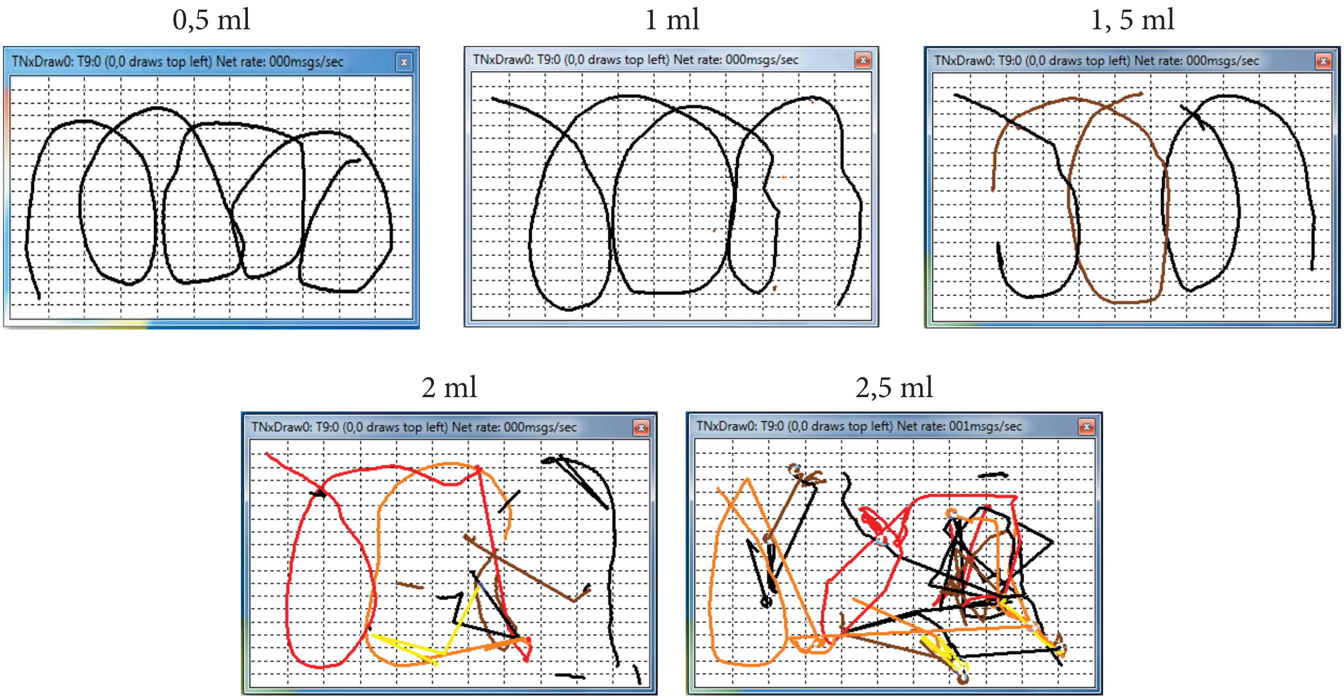



*Figure 1. Line drawings showing the touch panel's capability to detect touch when covered with freshwater.*

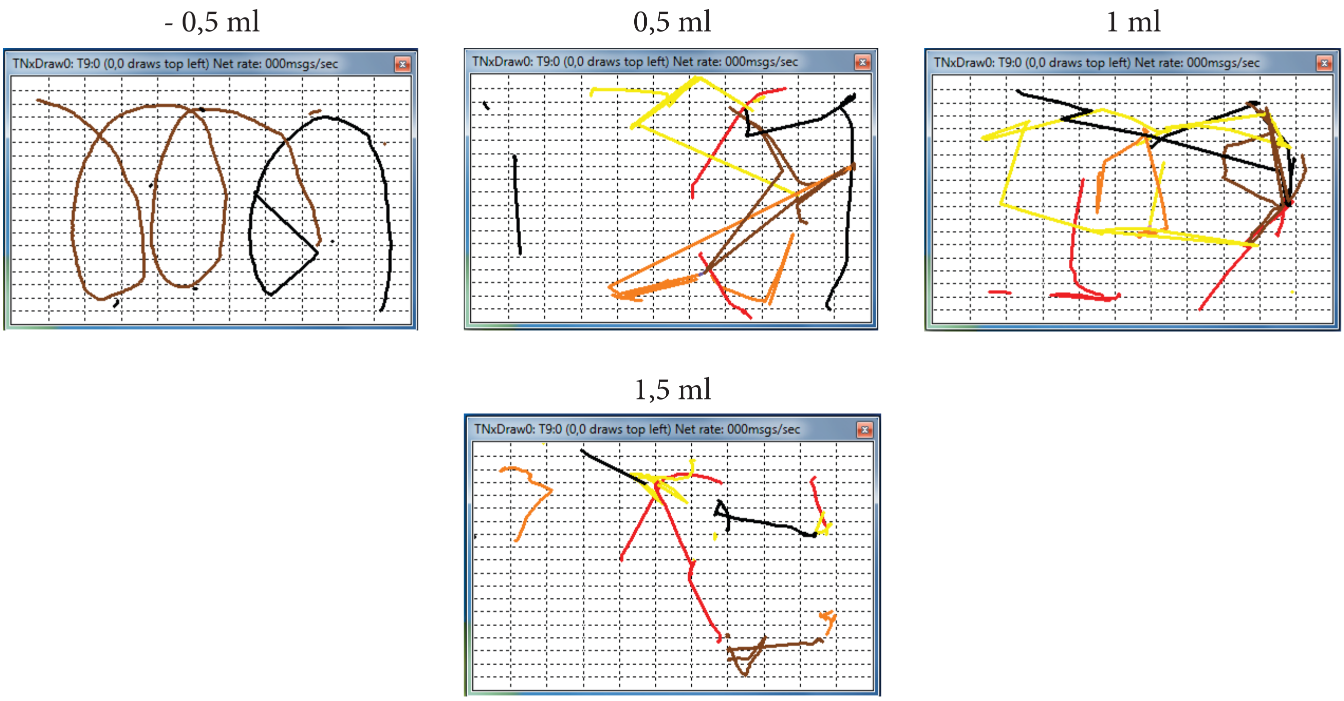



*Figure 2. Line drawings showing the touch panel's capability to detect touch when covered with saltwater.*