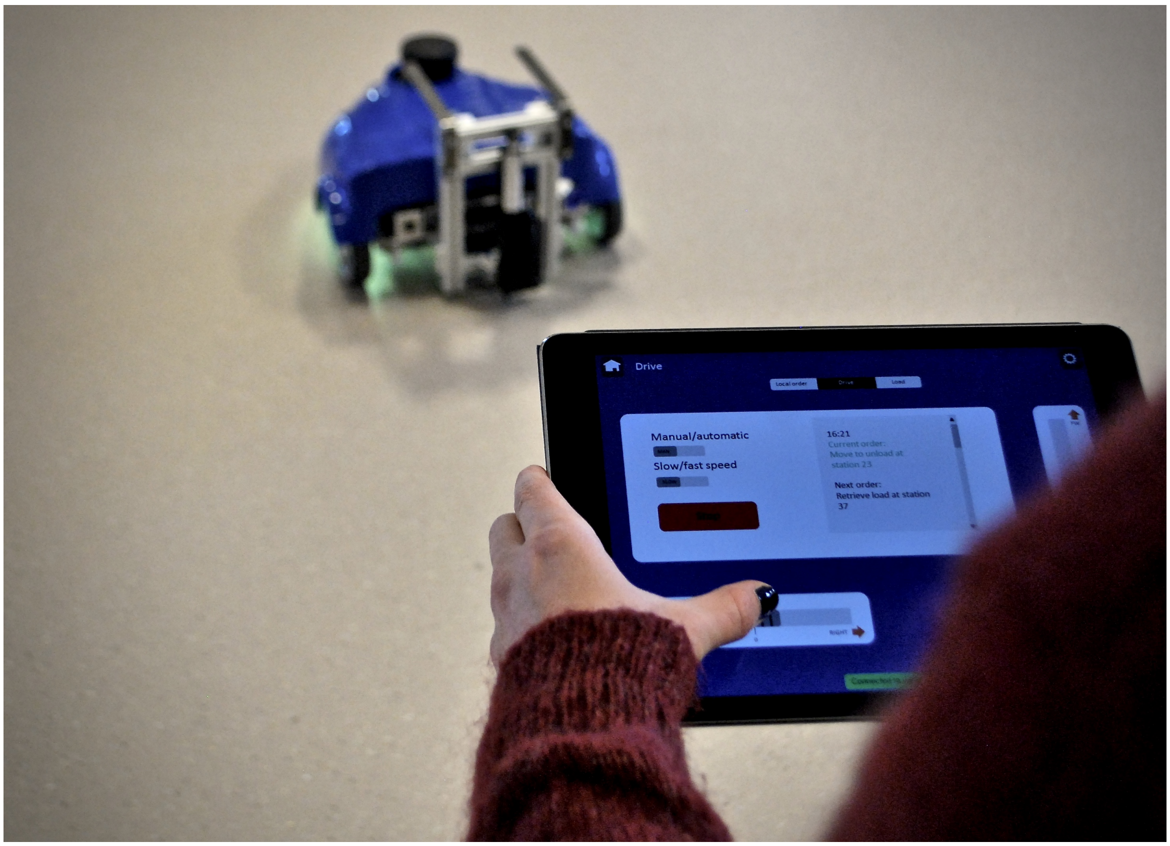
CHALMERS



Remote Control of an AGV

Development of a User Interface for Automated Vehicles

Master's Thesis in Product Development

JOHANNA TURESSON

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Master's thesis 2016

Remote Control of an AGV

Development of a User Interface for Automated Vehicles

JOHANNA TURESSON

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Product and Production Development
Division of Product Development
Chalmers University of Technology
Gothenburg, Sweden 2016

Remote Control of an AGV
Development of a User Interface for Automated Vehicles
JOHANNA TURESSON

© JOHANNA TURESSON, 2016.

Supervisor: Fredrik Ludvigsson, Kollmorgen Automation AB
Examiner: Lars-Ola Bligård, Product and Production Development

Master's Thesis 2016
Department of Product and Production Development
Division of Product Development
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: The functional app prototype steering an AGV.

Typeset in LaTeX
Printed by The company printing the report
Gothenburg, Sweden 2016

Remote Control of an AGV
Development of a User Interface for Automated Vehicles

JOHANNA TURESSON
Department of Product and Production Development
Chalmers University of Technology

Abstract

Automated Guided Vehicles (AGVs) are used in many kinds of industries especially for moving material in production facilities or in warehouses. The AGVs get orders that they process automatically by driving to designated destination points with the help of navigation systems, performing operations. There are certain situations where the AGV needs to be diagnosed or steered manually, for instance if an error has occurred and a sensor has been blocked or the navigation is lost. Today two different hardware units can be used for viewing diagnostics and for manually controlling the vehicle. In order to create an integrated user interface that combines the function of these hardware units and includes other functions that could simplify the manual handling of the AGVs, this Master's Thesis project has been conducted trying to understand the needs of the AGV operators with the goal to develop a usable and helpful interface.

The needs have been elicited by first using methods to understand the environments where the AGV systems are used, then moving on to how users interact with the AGVs, and what functions they use for steering the AGV and for viewing information and diagnostics about it. The technical aspects were then investigated leading to some functional prototypes that were evaluated by users by letting them interact with the prototypes to see if the functions and the interface layout matched their expectations. Based on these results a final interface was designed and described.

The functional prototype was created formed as an app used on an Android tablet that connects to the AGV wirelessly and steers the vehicle manually using an easy drive interface. The final complete interface also includes a splash view effectively conveying the system status, a start screen with the most important information presented in a visually descriptive way, a diagnostics view including all necessary diagnostics in a structured way, and a settings view where the app can be customized.

The interface includes all functionality of the current hardware steering units as well as new functions that proved to be appreciated by end users. However, there are several safety aspects that must be handled before an app can be used commercially on a mobile device.

Keywords: AGV, automation, HMI, User Interface, mobile app

Preface

This report is the final examination for a Master in Product Development at Chalmers University of Technology. Many people have been involved in the project and many people have supported me both during the project and during my years at Chalmers. I am thankful to all of you.

The Master's thesis was conducted in cooperation with Kollmorgen Automation AB and I had the pleasure of working in their offices and being surrounded by helpful colleagues throughout the project. They provided me with information, volunteered in user studies and generally showed a great interest in this project. I would like to especially thank my company supervisor Fredrik Ludvigsson who gave valuable advice and support and who encouraged me to try software developing, Patrik Silverby for believing in this project and my involvement in it, and David Lundqvist for his unwavering enthusiasm.

I would also like to thank my supervisor Lars-Ola Bligård at Product and Production Development at Chalmers University of Technology who challenged me to move forward in directions I would not have chosen otherwise and who gave useful and constructive feedback. Our collaboration started with him giving me his book with the ACD^3 methodology which has been a great help.

Finally I would like to thank my husband Martin, not only for being a great support in this project where he has listened to my concerns and helped me stay motivated but also for encouraging me to become an engineer and for believing in me throughout these years.

Johanna Turesson,
Gothenburg, 2016

List of Abbreviations

AGV	Automated Guided Vehicle
CAN	Controller Area Network
GUI	Graphical User Interface
HMI	Human-Machine Interface
MCD	Manual Control Device
PLC	Programmable Logic Controller
UI	User Interface
UTP	User-Technical Process

Contents

Page

Contents **x**

List of Figures **xv**

List of Tables **xvi**

1 Introduction **1**
- 1.1 Background . . . 1
- 1.2 Purpose and Aim . . . 2
- 1.3 Limitations . . . 2
- 1.4 Definitions . . . 2
- 1.5 Report Outline . . . 3

2 The Automated Guided Vehicle **5**
- 2.1 Hardware . . . 6
  - 2.1.1 The Manual Control Device . . . 6
  - 2.1.2 The Operator Terminal . . . 10
  - 2.1.3 Sensors . . . 11
- 2.2 Software . . . 12
  - 2.2.1 CWay . . . 12
- 2.3 Navigation . . . 13

3 Theoretical Framework **15**
- 3.1 Cognitive Processes . . . 15
  - 3.1.1 Attention . . . 16
  - 3.1.2 Memory . . . 16
  - 3.1.3 Perception . . . 17
  - 3.1.4 Learning . . . 17
  - 3.1.5 Sensory processing . . . 17
- 3.2 Usability . . . 19
  - 3.2.1 Usable Interfaces . . . 19
- 3.3 Mobile Applications . . . 20
  - 3.3.1 Navigation Methods . . . 20

4 Process and Methods **22**

4.1 Procedure . . . 22
4.2 Needs Mapping . . . 23
4.2.1 Interviews . . . 24
4.2.2 Observations . . . 26
4.2.3 Benchmarking . . . 26
4.2.4 User Personas . . . 26
4.3 User Design . . . 27
4.3.1 Usability Test . . . 27
4.3.2 User-Technical Process . . . 31
4.3.3 Customer Feedback . . . 32
4.3.4 Brainstorming . . . 32
4.3.5 Evaluation . . . 32
4.4 Technical Design . . . 33
4.4.1 Benchmarking . . . 33
4.4.2 Prototyping . . . 34
4.5 Detailed Design . . . 34
4.5.1 Usability Test . . . 34
4.5.2 Evaluation - Drive view . . . 35
4.5.3 Evaluation - Start View . . . 36
4.6 Final Design . . . 36

5 Needs Mapping **37**
5.1 Use Situation . . . 37
5.1.1 Usage . . . 37
5.1.2 Context . . . 38
5.1.3 Users and Stakeholders . . . 39
5.1.4 Functions . . . 40
5.2 Existing Products . . . 41
5.3 User Personas . . . 43
5.4 Concept Ideas . . . 46
5.5 List of Needs . . . 47

6 User Design **49**
6.1 The Manual Control Device . . . 49
6.1.1 Interface . . . 52
6.1.2 Steering Potentiometer . . . 52
6.1.3 Connecting Cable . . . 53
6.1.4 General Functionality . . . 53
6.2 The Operator Terminal . . . 53
6.3 Concept Principles . . . 55
6.3.1 The Haptic Principles . . . 56
6.3.2 The Visual Principles . . . 57
6.3.3 The Motion Principles . . . 58
6.3.4 The Gestural Principles . . . 59
6.4 Evaluation . . . 60

6.5 List of User Needs . . . 60

7 Technical Design 62
7.1 Software Architecture . . . 62
7.1.1 Steering . . . 63
7.1.2 Information Gathering . . . 69
7.2 Hardware System Architecture . . . 69
7.2.1 Display . . . 69
7.2.2 Sensors . . . 70
7.2.3 General . . . 70
7.2.4 Communication . . . 70
7.2.5 Hardware Options . . . 71
7.3 List of Technical Needs . . . 73

8 Detailed Design 74
8.1 Application Navigation . . . 74
8.1.1 Drive View . . . 75
8.1.2 Start Screen . . . 80
8.1.3 Splash Screen . . . 82
8.1.4 Diagnostics View and Settings . . . 83
8.2 Graphical User Interface . . . 84
8.2.1 Icons . . . 84
8.2.2 Colors . . . 86
8.2.3 Graphic Elements . . . 87
8.3 List of Detailed Needs . . . 87

9 Final Design 89
9.1 The AGV Interface App . . . 89
9.2 Device . . . 100
9.3 Evaluation . . . 101
9.3.1 User-Technical Process . . . 101
9.3.2 Personas . . . 102
9.3.3 Needs Fulfillment . . . 102
9.4 Summary . . . 106

10 Discussion 107
10.1 Fulfillment of Project Aim . . . 107
10.2 Project Process . . . 108
10.2.1 Data Gathering . . . 108
10.2.2 Integration of Hardware Units . . . 109
10.2.3 Prototyping . . . 109
10.3 Future Development . . . 109
10.3.1 Safety Measures . . . 109
10.3.2 The Future User . . . 110
10.3.3 The User Interface . . . 110

10.4 Learnings 111

11 Conclusion 113

References 115

List of Appendices I

A Interview Guide - Users II

B Interview Guide - Users (English Version) IV

C Interview Guide - Application Engineer VI

D Script - User Study VIII

E Script - User Study (English version) XI

F Script - User Study Prototypes XIV

G Script - User Study Prototypes (English version) XVII

H Script - Evaluation Drive View XX

I Script - Evaluation Start View XXIII

List of Figures

		Page
Figure 2.1	An overview of the hardware system.	5
Figure 2.2	A forklift with a tiller handle.	7
Figure 2.3	The controls of the MCD.	8
Figure 2.4	The potentiometer of the MCD.	8
Figure 2.5	The LEDs of the MCD.	10
Figure 2.6	The Operator Terminal.	11
Figure 2.7	The menu system of the Operator Terminal.	11
Figure 2.8	CWay.	13
Figure 2.9	The navigation technologies.	14
Figure 3.1	App navigation methods.	21
Figure 4.1	The project process.	23
Figure 4.2	Intended driving path.	29
Figure 4.3	Driving path according to floor markings.	29
Figure 4.4	Intended driving path.	35
Figure 5.1	User Persona: Application Engineer.	43
Figure 5.2	User Persona: Younger Operator.	44
Figure 5.3	User Persona: Older Operator.	45
Figure 5.4	Concept idea: Ability to make service requests.	46
Figure 5.5	Concept idea: Graphical representation of errors.	47
Figure 6.1	User study results participants	50
Figure 6.2	A User-Technical Process for the MCD.	51
Figure 6.3	The MCD.	52
Figure 6.4	System overview.	55
Figure 6.5	Concepts from the user design phase.	56
Figure 6.6	Concept solution for the haptic principle.	57
Figure 6.7	Concept solution for the visual principle.	58
Figure 6.8	Concept solution for the motion principle.	59
Figure 6.9	Concept solution for the gestural principle.	60
Figure 7.1	The Button App.	67
Figure 7.2	The Slider App.	67
Figure 7.3	The Gyro App.	68

Figure 7.4 The Joystick App. 68

Figure 8.1 The view hierarchy of the app. 75
Figure 8.2 The apps being tested in the user study. 76
Figure 8.3 The Slider App, second prototype. 79
Figure 8.4 The start views evaluated. 81
Figure 8.5 Alternatives for a splash screen. 83
Figure 8.6 Icons. 84
Figure 8.7 Icons. 85
Figure 8.8 Icons. 86
Figure 8.9 The Company's corporate colors. 87

Figure 9.1 The different views of the AGV Interface App. 90
Figure 9.2 The start screen of the final app. 91
Figure 9.3 The final start view displaying an error. 92
Figure 9.4 The local order view. 94
Figure 9.5 The drive view. 95
Figure 9.6 The load view. 96
Figure 9.7 The diagnostics view. 96
Figure 9.8 The service request view. 97
Figure 9.9 The settings view. 98
Figure 9.10 The view for setting the maximum driving speed. 99
Figure 9.11 Splash screens indicating different statuses. 100
Figure 9.12 A User-Technical Process for the final drive view. 101
Figure 9.13 The degree of needs fulfillment of the final app. 102

List of Tables

Page

Table 4.1 Interviews with users. . . . 25
Table 4.2 Interviews with application engineers. . . . 25
Table 4.3 Interviews with other employees at the Company. . . . 26
Table 4.4 Participants user study. . . . 28
Table 4.5 Observations during task. . . . 30
Table 4.6 Questions for determining technical profile. . . . 31
Table 4.7 Participants in the evaluation of user interface. . . . 36

Table 5.1 Benchmark of operator devices. . . . 42

Table 6.1 Ratings of important contextual features. . . . 53
Table 6.2 Ratings of important features for a screen. . . . 54
Table 6.3 Ratings of general important features for an Operator Terminal. . . . 54

Table 7.1 Benchmarking of game simulators. . . . 64
Table 7.2 Benchmarking of adventure games. . . . 65
Table 7.3 Options for mobile devices. . . . 72

Table 8.1 Results user study. . . . 77

Table 9.1 Status texts. . . . 93
Table 9.2 Evaluation of needs fulfillment. . . . 103
Table 9.3 Evaluation of needs fulfillment. . . . 104
Table 9.4 Evaluation of needs fulfillment. . . . 105

1 Introduction

This report is a Master's thesis that is done in collaboration with Kollmorgen Automation AB to investigate how a user interface can be designed to control an automated vehicle manually and display necessary information and diagnostics about the vehicle. The company works with vehicle automation and Automated Guided Vehicles (AGV) specifically. The first chapter gives a background to the project and states the purpose and aim of the Master's thesis as well as some necessary limitations helping to set a scope. The last section of the chapter gives an outline of the report and what can be expected from each chapter.

1.1 Background

Cruise control and anti-skidding systems are two examples of applications using automation that we have had in cars for many years, and more features are being introduced in order to have fully autonomous cars in a not too distant future. There is a lot to read about the progress in automating road vehicles but there are other vehicles that benefit from automation, such as vehicles used for transporting goods within distribution centers, warehouses and hospitals. Using Automated Guided Vehicles (AGV) for these situations can reduce operating costs, minimize use of energy and lower risk of damaging goods and injuring people (Kollmorgen Automation, 2016h).

The AGVs use navigation technologies such as laser, magnetic tape and inductive wire, together with traffic control solutions to navigate independently (Kollmorgen Automation, 2016f). Although the independence is required, there are also situations where it is necessary to take control of a vehicle and steer it manually as well as access vehicle status information remotely.

Kollmorgen Automation AB (the Company) is a company founded in 1962 and has ever since been working with vehicle automation kits for AGVs (Kollmorgen Automation, 2016a). Many of their vehicles are equipped with a Manual Control Device (MCD) used for steering. These MCDs are connected to the vehicle through wired communication and requires the operator to be located in the close vicinity of the vehicle, see section 2.1.1 for more information. The vehicles also have an Operator Terminal that informs about the moving orders and that can be used for viewing diagnostics, see section 2.1.2 for more information. Looking into the future it is believed that these two features can be further developed and integrated to better satisfy customer needs and meet modern demands.

1.2 Purpose and Aim

The purpose of the project is to understand what kind of information an operator wants to be able to access about an AGV, how to access it and how the AGV should be able to be controlled in a manual state, and find concepts for this. The main purpose is to investigate future possibilities of development for AGVs rather than to develop a prototype ready for commercialization.

Customer needs are obtained through previously collected data as well as end-user interviews and observations of current deployment. The major questions to be answered in order to elicit the customer needs are:

- What information does the customer want displayed about the vehicles?
- In what kind of hardware does the customer want this information to be accessible?
- How should the manual steering of the vehicles be done?

Based on end-user needs a few different concepts for an interface for automated vehicles are developed. The concepts are designed to both display information and enable control of a vehicle. The concepts also include the ability to override the automated steering system of a vehicle and let the user take over control manually from the interface.
The end result of the project is a functional prototype of one of the concepts that, to some extent, both can control and display information about at least one vehicle, as well as a detailed description of the layout of the interface.

1.3 Limitations

The project will not include aspects regarding safety, namely:

- how to secure control over a specific vehicle (and not accidentally control the wrong one),
- how to ensure that only one operator at a time controls a specific vehicle,
- how to guarantee that only authorized persons get access over a control and information unit, and
- how to ensure the safety of the operator controlling the vehicle.

There are today two regulations, ISO 3691-1 and EN-1525, that define that an automated driverless vehicle only may be manually steered by a device connected to the vehicle by a cable. These regulations will not be taken in consideration for the project since the project aims at looking for innovative solutions rather than creating a product ready for commercialization.

1.4 Definitions

The goal of the project is to find an interface to obtain information and control AGVs, which today is done by using two different interfaces; a Manual Control Device and an Operator Terminal. As described in section 1.1, the Operator Terminal is located on the AGV while the MCD is attached to the AGV with a cable. Since the goal is to find an interface that integrates the control unit with the information unit, this interface/unit will hereafter be referred to as *the Product*. Although the Product cannot function without the vehicle, the vehicle as a whole will simply be referred to as *the AGV* or *the vehicle*.

The Company sells all their products through partners and the end-users of the AGV are therefore not the direct customers of the Company. They will however be referred to as the customers as long as they are using the Company's products.

1.5 Report Outline

This section presents a summary of the contents of the chapters in the report.

Chapter 1 - Introduction: The first chapter gives an introduction to the project and to the company that the project is done in collaboration with. It is clarified what the goal with the Master's thesis is and definitions that can help the reader are stated.

Chapter 2 - The Automated Guided Vehicle: This chapter serves as an introduction to the AGV and its components. The hardware units are described to give the reader a better understanding of the functions and the usability that can today be found in the vehicle. There are several software programs used together with the AGV and a few of those that are most frequently used are described briefly as well as the different navigation technologies available.

Chapter 3 - Theoretical Framework: In this chapter the theory that is used for the development of the product is described. The chapter can act as a guideline for design aspects in chapters 5 to 8.

Chapter 4 - Process and Methods: The methods used in the phases are described in this chapter to give the reader an understanding of the project's progress and why certain methods can be useful for certain activities. The methods used in each phase are described both theoretically and how they have been applied in the project.

Chapter 5 - Needs Mapping: This chapter describes the results from the first phase where focus was set on understanding the user and the context of the AGV as well as how the AGV is used in different industries. The main methods used for eliciting this information are interviews and observations with end users.

Chapter 6 - User Design: This phase focuses on understanding more about how the MCD and the Operator Terminals are used today. A user study is conducted to be able to see how people that have never been in contact with the MCD before understand it. This gives, together with customer feedback collected about the Operator Terminal, a better understanding of the functions required in the Product.

Chapter 7 - **Technical Design:** After having looked into possible solutions for creating an interface for steering a vehicle and viewing different kinds of information, this chapter focuses on how these solutions are technically feasible both in terms of hardware components and software applications. The different hardware components are discussed and their specifications based on previous elicited requirements are given. Different ways to steer a vehicle using software applications are tested.

Chapter 8 - **Detailed Design:** While previously focusing on technical aspects of a user interface this phase rather focuses on how to create an interface enabling a user to interact with the interface. Different steering methods are tested and different layouts of a start screen for the user interface are evaluated.

Chapter 9 - **Final Design:** In the last phase the final design of the user interface for an app that can be used on a mobile device is presented. It is also evaluated how it has fulfilled the elicited needs throughout the process.

Chapter 10 - **Discussion:** The discussion takes up the fulfillment of the project's aim, discusses the process of the project, and gives suggestions for future development.

Chapter 11 - **Conclusion:** The last chapter is a conclusion of the whole project and what happened during the project course.

2

The Automated Guided Vehicle

An Automated Guided Vehicle (AGV) is a vehicle that can follow a specified path using different navigation techniques and that is used for industrial needs, such as moving material in production facilities or warehouses. The AGV consists of three parts; navigation, hardware and software. Any vehicle, such a forklift, pallet truck or reach truck, can be fully automated by adding these three parts and used for various kinds of applications in different industries. The navigation methods available are described in this chapter as well as the hardware components and software tools that are relevant for the project to give an understanding of the AGV system.

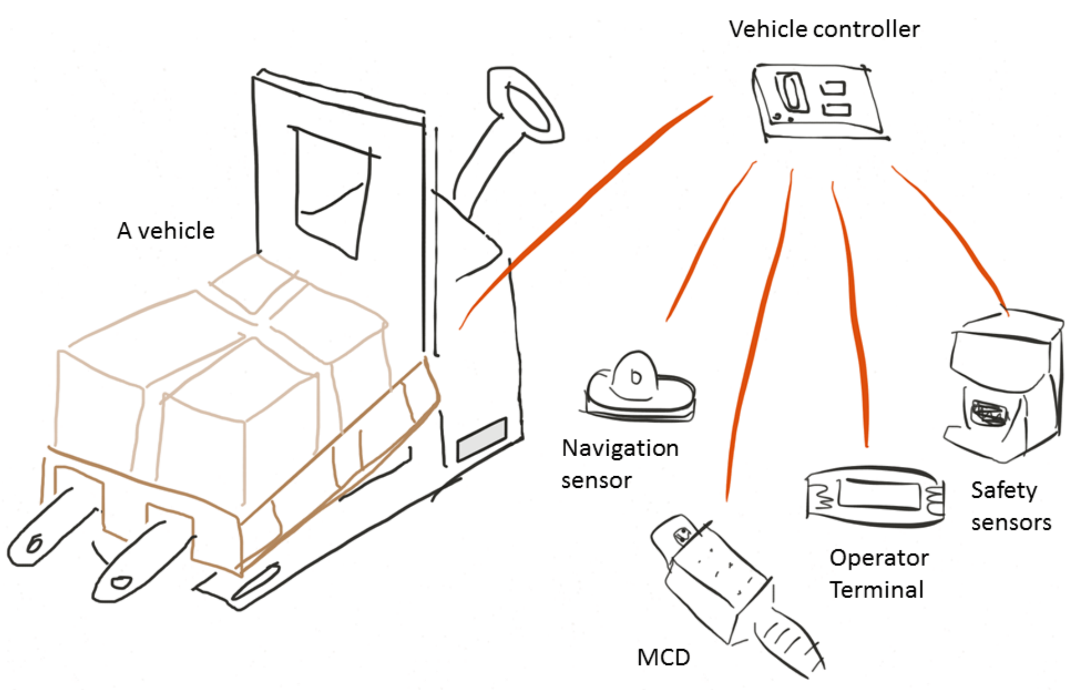


Figure 2.1: An overview of the hardware system.

2.1 Hardware

Every AGV is equipped with a vehicle controller CVC600 that can be divided into an application part and a background part. The application part consists of a Programmable Logic Controller (PLC) that executes programs that are mainly programmed with software tools. The background part helps with keeping track of the vehicle's position and guidance, handles orders, and provides both network and CAN communication (Kollmorgen Automation, 2016c).

Several hardware units can be connected through the vehicle controller and used with the vehicle, see figure 2.1. Some of the components that are used for the AGV are drivers, encoders, sensors used for both navigation and safety, a Manual Control Device, and an Operator Terminal. The Manual Control device and the Operator Terminal that are the focus for this project will be presented further as well as the sensors that make up an important part of the functionality of the AGV.

2.1.1 The Manual Control Device

The control device used for steering the AGVs today is called MCD8 by the company and is referred to as the *MCD*. It is attached to the chassis of the vehicle with a cable and a 5 pin connector. The MCD has several controls and three LEDs in its interface, as can be seen in figure 2.3. The interface panel is fixated below the edge of the MCD chassis so that the controls will not get affected if the MCD is dropped. Some of the MCDs are also equipped with a dead man's grip on the handle that ensures a higher safety for the manual steering (Kollmorgen Automation, 2016d). The MCDs contain a microprocessor that reads the status of the controls and continuously transmits the information to the vehicle controller.

Some of the AGVs that are equipped with the Company's technology do not use the MCD for manual steering, see figure 2.2. These vehicles are usually forklifts that have a tiller handle for manual loading and driving and are used in the same way as a non-automated vehicle for manual control. Instead of choosing between manual and automatic mode with a switch on the MCD, the vehicle is in automatic mode when the handle is in its upright position and in manual mode when the handle is moved downward.

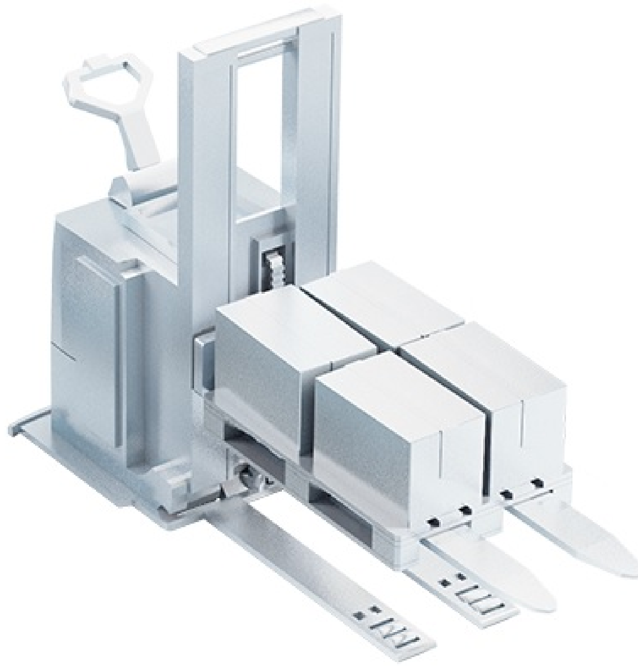


Figure 2.2: A forklift with a tiller handle.

2.1.1.1 Controls

To start driving the AGV manually, the first thing to do is to use the Mode Selector (switch 2 in figure 2.3) to choose the operating mode (Kollmorgen Automation, 2016d). It has three positions; AUT for automatic mode, MAN for manual mode and SEA for semi-automatic mode where speed is controlled manually but guidance is automatic. Switch 4 will indicate the direction (forward or backward motion) and by using switch 3 the AGV will drive either slowly in that direction by holding the switch to the right or faster by holding it to the left as indicated with a smaller and a bigger arrow. When releasing this switch, it will resume neutral position and motion will halt.

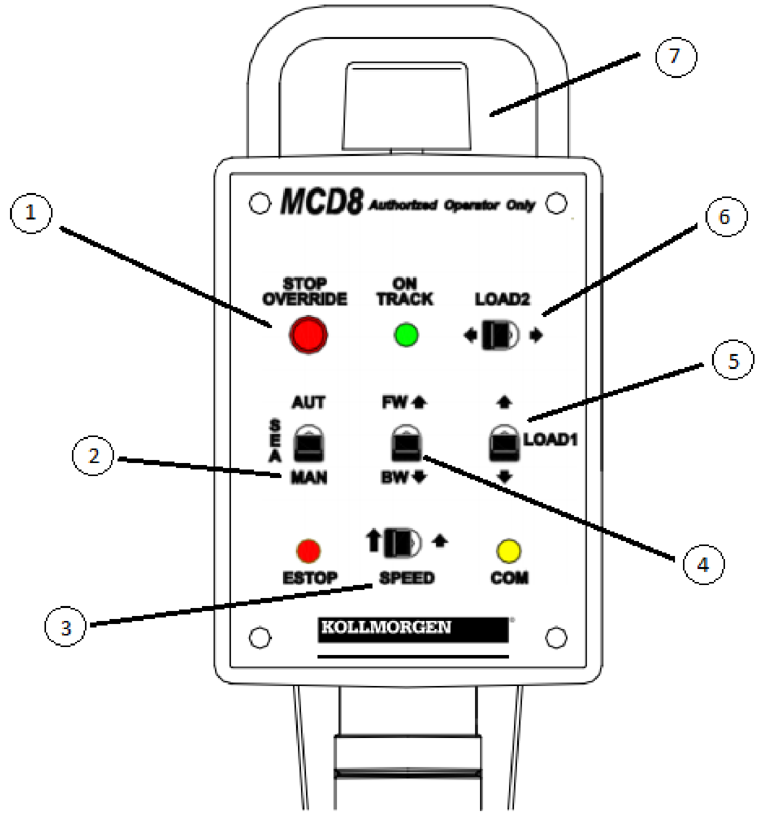


Figure 2.3: The interface of the MCD with the following controls: 1. Stop Override Button 2. Mode Selector 3. Speed Selector 4. Direction Selector 5. and 6. Load Function Controls 7. Steering Potentiometer.

For steering the AGV a potentiometer is located at the top of the MCD (see number 7) that steers to the left when turned clockwise (from the driver's view) and consequently to the right when turned counter-clockwise. The potentiometer is protected by a bracket to avoid breakage if the MCD is dropped. It does not have a neutral position that it will return to, why it is important to be aware of the steering position before putting the vehicle in motion. For driving straight forward, there is an indication on the potentiometer that should be pointing in -90 degrees (see figure 2.4). Consequently this indication can only be seen by turning the MCD to an upright position.

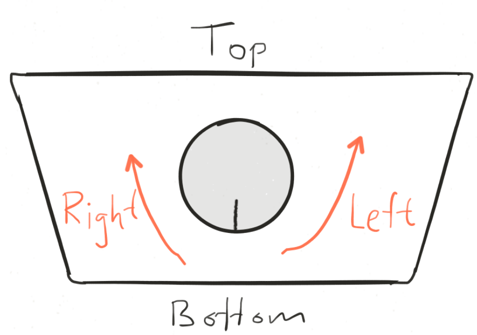


Figure 2.4: View of the Steering Potentiometer located on the upper side of the MCD.

The Load Function Controls, switches 5 and 6, can be used for controlling a load unit vertically and horizontally but are not part of the standard configuration. They need to be defined and configured by the application PLC (Kollmorgen Automation, 2016d). The Stop Override Button, button 1, also needs to be configured and can then be used for overriding safety stop conditions. By enabling this button, a vehicle that is equipped with obstacle detection can then be put in manual motion although there are obstacles in its path.

All the controls used in the MCD can be configured to have other functions than the ones described above. Two systems may therefore differ depending on the PLC application.

2.1.1.2 LEDs

The interface of the MCD has three different LEDs as can be seen in figure 2.5. The first is a green LED that indicates that the AGV is being guided on track or when it is flashing that the AGV is in semi-automatic mode looking for its path (Kollmorgen Automation, 2016d). The second LED is red and indicates emergency or when flashing that safety stop conditions have been enabled allowing the AGV to be navigated although there are obstacles in its path. The third LED is yellow and indicates that communication is established between the MCD and the vehicle. If this light flashes, the communication is not yet ready for operation.

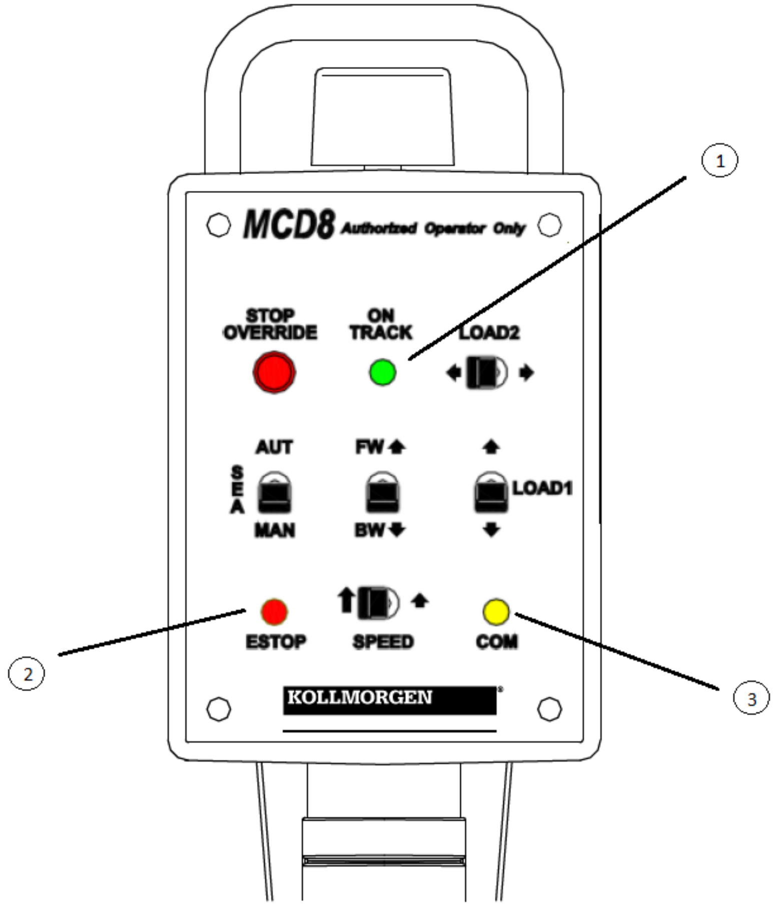


Figure 2.5: The interface of the MCD with the following LEDs: 1. ON TRACK 2. ESTOP 3. COM.

2.1.2 The Operator Terminal

There is mainly one Operator Terminal available to be used with the AGV, the OPT100-DL. Its function is to display information and setup, and provide diagnostics for the operators. The Operator Terminal is mounted on the vehicle by cutting a hole in the chassis, mounting the Operator Terminal and attaching a mating connector between it and the vehicle controller via the CAN interface (Kollmorgen Automation, 2016e). The OPT100's display is graphic and can be set in normal mode where the display shows status information and menu mode for setup functions and diagnostics. It also has a key pad for navigating the menus and entering data such as a password, see figure 2.6.

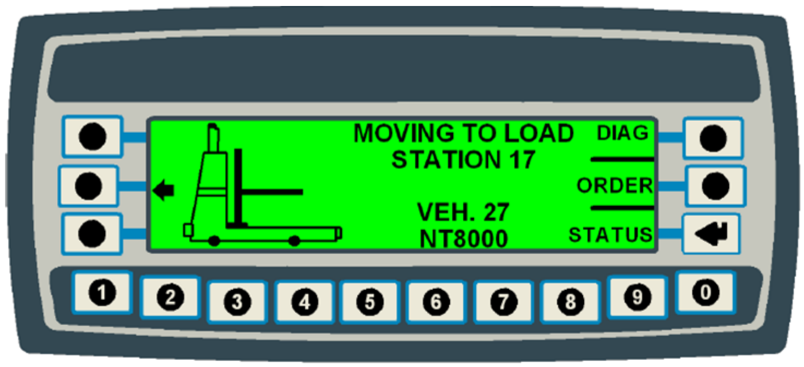


Figure 2.6: The current Operator Terminal (OPT100-DL).

How to setup the menu structure is a matter of configuration. In figure 2.7 is an example of how to navigate between menus.

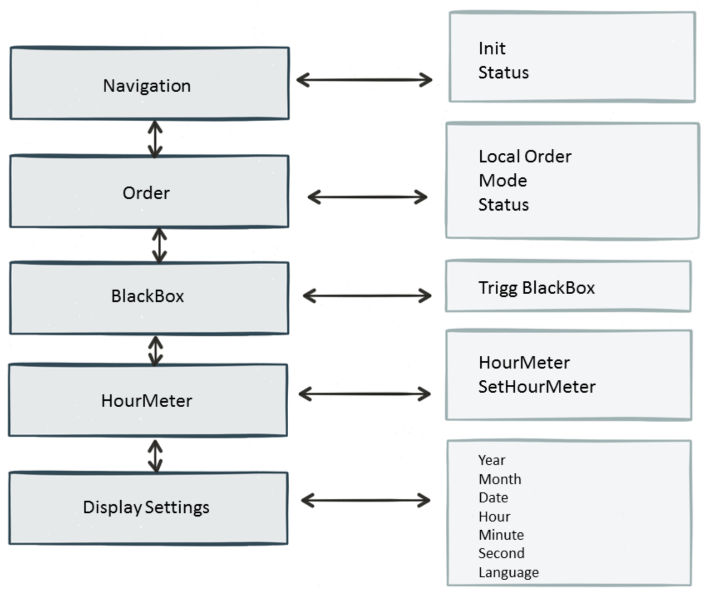


Figure 2.7: The menu-system of the Operator Terminal.

There are several other models of the Operator Terminal that are still in use on some AGVs, in particular the OPT10 and OPT7. They both have a text-based display and just like the OPT100 a key pad for entering data.

Some AGVs are equipped with another Operator Terminal than the ones described such as a touch display. This is usually due to a partner company wanting another kind of hardware for displaying information and diagnostics.

2.1.3 Sensors

The AGVs are equipped with sensors both for information monitoring and for safety. The safety sensors scan the environment to find obstacles in the path and the information monitoring sensors can for instance be a sensor on the forks of a forklift to monitor if the vehicle is loaded or unloaded. The types of sensors and number of sensors used vary for the vehicles since it is up to the partner companies to decide this setup with the customers.

2.2 Software

There are several software programs, or tools, that are used to operate the AGV. Many of them are only used by application engineers when installing a new system or when making modifications.

Vehicle Application Designer, or AppDesigner, is a tool used to tailor the vehicle controller software to each vehicle by setting parameters and programming vehicle PLC applications (Kollmorgen Automation, 2014b). With the help of AppDesigner the application engineers can for instance redefine the controls of the MCD and configure what information and diagnostics to view in the Operator Terminal.

To decide the layout of the environment where the AGV is operated a tool called Layout Designer is used (Kollmorgen Automation, 2014a). It has three main functions; to define the vehicle paths, to define how the vehicles will navigate, and to generate information about traffic control.

The Vehicle Diagnostics Tool (VDT) is used to analyze data from the vehicle controller (Kollmorgen Automation, 2016g). It is amongst other possible to record a path that has been driven and analyze the navigation data, such as speed and level of navigation.

2.2.1 CWay

The CWay tool is frequently utilized by operators and other users to view the layout and the vehicles operating in the layout, see figure 2.8 for an example. The vehicles are displayed in different colors depending on their state, for instance red for emergency, green for unloaded, light blue for loaded, and magenta for low battery (Kollmorgen Automation, 2014d). These colors can be configured to signify other states.

It is also possible to give orders to the vehicles, such as to drive to a charge station or to fetch at a certain load station and unload at another station. There is an event log that shows when something in the system has gone wrong or when there are unexpected events in the system. A description of the event can be seen and for some events it is also possible to view the reasons for the event and actions that can be taken to solve the problem. (Kollmorgen Automation, 2014c)

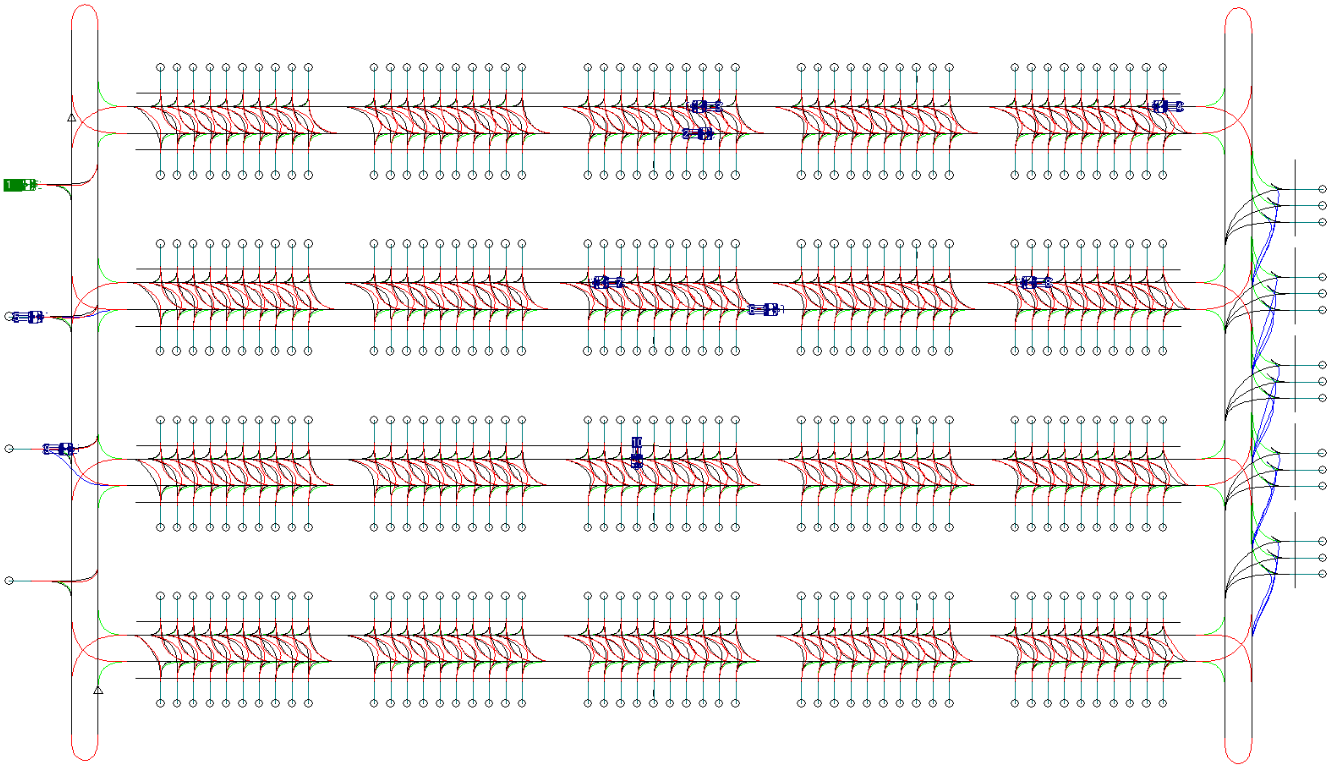


Figure 2.8: An image taken from a fictive layout in CWay with fictive vehicles.

2.3 Navigation

The navigation technologies used with the AGVs (see figure 2.9) are magnetic tape, inductive wire, laser (both natural navigation and laser using reflectors), spot (using magnets and antennas), and multi-navigation which is a combination of the technologies (Kollmorgen Automation, 2014e, 2016f). The most common navigation method is using reflectors with a laser scanner. The reflectors are mounted in the same height as the laser scanner in the building.

Using natural navigation the AGV is guided with respect to objects in the environment as opposed to other methods such as spot and laser navigation where different landmarks are mounted to help the AGV navigate (Kollmorgen Automation, 2016b).

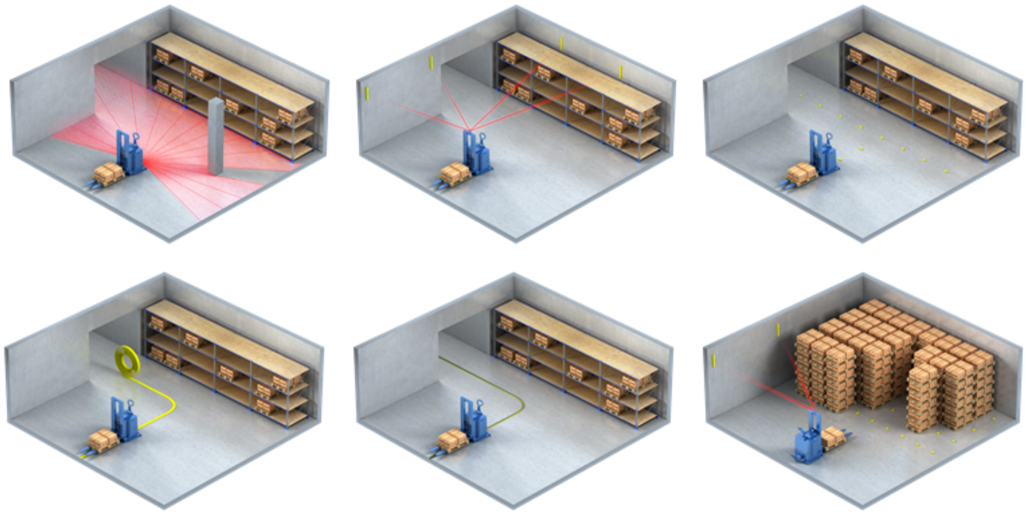


Figure 2.9: The navigation technologies.

3

Theoretical Framework

The human-machine interaction became a concept due to automation being introduced in machines and humans interacting with the machines through software (Boy, 2011). The reason for this interaction is the need to perform some kind of task. The interaction must therefore be able to be performed with the help of the machine and executed by the human. A task can be more or less complex depending on how many sub-tasks exist, if the task itself is difficult, if there is a time constraint, and if there are risks involved (Boy, 2011).

A theoretical framework of how to develop design that helps the human interact with a machine independent of the kind of task is therefore presented in this chapter both with regards to the cognitive processes in the humans and the usability aspects in a machine. The theory presented acts as a foundation to design decisions taken throughout the project's process.

Lastly some theory about mobile applications is presented to provide a basis for design decisions that can be taken with regards to how navigation within an app can be done.

3.1 Cognitive Processes

Cognitive processes are something every person experiences as long as they are awake, for instance thinking, day-dreaming, remembering, talking and writing.

The different kinds of cognition require different technical support to function well (Preece, Rogers, and Sharp, 2007). Demanding too much from the cognitive processes can create a cognitive workload that results in slower processing of information, poorer capability in decision-making and a worse reaction to stimuli (Bohgard et al., 2010). It is important to create human-machine systems that support the cognitive processes in the human-machine interaction to increase the user's comfort, diminish the risk for accidents and raise the competitiveness for the product (Bohgard et al., 2010).

Some examples of cognitive processes that are important in a human-machine interaction are hereafter described as well as suggestions on design aspects that can diminish the cognitive workload and make the product more usable.

3.1.1 Attention

Attention is the notion of focusing your sight or hearing on a certain item out of many other choices in order to get relevant information, or focusing one of your senses to take in as much information as possible while excluding the others (Bohgard et al., 2010). Two requisites that can make it easier to focus is having a clear goal of what information to find and having the information presented so that it is salient to its environment (Preece, Rogers, and Sharp, 2007).

The design can be adapted to make the information easy to survey by avoiding clutter and by using graphics like animations, fonts and colors. Things that are related to one another can for instance have the same font or color to show that they are connected (Preece, Rogers, and Sharp, 2007). If there is a lot of information to present in text, an auditive stimuli can be added to give a particular piece of information attention (Bohgard et al., 2010).

The main design guidelines concerning attention are:

- Avoid clutter
- Group related items by color and font
- Use graphics
- Add sounds

3.1.2 Memory

The memory is a vital part of every person's life and helps us think, learn and act, and its primary functions are to register information, store it and help extracting it when needed. The memory can be divided into the short term memory and the long term memory. The latter contains four different types of memory; a semantic memory processing knowledge and language, an episodic memory handling events that have been experienced, a procedural memory treating skills like riding a bike and the perceptual memory that helps in identifying things like environment or someone's face (Bohgard et al., 2010). The short term memory is sometimes called the working memory. Some of the information from the short term memory will be registered and stored in the long term memory.

Many people remember visual things like the cover of a movie or a CD better than they would remember someone's birthday or telephone number (Preece, Rogers, and Sharp, 2007). This is one reason why graphical user interfaces are helpful to users; when browsing through many options, there is a chance of sooner or later recognizing what they were looking for. Getting clues or recognizing things that have previously been experienced can help extracting data from the long term memory (Bohgard et al., 2010).

There is also a theory that most people can remember 7 ± 2 pieces of information with their short-term memory (Preece, Rogers, and Sharp, 2007). The consequence of this is that it is advised to not have more than seven options in a menu, have seven or less bullet-points in a list and to have maximum seven icons on a tool bar or at the top of a website page. One can however argument that as long as the items can be read from the screen, they will not require any capacity from your memory (Preece, Rogers, and Sharp, 2007). Another way of helping the memory is to use conventional standards when introducing a new product (Bohgard et al., 2010). To raise the volume it is for instance standard to slide a control to the right and by using this method, the user will recognize how to change the volume.

The main design guidelines collected for helping the memory are:

- Provide clues and items to recognize
- Reduce the amount of information the long term memory needs to remember
- Use standard conventions

3.1.3 Perception

How to help people absorb information is a matter of perception, whether it is perceived through the eyes, ears or fingers. Perception involves other processes like attention, memory and language, which is why it is complicated to ensure that the right information is perceived. Some design implications to ease this process is using graphical representations that can be understood by the mass (like a toilet sign), using several stimuli to present a message (like most exit signs that have both text and an icon), grouping information in visually distinguishable fractions using spaces or lines, and making auditive information recognizable and easy to understand by removing disturbing noise and speaking articulated and with a neutral accent (Bohgard et al., 2010; Preece, Rogers, and Sharp, 2007).

The main design guidelines regarding perception are:

- Use graphical representations together with text
- Group related items with spaces and lines
- Use distinguishable stimuli

3.1.4 Learning

When it comes to learning in a human-machine context there are two options, either learning with the help of the machine interface, or learning how to use the machine interface (Preece, Rogers, and Sharp, 2007). It has been observed that when gaining computer-based skills it is hard to do so by following written instructions whereas learning by exploring gives a better result. Therefore it is good to create interfaces that encourage exploration and where it is easy to return to previous menu when choosing the wrong option.

The main design guideline to help the learning process is:

- Use interfaces that encourage exploration

3.1.5 Sensory processing

The human's senses assist in taking in stimuli and expressing information. It is often debated that the human only has five senses but if you allow the definition to be broader, there is also the

haptic sense that includes body movements and pressure to the skin (Bohgard et al., 2010). There are design considerations to help users fully perceive information. This need could arise due to a deficiency, like having impaired vision or color vision, but it could also be to better help the users pay attention, learn and remember, as previously stated.
The sight is one of the human's most important senses since it registers about 80 percent of all sensory input. Some aspects that simplify the sensory processing of sight is having good lightning to be able to see contrasts, avoiding the use of green and red together since they are difficult to distinguish for someone with decreased color vision, and choosing helpful indications like lines and pointers when absolute values are needed to be distinguished. Telling the time is for instance easier when the clock has twelve hour pointers rather than four or none.
The hearing is an important complement to the sight and has the best possibility to capture the human's attention, why it is often used as a warning signal (Bohgard et al., 2010). The ears have the best ability to register sounds with a frequency under 1500 Hz and over 3000 Hz why it is recommended to consider this when choosing sounds to use as signals. Sounds can as mentioned be used as a way to warn of danger but they can also be used to give attention to an object or used as confirmation, that an e-mail is sent or that a door is properly locked. When using a sound to warn it is also recommended to add a visual description of the problem that has occurred and how to solve it.
The tactile sense reacts to mechanical properties affecting the skin like pressure and temperature variation but also pain and itching sensations (Bohgard et al., 2010). The haptic sense is what translates tactile and kinetic sensory inputs to information to help fill in gaps, for instance in a dimly lit room where the hands will be used to find the way. Using haptics in an interface can give an extended sensory input by using structured surfaces, size, force feedback or vibration.

The main design guidelines collected from the sensory processing are:

- Sight
  - Use contrasts
  - Avoid certain colors like red and green together
  - Use indicators and arrows
- Hearing
  - Use sounds with a frequency under 1500 Hz or over 3000 Hz
  - Use sounds and add a descriptive text
- Tactile sense
  - Use haptics for feedback

3.2 Usability

According to Oxford Dictionaries, the definition of usability is *the degree to which something is able or fit to be used* (Press, 2016). This can be seen from two angles; that a system has the intended functions and that it can be used in a satisfying way where the user can do what he or she expects without having to ask questions or being hindered in any way (Bohgard et al., 2010; Chisnell, Rubin, and Spool, 2011).

Another aspect to usability is how to determine the quality of use. This can be difficult but there are several attributes that usually are present in a high-qualitative usable system (Castro Lozano et al., 2011):

Effectivity The intended goals for the system are possible to reach.
Efficiency The goals for the system can be reached in a certain amount of time. This aspect however depends on both the user's abilities and the system's characteristics.
Satisfaction The system can be used as intended by the user without frustration.
Learnability A first time user can easily learn how to operate the system.
Memorability After having operated the system several times the user should be able to remember how different functionalities work.
Retainability It should be possible to keep control over the system and limit the possible errors.

To be able to develop a design that minimizes the risk of errors and that focuses on usability, it is important to understand the context of the human-machine interaction; who the different kinds of users are and what characteristics they have, in which environment the interaction takes place and what the main activities are (Castro Lozano et al., 2011). Taking usability in consideration when developing a product and thus focusing primarily on the user's needs and characteristics also has a greater likelihood of generating user acceptance, which can lead to a successful product in the market (Abbas and Aggarwal, 2010). Considering usability should not be a one-time happening but should rather be evaluated during the whole development process to make sure that it is usable, not only theoretically but practically (Castro Lozano et al., 2011).

3.2.1 Usable Interfaces

The user interface (UI) or the human-machine interface (HMI) is what gives the user access to the machine's resources. It is suggested that the user is not interested in the underlying structure (hardware and software) but that it's HMI will determine the user's perception of the machine (Castro Lozano et al., 2011). It is therefore important to create usable interfaces. Some principles are established to accomplish this (Castro Lozano et al., 2011):

- Understand who the user is.
- Diminish the number of cognitive processes needed.
- Help the user by minimizing the risk of errors.
- Use a clear and consistent layout.

- Understand the factors such as technological, social, psychological, and ergonomic that affect the human-machine interaction.

If a user interface is created as a software application it is not possible to enclose a user manual. Instead the application should be self-explanatory without the need to have the production team present to explain the features (Banga and Weinhold, 2014). To obtain this, a technical-minded person outside the team can be used to evaluate the design and see if the intended features are interpreted correctly. It is important to be able to evaluate and change design features if you are unable to defend their existence in order to enhance the user experience.

3.3 Mobile Applications

There are generally three types of mobile applications (apps): Native, Web, and Hybrid (Banga and Weinhold, 2014). The Native app is programmed in a native language of the specific platform. For an Android device the app is written in Java or C/C++ and for an iOS device it is written in Objective-C. The Native apps follow the standards for their specific platform making them more compatible with the hardware of the specific system. A Web app on the other hand is an app that is executed in a web browser. Its interface is built in HTML or CSS and it is programmed in a web programming language, such as JavaScript or Python. Lastly the Hybrid app can be seen as a combination of the Native and the Web apps. It is usually programmed in a way so it can be used cross-platform.

3.3.1 Navigation Methods

There are several ways to navigate through an app where four of them are hereafter described and depicted, see figure 3.1. A mobile app does not have to use only one kind of navigation method but it can use a combination of them.

A Single View app is, like the name implies, a single page program. Some examples of app that are usually single viewed are calculators and cameras on mobile devices.

A Stacked Navigation Bar, sometimes referred to as Action Bar, contains several items stacked above one another. When choosing one of them they lead to another view and there will usually appear a back arrow at the top left corner to return to the previous view. This navigation method is commonly used for browsing e-mails or for contact lists.

The Tab Controller gives the user three to five alternate views that can be chosen from the bottom of the screen with tabbed icons. An example where this navigation method is used is for the clock both on Android and iOS where you can choose between an alarm clock view, a timer view, and a stopwatch view.

A Scroll View is used for a view that takes up more space than the screen can offer. In order to see all information the user can scroll vertically or horizontally, like for instance to view the weather not only today and tomorrow but also a few more days, or for viewing a calendar (Banga and Weinhold, 2014).

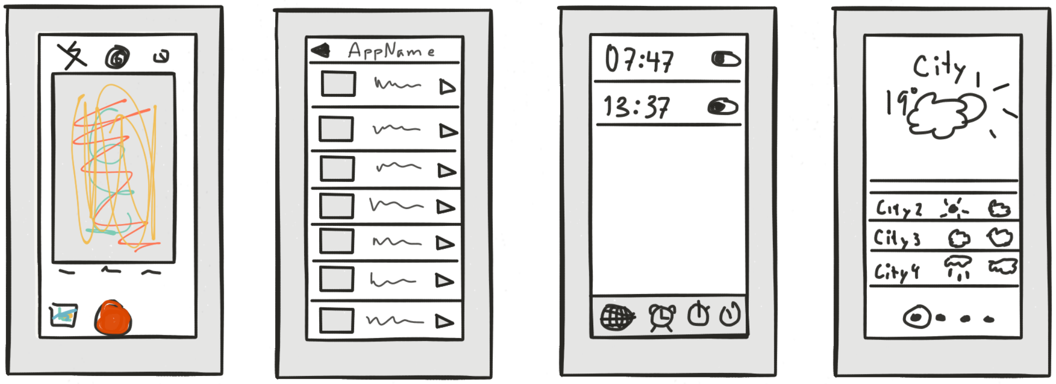


Figure 3.1: Different navigation methods within apps, from the left: a Single View, a Stacked Navigation Bar, a Tab Controller, and a Scroll View.

4

Process and Methods

This chapter gives a description of the process that the project follows. The process consists of five phases that are described as well as the methods used within each phase. The general methodology of the project is first described to give an understanding of what can be expected. Every phase is then given a section to describe the goal of the phase and the specific methods used to accomplish it. Every phase has more detailed requirements and design specifications until reaching the final phase, final design. At this stage, the final design should be presented, explained and evaluated.

4.1 Procedure

The process the project follows is based on Bligård's ACD^3 methodology described in ACD^3 - the Development Process from a Human-Machine Perspective (Bligård, 2015). It consists of five phases where the first four of them are the development phases that should go through an iteration with the following activities:

- Planning what the goal for the phase is, who should be involved, and what methods to use
- Collecting data, usually by applying the methods chosen for the phase
- Analyzing the collected data, also by applying
- Generating ideas based on the results
- Evaluating the ideas and results continuously

This is done in order to reach a better understanding of the problems and solutions. The activities are both done by using different methods but also by summarizing the results, for instance by listing the elicited needs from each development phase. The process is depicted in figure 4.1 where it can also be seen that the level of detail narrows down in each phase. This is due to more information becoming available through the activities done in the phases. Going through these activities also leads to a better understanding of the design aspects and needs for the Product.

As a help to set a scope for every phase there are certain questions to answer in all of these phases; what is the problem, how should the structure be, what functions are important, how can the functions be realized and what requirements should be set. For each phase these questions become more detailed. In the first phase (Needs mapping) they are focused on a system level, in the second (User design) on user tasks, in the third (Technical design) on the architecture of the product, and in the fourth phase (Detailed design) they are looking at how different components interact on a detailed level. In the last phase (Final design) a specification of the final user interface is presented in detail. At this stage the design cannot be changed but it is however evaluated.

A more detailed description of the contents in the phases, as well as which methods have been used and how they have been applied, can be found in the forthcoming sections. A short theoretic description of the methods is also given.

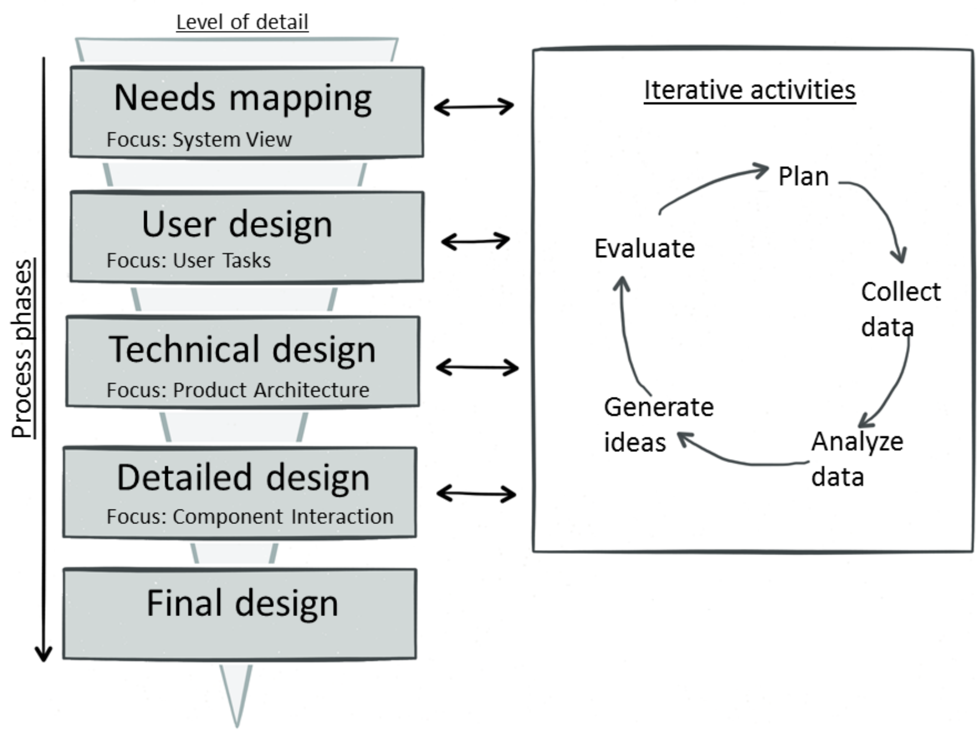


Figure 4.1: A graphic representation of the project's process with five phases.

4.2 Needs Mapping

The main goal of this first phase is to understand:

- Who the user is,
- What the user's needs are in large, and
- In which context the AGV (including the MCD and the Operator Terminal) is used.

Since the Company sells their products through partners it is also important to understand their needs. Altogether this should lead to an understanding of the main challenges using the vehicle and how both the vehicle affects its usage environment and how the usage environment affects it back.

The methods that are used for collecting and analyzing data in this phase are hereafter presented including how they have been applied.

4.2.1 Interviews

Interviews are a common method to elicit customer needs from a user and are usually done in the user's environment (Ulrich and Eppinger, 2012). The interviews can be unstructured, semi-structured or structured. In an unstructured interview questions are not prepared in advance, instead there is a discussion around a certain topic and questions that arise are posed. A structured interview is instead prepared with specific questions and an outlined order for the questions. This is a good method when it is important to get quantitative data while the unstructured is better for eliciting qualitative data. The semi-structured interview is a compromise between the two mentioned methods where the subjects to discuss are decided in advance but where a strict order or specific formulations are avoided (Bligård, 2015).

Thirteen interviews were conducted in the needs mapping phase, seven of them with users such as operators and other personnel responsible for the AGVs, two with application engineers and the remaining four with different personnel at the Company. The interviews were noted, summarized and analyzed by grouping information in fractions, for instance all future needs in one fraction and all input on the AGVs current functions in another.

4.2.1.1 Users

The seven user interviews were done with professionals from four different industries, see table 4.1 where it is also stated how many AGVs are used in each industry and how they are equipped. Since the Company is international and has partners all over the world, the industries that were chosen were located within two hours from Gothenburg. The interviews were semi-structured with potential questions prepared but with the possibility to adapt them after the interviewee, add new questions or to skip questions that seemed redundant. The interview guide can be seen in appendix A and appendix B (English version).

The main subjects to find out more information about in each interview were:

- What the AGV is used for in the specific industry.
- How the user interacts with the AGV (in general but also specifically with the MCD and the operator terminal) and how often it happens.
- What functions are used today.
- What future changes the user wants.

Table 4.1: Interviews with users.

Name	Profession	Industry	# of AGVs	Type of manual control device	Type of op. terminal
C1	Technician	Printing	1	Tiller handle	OPT100
C2.1	System engineer	Newspaper printing	2	MCD	Other touchscreen
C2.2	Electrician	Newspaper printing	2	MCD	Other touchscreen
C3	Function coordinator	Food production	11	Tiller handle	OPT100
C4.1	Operator	Chemical production	14	MCD	OPT7 and OPT10
C4.2	Operator	Chemical production	14	MCD	OPT7 and OPT10
C4.3	Operator	Chemical production	14	MCD	OPT7 and OPT10

4.2.1.2 Application Engineers

It was important to understand users working in different environments but also to recognize the challenges facing the application engineers during the installation phase and possible maintenance. It was however perceived that the use phase is larger and that it therefore was more critical interviewing a majority of those users. Therefore two application engineers were interviewed, one from the Company and one from a partner company.

The first interview with the application engineer from the Company was unstructured to learn more about the tasks included in the job. The second interview with an application engineer at a partner company was semi-structured but had a set of questions prepared, see appendix C.

Table 4.2: Interviews with application engineers.

Name	Profession	Company
A1	Application engineer	Kollmorgen
A2	Application engineer	Partner Company

4.2.1.3 Company Employees

An additional four interviews were conducted with personnel from within the Company. The interviews were done in an unstructured way mainly to understand the products the Company is selling, to learn more about the market and to gain knowledge about the products that have already been developed by the Company and the ideas that were never turned into products.

Table 4.3: Interviews with other employees at the Company.

Name	**Profession**
P1	Technical Product Manager
P2	Business Productivity Analyst
P3	Hardware and Safety Engineer
P4	Technical Production Manager

4.2.2 Observations

Observations can be done in the user's work environment or in a lab environment to see how a user handles an existing product or perform certain tasks (Ulrich and Eppinger, 2012). It is done to better understand the needs of a user, even those that are not outspoken but that are shown as actions, solutions (home-made tools used to solve a problem) or compensating behaviors (an activity is avoided) (Wallgren, 2015). The observation can be done passively allowing the user to work as normal or can be more participatory where the observer takes part in the work activities (Ulrich and Eppinger, 2012).

Observations of the AGVs in their environment were done in conjunction with the interviews. The interviewees gave a tour of their workplace allowing to experience the context of the AGVs, how other personnel interacts with the AGVs and possible challenges in the environment. The observations were noted and questions were asked about the environment and about the interaction with the AGVs when needed.

4.2.3 Benchmarking

A benchmarking is a competitive assessment used for identifying the competitor's products and their performance (Ulrich and Eppinger, 2012). This can be used as inspiration when generating new or updated product solutions (Beitz et al., 2007). Information about the products is collected with regards to certain information, or metrics, for instance speed, emissions, or bending strengths.

A benchmarking was done looking for other products with an integrated control and information monitoring device for steering an automated vehicle. The criteria that were examined were the functionality of the product, if the product was wireless, if it had a touch interface, its weight, operating temperature and its ingress protection.

4.2.4 User Personas

The main function of user personas is to describe the goals and the commonalities of the potential users of a product (Varma, 2015). By capturing certain specifications about the users, it can be easier to know who to focus on. The personas represent an archetype and are usually described in terms of profile, personality, technology experience, goals for user experience, and brand and product relationship, to name a few. The personas should be based on user research but when time is limited estimations and guesses can be done.

Based on the observations and interviews in the first phase three personas were created to capture the main users.

4.3 User Design

This next phase is focused on the usage of the Product and what functions are needed in a new product in order to reach the objective and to fulfill the user needs elicited through the prior phase. The goal is to gain an understanding for what problems exist with the usage of the Manual Control Device and the Operator Terminal. As a part of this phase, the current MCD and Operator Terminal are explored to gain knowledge about their functionality and usability today.

After this phase is completed, the functions for the intended usage of the Product should be decided as well as the needs concerning the user and the usage.

The methods that will be used for collecting data in this phase are observations, interviews and user studies, and for analyzing data a User-Technical Process is done. The phase is ended by presenting some ideas for principles that can be used for steering a vehicle manually and these principles are also evaluated.

4.3.1 Usability Test

Usability testing is a way of verifying how well the desired usability of a product is met by letting a target audience test it. The main purpose of this test is to find design issues so the product can be improved before it is released (Chisnell, Rubin, and Spool, 2011).Testing a feature instead of taking a decision based on discussions can be time-saving (Nielsen, 1993) and improve profitability, since less time may be spent on future service and support and since a customer that is satisfied with a product is more likely to purchase from the same company (Chisnell, Rubin, and Spool, 2011).

There are different aspects that can be verified through the tests; the usefulness of the product, the learnability, to which grade the product helps the target audience accomplish their goals, and the satisfaction the usage of the product brings (Deaner et al., 2009). The main importance is that the criteria chosen for the test are set before the test starts. The next thing to decide is what method should be used to find the information you are eliciting and then to design the tasks. The tasks should be described in an informative way without affecting the participant. The user study should preferably be held in the environment where the product is normally used, otherwise a lab environment is recommended. Lastly it should be decided if the test should be recorded or not.

It is advised to make preparations so that the participants have a positive experience and that they feel they have been successful in the task they are performing (Deaner et al., 2009). This can be done by for instance preparing the activity so it can be carried out efficiently, by giving helpful information, and by choosing tasks that will be possible for the participants to do.

A user study with nine participants was conducted in the user design phase to test the MCD. The objective was to explore how the users experience the intuitiveness and the usability of the MCD while performing a task, and how well the MCD fulfills the expectations for how an AGV should be steered. The main methods used were interviews and observations. A script was prepared in advance with the order to present information, with questions to pose before and after the task, and with lists of things to observe during the task. The user study had a trial run with a person that would not participate in the real study a few days in advance. This was done to help decide the final questions to ask, how to present information, and to find other hinders in the execution. The final script can be seen in appendix D and appendix E (English version).

The main criterion for the participants was that they should not have used the MCD prior to the study. The age of the participants ranged from 32 to 55 years old with an average of 43 years old. The participants were all working at the Company and the study was held in a test environment at the Company. Each study was done with one participant at a time to ensure that they would not get influenced by each other. The list of the participants can be seen in table 4.4.

Table 4.4: Participants user study.

Name	Work department	Age	Left or right handed
U1	Finance	52	Right
U2	Sales	34	Right
U3	R&D	41	Right
U4	Sales	53	Right
U5	Customer Service	34	Right
U6	R&D	36	Right
U7	Finance	32	Right
U8	Marketing	51	Right
U9	Human Resources	55	Right

4.3.1.1 The Task

The task consisted of asking the participants to drive an AGV along a path marked in the floor using the MCD. The participants were asked to drive forward until reaching two lines perpendicular to the path, see figure 4.2 and 4.3, where they would instead continue driving backwards until reaching a final orthogonal line. Instructions of how to handle the MCD were not given, instead the participants were informed that they were allowed to ask questions but to try their best first. Questions were posed both before and after the task and when all questions were posed, the participants were given the opportunity to do the task one more time. The answers to the questions and the observations made were noted in the script.

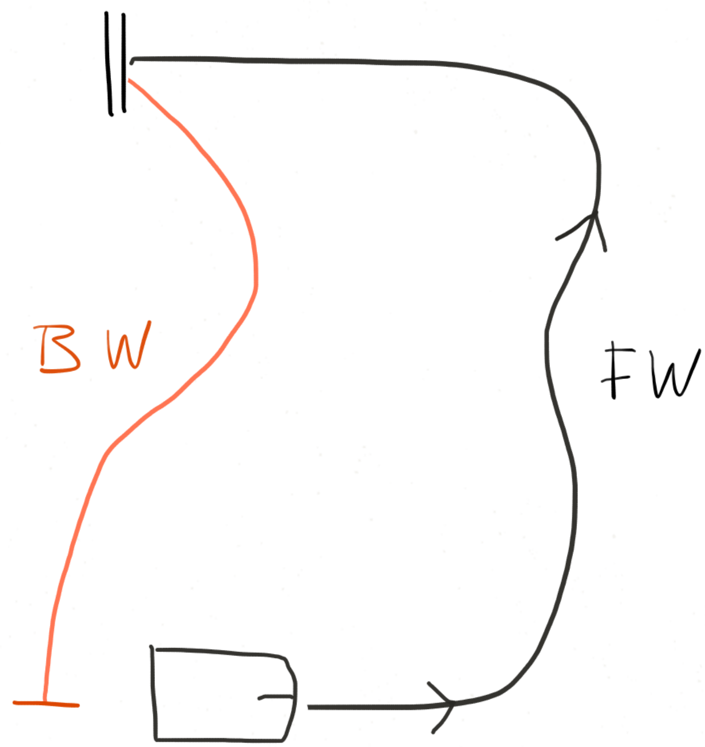
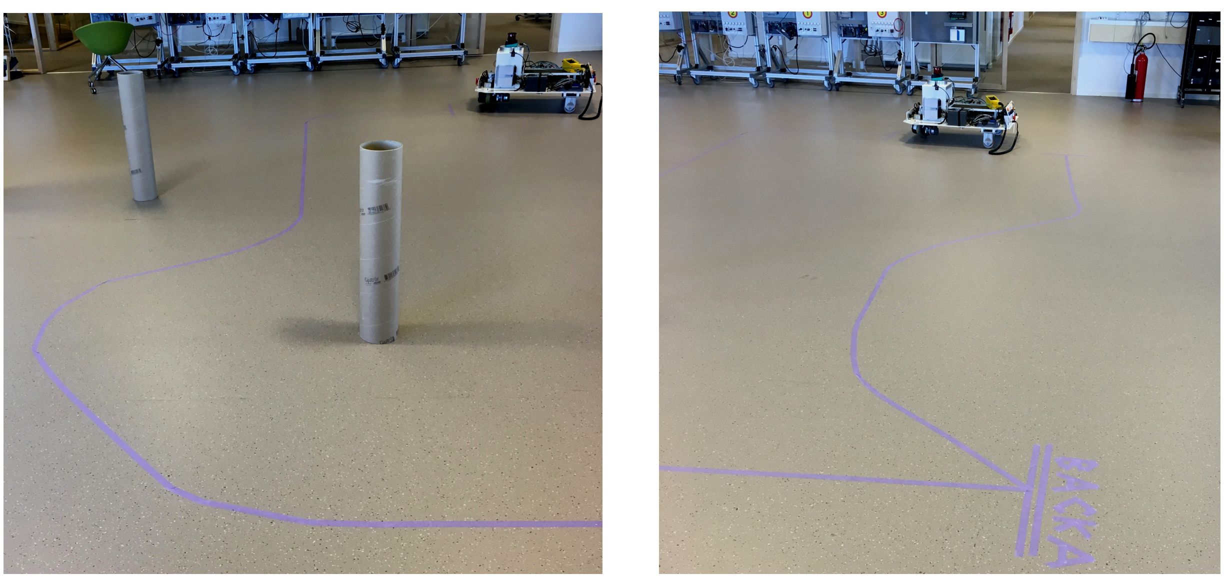


Figure 4.2: The intended driving path in the user study.



(a) The first half of the driving path in the user study.

(b) The second half of the driving path in the user study.

Figure 4.3: Driving path according to floor markings.

4.3.1.2 Observations

The script for the user study included two lists with possible observations. The first list was an assessment of how fast the participants understood certain functions of the MCD, like using the potentiometer to turn, see table 4.5. Based on their behavior, they were rated between one and three where one corresponded to them understanding directly and three that they understood after a while. The assessment was done based on how long time it took before it was perceived that the participant had understood each function. Those that were given a hint were marked in the second list and automatically earned a four. An average was taken based on the values given from the performance to be able to see if participants that viewed themselves as more technical also could understand a technical product that they had not used before, in this case the MCD, better. The list also served as a reminder of what to look for in the participant's behavior. Other observations were also noted in the script.

Table 4.5: Observations during task.

Observations \Value given to performance	**1**	**2**	**3**	**4**
How to turn using the potentiometer driving FW	Directly	Quite soon	Eventually	Hint was given
How to choose FW/BW drive	Directly	Quite soon	Eventually	Hint was given
How to choose speed (that there are two modes)	Directly	Quite soon	Eventually	Hint was given
How to turn driving BW	Directly	Quite soon	Eventually	Hint was given

4.3.1.3 Interviews

One interview session was held before the task and another after the task. In the first session some basic questions about the participant were posed, such as age, profession and if the participant was left or right handed. This was done to see if there was a pattern with the way the participants handled the MCD and their handedness.

Some additional questions were asked to distinguish if the participant was used to technology and whether or not he or she felt comfortable using new technology, see table 4.6. The answers were given a rating between one and three, one if the participant felt that the technology was easy to handle and three if it was hard. A question about how the participant would do to learn how to use a completely new technical item was posed; would they want to test it, read a manual or ask for help. It was perceived that someone who felt comfortable with testing a technical item without reading a manual or asking a question would score a value of one and the person asking for help would score three points. An average was taken of the values of the answers to establish the participant's technical profile. The lower values would indicate a more technical profile. The last question posed before performing the task was how the participant would like to steer an AGV if they would think freely. This question was posed before the task to prevent the participants from getting influenced by the steering done with the MCD but to get ideas for alternate solutions.

Table 4.6: Questions asked to determine technical profile.

Questions to ask \Value given to answer	**1**	**2**	**3**
If you purchase a new technical item, i.e. a new dishwasher or food processor, which of the following options coincide best with how you learn to use your new product?	Test it	Read manual	Ask for help
When you get in contact with a technical gadget you haven't used before, i.e. a new phone, how comfortable do you feel using it? (Rate between 1 and 3)	Comfortable	In between	Uncomfortable
If you have the habit of using a smartphone or a tablet, is it easy/hard to use a new one? (Rate between 1 and 3)	Easy	Average	Hard
If you have the habit of using a gaming control, is it easy/hard to use a new one? (Rate between 1 and 3)	Easy	Average	Hard

The interview session after the task was focused on the participant's experience from the task; what parts of using the MCD was easy or difficult, did the MCD function as expected and how was the MCD designed ergonomically. Questions were asked about the same observations that were made during the task (see table 4.5) and the participants were asked to rate how easy or difficult these functions were. If they felt it was easy to turn while driving forward this would correspond to a value of one and if they felt it was difficult they would obtain a value of three. An average was also taken of these values to be able to compare the values of the three rated categories: the participant's technical profile, the observed performance and the self-assessed performance. The comparison would help in seeing if there is a relationship between a technical profile and an observed performance and if the participants have a realistic view of their performance. If those with a strong technical profile would have problems performing the task but consider that it was not difficult this could indicate that they just need to repeat the task a few times but if they also felt that it was difficult then there could be room for improvement.

4.3.2 User-Technical Process

The User-Technical Process (UTP) is used for illustrating how tasks are done when using a product (Janhager, 2005). It consists of pinpointing the tasks related to a user process and a technical process along a time line. The user process constitutes of mental activities and user actions, and the technical process of interface functions and technical functions. The method can be used to represent the interaction between the user and the product, or the human and the machine. It shows visually how many different tasks are needed to use a product which can help the development of a new product that should be easier to use and that should include fewer user tasks and technical tasks.

A UTP was done to analyze how users handle the MCD for driving a vehicle first forward and then backward. The data used for this was the observations in the user study.

4.3.3 Customer Feedback

Customer feedback from six partners was collected by the Company regarding the Operator Terminal. The data was collected between 2014 and 2015 and was considered to be recent enough seeing that there has not been any new releases of an Operator Terminal since before 2014.

The partners rated how important a list of functions were between one and five and gave comments if they had any. This material was analyzed by looking at each function and taking the average value of the ratings. The functions were divided in three categories; context, screen, and miscellaneous.

The questions regarding the context where the Operator Terminal is used concerned if the Operator Terminal needs to be able to support temperatures lower than minus ten degrees Celsius or higher than 55 degrees Celsius, if it needs to handle dynamic temperature changes like going from a cold to a warm environment, and if it needs to support standards like the IP65 and the UL 583. The IP65 standard declares that the product should be sealed from dust and that it should be possible to pour 12,5 liter of water per minute over it without damaging it (Security, 2016). The UL583-listing consists of requirements for how a product should handle the risk of fire, electric shocks, and explosions (Globalspec., 2016).

The customer feedback regarding the screen was focused on screen qualities like if it should enable touch and if it should support colors, and screen size.

The miscellaneous features that were rated were amongst others if it should be programmable and configurable.

4.3.4 Brainstorming

Brainstorming is a method used by groups for generating numerous ideas. It is advised to use a mix of group members with different competences and experiences to get a broad range of ideas and to be between five and fifteen group members with a leader of the group that can structure the session and make sure that all ideas are allowed without criticism (Beitz et al., 2007). The ideas are noted, sketched or recorded in some way.

Brainstorming was used in several phases of the process but with different levels of detail. In the user design phase the method was used to generate ideas at a system level where it was not yet decided what subsystems would exist. Since the project group consists of one member, an actual brainstorming was hard to accomplish. Instead the basic idea of generating ideas was used but not in a group. All ideas that came up during the development were noted or sketched and opportunities to elicit ideas from others were taken. The user study was used as one of these opportunities where the participants were asked for ideas how to steer an AGV.

4.3.5 Evaluation

At the end of the user design phase, an evaluation session with representatives from different departments within the Company was held. The goal with the session was to have a discussion about the findings and about the principles that the product could use for steering an AGV manually which could lead to more knowledge about the system and which could also help narrowing down the scope.

The information gathered in the first two phases was summarized and presented and four different concept principles including a summary of their strengths and weaknesses were given. The evaluation session resulted in a decision about what principle to continue developing in the future phases by noting everything that was said and analyzing it to see common denominators. The needs that were elicited through the needs mapping and the user design phases were also taken into account for the final decision.

4.4 Technical Design

In this part of the project focus is set on the technical architecture of the Product. The technical solutions needed for the Product to function in a satisfactory way according to previous elicited needs should be investigated from a system view and with focus set on the different components in the system. It will therefore be investigated which requirements are important for the different parts in a mobile device; the display, the sensors, and the communication. Some mobile devices are also benchmarked to look at which device could be used for the future product.

In the other half of this phase technical software solutions were considered to make sure that it is possible to steer a vehicle manually and view information and diagnostics about it through an app. To understand what control methods are used in application based games for steering vehicles and fictive characters different games were benchmarked. Finally some functional app prototypes were programmed and tested.

4.4.1 Benchmarking

A benchmarking of different application-based games was done to investigate the possible technical methods that exist in apps and how they are used and also for rating how well they correspond to the expectations that are set for an app used for steering AGVs.

The games that were chosen for the benchmark had in common that a vehicle or a person was in some way steered through the game. Every game was categorized and the manner of steering was explained as well as the technology that is used. The games either had a first person perspective where the view for instance was from within the vehicle being steered or in a third person perspective where you could see the vehicle being steered from the outside. None of the games steered a second product like a toy car which meant that the screen of the tablet was used both for the means of steering and for looking at the object being steered.

After testing every game several times they were evaluated according to:

- How good driving experience they produced
- If there was any feedback given
- The level of precision
- The level of control that could be produced

4.4.2 Prototyping

A prototype can be either physical where a tangible object similar to the real product is created, or analytical where simulations and models are used for visualizing the intended product (Ulrich and Eppinger, 2012). A prototype can also be comprehensive or focused, where the comprehensive prototype includes the entire system while the focused only tests one attribute. One of the main reasons for using a prototype is to learn if a product will work as intended and if it will satisfy the customer needs. Other reasons for prototyping is to be able to communicate to for instance company management and partners how the final product will be, to ensure that the product can be integrated in the bigger system, and as milestones to show how far the development has reached.

Physical prototypes in the shape of mobile apps were created to demonstrate that certain attributes worked as intended and that they functioned together with a real vehicle. The attributes that were tested were if it was possible to steer a vehicle with the help of an app and if information could be collected from a vehicle and displayed on a tablet.

4.5 Detailed Design

The following phase is focused on both the interaction between the different parts of the Product and the interaction between the Product and its usage environment. The goal is to design a good interaction between the interface and the user and to choose which principles that should be used in the final design.

To better develop the interaction between the Product and its environment, it is included to look at the human-machine interaction, in this case how to form the interface. This is done by doing a usability test letting several participants try three different app based steering methods and then by evaluating the drive view and the start view.

4.5.1 Usability Test

Just like in the user design phase a usability test was done in this phase but this time to test and evaluate the prototypes of apps that steer an AGV. Focus was set on testing the technical principles rather than the graphical user interface. The three apps that were tested were an app using a fictive joystick, another using the built-in gyroscope for steering and a seek bar for giving speed and a third that used two seek bars both for steering and giving speed.

Seven of the participants from the first usability test participated and the task was similar to the previous one, to drive the vehicle along a path testing to steer and drive forward and then backward. A sketch of the path can be found in figure 4.4. There was no need to ask questions about the participants' user profiles, instead the user task was described directly and then the first app was tested. During the task, it was noted how fast the participant understood how to steer, drive forward or backward, choose speed and steer while driving backward, just like in table 4.5. After testing each app a few questions were posed to determine what the participant thought was difficult with the app, what was good, if the steering could be done in a satisfactory way and if the levels of safety and precision could be obtained, see all questions in the script in appendix F and G (English version). Finally, the participant was asked to give ideas for improvement. When all apps were tested, some concluding questions about the apps were posed to determine which steering alternative the participants preferred out of the three and which one was best suited for steering with precision and for steering a longer distance without precision. The participants were also asked if they would have wanted to steer the vehicle in some other way and how they liked using a tablet for steering.

The performances of the participants were noted and the time it took to drive along the path was recorded. The usability test resulted in deciding which steering method represented through an app to further develop.

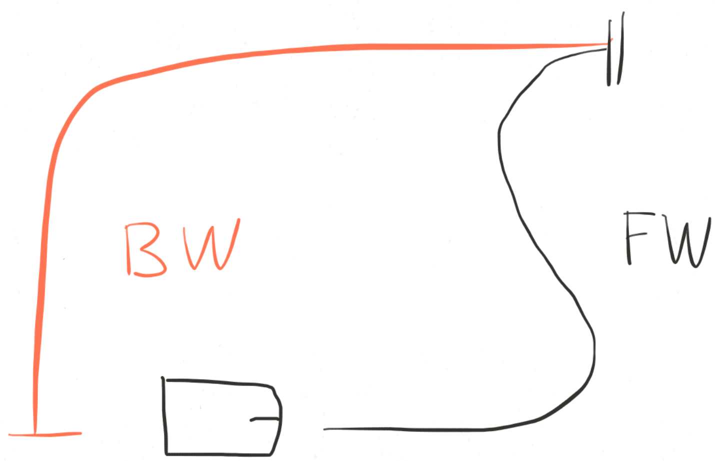


Figure 4.4: The intended driving path in the second usability test.

4.5.2 Evaluation - Drive view

After testing three apps with different techniques for steering an AGV manually and choosing one of the techniques the remaining app was tested again but this time by experienced users. Three application engineers were given the task to drive zigzag around cones that were placed in a line with approximately two meters in between. The task in itself was not important, it was more important letting the participants experience the steering. Just like during the user studies, the participants were observed and it was noted how soon they understood the tasks according to table 4.5. Several questions were then posed (for the full script, see appendix H):

- If there were functions in the app that were difficult to handle,
- If there are situations in a real usage environment where it will be more difficult to use the app than the MCD,
- If the steering could be done safely and with precision, and
- What kind of information you want about the vehicle while you are driving.

After this, several questions related to the Operator Terminal's functions were posed to understand what functions that are normally used and what information that is important for the application engineers to be able to view quickly.

4.5.3 Evaluation - Start View

Four different start views with different layouts and different methods for navigating to the next view were evaluated with the help of four participants, see table 4.7. The participants were asked to look at each start view and describe how they thought they would do to navigate to another view and then return to the start view. They were also asked which layout they thought was easiest to understand, which one they thought matched the Company's profile the best and which one they personally preferred. The full script can be seen in appendix I. The evaluation was done to get a better understanding of suitable navigation methods within an app and to find an intuitive layout that also matches the Company's profile.

Table 4.7: Participants in the evaluation of user interface.

Name	Profession
M1	Test Engineer
M2	Product Marketing Manager
M3	SW Engineer (former Application Engineer)
M4	UX Specialist

4.6 Final Design

In the methodology described by Bligård, this last phase should include a detailed specification that can lead to a decision concerning manufacturing. The aim of this project is however to create a user interface why this last phase focuses on the design of the app and which hardware should be used.

The final design will be evaluated by doing a new User-Technical Profile and by looking at the different needs stated in the earlier phases and see if the needs have been met.

5

Needs Mapping

When developing a new product it is important to have a broad understanding of the environment where it will be used, partly because it will affect its environment and partly because the environment also will affect it back and put some constraints on it. This could be physical constraints like the air being dusty but it could also be related to how the product should be able to function in a larger system. Another important aspect in a development project is understanding who the users are and what needs they have. Understanding their needs could both be done by recognizing how they use their current products, the MCD and the Operator Terminal, but also by eliciting what they would like to be able to do with a future product.

The needs have been obtained by interviewing and observing several kinds of users in their working environment. The first part of the chapter will be dedicated to presenting the results from the interviews and the observations. The results from a benchmarking of competitor's products will also be presented to understand the market and what other similar products exist. The chapter ends by describing three personas with the characteristics of potential customers, and with a list of customer needs elicited in the phase. The methods used in this chapter are described in section 4.2.

5.1 Use Situation

In the following section, the results from the interviews and observations are presented. They serve as a way to define the different kinds of users and stakeholders, how the AGVs including the MCDs and Operator Terminals are used, what the context of the AGV is like, and see what functions the users want in the future and what functions they use today.

5.1.1 Usage

During the interviews and observations four different industries were visited. In all four of them the AGVs were used for transporting goods from a production-related space to a warehouse, and from a warehouse to a shipping area. The goods were placed in racks, on the ground creating stacks, or in an area adjacent to a racking system for manual transports to the racks. In three of the four industries the goods were placed on pallets when transported.

Most of the interviewees claimed to have little interaction with the AGVs due to them usually functioning as intended and thus managing their tasks automatically. The most common interaction was when there was an error, such as a blocked sensor or that the forks had gotten stuck in a pallet. There errors could require an action such as removing an item blocking a sensor or manually driving back the AGV to its path, or simply to press a reset button.

In one of the industries, the vehicles used batteries that were recharged when removed from the vehicle. When the batteries needed to be recharged, the AGV would park in a certain space and an operator would then drive it manually to a battery room where the battery was changed to a charged one and the AGV would then manually be taken back to its path.

In the other industries, the AGVs automatically drive to a battery charging station when the battery reaches a certain level. Manual interaction would only be needed if an AGV for some reason does not recharge its battery.

The fourth industry stated that they used the Operator Terminal a lot for viewing what kind of order an AGV was handling when it got an error. If the AGV for instance had a pallet on its forks, it was important to know if it was fetching or leaving the pallet to be able to help it finish the order.

The most common error was declared to be related to sensors, either that one of the safety sensors was blocked or that a load sensor claimed to be loaded when it was not and vice versa. The errors are shown on the Operator Terminal and on the CWay software.

The frequency of interacting with an AGV, either with the MCD or the Operator Terminal, varied between once a month to 30 times a day, depending on how many AGVs were used. At the printing industry where only one AGV was used in that industry, all interaction was scarce while at the chemical production where fourteen AGVs were used it was more frequent.

5.1.2 Context

The two first industries visited were both working with printing, one printing wallpapers and the other printing newspapers. Neither of these industries demanded any special temperatures but were however dusty, which one of the interviewees pointed out as a problem because they needed to clean the sensors quite often. In both of these industries there were many different machines used for the printing process and the users were responsible for surveying and fixing many different machines. One of the interviewees felt that this was problematic since it is hard to remember the specific error codes and the specific details of use for every machine. Another interviewee from the fourth industry could also testify to the fact that it is difficult remembering specifics about the AGVs since the workplace used shifts which meant that every operator would be responsible for the AGV every eighth week in average.

The third industry handling food production had a temperature between 4 and 6 degrees Celsius but was otherwise very dust-free. A challenge when working with food can be if packages break and liquid spreads on the equipment.

The fourth industry had AGVs in an uninsulated warehouse where the temperature and humidity reportedly were similar to outside. One of the interviewees claimed this to be a problem and meant that this required robust machines and products. At this workplace they had another machine that used an Operator Terminal with touch screen that reportedly was difficult to use since you would need to push very hard to get a reaction.

In both the third and fourth industry the pallets were automatically placed in certain slots on the floor and piled on one another. The slots were placed creating a grid where every slot had a specific code matching the coordinates of its location. It was very important that every pallet was placed on the exact right location, otherwise the piles could become unstable if one of the pallets was placed too much sideways. Another consequence of a pallet being shifted, which could happen if a vehicle had lost its calibration due to reflectors missing or the floor being bumpy, is that another automated forklift could assume that a pallet was placed on the correct location and that its forks could jam into the pallet and create an error. An operator would then need to manually pick up the pallet. The passages were sometimes narrow demanding precision and decreasing the velocity of the AGV.

AGVs can be used in any kind of industry where there is a need to transport goods. There are therefore many different environments the AGV needs to be able to handle and those environments that were visited and described in this chapter show some of the challenges an AGV with its equipment needs to be able to handle.

5.1.3 Users and Stakeholders

Primary user The customers that interact with the AGVs in their working environment, such as operators, maintenance and service technicians, and system engineers. As can be seen in section 1.3, they are the customers of the partners but will generally be referred to as the customers of the Company.

Secondary user Application engineers both from the Company and the partner companies that help with the installation of systems and technical support. The application engineers from the Company also act as technical coordinators to teach the partner company's application engineers how to install products.

Stakeholders

- The Company.
- The partners of the Company.
- Hardware manufacturers producing hardware after the Company's instructions.
- Personnel handling storage of hardware.

When referring to the *users* from now on, it is the primary users that are intended. The application engineers are in one way also users since they need to use both the MCD and the operator terminal when installing a system, but as they are secondary users they are not included in this defintion.

In the first industry the users consisted of five technicians responsible for all machines including the AGV.

In the second industry the users responsible for managing the AGVs had previously been all the operators in each work shift. This was however changed recently to only include the electricians as those who managed the AGVs.

In the third industry all operators managed the AGVs. They had tried having one person responsible for the AGVs per shift but saw that it did not work. Therefore everybody should be available for managing the AGVs if there is a problem.

In the fourth industry there was one to two persons responsible for the AGVs per shift. Every shift team would work in the warehouse where the AGVs are used for one week every six to eight weeks. They also had a technician that worked full time with maintenance of the AGVs. The technician did however not fix the normal errors that occur on a daily basis (like a sensor being blocked).

5.1.4 Functions

The interviewees were both inquired about their opinions about the current functions of the AGV but also about future improvements, especially for the MCD and the Operator Terminal.

5.1.4.1 Current Functions

As mentioned in section 5.1.2, some of the users work in shifts and have the responsibility for many different machines which means that they can not remember all functions. One of the interviewees expressed the sentiment that the function of the LED lamps on the MCD interface was mysterious and that both they and the error codes on the Operator Terminal demanded the use of a manual to understand their meaning. The interviewee also felt that there were too many controls and that it was difficult to know what button to push. Another interviewee felt that the MCD was good for steering but that it could be hard to understand the position of the steering wheel. It would have been appreciated to get some kind of feedback of this.

Not all industries that use the MCDs have one unit for every vehicle which means that an MCD first has to be located before being able to steer the vehicle.

One of the interviewees expressed that the Operator Terminal was located in a place where the operators stand in the way of a sensor to reach it, causing errors to trigger.

5.1.4.2 Future Functions

Error codes and messages are both shown on the Operator Terminal and in CWay today. The error codes shown on the Operator Terminal were however considered to be too brief according to six of the seven interviewees and many of them asked for more detailed error messages that would also use animations to specify where the error was located. This would be especially helpful for errors related to the sensors where it could be difficult to distinguish what part of the AGV is the front and what part is the back, respectively right and left. Instead of having to clean every sensor, it would be clear which one of all sensors that was affected.

A function that was required from several interviewees was a touch screen that supported graphical animations. One of the industries already used Operator Terminals with a touch screen. They however had approximately the same contents as in the OPT100 but with a more graphical representation. The graphical contents that was mostly requested was animations showing where on the AGV an error is located, and having the possibility to view CWay somewhere other than on a desktop or a laptap. The three interviewees that wanted to be able to see CWay preferred if it was shown on a wireless unit, both a tablet and a smartphone would be possible solutions that they could use for viewing CWay. One of them explained that since the warehouse was big and CWay only was accessible from a desktop in a control room in one corner of the warehouse, an AGV with an error could easily be missed if the interviewee was out fixing another AGV and it would thus take longer time before discovering the error.

When asked if the interviewees would like to have a camera attached to the AGV to see its view, most felt that this would be an unnecessary feature but that it could however be helpful to see the sensors' views. One of the interviewees claimed that it would be useful to be able to see the AGV from a distance, like if there was a camera a few meters from the AGV pointing at it. This could be used if there was an error. The interviewee stated that nowadays if something had happened to the AGV that needed fixing, he would take a photo with his smartphone and send it to support.

One of the users felt that the MCD was not self explanatory and that if you are not used to handling it, there is a need to learn it. The response to the question what the interviewee would prefer using was *"It does not matter what you use for steering, as long as one can understand how it works"*.

5.2 Existing Products

A benchmarking was done looking at the control units that competitors use for their AGVs for steering manually and viewing information. As can be seen in table 5.1 most of the competitors' products have touch interfaces but are not wireless. Most devices do not handle negative temperatures but do however have IP65 ingress protection rating.

Two of the models (Adept T2 and Mobile Panel 277 IWLAN) weigh over a kilogram and although none of the models are depicted, many of their dimensions are quite big and bulky.

Other products corresponding to the Operator Terminal were also found but since this product development project is an integrated product, these results did not seem relevant.

Table 5.1: Benchmark for manual control devices with displays integrated.

Product name	**KeTop T10 direct Move & KeTop T20 eco / techno**	**Adept Lynx Touchscreen**	**Adept T2 & Adept T20 Pendant**	**Mobile Panel 277 IWLAN**
Company name	KEBA	Omron Adept Technologies	Omron Adept Technologies	Siemens
Type of product	Handheld terminal	Operator interface	Manual Control Pendant	Operator device
Functio-nality	Can drive and maneuver a robot	Display allowing vehicle control and presenting information and diagnostics	Pendant allowing information retrieval and manual vehicle control	Mobile panel for HMI tasks
Size [mm]	190 x 60 x 50 & 226 x 162 x 55	N/A	Round shape $\oslash$ 252mm, 114 mm depth (T2) & 224 x 162 x 45 (T20)	Round shape $\oslash$ 290mm, 109 mm depth
Wireless?	No	No	No	Yes
Touch interface?	No (T10) & Yes (T20)	Yes	Yes	Yes
Weight	0,25 kg (w/o cable) & 0,48/0,52 kg	N/A	1,25 kg & 0,48 kg	1,7 kg
Operating temp-erature	0 - 45° C	0 - 60° C	0-50° C & 0 - 45° C	0 - 40° C
Ingress protection	IP54 & IP65	N/A	IP65	IP65
Website	www.keba.com/en/industrial-automation/products/hmi/mobile/mobile	www.adept.com/products/mobile-robots/mobile-options/touchscreen/general	www.adept.com/products/controls	w3.siemens.com/mcms/human-machine-interface/en/operator-devices/advanced-hmi-panel-based/mobile-panels/Pages/Default.aspx?tabcardname=wireless

5.3 User Personas

To understand better who the potential customers of the product are, three fictive users were created. They represent the needs and the characteristics that real users might have when they are in contact with AGVs.

Figure 5.1: User Persona: Application Engineer. Picture source: https://pbs.twimg.com /profile_images/499262162544893952/YN62ugj4.jpeg

The first persona is Fabian who works as an application engineer at the Company. His main work is to help partner companies understand the AGV system and to help with support cases that the partners cannot solve themselves. The support cases usually require Fabian to travel abroad and he is getting more and more tired of being away from his family.

Fabian is rather technical and can usually solve all problems that come in his way. He is however getting tired of it taking long time and he would like to spend some time working on solutions that can make his work more effective, see figure 5.1.

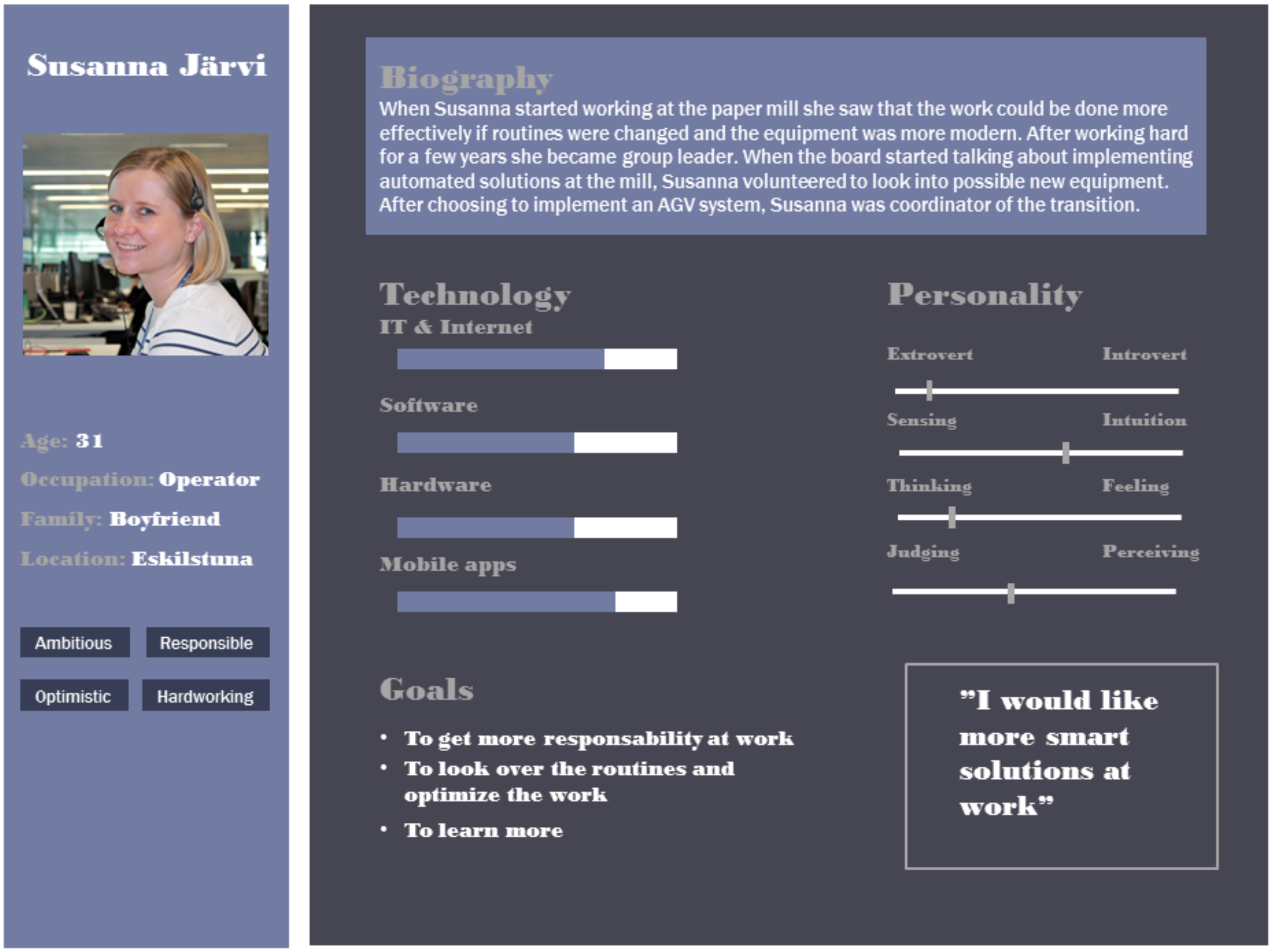


Figure 5.2: User Persona: Younger Operator. Picture source: $https://www.internationalsos.com/\sim/media/corporate/files/images/sarah-kong-user-story.jpg?h=573la=enw=650$

Susanna started at the paper mill in Eskilstuna shortly after finishing high-school, see figure 5.2. She is hardworking and ambitious and was given group responsibility after working for a few years. Susanna likes to see how changes can be made to be able to work better and was happy to be part of a group that would give proposals for how the mill could be improved by adding modern technology. The group came to the conclusion that AGVs could be used for transporting material and products and the board agreed that this would be a good change. Susanna hopes for more changes and embraces newer technology although some of her co-workers sometimes complain a bit too much.

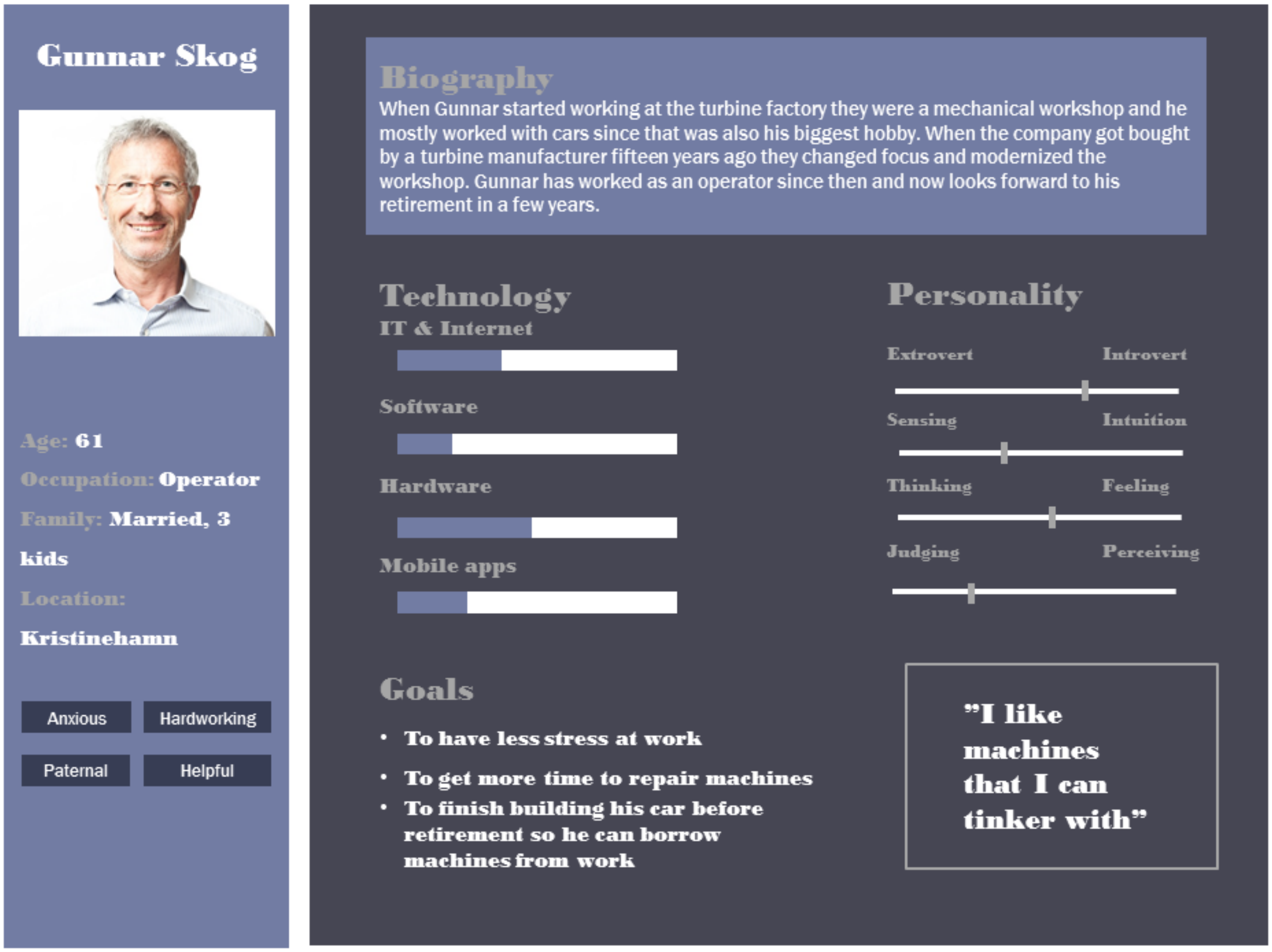


Figure 5.3: User Persona: Older Operator. Picture source: http://static1.squarespace.com/static/55bf9760e4b049c06ab7b906/55e60fefe4b06e44ad234378/55e719b9e4b0139f372bf857/1441209022134/descarga+(1).jpg

Gunnar is an old mechanic who has worked at the same company during his whole adult life, see figure 5.3. At first the company was a workshop where he repaired mostly car motors but the workshop was bought by a turbine manufacturer and new focus was set on building turbines. Gunnar has been an operator for ten years supervising the machines and sometimes repairing a machine but he misses tinkering with motors. A few years ago, an AGV system was installed at work to help in the production chain. Gunnar is rather reluctant to take care of the AGVs when they have errors which according to him happens too often.

The three personas represent different kinds of users. Gunnar and Susanna are both primary users but with different approaches to technology. Susanna wants to lead the development to a more technologic work environment while Gunnar is having a hard time keeping up with the technology and needs to have time to learn the latest machine before the next one arrives. He needs the machine interfaces to be easy to understand and easy to use. Fabian is a secondary user of the AGVs. When he installs an AGV system or helps a customer with a problem he usually uses the MCD and the Operator Terminal for a longer period of time than a primary user and he needs to be able to use the machine interface in a quick and effective way.

5.4 Concept Ideas

Ideas for functions and abilities in the product came up during the phase. The ideas are brought into the coming phases and evaluated further on.

- Making the product wireless would remove problems related to where the Operator Terminal or the MCD are located today, for instance accidently blocking a sensor when reaching for the Operator Terminal.
- Being able to take photos with the product and adding text to be able to fully describe a problem and send to support or maintenance, see figure 5.4 for example.

Figure 5.4: Concept idea: Ability to make service request.

- Being able to view manuals in the product, both for the AGV and its related hardware and software but also for other machines in the facility. Bringing them in a wireless format could save time and give better accessability to information.
- Showing an animation of the AGV as front screen of the interface and adding a sign next to the parts where an error is located that can be clicked on to get more information about the error, see figure 5.5. Each error should be thoroughly described and instructions on how to fix the problem should be given.

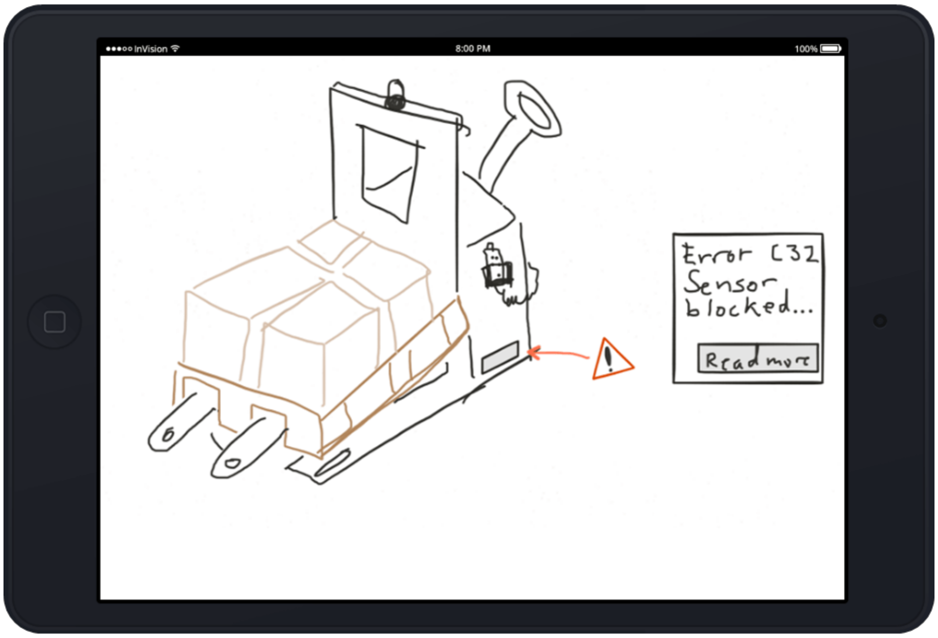


Figure 5.5: Concept idea: Graphical representation of errors.

- Create one product that can manage all AGVs in a fleet. Which AGV to manage could be chosen from a layout view showing all AGVs and their status by pressing the one you want to choose, or by getting the option to manage the AGV you are situated closest to. Safety measures would need to be taken to not make it too easy to take over the control of an AGV. Being able to access the information that can nowadays be seen on the Operator Terminal would not need the same safety measures.

5.5 List of Needs

The first set of needs that were elicited in this first phase are listed below. They mainly concern how the product is used, in what environment it should be able to be used and what functions it should have.

Usage

- Be easy to use seldom or often
- Should not require remembering specific information

Context

- Should handle dust
- Function in different temperatures

- Should handle water and humidity
- Should keep a low weight

Functions

- Make information about all the AGVs in a fleet accessible remotely
- Make sure that the product is compatible with all other hardware and software to make sure that it is always working without any hindrance
- Be able to steer a vehicle manually in an intuitive way
- Easily access detailed error information

6

User Design

In this chapter the focus is set on how the MCD and the Operator Terminal are used today and what expectations exist for a new product. For the MCD some of this information was already elicited during the first phase but it was however not investigated how new users perceive the control and how they understand its functions. To find out more about this, a user study with nine participants that had not operated the MCD before was done. Customer feedback on how six partner companies appreciate the Operator Terminal and what wishes and demands they have for it in the future was also collected. The chapter ends with several concept principles for a future product with the MCD and the Operator Terminal integrated into one unit. The methods used in the chapter can be found in section 4.3.

6.1 The Manual Control Device

In the user study nine participants that had not used the MCD before were given a task to drive a vehicle around a path using the MCD. The participants' performances were observed and questions were asked both before and after the task to find out more about the participants' backgrounds and to gain knowledge about their experiences during the task. When all questions were posed the participants were given the opportunity to do the task one more time. All but one of the participants took this opportunity.

The questions that were posed before the task were used to gather a technical profile between one and three of the participants where one would indicate that the participant perceived themself as good at handling new technical items and three that they felt uncertain in contact with new technical items. The participants were also observed during the task and the success of performing certain parts of the tasks was rated and given an average observed performance value. The participants were asked about their opinion about the same parts and asked to rate how easy or difficult they experienced these parts to be to gather a self-assessed performance value. The average values for these three categories for each participant can be seen in figure 6.1. The y-axis represents the nine participants that can be found in table 4.4 and the x-axis their average values. Having an average of one in all three categories indicates that the participant perceives himself or herself as being technically skilled and that their results from the user study also suggests this.

In many cases the observed performance was worse than how the participants estimated their performance and worse than their technical profile would indicate. This could mean that the MCD is more difficult to use than it should be but that practising a few times would give a better result.

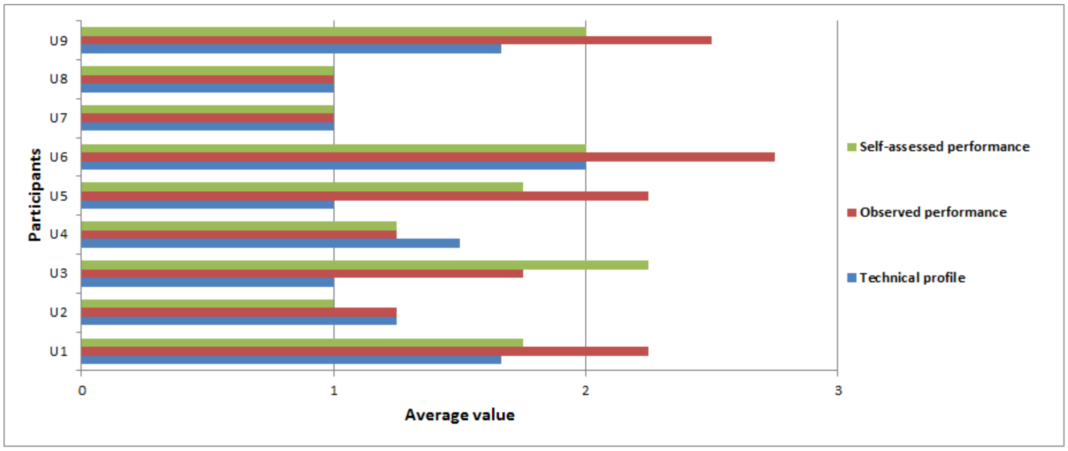


Figure 6.1: A comparison of the participant's technical profile compared to their observed and self-assessed performance.

To understand the interaction between the participant and the MCD, a User-Technical Process was done for the performed task, see figure 6.2.

The first interaction with the MCD was the mental activity of looking at the interface to understand the controls. Then manual driving must be set in order to be able to steer the AGV. This is both a user action, the decision to switch to manual driving, but also a technical function that needs to be set in the machine. When the yellow LED is enabled there is communication between the MCD and the vehicle which indicates that manual mode is set. The light will be active during the remaining sequence and this is the only interface function in the process. To drive forward, the direction selector is set to forward and the speed selector is either set to the faster or the slower speed. To steer the potentiometer needs to be turned. The same procedure is done for driving backward but the direction selector is set to backward.

The process showed that there are quite many actions to take for the user and quite many cognitive processes involved for the simple task of driving a vehicle forward along a path and then backward. The interface can be made simple to include fewer processes.

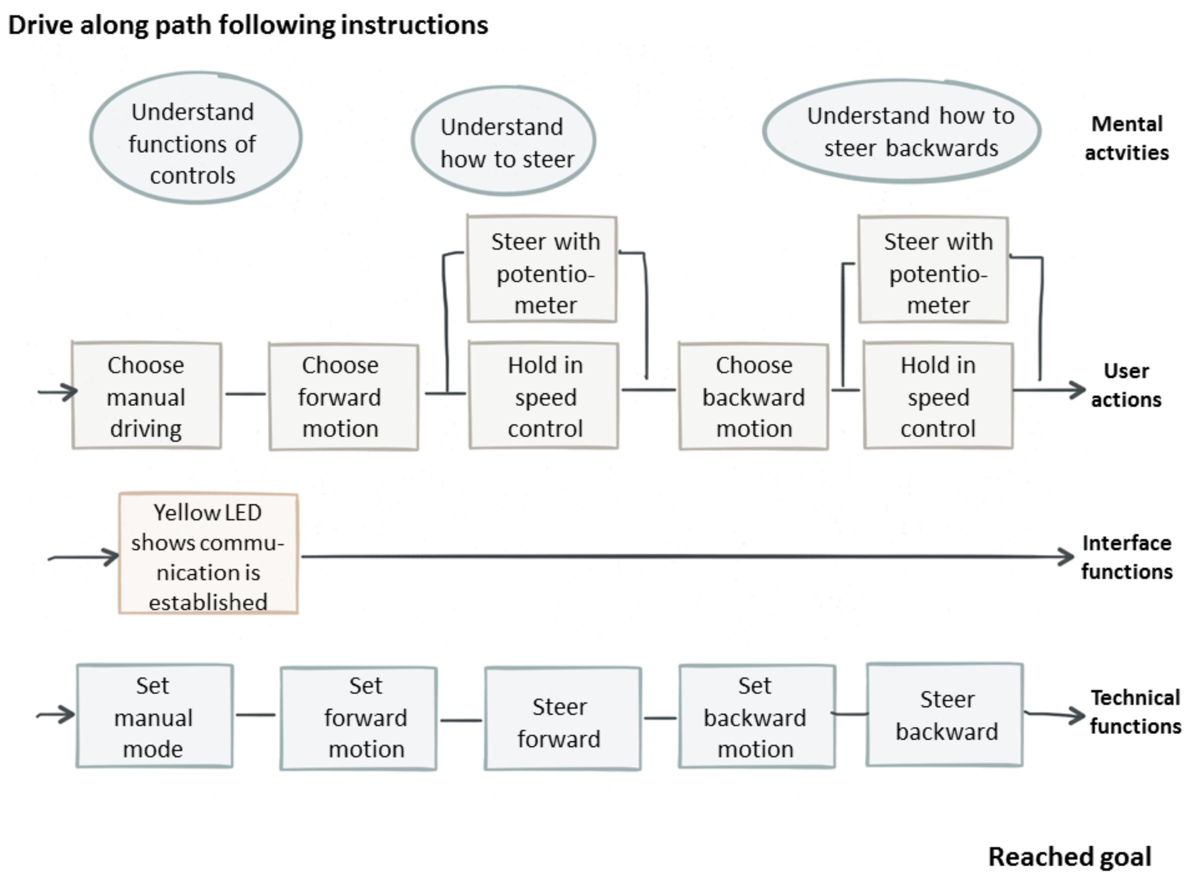


Figure 6.2: The User-Technical Process for performing the task in the user study; to drive forward along a path and then continue driving backward. When the goal is reached, the vehicle has been driven the whole path.

The participants' opinions about the interface, the potentiometer and the cable (see figure 6.3) are hereafter presented as well as their opinions about the general function of the MCD.

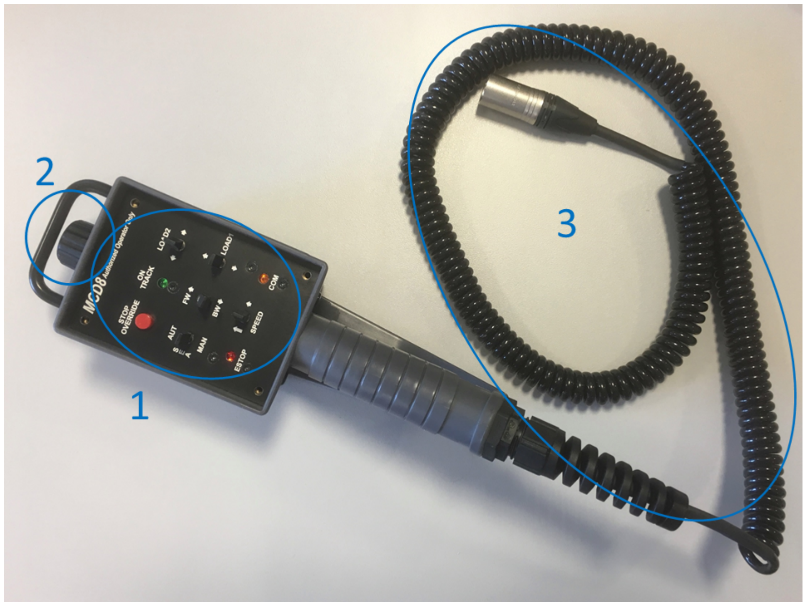


Figure 6.3: The parts of the MCD that will be discussed: 1. the interface 2. the potentiometer 3. the cable.

6.1.1 Interface

Some participants considered that there were too many switches and LEDs on the interface and that there was a need to use too many controls in order to drive the AGV. It was suggested to eliminate the speed selector, direction selector and steering potentiometer and replace them with a joystick. One participant however pointed out that it was easy to see what each control would do when looking at the icons and was therefore satisfied with the controls of the interface.

It was perceived that the slower speed that can be chosen with the speed selector (approximately 0.3 m/s) was too slow and that the faster speed (approximately 0.7 m/s) was too fast and made the AGV difficult to steer properly. Some did not understand that there were two different speeds available and some thought that pulling the speed selector to the right was the forward drive and switching it to the left was the backward drive, when instead this was the faster speed.

6.1.2 Steering Potentiometer

Out of the nine participants, four did not see the potentiometer directly and tried to search for a control used for steering on the interface. Some of these found the potentiometer eventually and some were given hints. Several participants felt it was irritating that the indicator on the potentiometer that marks the angle of the steering wheel was not visible and that it did not have a neutral position it would return to when released. Two of the participants solved this by kneeling down to observe how their movement turning the potentiometer affected the position of the wheels and a third participant held the MCD vertically to get an overview of the potentiometer. Several participants requested better feedback of what would happen instead of having to test different controls to see what happened.

A few of the participants requested an indication of the potentiometer's turning radius and that the potentiometer would give less reactive outputs. The potentiometer currently has little friction and inertia when turning it which results in easily taking steep turns. Some of the participants felt that this would be an issue if driving the AGV in an environment with sensitive objects.

6.1.3 Connecting Cable

Four out of the nine participants requested a wireless control device, some because it would simply feel good with a wireless control, others becuase they felt it was unflexible having a long cable to handle and that it would be easier to get an overview of the surroundings without it. One of the participants claimed that the cable was so long that is was in the way and that there could be a risk of it getting stuck somewhere.

6.1.4 General Functionality

Several participants stated that they thought the chassis of the MCD was bulky and that the whole MCD felt old-fashioned. Another opinion was that it lacked intuitiveness and that it could be more ergonomic, for instance by not requiring the use of both hands.

Although several participants expressed that the MCD was hard to use for steering, they believed that if they got to practice a few times they would learn how to use it. This was also observed during the tasks that the participants seldom did the same mistake the first and second time. Many participants however used the faster speed the second time which resulted in a less precise steering.

6.2 The Operator Terminal

Customer feedback from six partner companies was gathered where different functions of the Operator Terminal were rated with regards to the partners' opinions and their customers' input of how important several functions are. An average of all the ratings in each category were taken where five indicates that something is important and one that it is less important.

The results of the ratings concerning the context where the Operator Terminal is used showed that having IP65 support (having a display sealed from dust and that can withstand large amounts of water) was the highest rated function, followed by being able to support dynamic temperatures where the temperatures of the environment can shift a lot, see table 6.1. Low temperatures seemed more problematic than high temperatures and were given a higher importance.

Table 6.1: Ratings of important contextual features.

Function / feature	**Average importance** 5 = important 1 = less important
IP65-support	3,83
Dynamic temperature support	3,17
UL583-listing	2,67
High temperatures (>55° C)	2,33
Low temperatures (<-10° C)	1,83

Different abilities related to a screen were rated, see table 6.2. The feature that was rated with highest importance was having a touch screen, closely followed by a color screen. Being able to use the screen in direct sun light without lowered visibility was also given an important rating.

Table 6.2: Ratings of important features for a screen.

Function / feature	**Average importance** 5 = important 1 = less important
Touch screen	4,67
Color screen	4,50
Clear visibility in sunlight	3,17
Large screen size (>= 10")	2,33
Small screen size (<= 4")	1,67

The other features that were rated are regarding the ability to configure the Operator Terminal easily, the ability to program it and customize it after specific needs, and how compatible it should be with the earlier models of the Operator Terminal. The question if it is important having different password levels was only answered by one respondent who thought this was important. The results can be seen in table 6.3 where it can be seen that the ability to configure and program the Operator Terminal both were very important as well as the ability to customize it after own needs.

Table 6.3: Ratings of general important features for an Operator Terminal.

Function / feature	**Average importance** 5 = important 1 = less important
Easy and fast configuration	4,83
Programmable	4,33
High level of customization	4,00
Several levels of passwords (NB! Only one respondent)	4,00
Compability with earlier models of the Operator Terminal	2,00

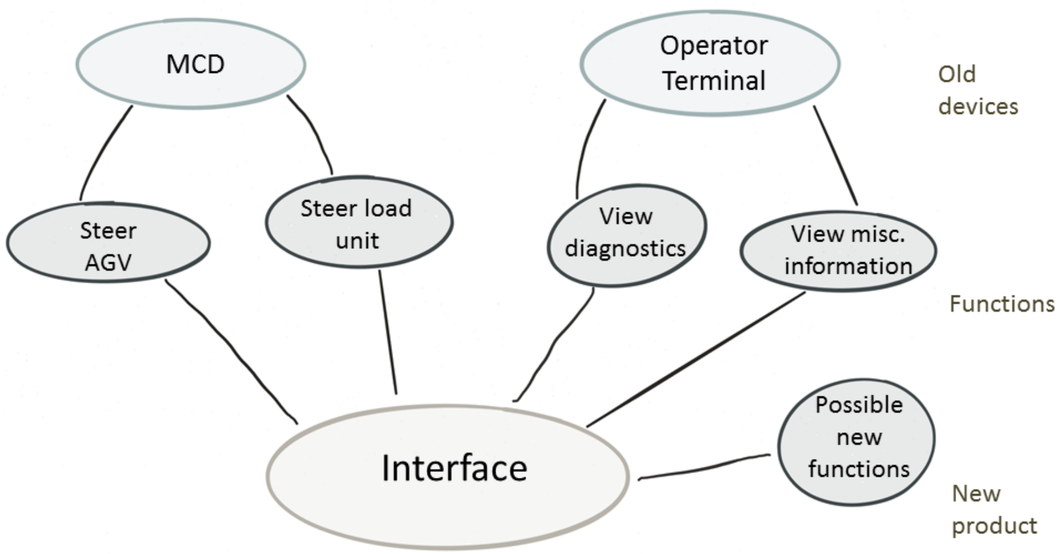
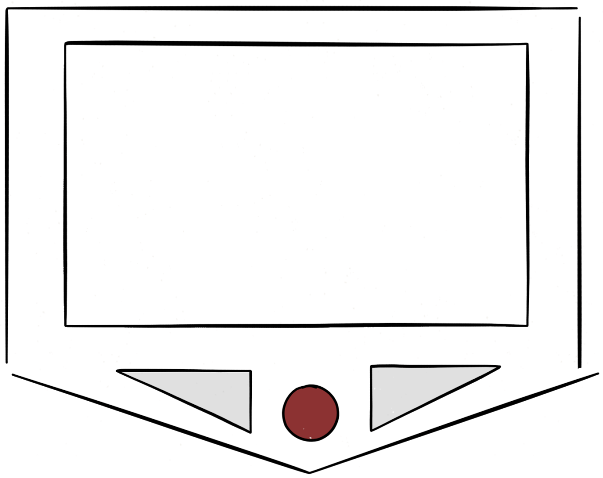


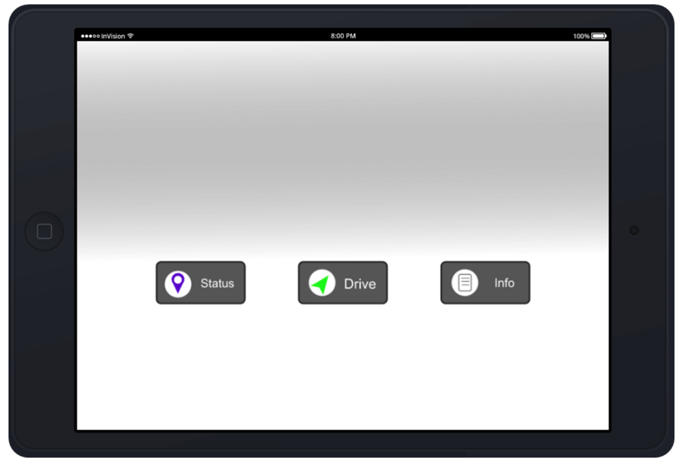
Figure 6.4: The two products MCD and Operator Terminal have seperate functions that will be represented in a new interface where there is also a possibility for adding functions that do not exist currently.

6.3 Concept Principles

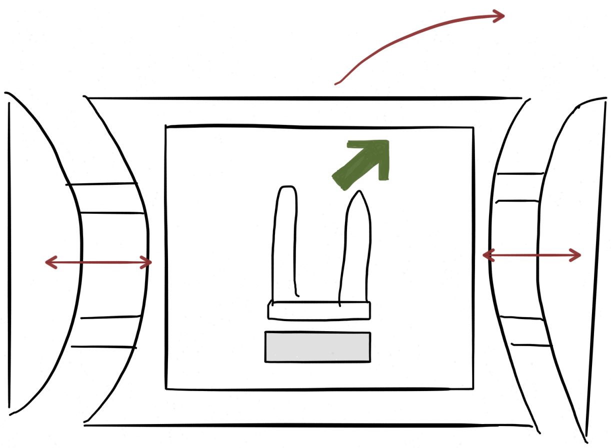
An opinion that was gathered from the two first phases was that it would be good using a touch screen for information monitoring, at least if the touch function would work. For steering, several concepts were brainstormed and grouped in four categories; haptic, visual, motion and gestural principles, see figure 6.5 for examples. All of these concepts include a touch screen since the product is an integration of two devices with several functions, as described in figure 6.4. The new product needs to be able to view information and diagnostics, and steer an AGV. The categories for steering the AGV are further on described and a few solutions within each category are given.



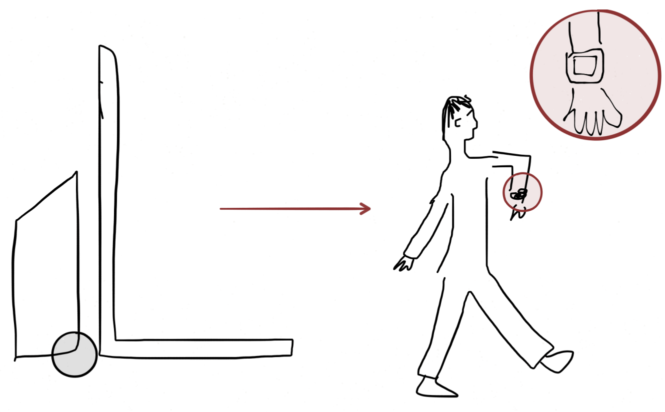
(a) *Example of a haptic concept.*



(b) *Example of a visual concept.*



(c) *Example of a motion concept.*



(d) *Example of a gestural concept.*

Figure 6.5: Concepts from the user design phase.

6.3.1 The Haptic Principles

The haptic principles are, as the name implies, based on haptic technical solutions such as buttons, switches and joysticks that you touch in order to steer the AGV. An example of one of these concepts can be seen in figure 6.5a where a joystick is used for steering and two buttons are used for choosing to steer the vehicle or the loading unit.

An alternative to using a complex hardware unit like in figure 6.5a, is to use a regular tablet and add a controller either wirelessly or through the docking port (see figure 6.6). This solution could be more difficult to make robust and it would need some work to make it ergonomically suitable.

Concepts from this category resemble the current one the most and have the most complex hardware. Making sure that if you drop this unit, you would not accidentally give the AGV speed would be very important, especially if using a joystick. A strength is however the possibility to give the user a driving experience without having to fixate the sight on the device.

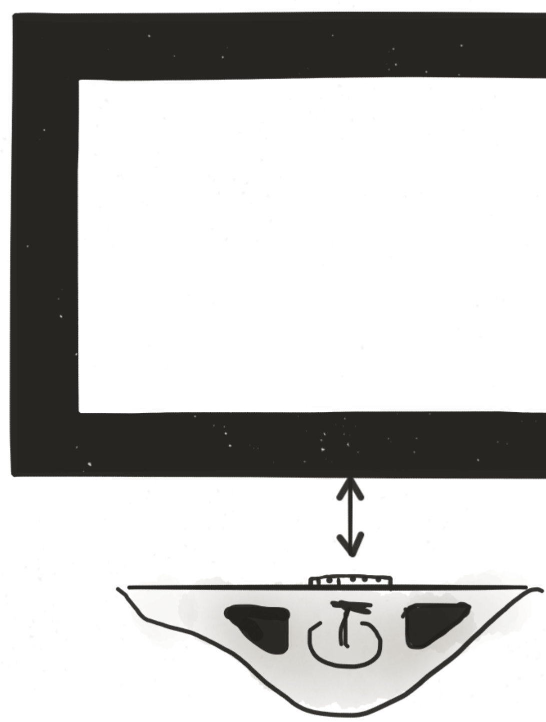


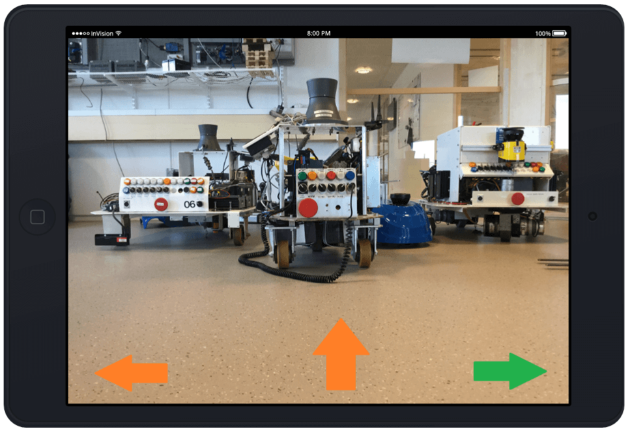
Figure 6.6: Concept solution for the haptic principle.

6.3.2 The Visual Principles

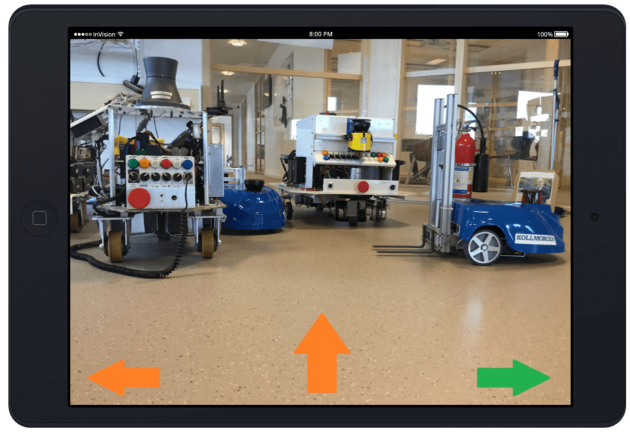
The visual principles use a touch screen for steering, see figure 6.5b for an example. The solution has a menu system where one option is to steer the AGV with the help of the screen and where other menu options lead to diagnostics and information. The steering could be done in several ways, for example:

- Viewing the layout of the environment and drawing the path you want to drive with your finger.
- Having a camera installed on the front of an AGV and seeing its view on the screen. The steering would be done with the help of arrows placed in the camera view, see figure 6.7 for examples of how it could look on the screen. The colors of the arrows indicate the proximity to an object in the three directions. If an arrow is red, an object is very close, if it is orange an object is quite close and if the arrow is green there are no hinders close to the vehicle. By pressing the arrows the vehicle either turns in the stated direction or moves forward. The velocity is adapted to the proximity of objects and the vehicle would thus moves the fastest when pressing a green arrow.
- A third option is to create fictive buttons and controls on the screen used for steering.

Some of the benefits with using software on a tablet or a similar device for steering an AGV are that the hardware is simple, that the software easily can be updated and that there are many alternatives for what device to use with the software. A challenge can however be that most users want to look at the vehicle when they are steering, and not on the screen. In order for this to work they need to be able to find the controls without having to look too much on the screen alternatively have the possibility to steer the vehicle by only looking at the screen.



(a) The first view seen on the screen.



(b) After pressing the right green arrow seen in the first image, the AGV turns to the right and this is the new view.

(c) After once again pressing the right green arrow, the AGV has turned some more to the right.

(d) After pressing the right arrow a third time, the AGV has turned around and the room is visible.

Figure 6.7: Concept solution for steering with the help of the visual principle.

6.3.3 The Motion Principles

These concepts are based on translating movement created while holding some kind of hardware into steering signals. An example is shown in figure 6.5c where the vehicle is steered by tilting a device sideways. To add safety, the steering is only enabled when two side bars are pulled out from the device and held with both hands. Sensors are placed on these bars and when holding each bar and shifting the hardware, an animation of how you are steering the AGV is shown on the screen and the AGV is put into motion. The hardware can be made easier by for instance initiating the steering by placing both thumbs on the screen instead of using the more complex hardware unit with special handles.

Another option is to use two units; one wireless screen handling information and one handheld object that steers the AGV when pressing a button and moving it around, see figure 6.8. One positive thing is that these kinds of concepts do not require that you look on an interface, you can rely on looking at the vehicle itself. It can however be difficult to obtain a high level of precision.

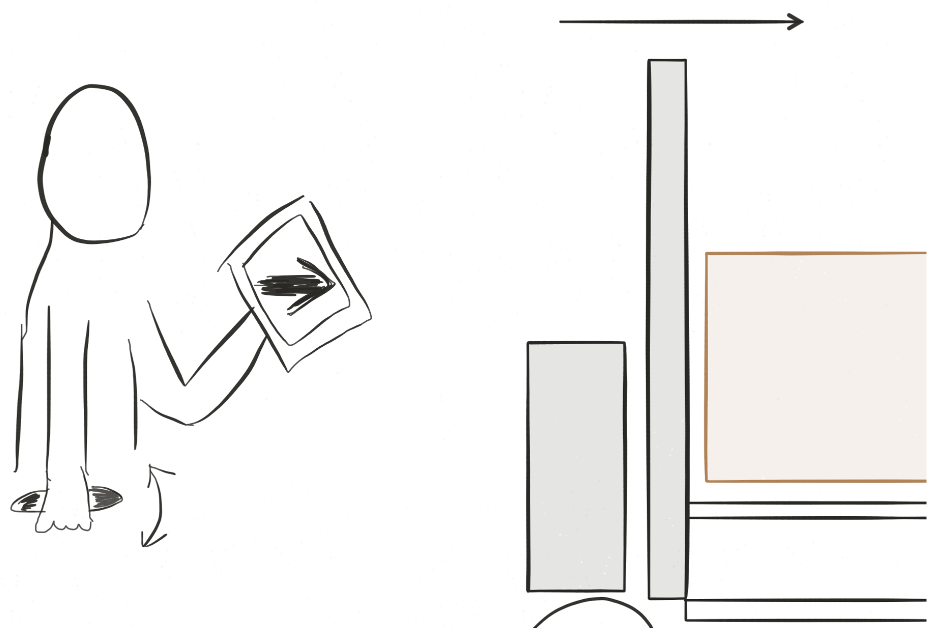


Figure 6.8: Concept solution for the motion principle.

6.3.4 The Gestural Principles

These concepts differ from the motion concepts due to the steering being created by gestures perceived by sensors rather than translating mechanical motion to actions. There can for instance be an RFID tag placed on a tablet or on a bracelet equipped with a small screen, see figure 6.5d, where the vehicle follows the operator wearing the bracelet or holding the tablet in an optimized path alternatively drive before in the same direction as the operator.

Another option is to talk to the vehicle and use voice recognition to translate the orders into movement, see figure 6.9.

These kinds of concepts can be helpful when transporting an AGV a longer distance. They also give the user the possibility to look up instead of having to stare at a screen when steering the vehicle. They would however be difficult to use when in need of precision (depending on their configuration) and there are several situations that could be dangerous, for instance if a vehicle moves in front of the operator when walking around a corner.

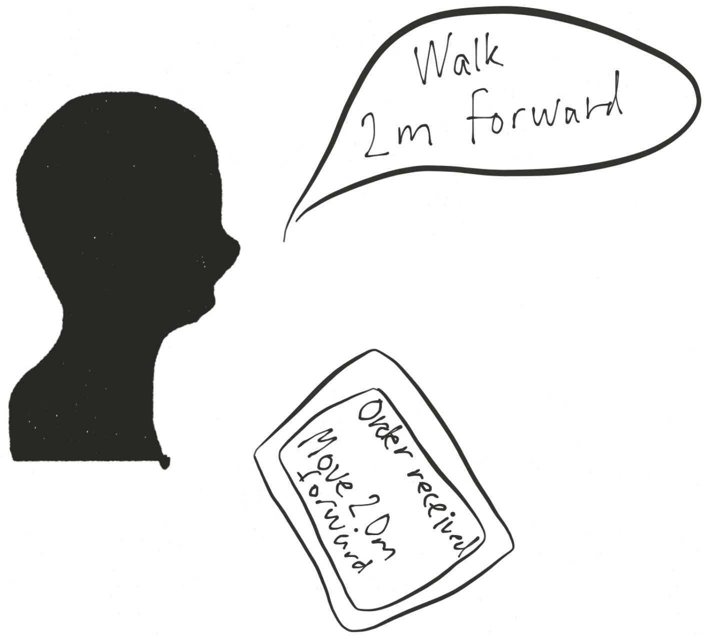


Figure 6.9: Concept solution for the gestural principle.

6.4 Evaluation

An evaluation session was held with a group from the Company where the results from the needs mapping and the user design phases were presented and a discussion was held. The aim of the session was to get input from the group members that represented different departments and thus get a broader understanding of how the project would progress in the forthcoming phases.

The four different principles for the Product were presented and during the discussion it was understood that it is preferred to use existing hardware rather than producing new products, which excluded the haptic principles with customized hardware. It was also suggested to use different parts of the principles in a concept, for instance using vibration together with a visual principle.

For the next phase it was decided to look into standard hardware with as few components as possible. The visual principle would primarily be used with the possibility of adding methods from the other principles.

6.5 List of User Needs

In this second phase some more specific needs were elicited. Although the needs for the MCD and the Operator Terminal were handled separately in this phase the aim is to develop an integrated product like in figure 6.4.

Context

- Dynamic temperature support
- IP65-support

Usability

- Clean interface
- Descriptive icons
- All controls visible
- Self-descriptive function of elements visible in the interface

Functions

- Possibility to steer vehicle manually with more than two different speeds
- Possibility to configure reactiveness of controls used for steering vehicle manually
- Configurable unit
- Programmable unit
- High level of customization
- Possibility to add password

Hardware

- Wireless
- Touch screen
- Color screen
- Use standard components

7

Technical Design

In the first two phases the needs and requirements for a new product were elicited with focus set on the usage and the functions of the current MCD and Operator Terminal. The aim was to understand how the units are used today and by whom, and what functions and features the new product should have. This chapter presenting the Technical Design phase takes the development further by investigating if the functions and features are technically feasible. This is done by finding information through literature, by brainstorming alternative steering methods, and by building and testing functional prototypes. The methods used in this chapter are further described in section 4.4.

7.1 Software Architecture

The current devices that are used for steering the AGV manually and for viewing diagnostics and information about the AGV are the MCD and the Operator Terminal. When integrating the functions of these two devices and possibly adding new functions it was decided that the new device would have the possibility to be used wirelessly, that it would have an interface that can be easily understood by many different kinds of users and that it would use standard components. The Company does not produce or assemble their own products, why it was preferred to use a product that would not need to be assembled to function.

It was therefore decided to create an application (app) and use a tablet computer (tablet) or a smart phone as device and the display together with built-in sensors for fulfilling the functions. A majority of the market uses Android as operating system in their tablets and mobile devices and therefore an app was designed for Android devices (Marketshare, 2016).
The steering can be done in various ways but the final method chosen for the product should be easy for the user to understand, should not demand that the user remembers specific information to know how it works, and should assist with a safe and precise steering. Many of these factors depend on how the steering is graphically presented and this will be the focus in chapter 8 (Detailed Design). The focus in this chapter will be to look at how these methods could technically be done in order to know if they are feasible.

Besides being able to steer a vehicle manually the product should make it easier to view information about the vehicle, including diagnostics and order status. Therefore it is also investigated how this data can be read from the vehicle controller and presented in an app.

7.1.1 Steering

One of the most important parts within the software architecture is how to steer a vehicle with the help of an app. To understand which methods that are already used in apps a benchmarking of games was done. This showed the methods available and how they could be used. Different alternatives for steering the AGV was then implented as apps and tested in a simulated environment and with real vehicles to see if their technical principles worked.

7.1.1.1 Benchmarking

A benchmarking was done of different ways to steer vehicles or other objects in application based games. The goal was to test different technologies and see their strengths and weaknesses to know if their principles were applicable in the project. The games were primarily vehicle simulators or adventure games where a character was led through a course.

The games with vehicle simulators used different methods for steering cars, planes or helicopters on for example a racing track or on streets, see table 7.1. Several steering methods could be chosen in all of them but one. In the two car games you could steer by tilting the device, by using a fictive steering wheel, or by pressing buttons. The speed was either set automatically or by pressing a fictive gas pedal. The method where you used a fictive steering wheel proved to be difficult for obtaining a high level of precision, due to the finger turning the wheel easily sliding too far from the designated touch area. Steering by tilting the device proved to be too reactive but giving a good driving experience resulting in a better feeling of control.

In the game Real Racing 3 you had to remember what steering you had chosen since the location of the brake, the wheel and the arrows only were visible in the beginning of the game and when touching the right area of the screen.

In Taxi Sim 2016 the steering seemed hard due to the speed being variable. While pressing the gas pedal the car accelerated until releasing it or pressing the brake. Many specifications could be done to the steering, for instance using sliders for the gas pedal and the brake. The driving interface was similar to the one in a car with many choices like an ignition and blinkers. It was not apparent in the game if the blinkers had a purpose, like giving a higher score when used correctly.

The Cube Runner game was very simple and only required the player to turn. The speed and the height of the airplane were fixed. This however had to be manually set in the Helidroid 3D game. This made it harder to control the helicopter due to there being more degrees of freedom. This was especially apparent when using the gyroscope for both steering and driving the helicopter resulting in instability.

These four games steered fictive vehicles where the vehicle or its driver's view could be seen on the device together with the steering controls (except when using the gyroscope for turning). The player only had to focus on the screen, not on a toy car outside the screen also. This makes it more difficult to compare the games with the real interface why the games served mostly as inspiration. The games were played both on a tablet with a screen measuring 9,7" and on a smart phone with 4,7" in screen size. It was preferred using the larger display to get a good view and to have more space for interacting with the controls.

Table 7.1: Benchmarking of games for steering vehicles.

	Real Racing 3	Taxi Sim 2016	Cube Runner	Helidroid 3D
Developer	EA Games	Alexandru Marusac	Andy Qua	MH Production
Category	Racing (car simulator)	Car simulator	Flight simulator	Helicopter simulator
Means of steering	Fictive wheel/Tilt device/Press the right or left side of the screen.	Fictive wheel/Tilt device/Press arrows	Tilt device	Arrows or tilt device. Arrows also used for adjusting the position in height.
Means of giving speed	Automatic or press a fictive speed pedal and a fictive brake.	Fictive speed pedal and brake. Change between drive and reverse to choose direction.	Automatic speed	Tilt device or use arrows. Using the arrows only gives one speed.
Technology	Touch and gyroscope	Touch and gyroscope	Gyroscope	Touch and gyroscope
Perspective	First- or third-person	First- or third-person	First- or third-person	First-, second- or third-person
Driving experience	Best when steering by tilting the device, not as good when pressing either side of the screen.	Difficult using the wheel. Ineffective changing between drive and reverse.	Good, especially with first-person perspective.	Average for all three steering methods.
Feedback	The best feedback is obtained with the tilt and the fictive wheel.	The best feedback is obtained with the tilt. The steering wheel can be turned too easily.	Good.	When using tilting for both speed (and direction) and for steering, the feedback becomes difficult to understand.
Precision	The highest precision is obtained by pressing left or right on the screen. The wheel required a perfect touch on the wheel area. If the finger slipt, steering was lost.	The highest precision was obtained when using the arrows for steering.	Good precision, especially in first-person perspective.	The highest precision was obtained when using the arrows for steering. Tilting the device created instability.
Safety/ control	Not so good when using the fictive wheel, otherwise good.	Good when using arrows.	Good.	Bad when tilting the device for speed and steering.

The remaining three adventures games contained a character to move around, see table 7.2. The only one that proved to give both feedback and precision was the game Batterijakten where a virtual joystick is used. In this game, the character walks facing the same direction as the joystick is pulled toward. If it for instance has been walking forward (toward the upper edge of the screen) and the joystick is pulled in the complete opposite direction, the character turns around before starting to walk. Although it makes it predictable how the character will move, this is something that would not be possible for a car since it needs to be able to back. In Path to Luma, the player touches a map to control where the character should walk and in Pokémon Go the character follows your movement with the help of GPS, both methods resulting in rendering a low precision.

Table 7.2: Benchmarking of adventure games where a character is moved around.

	Batterijakten	**Pokémon Go**	**Path to Luma**
Developer	VARTA Consumer Batteries GmBH & Co	Niantic	NRG Energy, Inc
Category	Adventure, collect	Adventure, collect	Adventure, explore
Means of navigating	Fictive joystick that steers a character	The movement of the person holding the device moves a character in the game	Press on a map where a character in the game should move
Technology	Touch	GPS	Touch
Perspective	Third-person	First- and third-person	Third-person
Feedback	The character turns around so that it is always facing the direction you are giving it with the joystick which makes it easier to understand its movements.	Low level of feedback since you need to know in what direction you are heading to understand your character's whereabouts.	The game does not provide any feedback.
Precision	The character can move in different speeds depending on how far you move the joystick but usually the fastest speed is used and it renders low precision due to the joystick being rather reactive.	The precision is low depending mainly on how well the GPS is functioning.	Low precision since the character will only go to the places where you point.

The evaluation of these games ended in a decision that steering a vehicle by letting it follow your movement or by pressing on a map to indicate where it should drive gives a too low precision.

Using a fictive steering wheel was also considered as an option that could be difficult to develop in a safe and precise way. It was however perceived that it was a good idea to be able to choose between several kinds of steering.

Another decision that was made was to use a tablet with a screen size bigger than 5" in the future development. It was perceived that this gives the biggest chance of an uncluttered and usable interface.

7.1.1.2 Mobile Applications

To examine how mobile applications can be used for steering an AGV, a few apps testing different steering methods and functions were developed. Using the integrated development environment (IDE) Visual Studio with Xamarin, a platform for creating mobile apps for android and iOS writing code in C #, simple mock-ups were created and tested. The focus was set on testing several aspects, namely:

- If multi-touch can be used.
- If virtual buttons and a virtual joystick can be used for steering.
- If a gyroscope together with virtual buttons can be used for steering.

The apps were first tested in a simulated environment using a vehicle with differential drive and the same vehicle controller that the real vehicles use. By setting the parameters for angle and speed in the vehicle controller through the apps the vehicle was set in motion. After testing them in the simulated environment, the apps were tested with a real vehicle in a test environment. The apps were uploaded to a Google Tango tablet that communicated with the vehicle controller through WLAN.

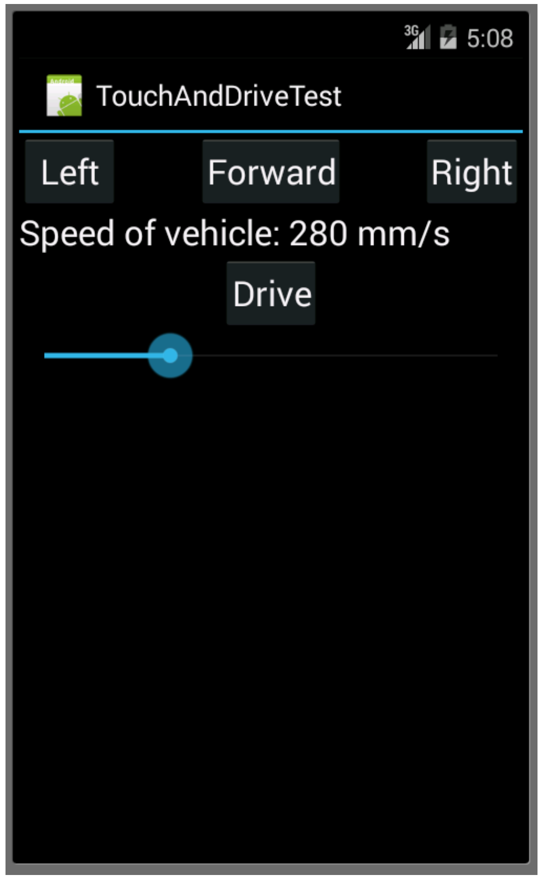


Figure 7.1: App used for steering a vehicle with buttons and a seek bar, called the Button App.

An app using virtual buttons was created where a seek bar changed the speed of the vehicle with a maximum speed of 0,5 m/s and where buttons changed the steering angle, see figure 7.1. The left button changed the steering angle -1,5 degrees, the right button changed it 1,5 degrees and the forward button reset the angle to 0 degrees. This app is called *the Button App*.

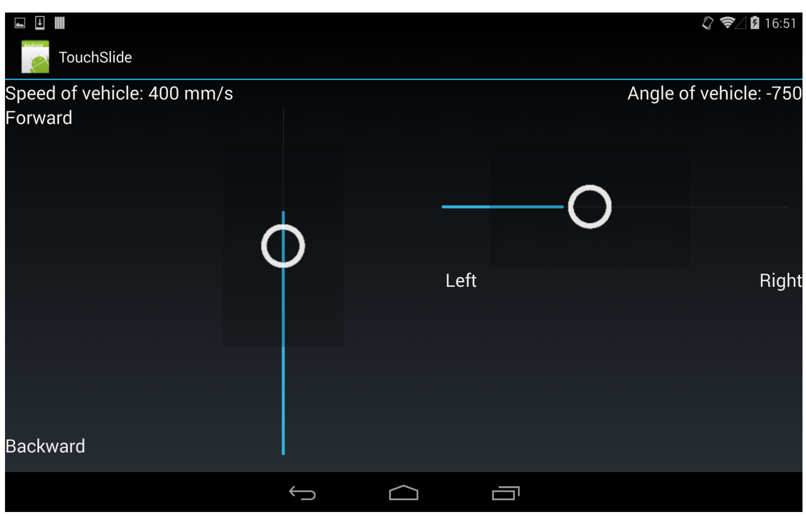


Figure 7.2: App used for steering a vehicle with two seekbars, called the Slider App.

A variation to the first app was created where a seek bar was used both for setting the speed and direction, and for setting the steering angle, see figure 7.2. The left seek bar gave a forward motion when dragged upward with a higher speed at the top and a backwards motion when slid downward. When released, both seek bars returned to the center and the angle and speed were set to 0. It was also possible to only release one of them, for instance if the vehicle was supposed to drive straight forward the angle seek bar could be released and the speed could be manoeuvred with the speed seek bar. This app is called *the Slider App*.

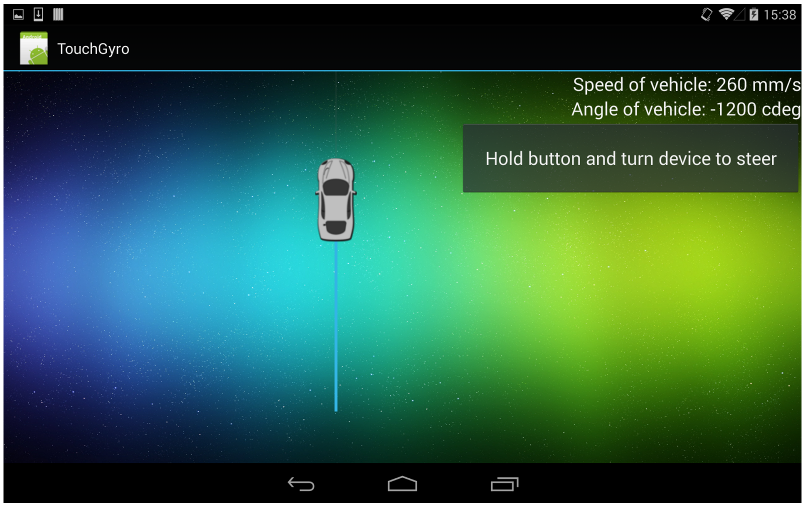


Figure 7.3: App used for steering a vehicle using a gyroscope, called the Gyro App.

A third variation to the first app was using a seek bar for setting the speed and the direction, but setting the steering angle by tilting the device and using the values from the accelerometer in the tablet. The angle was only set when the button to the right was held in to avoid accidental steering, see figure 7.3. This app is called *the Gyro App*.

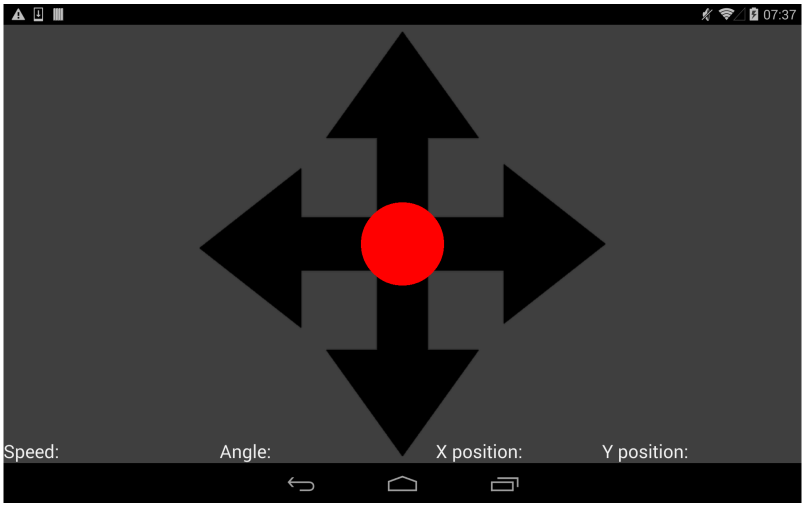


Figure 7.4: App used for steering a vehicle with a joystick, called the Joystick App.

Another app using a virtual joystick was created, see figure 7.4 . The joystick represented by a red button could be dragged in different directions and when released it returned to it's centered position. The steering angle was continuously calculated by using the coordinates of the centered position and the coordinates of the new position. The further the button was dragged from the center, the higher speed the vehicle was given. To be able to steer forward or backward in a straight line, an area of ten degrees around the middle both when pulling the joystick straight up and straight down rendered a steering angle of zero degrees. This was done so that the vehicle could be steered straight without having to hold the joystick in an exact position. The maximum turning angle was set to -40 or 40 degrees. This app is called *the Joystick App*.

The principles of the steering methods proved to work both when simulated and when tested with real vehicles. All of them except the Joystick App used multi-touch which worked with the screen and which was also easy to handle when steering. The Button App was not very flexible and required that the user pressed several different buttons. It was therefore decided that the other three apps would be tested in the next phase but not this one.

7.1.2 Information Gathering

Information about a vehicle should be able to be viewed both when the vehicle is being steered manually and when it is in automatic mode. While testing apps for steering, several kinds of information, like speed and steering angle, was visualized on the screen. To ensure that information also can be collected from the vehicle controller in the automatic mode, this was tested in a simulated mode by giving local driving orders to the vehicle controller in AppDesigner and reading the order status that was set and displaying it in an app.

7.2 Hardware System Architecture

By using an app on a tablet two hardware units (the MCD and the Operator Terminal) are exchanged by one hardware unit that can also be used for other purposes. If there is a need to upgrade the app the same mobile device can be used as long as it has the right specifications such as sensors or means for communication. These considerations can possibly give the product a longer life cycle.

The different components in the device like the display and the sensors are discussed in this section based on their functions and the demands on them. The section ends by a comparison of several tablets that could be used with the app.

7.2.1 Display

The display should be able to withstand water and humid environments. It should also function in environments with varying temperatures and where there is a lot of dust. Using a display with IP65-support would solve the problem of a product withstanding both dust and water.

The display should use touch screen technology with multi-touch support. In industries where gloves are used the touch technology should not be a hindrance since there are work gloves available on the market that can be used on touch screens. The display should support colors and have clear visibility in direct sunlight as well as in dimly lit environments.

The dimension of the display should be big enough to fit essential information and to allow an operator to steer a vehicle through screen interaction but not so big that it feels heavy and that it becomes difficult to hold it and reach items placed on different areas of the screen.

7.2.2 Sensors

Most mobile devices contain apparatus for detecting different events and changes, such as a gyroscope, an accelerometer, and a camera. These sensors should be accessible as well as the data collected by them to give more possibilities for steering alternatives.

7.2.3 General

The device should be easy to carry around but should also be dockable on a vehicle, either in a holder or in a dock where the device also can be charged. The MCD and the Operator Terminal get power supply through their wired connection. The device should therefore be able to be connected to a charger on board in an easy manner. When docked and attached to a charger it is not necessary to be able to steer the vehicle manually, instead it should be easy to remove and attach the device with the vehicle. For those that always want to carry the device with them it should be possible to charge the device elsewhere than on the vehicle's dock station.

7.2.4 Communication

The vehicle controller CVC600 most often communicates with a stationary controller through WLAN or more rarely through asynchronous radio communication (Kollmorgen Automation, 2016c). This communication is primarily used for sending and transmitting information about the traffic situation and order control which amongst other makes it possible to view the location and order status of every vehicle through the software CWay.

Numerous kinds of hardware can be connected to the vehicle controller, such as the MCD, the Operator Terminal and laser scanners. Other hardware that currently is not used could also be connected, for instance a web camera, either by connecting it through a main unit that streams the video feed through a wireless router, or by connecting it to the vehicle controller and sending the feed through wireless communication (Axis Communications, 2016).

Depending on how much data that is being sent through wireless communication and how far range the system should have, there are different network technologies that are better suited for connecting a device to the vehicle. For transmitting larger amounts of data with data exchange rates up to 54 Mbps and a wider range up to 90 meters, using Wi-Fi is recommended while Bluetooth can be good for a shorter range up to 9 meters and smaller amounts of data up to 720 kbps (Dalal, 2015). The advantage of using Bluetooth is that you are not depending on the WLAN connection so you can be connected to your vehicle as long as you are close enough to it even if you are in a spot with bad WLAN reception.

A safety aspect that is important for a wireless device steering a vehicle is how to connect a certain device to a specific vehicle. Although this aspect is not in the scope for the project, there are several methods that can be used for connecting two devices securely like using barcodes, RFID (Radio-Frequency Identification) and NFC (Near Field Communication). With NFC you are required to bring the two devices that are going to be connected within a few centimeters from each other while with RFID there are several options of proximity between the devices, from 1 cm to 100 m. There are both opportunities and challenges with these methods.

7.2.5 Hardware Options

A benchmarking of different tablets that can be used as a mobile device is hereafter presented, see table 7.3. Tablets that are rugged are chosen to meet the need of having a device that can be used in different contexts with different demands like dust and water and to also have a device that can withstand being dropped or handled roughly.

One of the criteria that was investigated was if the batteries of the devices are removable which all of them proved to be. This is one way of being able to use a device a longer time which can increase sustainability. Using rugged tablets can also give the device a longer life cycle since there is a higher chance of the device not breaking.

Table 7.3: Options for mobile devices.

Product name	Samsung Galaxy Tab Active LTE (Arena, 2014)	Getac Z710 (Getac, 2016)	Panasonic FZ-M1 (Panasonic, 2016)	ALGIZ RT7 (Group, 2016b)
Display size	8.0"	7.0"	7.0"	7.0"
Display type	LCD capacitive touchscreen, 16M colors	TFT LCD WSVGA Capacitive touchscreen with glove on	WXGA Capacitive	WSVGA Capacitive
Multi-touch	Yes, Samsung TouchWiz UI	Yes	10 finger multi-touch	5-point multi-touch
Resolution	1280 x 800	1024 x 600	1280x800	1024x600
Sunlight viewable	No	Yes	Yes	Yes
Operating system	Android 4.4.2	Android 4.1	Windows 10 Pro	Android 5.1.1
WLAN	Yes	Yes	Yes	Yes
Bluetooth	Yes	Yes	Yes	Yes
GPS	Yes	Yes	Yes	Yes
Other communications	NFC	Optional 1D/2D Barcode reader, Optional RFID, Smartcard Reader	NFC, UHF, RFID, Smartcard Reader, 2D barcode reader	NFC, 2D Barcode Imager, RFID reader
Camera	Front: 1.2 MP Back: 3.15 MP, autofocus (AF), LED flash	5M pixels AF camera	Front: 2 MP Back: (MP with AF and LED light	Front: 2MP Back: 8MP with AF and LED light
Sensors	Accelerometer, gyro, compass	eCompass, accelerometer	N/A	Accelerometer, gyro, eCompass
Ingress Protection	IP67	IP65	IP65	IP65
Other rugged features	Shock protection up to 1.2 meters drop	Vibration resistant, drop resistant (26 drops from 1.82m)	1.8 m shock resistant	26 drops from 1.22 m
Operating temperature	-20°C to 60°C (Samsung, 2016)	-20°C to 50°C	-10°C to 50°C (Review, 2014)	-20 °C to 50 °C
Weight	393 g	800 g	540 g	650 g
Removable battery	Yes (World, 2015)	Yes	Yes	Yes
Vehicle dock	No but can be purchased seperately (Phone, 2016)	Yes	Yes	Yes
Price	3859 SEK (Dustin, 2016)	10707 SEK (Prisjakt, 2016)	17 948 SEK (Nordic, 2016)	9699 SEK (Magasinet, 2016)

7.3 List of Technical Needs

The needs elicited in this phase are focused on the technical aspects that need to be accounted for in order to be able to create an app used in a tablet that can both steer a vehicle manually, and display information and diagnostics.

Display

- Support multi-touch
- Screen dimension big enough to view important information clearly, but small enough to allow users to reach different areas on the screen

Sensors

- Provide access to gyroscope
- Provide access to camera
- Provide access to accelerometer

General

- Dockable on vehicle
- Chargeable both on vehicle and elsewhere
- Easy to carry with you
- Easy to hold

Communication

- Wi-Fi
- Bluetooth
- RFID, barcode or NFC reader

8

Detailed Design

This phase focuses on the product's interaction with the user. It is investigated how an interface can be created to provide information and the ability to control a vehicle in an appropriate and intuitive way. It is explored how to navigate in the app and how the different views can be designed to convey relevant information to the right user. The phase should lead to more decisions being taken regarding the final design.

At this stage of the development, it is assumed that one tablet is used for each vehicle and that there is thus a fixed connection between the device and the vehicle. This solution is furthermost used for safety reasons since it is possible to steer a vehicle with the app. In the future it could be possible to use one or a few devices for several vehicles. Different options for choosing which vehicle to connect to in that scenario is described in chapter 10 (Discussion). The methods used in this chapter are further described in section 4.5.

8.1 Application Navigation

The app being developed consists of two parts; being able to steer an AGV manually and being able to view information and diagnostics about the vehicle. Some AGVs, especially forklifts, have a tiller handle used for manual steering as mentioned in section 2.1.1 (The Manual Control Device). The companies using these vehicles might not be interested in utilizing an app for manual steering, at least not if it is assumed that the vehicles only will be able to be driven with the app when the driver is standing in the proximity of the vehicle. There are however many other functions in the app that could appeal to these kinds of users.

The app contains several views with different functions which create a need to be able to navigate between the views in an easy and intuitive way. There is also a need to make the most vital information accessible quickly. A splash screen is therefore displayed when there is no interaction with the tablet giving a quick status update. The start screen that is reached when touching the screen contains the most important information and displays how to navigate to other views, see figure 8.1. The different views and the means for navigating are hereafter explained.

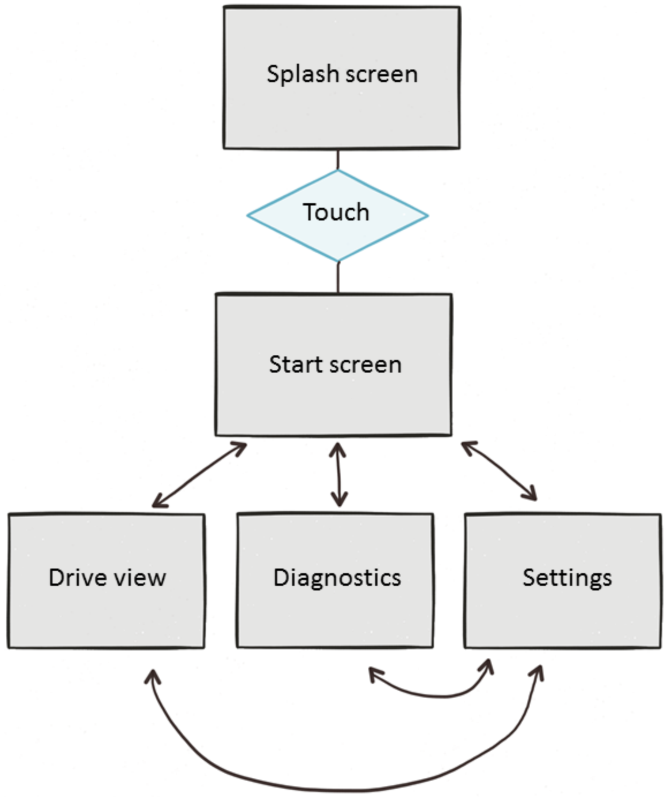


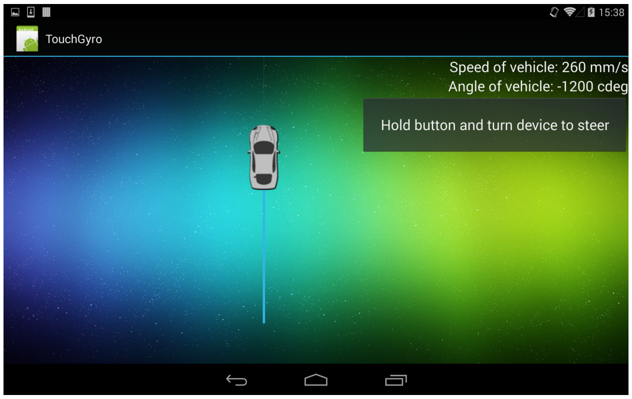
Figure 8.1: The different views in the app. When there is no interaction with the device, a splash screen with a simple icon is shown. When touching the screen, the start screen is reached and from there it is possible to navigate to the remaining three views.

8.1.1 Drive View

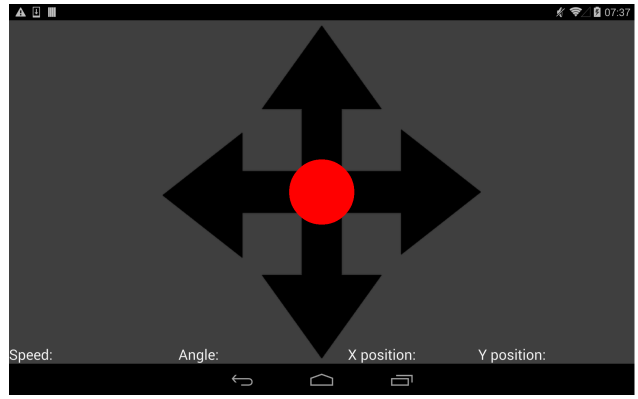
The drive view should include three functions: steering the vehicle, steering the load unit, and providing the means to do a local order. The steering function is primarily the focus for this section where a user study and an expert evaluation is conducted to find a user-friendly drive interface with the right information for the user.

8.1.1.1 User Study

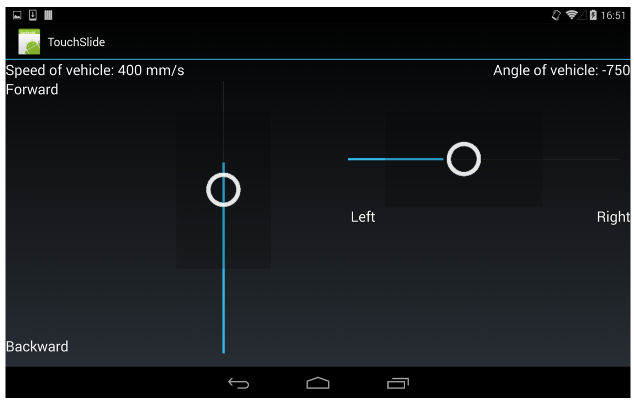
A user study was done to see how seven participants understood and appreciated three of the four apps described in section 7.1.1.2 (Mobile Applications): the Slider App, the Gyro App, and the Joystick App. These apps are focused on how to steer the vehicle mainly.



(a) The Gyro App.



(b) The Joystick App.



(c) The Slider App.

Figure 8.2: The apps being tested in the user study.

The app that the participants tested first was the Gyro App where the gyroscope in the device was used for steering and a seek bar was used for giving speed and direction, see figure 8.2a. The test app demanded that the participant held in a button with the text *Hold button and turn device to steer* to be able to use the gyroscope function and steer the vehicle. The seek bar had an image of a car to represent that pulling it upward would drive the vehicle forward and sliding it downward would make the vehicle move backward. Not all participants understood that they should slide the car to give speed and direction, and not all understood that they had to hold in the rectangular button to steer. Some started looking for something that looked more like a real button that they could press. One of the participants commented that the text on the button should have read that the device should be tilted instead of turned to be able to steer the vehicle. This was a relevant comment and it was corrected immediately for the remaining participants.

The second app to be tested was the Joystick App, see figure 8.2b. Most understood how it worked and thought that it was better for taking sharp turns than the Gyro App but most however thought that it was difficult to steer in a precise way and that it, unlike a real joystick, was difficult to know when it had been pulled to its maximum. They would need to keep their eyes fixed on the screen while steering to know this although they rather looked at the vehicle.

The third app that was tested was the Slider App with two seek bars, see figure 8.2c. Driving the path with this app took the shortest time for all but one of the participants and most participants displayed that they could steer the vehicle with precision and also claimed that they were satisfied with the level of precision obtained. Something that was noted was that most participants drove with a slower speed using this app although it had the same maximum speed as the others. It was assumed that this was due to it being the third app to be tested and that the participants had become more adjusted to steering with an app.

A few of the participants commented that they liked that there was one control for the speed and another for steering but one participant however pointed out that it would have been good knowing when the maximum speed forward and backward was reached without having to observe the screen.

Table 8.1: Results from the observations during the user study.

	Gyro App	Joystick App	Slider App
Drive FW and steer	2,4	1,3	1,3
Drive FW/BW	1,7	1,3	1,0
Choose speed	1,3	1,4	1,0
Drive BW and steer	2,0	1,1	1,3
Average total performance	**1,9**	**1,3**	**1,1**
Average time to drive the path [min]	**01:41**	**1:23**	**01:09**

The participants were unanimous that the the Slider App rendered the highest precision and feeling of safety and that it was therefore preferred over the other alternatives. In table 8.1 the results from the observations made during the user study are compiled. The first four rows give an average of how the seven participants were able to drive forward and steer, know how to choose between driving forward and backward, choose speed, and drive backward and steer. By dividing the task into these four categories, it became more clear what part of using each app that was hardest. On the fifth row the average of these four tasks for each app are given to see which steering method in average was easiest to handle. On the last row is the participants' average time for driving the whole path where it can be seen that it went fastest to drive using the Slider App. Although it took longer time for most to drive with the Gyro App than with the Joystick App, most were more satisfied with the prior. Most participants wanted to use the Gyro App if they had to move a vehicle on a large surface where little precision was required.

A function that was requested from some of the participants was to be able to choose between two different maximum speeds. This could help to not go too fast by accident when steering in a narrow environment where higher precision is needed but still have the possibility to drive faster in a more safe environment.

Another function that was required by some participants was to have indicators on the seek bars to know what percentage of the maximum speed that was reached. An alternative could be to add vibration when the maximum speed was reached.

Several participants requested some kind of visual feedback to know how the vehicle was moving, especially when it was driving backward. Some suggestions for how this could be obtained was to have a camera on the front and on the back of the vehicle to see its views, to use a compass both for the device and for the vehicle as a comparison, and to see a map of the layout and follow the vehicle's movement (similar to CWay).

8.1.1.2 Expert Evaluation

After testing the three apps in the second user study it was decided to only proceed developing the Slider App since most participants preferred it and could handle it with greatest ease. Some modifications were done with the app, like changing the location of the seek bars, removing unnecessary information, adding a sign saying if the app was connected to a vehicle or not, and adding a switch where you can set the maximum speed to a slower or a faster speed. The slower maximum speed was set to 0,4 m/s and the faster to 0,8 m/s but this information was however not given in the app. The new app can be seen in figure 8.3.

After the modifications of the app were done the new Slider App was tested on three application engineers that were considered to possess more information about the use situations and who could therefore not only evaluate the functions of the app but what functions a user wants and expects. The following observations and feedback was collected:

- All three participants displayed that they could steer the vehicle with ease, one of them however did not notice that there was a slow and a fast mode that could be chosen.

- The fact that both seek bars return to zero position when released was both seen as something positive and negative. A situation where a heavy vehicle is turning and where you would accidentally slide your thumb so far left that you end outside the screen so the vehicle starts driving straight forward instead of turning was described as an example of a problem that could occur. Another application engineer however stated that it was a nice feature that the vehicle could drive straight forward with the app since this is harder to accomplish with the MCD.

- Compared to the MCD that has two fix speeds it was appreciated that there were two different maximum speeds and that the speed was adjustable and continuous.

- The app was considered unresponsive and rather slow. One of the participants claimed that he quickly started adjusting his steering due to the slowness and that this affected the level of precision.

- One of the participants felt that the app could be used for steering safely but the other two were hesitant, one of them because he felt that with an app you stood too far from the vehicle when steering the vehicle, and the other because of the risk of accidentally ending up outside the screen and loosing the steering.

- The information the participants would like to be able to view while steering is whether the E-Stop is activated, what the maximum speeds are, and the vehicle ID of the vehicle you are connected to. It was also requested to be able to have an expert mode for application engineers where they can choose the maximum speed themselves, to be able to choose if the seek bars return to zero when released or not, and to be able to connect the device and the vehicle through Bluetooth instead of via WLAN.

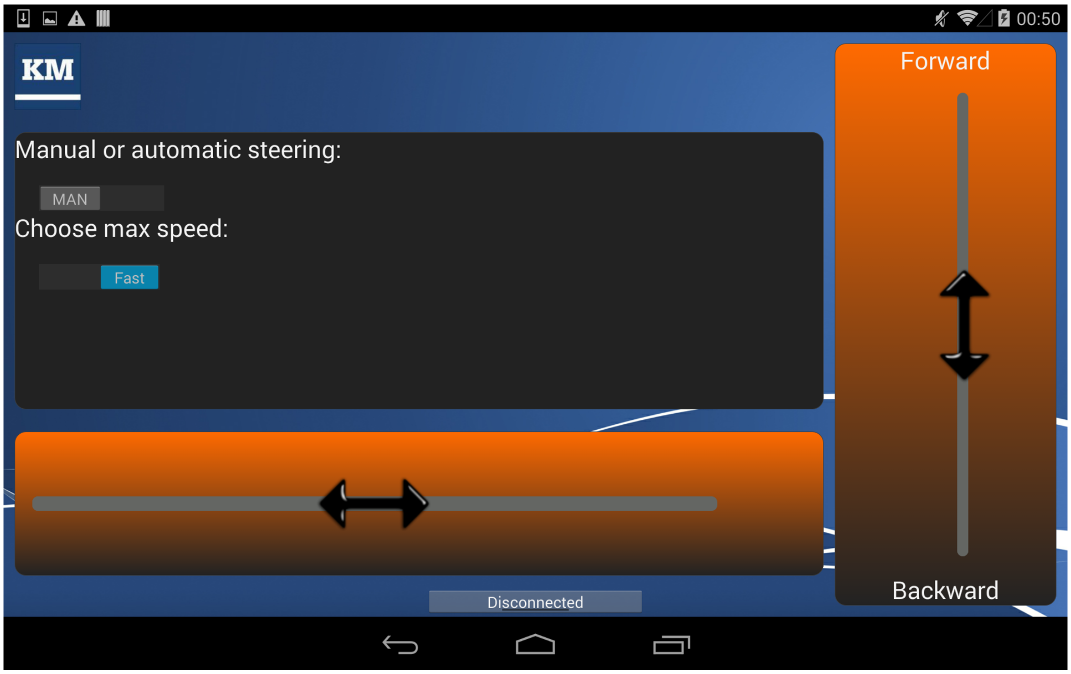


Figure 8.3: Second functional prototype of the Slider App.

When it comes to what information the application engineers felt was important to get in a start screen, one of the participants wanted the screen to show a simple sign of the vehicle's status when no one was interacting with the device. It could for instance be an icon showing that the system was functioning and another icon if there was an error. If a vehicle has been blocked by another vehicle, it should be specified which vehicle has blocked it. The current operation mode (manual or automatic) should also be shown as well as the order status and information about the communication to the system.

Another opinion was that it should be listed what other devices are connected to the vehicle controller and information about them as well as the possibility to trim their parameters. The safety sensors' views could also be displayed, something that could be helpful if the sensor is blocked giving an error.

The menus in the current Operator Terminal that were stated as those most often used were local order where the vehicle can be sent to a certain point in the system, choosing between Master and Local modes, triggering the BlackBox, and initializing the vehicle into the system with *init*.

The feedback about the steering method and about what information to display was taken into consideration in the feature development of the interface but the app was not further programmed.

8.1.2 Start Screen

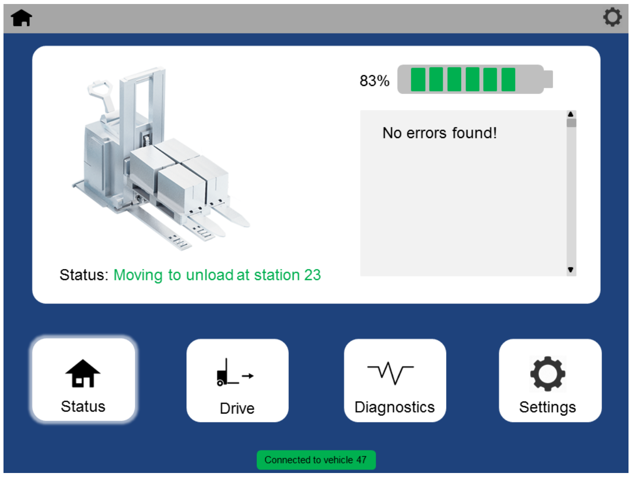
The start screen is the first view displayed when touching the screen and should include the most vital information presented with both icons and in writing. It should also enable an easy way to navigate to other views such as the diagnostics view, the drive view and the settings view.

At this stage the information that was identified as the most important was

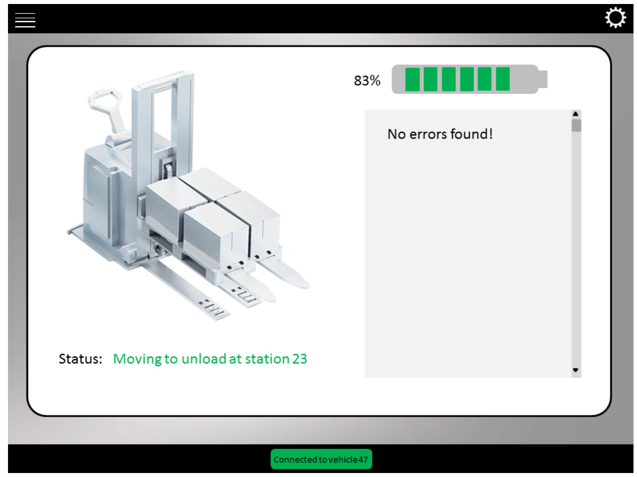
- The system status
- The order status
- The battery level
- Potential error information
- Vehicle information
- If there is communication between the vehicle and the device

In figures 8.4a - 8.4d four different options for start screens are displayed. They have different layouts but they have some features in common. All of them contain:

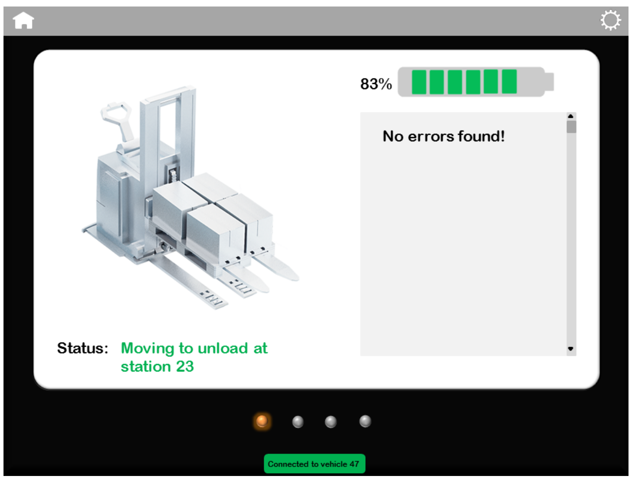
- An image of the vehicle being used where the image also portrays the order status with for instance a load displayed when the vehicle is transporting goods and the right level of the forks when they are being used. When there is an error concerning a hardware unit the affected part of the vehicle on the image should be highlighted or get another color. If for instance a safety sensor is blocked, the sensor could be portrayed in red on the image.
- An information text that not only gives the error code but also brief and descriptive information about the error and possible ways to fix it.
- A status text below the image stating what kind of order the vehicle is processing so that it is easy to know where the vehicle was heading if an error occurs and it halted. The color of the text should be green if the system is functioning, orange if the vehicle is on its way to get its battery charged, and red if there is an error.
- At the bottom of the screen is a sign indicating which vehicle the tablet is connected to with a green color if communication is established and in red if it is not.
- Finally there is a battery indicating the battery level of the vehicle. Depending on how charged it is the number of segments and their color varies.



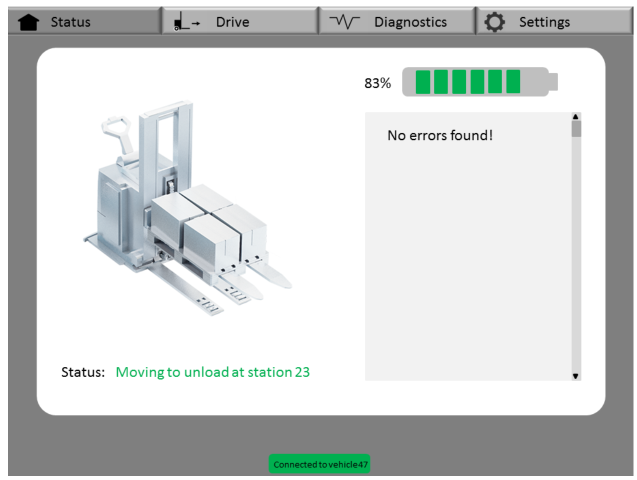
(a) *An option for a start screen.*



(b) *Second option for a start screen.*



(c) *Third option for a start screen.*



(d) *Fourth option for a start screen.*

Figure 8.4: The four options four start views that are being evaluated.

The first option (figure 8.4a) uses the Company's core corporate color as background. Big buttons are used for navigating to another view. The current view is shown by adding a glowing effect to that button.

The second layout (figure 8.4b) uses a grey and black color scale and all views can be seen when pressing the icon at the top left corner. A menu then appears where you can choose to which view you want to navigate.

The third layout (figure 8.4c) is darker than the prior. To navigate to next view a swiping from the right to the left should be done. The current view is marked in a glowing orange.

The last layout (figure 8.4d) uses tabs at the top to change views. The current view is marked in a darker shade of grey.

8.1.2.1 Evaluation

The interfaces of the start screens and the navigation methods within the apps were evaluated by four participants by asking questions about the different start screens and their navigation methods, see appendix I for the script that was used. The first start screen using large buttons with icons to navigate to other views was preferred by a majority of the participants because it was amongst other pointed out that it would be easier for someone with big hands or someone wearing gloves to press the buttons and because it was distinguished as having the most modern layout. It was assumed that the first button with the text *Status* was used as an indication of the vehicle's status while it should portray that it is the current view.

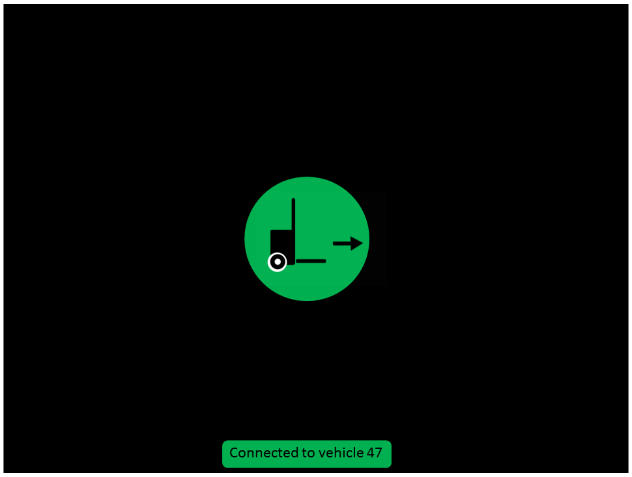
A few of the participants appreciated the blue background in the first start screen and all but one welcomed that the layout was clean without too many details. The remaining participant thought that more information should be fit on the start screen, like which segment of the driving layout the vehicle is located closest to, and which the next order is, while one of the other participants rather would have preferred less information claiming that the best would be a screen that only lets the user know if the system is working or not. This should be visualized clearly and with appropriate colors.

A disadvantage of using a navigation method where you swipe to navigate to the next view like in the third option is that it should not be possible to accidentally change view when you are in the drive view. An advantage with the fourth layout that uses tabs at the top is that you can always move to any of the other views. This is also true for the second layout with the difference that the views are not visible at all times.

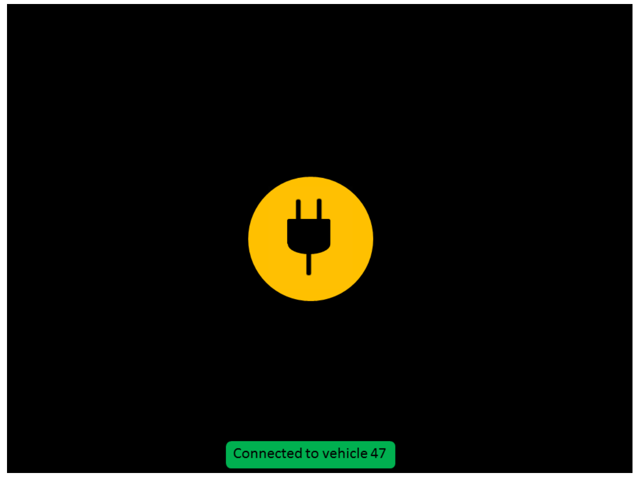
It was decided that the start screen to further develop was the first one where you navigate using tabs in the shape of big buttons. It was chosen since it had been appreciated by the participants for its uncluttered layout and because it was believed to be an uncomplicated way to navigate. The navigation buttons are only visible on the start screen which means that if a user is in the diagnostics view and wants to navigate to the drive view he has to pass through the start view. This was however considered as a strength since it should be a deliberate decision to enter the drive view instead of accidentally pressing the wrong tab.

8.1.3 Splash Screen

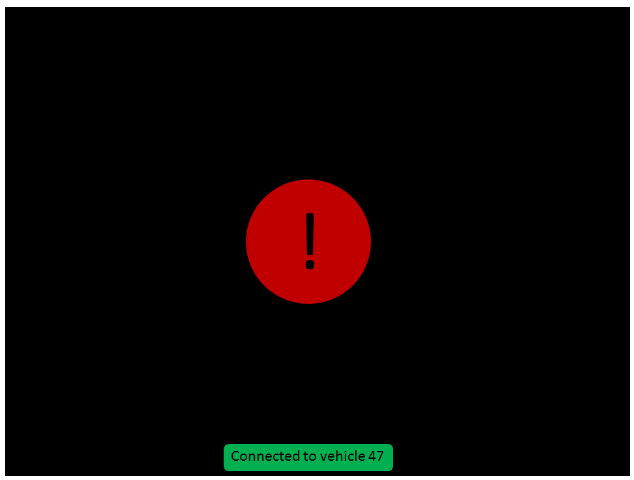
A splash screen is usually used when starting a computer or booting a program and often includes a logotype or something similar. It can also be used as a first screen of a website to let a user log in or choose language before moving on. A splash screen is used in this app to display the status of the vehicle. The screen should also communicate if there is connection established between the device and the vehicle. In figure 8.5 three alternatives for splash screens are shown. The first one uses an icon of a driving vehicle with a green background to portray that the system is functioning as it should and that the vehicle is managing orders. The second figure is used for when the vehicle is charging its battery or on its way to charge it and the third figure if there is an error.



(a) Splash screen for a system functioning like it should.



(b) Splash screen when vehicle's battery is being charged.



(c) Splash screen when there is an error.

Figure 8.5: A set of examples of splash screens with a dark screen and colorful icons to indicate the system status.

8.1.4 Diagnostics View and Settings

The diagnostics and settings views include most of the information that can be found in the Operator Terminal's menu, see figure 2.7. Many of the users are accustomed to these menus and the new views intend to be compliant to them. One change is to add descriptive icons for each menu and grouping them so that each group has a common denominator. The navigation method within the diagnostics and settings views will be stacked navigation bars where an arrow in the top left corner takes the user back one menu level. The menus are configurable and it is up to the application engineers to decide which menus are added to each company's app.

8.2 Graphical User Interface

Information can both be perceived through text but also through graphical expressions like icons and colors. Some examples of icons and what they can express is hereafter described as well as how colors and graphical elements can be used to make a clear and intuitive app layout.

8.2.1 Icons

While driving a vehicle manually or browsing other views there is certain information that can be useful to view in the interface. To make the information easier to perceive it is good to present it as icons and if needed, with a describing text.

Possible information and ideas for icons are presented in figures 8.6, 8.7, and 8.8.

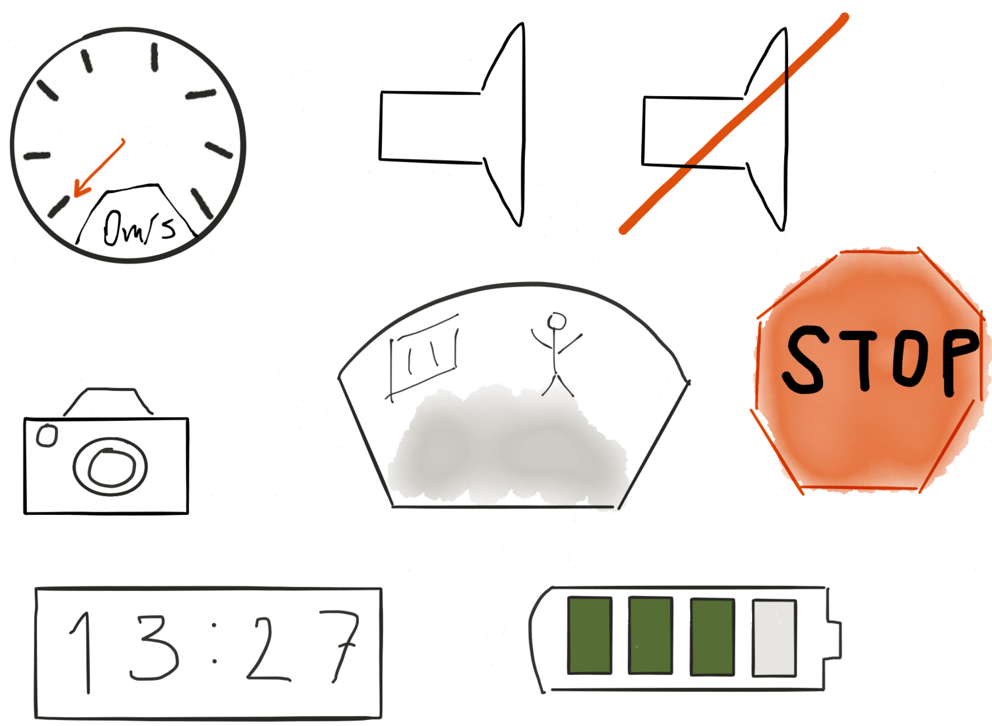


Figure 8.6: Icons.

In figure 8.6 the first possible information that can be displayed is speed, which can be presented like in many cars with an indicator that turns as the speed gets higher. If the steering app uses sounds for conveying information it can be useful to know if the sound is activated or not. A camera is a possible hardware unit that can be added to a vehicle and if that is the case, an icon can be used for turning on the video feed and another for looking at the view from the feed. An emergency stop button can be used ensuring that a vehicle cannot be steered while the button is enabled. Another feature can be to see the time and to see the battery level, either of the device or of the vehicle.

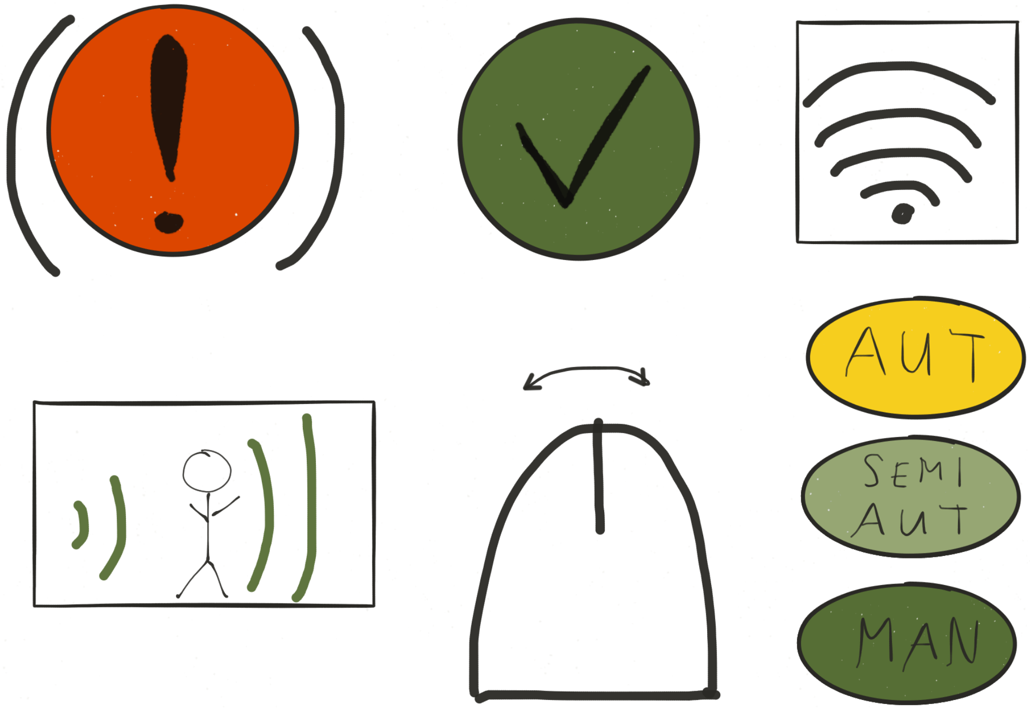


Figure 8.7: Icons.

The test apps created in chapter 7 (Technical Design) all contained some kind of safety measure, for instance that the speed and angle of the vehicle were zeroed when all touch was released. To present for the driver that he or she has taken the measures to be able to be steer can be useful, for instance by using a sign with a check, see figure 8.7. When it instead is not possible to steer, a sign similar to the one used in cars when the hand brake is not released can be shown and the measures that need to be taken can be high-lighted. Since many AGV systems stay connected through WLAN, there can be a sign used for showing the strength of the signal. If the safety sensors are activated, an icon can show this. To make it more clear in which direction the vehicle is heading, an image of the vehicle can be shown and the position of the wheels can be changed when the steering angles changes. The MCD can be set in three different steering modes; automatic, semi-automatic and manual.

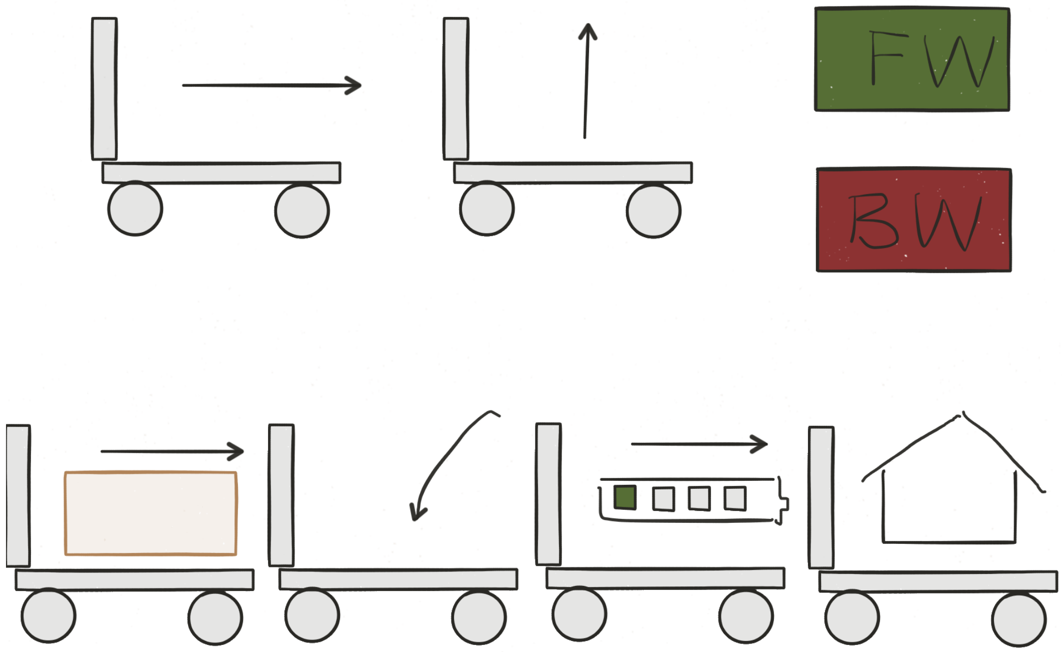


Figure 8.8: Icons.

In figure 8.8 the two first icons can be used for switching between steering the vehicle and the load unit. To indicate if the vehicle is driving forward or backward, two signs can be used for this. To know what kind of order a vehicle was doing before manual control of it was taken, different icons can be used.

8.2.2 Colors

Colors can be used for expressing a lot of different sentiments and meanings and one color might not mean the same thing in two different countries. Red has however come to be the color used for alerting, yellow for warning and green for progress and safety. The Company has some core corporate colors that can be seen in figure 8.9.

For the user interface the Company's corporate colors are used as the base colors while other colors like red and green is used mainly for informing. To make sure that the colors match with each other, different shades of the complementing colors are chosen.

Figure 8.9: The Company's corporate colors.

8.2.3 Graphic Elements

The Company has guidelines for the GUI elements, namely:

- Choosing a corner radius of 3 mm
- Letting buttons and bricks have a width 87,5% of the heighth
- Letting buttons and bricks that are placed close to each other have a distance of 2 mm in between

8.3 List of Detailed Needs

The elicited needs from the detailed design focused on how the interaction between the user and the interface is done are presented in this section.
Mobile Application

- Easy to navigate
- Intuitive
- Quick response to steering commands
- Information easy to reach

GUI

- Follow the corporate guidelines for colors
- Use colors in an informing way
- Follow the corporate guidelines for graphic elements

9

Final Design

This chapter presents the final design and specifications of a user interface the can communicate with an AGV. The results from chapters 5 to 8 have led to an understanding of the needs that exist when an operator of AGVs or an application engineer steer an AGV manually or diagnose why a vehicle malfunctions. Going through the phases have led to more knowledge and more ideas that have been used for the final design of the user interface that is presented in this chapter. The chapter ends with an evaluation of the improvements and the fulfillment of the elicited needs.

9.1 The AGV Interface App

The AGV Interface App is used for viewing information and diagnostics about an AGV as well as take control of it and steer it manually or command it to perform certain orders. The screen that is shown when there is no interaction with the tablet gives a brief status report showing if the system has an error, if the vehicle is blocked, if it needs to charge its batteries, or if everything is functioning like it should. When interacting with the screen the first view that is displayed is the start view, see figure 9.1. It provides more details about the status of the vehicle and it also provides the possibility to navigate to the drive view, the diagnostics view, and the settings view, see figure 9.1.

Figure 9.1: The different views of the AGV Interface App. The start view (marked with a blue glow) can be reached from all views except when entering tabs in the diagnostics and in the settings views. The settings view (with a glowing orange background) can be reached from all views.

The app accesses the vehicle controller of the AGV with Wi-Fi. By sending and reading signals to and from the vehicle controller the steering can be done and information and diagnostics can be collected. The app is designed for landscape orientation and is not adapted for portrait orientation. The app is configurable and can be customized to a certain industry's needs. The following views and menus are a suggestion for a basic app but there exists more parameters that can be read and written displaying more kinds of information.

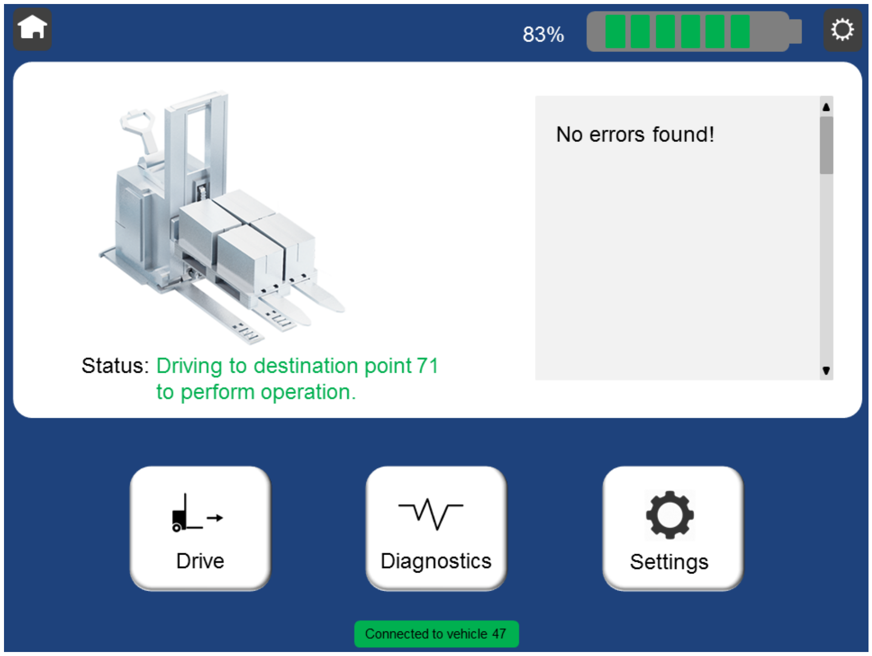


Figure 9.2: The start screen of the final app.

The start view seen in figure 9.2 shows an image of the vehicle. The image used does not need to be in 3D, it could be a 2D view seen from above. The image is used as a graphical representation of the vehicle's status. If it for instance carries a load, there should be a load shown and if there is an error like in figure 9.3, the location of the error should be shown. In a situation where the error is not linked to a specific hardware unit that can be shown in the image there should only be error information in writing in the box to the right of the image. All written information is presented with a description of the problem and a possible action of how to fix it. The information given on the start view should be brief and instead there is the possibility to read more about it by pressing the orange button and being transferred to diagnostics.

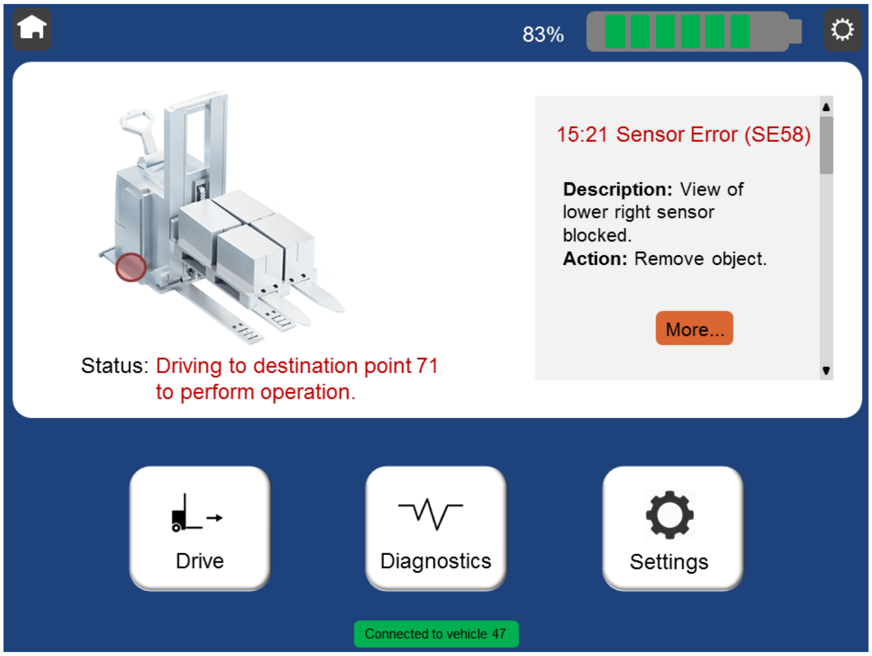


Figure 9.3: The final start view displaying an error.

To navigate to the other views you can press large buttons with texts and icons on in the bottom half of the view. The start and the settings views can always be reached from all views but the diagnostics and the drive views can only be reached from the start view. If a user wants to navigate from the drive view to the diagnostics view this will mean that there is one extra click required.

The battery at the top right corner shows how charged the AGV battery is by using segments and by writing how many percent of the battery is charged in numbers. The battery is shown in all views except in the drive views. A connection sign stating which vehicle the tablet is connected to is shown in all the views. The background of this button is green when there is connection and red otherwise.

Table 9.1: Status texts.

Order status number	Current text	Suggestion new text
0	No order.	Awaiting new order.
1	Have order with no operation and the vehicle is driving to the destination point.	Driving to destination point.
2	Have order with operation and the vehicle is driving to the destination point.	Driving to destination point to perform operation.
3	Standing on the operation point and wait for operation to finish.	Waiting for operation to finish.
4	Master has cancelled the non operation order and the vehicle is driving to the end of the last ordered segment.	Driving to last ordered segment. (Master Mode)
5	Master has cancelled the operation order and the vehicle is driving to the end of the last ordered segment.	Driving to last ordered segment. (Master Mode)
6	Master has cancelled the operation order and the vehicle is standing on the operation point, waiting for the PLC to cancel the order.	Waiting on operation point. (Master Mode)

The vehicle controller has six different states, see table 9.1, and every status has a matching string of text. These new texts that are used can be seen in the right column. All texts have been shortened to convey the message more briefly to make it easy for the user to perceive the contents.

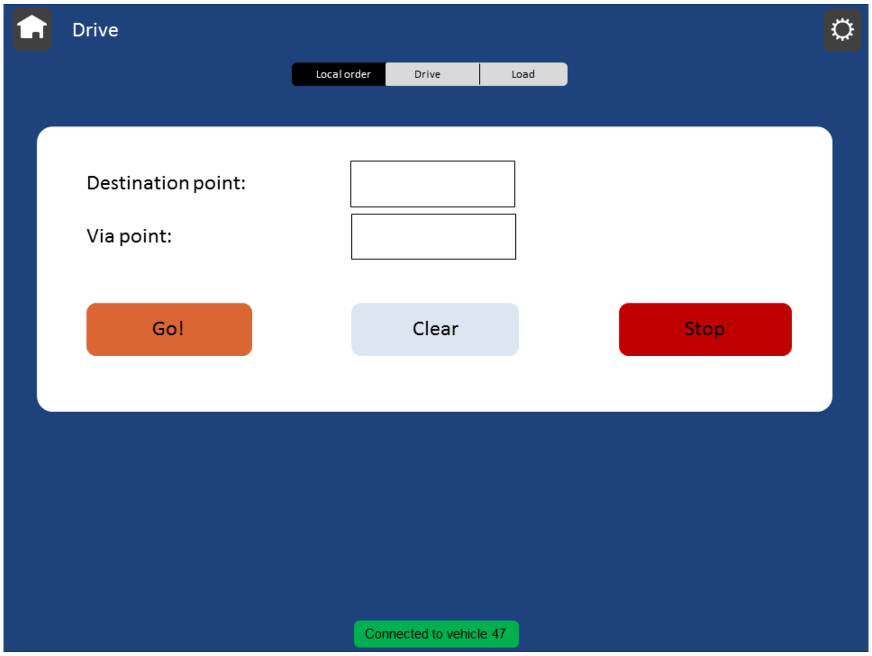


Figure 9.4: The drive view contains three views, the first one is the local order view.

The drive views contains three views; local order, drive and load. The local order view is reached first, see figure 9.4. It is used for sending the vehicle to a specific point in the system, a function that today is used a lot and that can be deployed with the Operator Terminal or through AppDesigner on a computer. This can only be done when the vehicle is in automatic mode. The local order view has a stop button that halts the order and a button for clearing the contents of the input fields. When the stop button has been pushed it will get a glowing effect to show the change.

Users that today do not utilize the MCD might not want to steer their vehicle with the app but most of them will still need to do a local order why this view is the first one to be viewed when entering the drive view.

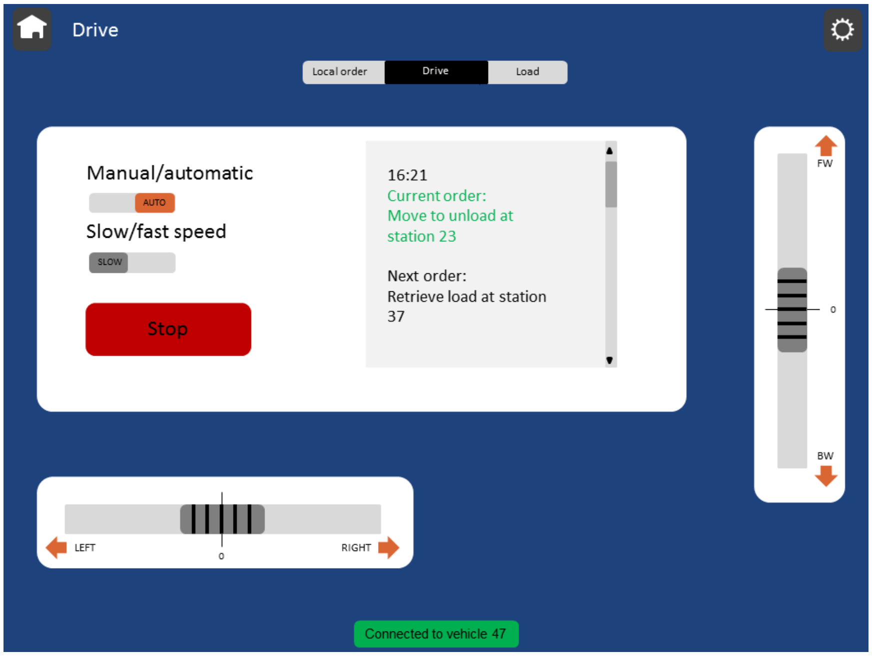


Figure 9.5: The drive view.

When entering the next view where manual steering can be done, the operation mode needs to be changed to *MAN* on the top switch if it has not already been changed in the settings view.

In case the vehicle was halted due to an error it might be in the middle of an order. In that case it is helpful that the order is shown in a box in the middle of the screen. This can help the operator to know how to continue steering the vehicle or the load unit.

The max speed of the vehicle has two modes; slow and fast. The speed of these modes can be changed in settings. When driving, the steering is done with a horizontal seek bar at the bottom left corner and the speed and direction is given with a vertical seek bar on the right side. The MCD provided two different set speeds whereas the seek bar lets he user adjust the speed varying from 0 m/s up to the maximum speed. Both seek bars are easy to reach but have a small distance from the display's edge to avoid ending up outside the display with the fingers. When releasing the seek bars they return to neutral position and the steering angle and speed are set to 0. When the seek bars are moved the indication on their middle will change to show the new speed or angle given.

Although the vehicle will halt when the seek bars are released it is also possible to press the stop button to stop it. When it has been pressed the vehicle cannot move until the button is pressed again. Just like in the local order view the stop button gets a glowing effect when it has been pressed.

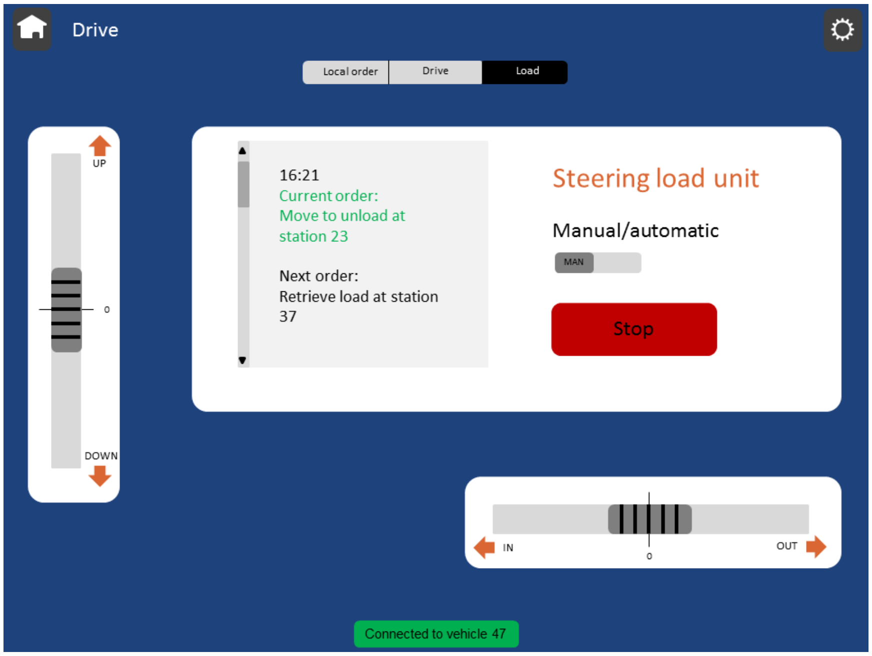


Figure 9.6: The load view used for steering the load.

The third view within the drive view is the load view. It is used for steering the load unit of the vehicle, like the forks of a forklift. This view is mirrored around the vertical axis compared to the view for steering the vehicle. This was done to make it clear for the user which view they are in. There is also a text added above the operation mode switch to emphasize which view is chosen. The vertical seek bar in this view is used for moving the load unit up and down and the horizontal seek bar is used for moving it in and out.

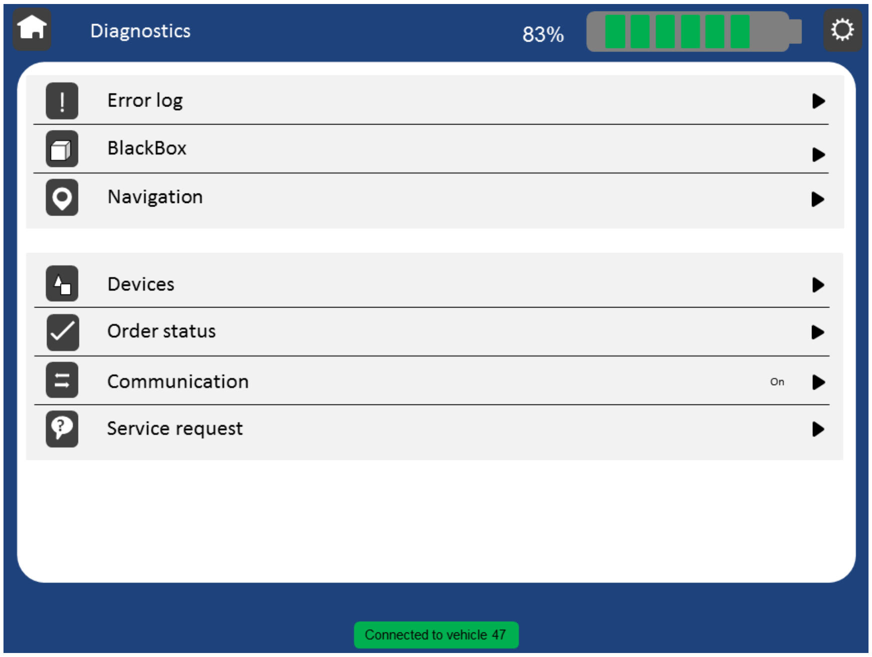


Figure 9.7: The diagnostics view.

The diagnostics view is a stacked navigation bar with two groups of menus that can be entered, see figure 9.7. The top three are related to diagnostics while the bottom ones are more related to information.

The Error Log gives thorough information about the errors with the most recent one at the top. The BlackBox tab allows the user to trigger a blackbox, just like in the Operator Terminal. The Navigation tab gives information about the navigational status of the vehicle, such as in which segment in the layout it is located at and at which point. It also gives the user the possibility to insert the vehicle in the navigational system if it is needed.

The second segment first contains a tab with a list of all devices that are connected to the vehicle controller, such as a laser scanner and security sensors. The Order Status tab lets the user see more specific information about the order status and the Communication tab gives information about the communication between the vehicle controller and the app. Finally the Service Request tab (see figure 9.8) contains the possibility to explain a problem and attach an image and send it to a technician or an application engineer that can be chosen from the send list or whose e-mail address is written manually. Pressing the top left arrow allows the user to return to the diagnostics view.

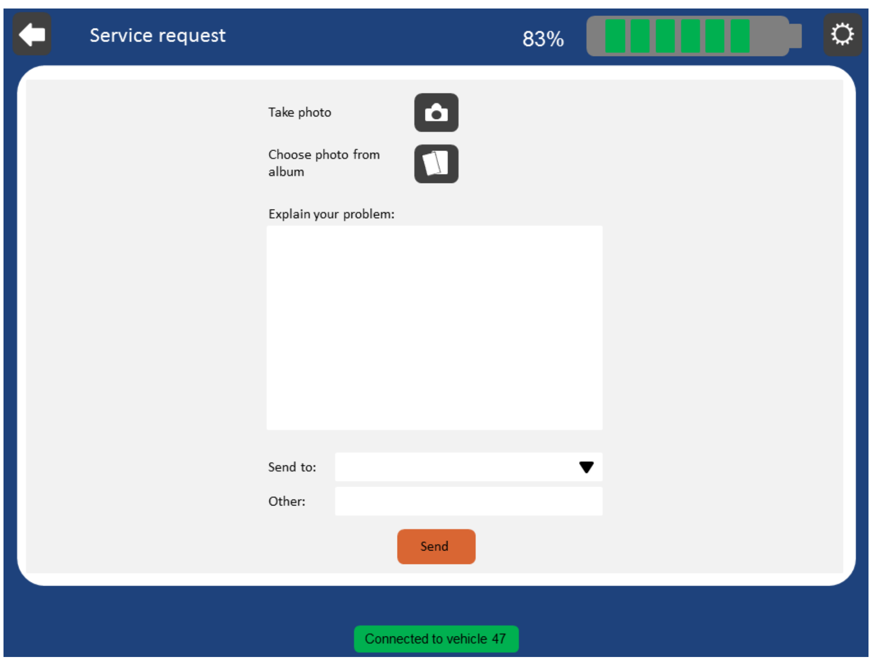


Figure 9.8: The view for sending a service request.

The final view is the Settings View that can be reached from all views with the icon in the top right corner. Different settings concerning the vehicle and concerning the app can be done in this view. Some of the current settings are presented in the settings view, like which language that is selected. By presenting it on the settings view the user does not need to enter the tab to verify the current setting. Some of the tabs only have one setting with two options and they are therefore displayed with a switch function like the text size tab where you can either choose a small or big text size. To help users with impaired color vision or others who do not appreciate colorful displays, there is an option to use a grey color scale. How the date and time should be formatted when presenting error and order information can be chosen from another tab.

As mentioned before it is possible to choose between two maximum driving speeds, see figure 9.10. It can also be added that only authorized personnel may change these speeds, for instance application engineers. To return to the settings view an arrow in the top left corner is pressed.

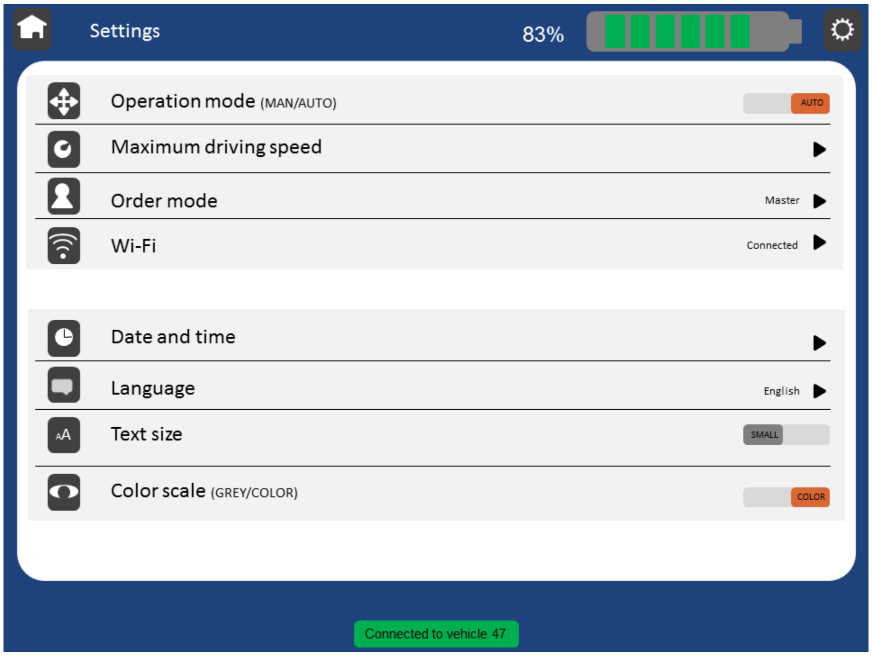


Figure 9.9: The settings view.

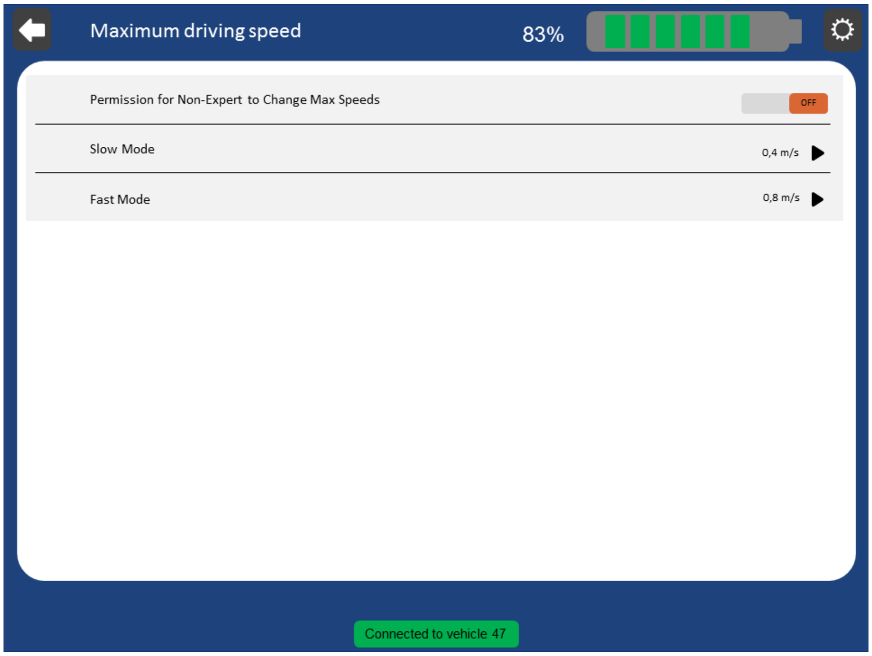
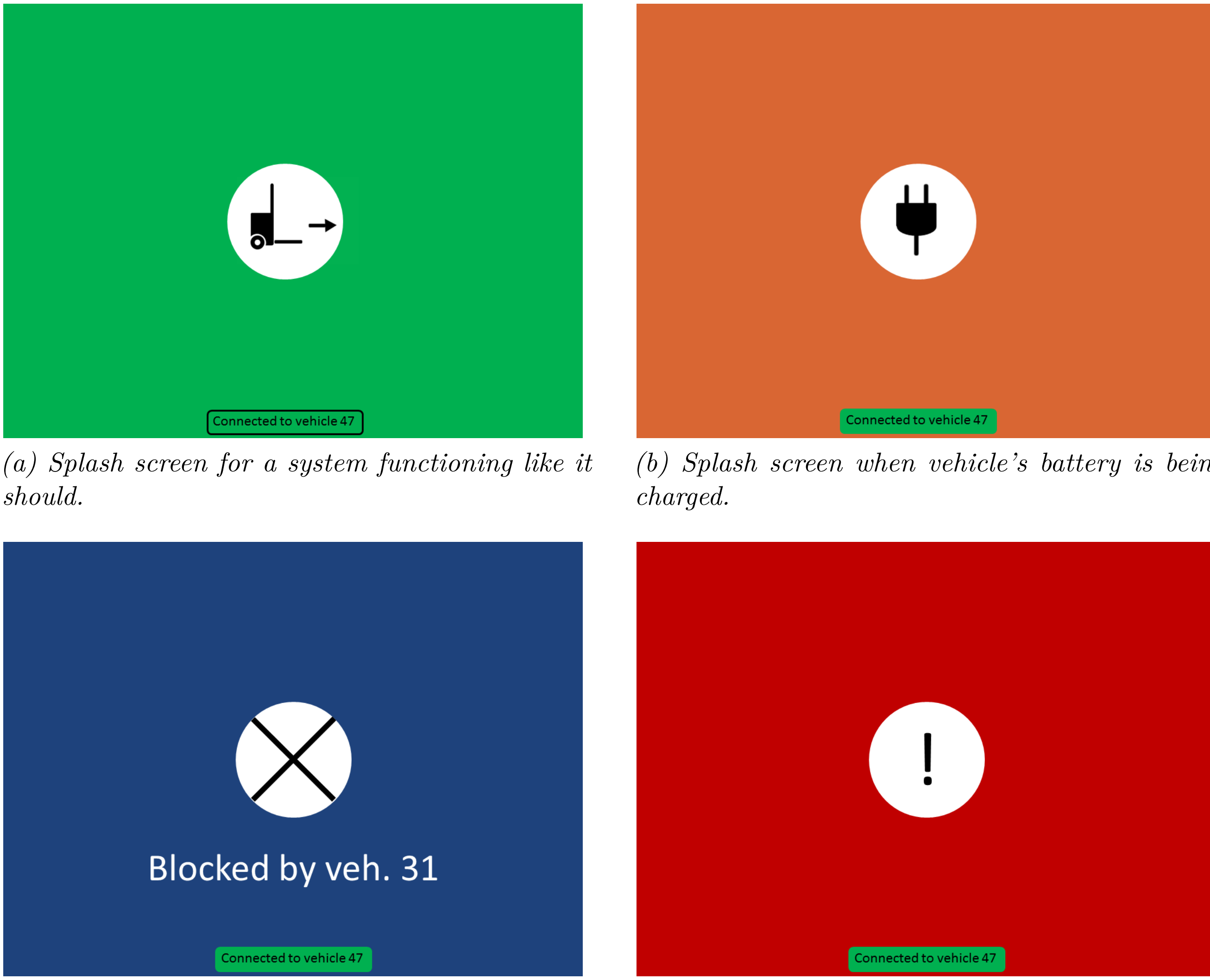


Figure 9.10: The view for setting the maximum driving speed.

There are four different splash screens that are shown when there is no interacting with the screen, see figure 9.11. When the system is functioning and the vehicle is taking orders the green screen shown in figure 9.11a is displayed. If the vehicle needs to get its battery charged a view like figure 9.11b is shown with an icon of an electric plug and an orange background. If the vehicle has been blocked by another vehicle it uses a blue background and displays a text like in figure 9.11c. Finally if there is an error this is portayed with a red background and an icon with an exclamation mark like in figure 9.11d. These four different screens should be easy for an operator to distinguish even if he is not so close to the vehicle and gives quick information about the vehicle's status.



(a) Splash screen for a system functioning like it should.

(b) Splash screen when vehicle's battery is being charged.

(c) Splash screen used when a vehicle is blocked.

(d) Splash screen when there is an error.

Figure 9.11: Splash screens indicating different statuses.

9.2 Device

In order to use the AGV Interface App it is recommended to use a rugged android tablet. The Company can find a manufacturer that sells tablets for industrial use with certain specifications and sell these devices with the apps pre-installed.
Out of the tablets that were benchmarked in section 7.2.5 (Hardware Options) the ALGIZ RT7 is otherwise recommended. In the future, if the Company wants to add security measures like pairing the device with the vehicle it can be good if the tablet supports these kinds of communications. If another steering method would be added, like the method used in the Gyro App (see section 7.1.1.2 (Mobile Applications)), it could also be good if the tablet has some sensors, like a gyroscope. There are several accessories that can be bought with the tablet, like a dock that can be mounted on a vehicle, a hand strap and a carry case (Group, 2016a).

The tablet is mounted on the vehicle and held in place with a dock. The tablet is easy to remove when being used and easy to replace in the dock. When placed in the dock the device is charged.

9.3 Evaluation

The final design was evaluated by doing a new User-Technical Process to see if the new interface requires fewer activities when steering a vehicle manually, by assessing how the personas would like the new interface and by evaluating if the needs elicited in the earlier phases were fulfilled.

9.3.1 User-Technical Process

In section 6.1 a User-Technical Process (UTP) of the MCD was done, see figure 6.2. To evaluate how the manual steering has changed with the app a new UTP was done, see figure 9.12. The result is that fewer user actions are required and that less technical functions are needed which is an improvement.

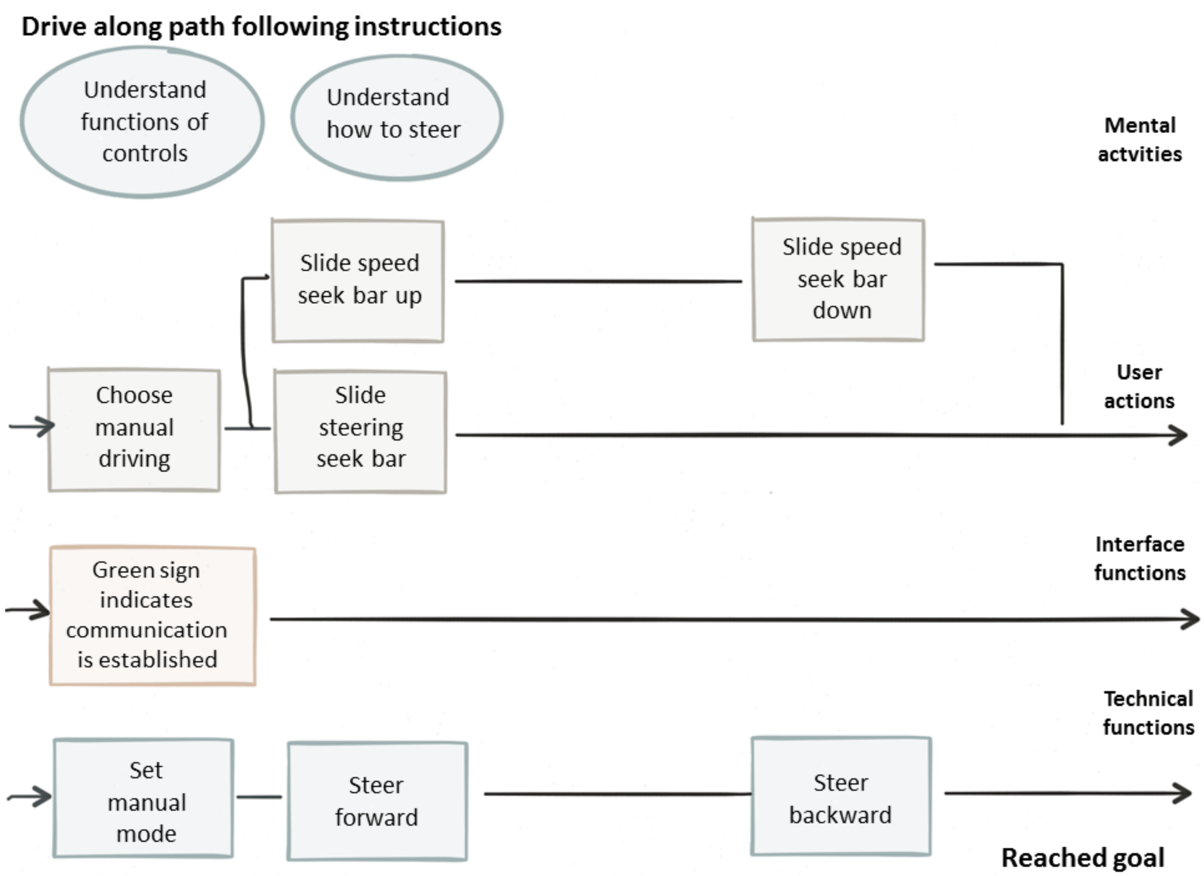


Figure 9.12: The User-Technical Process for performing the task from the first user study with the final design.

9.3.2 Personas

In section 5.3 three personas were described portraying three potential users of the new interface.

Susanna who wanted new technology can look forward to another smart solution that can optimize the manual operations performed on the AGVs. Gunnar who has been reluctant to take care of the AGVs found that the splash screen was an effective way to be given information about the vehicle status and even tried interacting with it. He felt that it was easier than he had anticipated and already managed to solve an error by reading the error action on the start screen. Finally, Fabian has started using a tablet for as many tasks as possible and is happy that he does not have to carry around a laptop when installing a new system. This has saved him time and inspired him to start thinking of new software applications that can be used on a tablet.

9.3.3 Needs Fulfillment

In chapters 5 to 8 different needs are elicited and presented in the end of each chapter. These needs are evaluated to see if they were fulfilled or not, see tables 9.2 - 9.4. If they were not fulfilled an action is presented. The result of the evaluation was that 86% of the needs were fulfilled while the remaining 14% need to be further investigated, see figure 9.13.

Some of the needs that were not fulfilled concerned the programming of the app, like adding password levels and being able to decide the sensitivity of the controls used for steering the AGV manually. These are functions that are possible to use in other apps but since it has not been tested it needs to be further investigated.

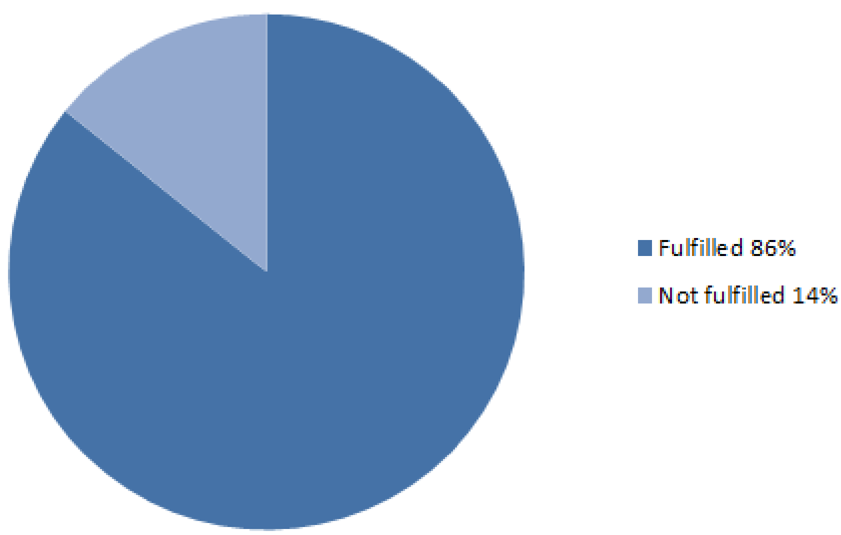


Figure 9.13: A pie chart that illustrates the degree of needs fulfillment of the final app.

Table 9.2: Evaluation of needs fulfillment.

Category	Criterion	Origin (phase)	Need fulfilled?	Action
Usage	**Be easy to use seldom or often**	Needs Mapping	Yes	-
	Should not require remembering specific information	Needs Mapping	Yes	-
Context	**IP65-support**	Needs Mapping & User Design	Yes	-
	Dynamic temperature support	User Design	No	Verify if this is available in a mobile device
	Should keep a low weight	Needs Mapping	Yes	-
Functions	**Make information about all the AGVs in a fleet accessible remotely**	Needs Mapping	No	Could be possible if safety allows it
	Compability between new product and other products	Needs Mapping	Yes	-
	Be able to steer a vehicle manually in an intuitive way.	Needs Mapping	Yes	-
	Easily access detailed error information	Needs Mapping	Yes	-
	Possibility to steer vehicle manually with more than two different speeds	User Design	Yes	-
	Possibility to configure reactiveness of controls used for steering vehicle manually	User Design	No	Can be programmed
	Configurable unit	User Design	Yes	-
	Programmable unit	User Design	Yes	-
	High level of customization	User Design	Yes	-
	Possibility to add password	User Design	No	Can be programmed

Table 9.3: Evaluation of needs fulfillment.

Category	Criterion	Origin (phase)	Need fulfilled?	Action
Usability	**Clean interface**	User Design	Yes	-
	Descriptive icons	User Design	Yes	-
	All controls visible	User Design	Yes	-
	Self-descriptive functions of elements visible in the interface	User Design	Yes	-
Hardware	**Wireless**	User Design	Yes	-
	Touch screen	User Design	Yes	-
	Color screen	User Design	Yes	-
	Use standard components	User Design	Yes	-
	Dockable on vehicle	Technical Design	Yes	-
	Chargeable both on vehicle and elsewhere	Technical Design	Yes	-
	Easy to carry with you	Technical Design	No	Could be if an accessory is used
	Easy to hold	Technical Design	Yes	-
Display	**Support multi-touch**	Technical Design	Yes	-
	Proper sized screen	Technical Design	Yes	-
Sensors	**Gyro**	Technical Design	Yes	-
	Accelerometer	Technical Design	Yes	-
	Camera	Technical Design	Yes	-
Communication	**Wi-Fi**	Technical Design	Yes	-
	Bluetooth	Technical Design	Yes	-
	Other communication that can be used for pairing two devices	Technical Design	Yes	-

Table 9.4: Evaluation of needs fulfillment.

Category	Criterion	Origin (phase)	Need fulfilled?	Action
Mobile Application	**Easy to navigate**	Detailed Design	Yes	-
	Intuitive	Detailed Design	Yes	-
	Quick response to steering commands	Detailed Design	No	The application can be programmed differently to be quicker
	Information easy to reach	Detailed Design	Yes	-
GUI	**Follow the corporate guidelines for colors**	Detailed Design	Yes	-
	Use colors in an informing way	Detailed Design	Yes	-
	Follow the corporate guidelines for graphic elements	Detailed Design	Yes	-

9.4 Summary

To be able to steer a vehicle manually in an easy and intuitive way and to view essential information about a vehicle quickly, an app used in a mobile tablet was developed. It connects wirelessly with the vehicle controller which makes the usage flexible.

This chapter has described how the interface is designed and which functions are used. An app was created in chapters 7 and 8 to test the technical feasibility which acted as a confirmation that it is possible to implement the functions in an app. An evaluation was also done to see that the final design has fulfilled the elicited needs for the interface and to see if it is an improvement compared to the old hardware devices. Instead of using the MCD for steering a vehicle manually and an Operator Terminal for viewing information and diagnostics about a vehicle, the interface includes the functions of both hardware units as well as new functions such as being able to drive the vehicle in more varying speeds with two different maximum speeds, viewing vehicle information visually as well as textually, and viewing status information clearly without having to stand close to the Operator Terminal.

A discussion about the fulfillment of the project aims and about future improvements can be found in the following chapter.

10

Discussion

This chapter consists of a discussion of the work that has been done in the development of a user interface. The fulfillment of the project is first discussed based on the Purpose and Aim that was set in the introduction and also based on the evaluation that was done in the final design. The project process is then discussed looking at certain parts that worked well or could have been done differently. Lastly some future improvements for the development of the user interface are stated.

10.1 Fulfillment of Project Aim

The end result of the project was a functional prototype of an app that can steer an AGV manually (see figure 8.3,) but it did however not have the right views and navigation methods according to the final design. Instead the layout of the final user interface was described in detail including how to navigate between the views and the functions of different interface elements.

There were three main questions that were investigated when eliciting customer needs; what information the customer wants displayed about the vehicle, in what kind of hardware this information should be accessible and how the manual steering of the vehicles can be done. These questions were explored by interviewing both end users and application engineers, through testing the current hardware units, the MCD and the Operator Terminal, and by letting users evaluate new concepts for a user interface. The main findings to the questions were:

- The information that users want displayed in the user interface varied a lot but a common need was to be able to view errors in a detailed way using graphic representations, and another to get quick status information; if the system is functioning normally or if there is some kind of error.
- Many wanted the interface to be viewed in a touch screen and many were positive to it being in a wireless device why a tablet was chosen as device.
- The manual steering that is today done with the MCD contains many actions and its interface gives the users many options that sometimes are not clear. Instead, the manual steering should be done in an easy and intuitive way. It should not matter if a user steers a vehicle

manually on a daily or a monthly basis; the means of steering should not have to be relearnt and should not be so complicated that it is tedious to use it often.

The new interface is designed to only include essential functions that are presented in a clear way. The design guidelines stated in chapter 3 concerning how to make usable interfaces that help the cognitive processes of a user interacting with an interface were considered throughout the process and for instance affected the design to include more icons, more grouped items, and more salient details with the help of colors.

10.2 Project Process

The ACD^3 methodology used in the project proved to have a structure that helped the project move forward. In the Technical Design phase it was examined if it was technically possible to create a working app according to the needs that were so far elicited. This part of the process took up a lot of time but was very helpful since ideas were tested early on instead of in the final phase making it possible to see how well the different ideas worked in reality.

A disadvantage of the methodology was that I sometimes did not plan ahead far enough, instead every phase was conducted once at a time and decisions concerning the following phases were not taken until all analyzes and evaluations had been done. This was apparent when concluding the interviews in the needs mapping phase and realizing later on that there were some questions that would have been good to ask the end users. It was then more difficult to contact the interviewees again. The benefits of using the process, such as keeping an open solution space for a longer time and taking decisions based on new data gathered from user tests, however outweighs the disadvantage. Some other parts of the process are hereafter discussed.

10.2.1 Data Gathering

One method that was used a lot for data gathering in the project was user studies both for evaluating how the old products were used but also for evaluating if the developed interface provided the right functions and the right intuitiveness. Data was also collected by interviewing and observing real users in their work environment. In these different gatherings of data the selection of interviewees and participants was limited due to most users being located in other countries or further away in Sweden.

When visiting some of the industries the main interviewee was someone that had taken part in deciding to install AGVs and these persons were generally supportive of new technology. They were also more prone to being positive to new technology that could replace the MCD and the Operator Terminal whilst others had a tendency to want to keep the hardware that was already in use. Something that could have been helpful was to distribute a questionnaire at every industry to get a wider distribution of responses. The persons responsible for installing AGVs can however be those that will also take the future decision to upgrade the current MCD and Operator Terminal and in that case their opinion has had the opportunity to affect this development.

A difference that was noticed between the participants in the user studies at the company was that those that had more experience of using the MCD that evaluated the new driving interface compared it to the MCD to a greater extent. The fact that the seek bars return to neutral position when released was therefore criticized at first but it was at the same time a feature that was appreciated for certain situations. This made it more difficult to understand what opinions were biased due to previous experience of the MCD and what opinions really were important to consider.

10.2.2 Integration of Hardware Units

The final interface was supposed to be an integration of two hardware units which it also accomplished. During the project, and especially in the beginning of the process, it was however difficult to deal with these hardware units and try to see them as an integrated product. Instead the work became focused on either the MCD or the Operator Terminal and admittedly it was the MCD that got most of the attention. This was mainly due to the Operator Interface's contents already being presented on a screen while the functions of the MCD would need to be presented and used in a different way and in another kind of hardware. This imbalance did not hurt the process but can be noticed in the report.

10.2.3 Prototyping

Due to limited programming experience there is a risk that some ideas were suppressed due to a lack of knowledge of how to actually program them. The Joystick App that was developed was supposed to have a fictive socket so that its outer bounds had a circular shape taking up one half of the screen (the right side since most people are right-handed). Instead the outer bounds were the edges of the screen which meant that the users had to reach quite far to move the joystick around. Many attempts of creating this circular bound was done but the result proved to function poorly and unsmoothly.

10.3 Future Development

The functional prototype of the app that was created was adapted to a 7" screen on an android platform. Creating a layout that is scaled to fit different sizes of screens and different platforms is a recommended activity unless specific mobile devices will be sold with the app preinstalled. Some users stated that they wanted to be able to use this kind of app on their smart phones. It should be evaluated if this can be profitable for the Company and how the app should be adapted to fit a smart phone.

Some other suggestions for future development are hereafter given.

10.3.1 Safety Measures

Something that could be very practical and good from an environmental perspective is using fewer devices than AGVs in a vehicle fleet. If one tablet was not used for a specific vehicle the app would need to be modified, it would for instance be fruitless using a splash screen. Instead there would be a need to be able to choose to which vehicle to connect the app. This could for instance be done by holding the tablet over a barcode on the vehicle or over an RFID tag. This would however mean that the user has to be in the close proximity of the vehicle which can be hard if the vehicle is situated in a place that is hard to reach. It can also be a good thing since it is harder to mix up which vehicle you are connected to. Another option could be that you get a list of which vehicles that are close to you and you can choose to which one you would like to connect. This would require a system that makes the vehicle unavailable when it is picked by a user. A third option could be that the start screen of this revised app had a view similar to CWay where the layout with the vehicles is shown. The user could pick a vehicle from this view and just like for the second option this would make that vehicle unavailable for everyone else.

When it comes to steering a vehicle with a mobile app, there is a risk of an intrusion in the system and that someone could take over a vehicle and potentially wreck something. This could especially be dangerous if the AGVs are located in an environment with hazardous elements. Something that can be looked into is using machine learning for letting the system get used to what behaviors the users normally have. This way it is easier to see when something abnormal happens and the system could in that case shut down.

As mentioned in chapter 1, there are currently regulations stating that controlling an AGV manually requires using a device connected to the vehicle by cable. These regulations could be modified in the future but if they are not and there is an interest to commercialize the user interface developed, it could be investigated if there are tablets that can sense if they have a power cable connected to them and if it would be possible to only use the drive view when the power cable is connected. Alternatively the drive view could be removed if there is an interest to use the rest of the interface.

10.3.2 The Future User

The development of the user interface has mainly been targeted at the primary users; operators, maintenance personnel and technicians working with AGVs. Although the interface will hopefully replace the MCD and the Operator Terminal and be utilized by this kind of user, it is also an interface that could be helpful for application engineers at the Company and at partner companies. The app would need to be modified for this kind of user and would for instance not need the splash screen. Instead there would need to be a function for choosing which vehicle to connect to. It could also be good adding a shortcut between the diagnostics and the drive view since they use local order frequently.

10.3.3 The User Interface

An option to choose two different maximum speeds was added to the drive view to help the user avoid too high speeds in a case where a vehicle was surrounded by sensitive objects for instance. This option that makes the drive interface more customizable can be expanded to also include the choice to have a narrow or broad turning radius when steering with the seek bar. For someone that appreciates a control that is not so reactive a narrow turning radius would make the steering less reactive.

The vehicles have emergency stop buttons that can be pressed. An indication on all three drive views of the interface should be added if this button has been pressed on the vehicle, for instance above the fictive stop button. Since the stop button on the vehicle needs to be disabled to be able to steer the vehicle again, a fictive light could be added to the interface showing if the emergency stop is enabled or not.

During the project some haptic elements were investigated but they were never used in the final product. It could however be useful to give attention to certain events and make the interface more informative. Some options for haptic elements are:

- A beeping sound used when moving the load unit vertically. When approaching the outer positions the sound could have a higher frequency and when the outer position was reached the sound could become a continuous beep.
- When driving the vehicle a vibration could be used when you reach the maximum speed. This would help the user to not have to look at the interface as much.
- A switching sound could be used for revealing that the operation mode (manual or automatic) has been changed.
- A short vibration when connecting successfully to a vehicle.

Adding sounds and vibrations would also require adding the possibility to turn off these features in the settings view.

10.3.3.1 Feedback

To better understand what views or functions a user usually interacts with and how long time the user spends on a certain view, it can be useful to collect data. The information can then be used to help the user get a better experience but it can also generate a bigger profit for the company. Improvements of the usability of the app can be done by collecting user data but for ethical reasons data from this usage should not be collected except if permission has been given through accepting a privacy policy or similar.

10.4 Learnings

The project was conducted by one project member which meant that the work was very independent. I had the benefit of having two interested and helpful supervisors; one academic and the other from the company. The autonomous work mostly suited me except when I needed to bounce ideas with someone and when there was a lot to write in the report. That said I would have chosen doing the project independently if I had to choose again because of the benefits of having large flexibility and because I had to base many decisions on the outcomes of user studies and interviews which drove me to interact more with users and theorize less. Another benefit was that I could not rely on another person's abilities and skills which meant that when subjected to something I had not done before, I had to learn how to do it myself. For this kind of project I was grateful that I got to learn so many things, like programming in C #, developing an app, and interface design.

The main thing I would have done differently in a similar project is letting the first half of the project take less time leaving more time for the main development (or simply take more time for development if there were no time limits). The activities from the first half were still important but could have been done more effectively.

11 Conclusion

This last chapter serves as a concluding remark of the Master's thesis project described in this report.

A user interface for an AGV has been developed in this project. The outcome is a functional prototype of an app that can connect to a vehicle and enable manual steering of it, and a description of the complete app with all its views and functions. Using design guidelines and considering customer needs elicited through various methods, generated several ideas that were rated through user studies and evaluations, resulting in a final design.

The final design of the user interface focuses on providing different information in an easy way to different kinds of users, as well as intuitive manual steering of an AGV. The resulting app shows a color-coded splash screen with a symbolic icon when there is no interaction with the screen. This view provides fast information about the vehicle's status. After touching the screen the start view contains the most essential information for the user; the detailed status of the system, the order the AGV is handling, if there is a connection between the AGV and the app, and if there has been an error, where it is located and how it can be fixed. The drive view is designed to handle a local order and gives the possibility to steer both a vehicle and its load unit. All diagnostics is found in a separate view, and all settings, either related to the settings of the AGV or of the user interface, can be done in another view.

Through interviews with AGV operators and observations of typical AGV environments it was clear that there is a need for a robust device for the user interface. The environments are dusty, have varying temperatures, and sometimes expose the device to liquids and moisture. A robust tablet was therefore chosen as the mobile device.

In order to create an app according to the final design specifications and using it in the industry there are certain safety aspects that must be considered. A law that today prohibits the use of wireless devices for steering an AGV needs to be modified, or else a cable has to be attached to the tablet when using the drive view.

The integrated devices for manual control of a vehicle, also monitoring diagnostics and information, that other companies have developed have specific hardware that is quite often more bulky than using an app on a tablet and most of them are not wireless. Although there are apps used for steering toy vehicles, none that are used for these purposes in the industry have been found within the scope for this report. This app used in the appropriate mobile device and with the adequate safety measures could act as a modern and helpful tool for controlling the AGVs in the future.

References

Abbas, S. Q. and A. Aggarwal (2010). "Development of a quality design framework for usable User Interfaces". In: *International journal on computer science and engineering* 2.5, pp. 1763–1767. DOI: `http://www.enggjournals.com/ijcse/issue.html?issue=20100205`.

Arena, GSM (2014). *Samsung Galaxy Tab Active LTE*. URL: `http://www.gsmarena.com/samsung_galaxy_tab_active_lte-6658.php`.

Axis Communications, AB (2016). *AXIS F34 Surveillance System*. URL: `http://www.axis.com/se/sv/products/axis-f34-surveillance-system`.

Banga, C. and J. Weinhold (2014). *Essential mobile interaction design: perfecting interface design in mobile apps*. 1st. Upper Saddle River, NJ: Addison-Wesley. ISBN: 9780321961570;0321961579;

Beitz, W. et al. (2007). *Engineering design: A Systematic Approach*. 3rd. London, England: Springer-Verlag London Ltd.

Bligård, L-O. (2015). *ACD^3 Utvecklingsprocessen ur ett människa – maskinperspektiv*. 2nd. Gothenburg, Sweden: Chalmers.

Bohgard, M. et al. (2010). *Arbete och teknik på människans villkor*. 2nd. Stockholm, Sweden: Prevent.

Boy, G.A. (2011). *The handbook of human-machine interaction: a human-centered design approach*. Burlington, England; Ashgate. ISBN: 9780754675808;0754675807;

Castro Lozano, C. de et al. (2011). "Usable Interface Design for Everyone". In: *Human-Computer Interaction, Tourism and Cultural Heritage: First International Workshop, HCITOCH 2010, Brescello, Italy, September 7-8, 2010. Revised Selected Papers*. Ed. by F. V. Cipolla Ficarra et al. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 157–172. ISBN: 978-3-642-18348-5. DOI: `10.1007/978-3-642-18348-5_15`. URL: `http://dx.doi.org/10.1007/978-3-642-18348-5_15`.

Chisnell, D., J. Rubin, and J. Spool (2011). *Handbook of Usability Testing : How to Plan, Design, and Conduct Effective Tests*. 2nd. Indianapolis, USA: Wiley Pub.

Dalal, U. (2015). *Wireless Communication and Networks*. 1st. New Delhi, India: Oxford University Press. ISBN: 019809888X;9780198098881;

Deaner, E. et al. (2009). *User Study Guidelines*. URL: `http://www.english.certec.lth.se/haptics/papers/HaptiMap_d12.pdf`.

Dustin (2016). *Sök*. URL: `https://www.dustinhome.se/search/samsunggalaxytabactive?ssel=false&gclid=Cj0KEQjwqMHABRDVl6_hqKGDyNIBEiQAN-O9hOAFhQV6O4vgpe0AWSq5MArnvNPGgLhAf`
`_ga=1.17061689.1258365077.1477474591`.

Getac (2016). *Getac Z710 Tech Specs*. URL: `http://en.getac.com/tablets/Z710/specs.html`.

Globalspec., IEEE (2016). *UL STANDARD FOR SAFETY ELECTRIC-BATTERY-POWERED INDUSTRIAL TRUCKS*. URL: `http://standards.globalspec.com/std/9911306/ul-583`.

Group, Handheld (2016a). *ALGIZ RT7 Accessories*. URL: `http://www.handheldgroup.com/en/rugged-computer/tablets-notebooks/algiz-rt7/?gclid=CjwKEAjwy8bABRD5osXMovTHpmQSJACfZY`
`18jhR1ypZPI0SDbO5WnIE0kYcu5mx2dS4KzAWORhoCuqDw_wcB#tab=accessories`.

— (2016b). *Algiz RT7 Heavyweight Field Performance*. URL: `https://static.handheldgroup.com/globalassets/downloads/product-information/data-sheets/low-res-website/en/algiz-rt7-data-sheet-en.pdf`.

Janhager, J. (2005). "User Consideration in Early Stages of Product Development – Theories and Methods". PhD thesis. Stockholm, Sweden: Royal Institute of Technology.

Kollmorgen Automation, AB (2016a). *About*. URL: `http://ndcsolutions.com/about/`.

— (2014a). *Create Layout, 2014*. 12/2014. NDC8 Online January 2016.

— (2014b). *Create Vehicle Application, 2014*. 12/2014. NDC8 Online January 2016.

— (2014c). *CWay Online Guide, 2014*. 12/2014. NDC8 Online June 2016.

— (2016b). *NDC Solutions*. URL: `http://ndcsolutions.com/ndc-solutions/#ndcconcept`.

— (2014d). *NDC8 Demo CWay Specification, 2014*. 12/2014. NDC8 Online June 2016.

— (2016c). *Product Description CVC600, 2016*. NDC8 Online January 2016.

— (2016d). *Product Description MCD8, 2016*. NDC8 Online January 2016.

— (2016e). *Product Description OPT100-DL, 2016*. NDC8 Online January 2016.

— (2014e). *Product Description Spot Antenna and Magnets, 2014*. NDC8 Online January 2016.

Kollmorgen Automation, AB (2016f). *Total Commitment for Lower Total Costs*. URL: http://ndcsolutions.com/wp/wp-content/uploads/2016/07/35200-005H_NDC_Solutions.pdf.

— (2016g). *Vehicle Diagnostic Tool Online Guide, 2016*. 1.6.0. NDC8 Online January 2016.

— (2016h). *Why AGV?* URL: http://ndcsolutions.com/why-agv/.

Magasinet, Proffs (2016). *Handheld Algiz RT7 Med 2D streckkodsläsare*. URL: http://www.proffsmagasinet.se/kommunikation/barbar-dator/barbar-dator/handheld-algiz-rt7.

Marketshare, Net (2016). *Mobile/Tablet Operating System Market Share*. URL: https://www.netmarketshare.com/operating-system-market-share.aspx?qprid=8&qpcustomd=1.

Nielsen, J. (1993). *Usability Engineering*. 1st. Massachusetts, USA: Academic Press Inc.

Nordic, Micro (2016). *FZ-M1*. URL: http://micronordic.se/panasonic/fz-m1.html?keywords=Panasonic%20fzm1&gclid=Cj0KEQjwqMHABRDVl6_hqKGDyNIBEiQAN-O9hPjrMx--3JXux_s9Qr8cZ6XXZWHz033HD6sVakwr8qgaAjpc8P8HAQ.

Panasonic (2016). *Toughpad FZ-M1*. URL: ftp://ftp.panasonic.com/computer/fzm1/fz-m1_specsheet.pdf.

Phone, My Trendy (2016). *SAMSUNG GALAXY TAB ACTIVE LTE HÅLLARE*. URL: http://www.mytrendyphone.se/shop/samsung-galaxy-tab-245038c1.html.

Preece, J., Y. Rogers, and H. Sharp (2007). *Interaction design : beyond human-computer interaction*. 2nd. Hoboken, USA: John Wiley Sons.

Press, Oxford University (2016). *Oxford Dictionaries*. URL: http://www.oxforddictionaries.com/.

Prisjakt (2016). *Surfplattor*. URL: http://www.prisjakt.nu/produkt.php?p=1697773.

Review, Rugged PC (2014). *Panasonic Toughpad FZ-M1*. URL: http://www.ruggedpcreview.com/3_slates_panasonic_toughpad_m1_full.html.

Samsung (2016). *Galaxy Tab Active (8.0, 4G) Funktioner*. URL: http://www.samsung.com/se/consumer/mobile-devices/tablets/others/SM-T365NNGANEE.

Security, Acquris Media (2016). *Tabell - IP-tätning*. URL: http://www.acquris.se/media/index.php?id=37.

Ulrich, K. T. and S.D. Eppinger (2012). *Product design and development*. 5th. New York, USA: McGraw-Hill.

Varma, T. (2015). *Agile Product Development: How to Design Innovative Products That Create Customer Value*. English. 1st. Berkeley, CA: Apress. ISBN: 1484210689;9781484210680;1484210670;97814842106

Wallgren, P. (2015). *Qualitative methods - Data collection*.

World, Computer (2015). *Break me if you can: 4 rugged tablets put to the test*. URL: http://www.computerworld.com/article/2882568/tablets/break-me-if-you-can-4-rugged-tablets-put-to-the-test.html?page=2.

List of Appendices

A Interview Guide - Users ... II

B Interview Guide - Users (English Version) ... IV

C Interview Guide - Application Engineer ... VI

D Script - User Study ... VIII

E Script - User Study (English version) ... XI

F Script - User Study Prototypes ... XIV

G Script - User Study Prototypes (English version) ... XVII

H Script - Evaluation Drive View ... XX

I Script - Evaluation Start View ... XXIII

A

Interview Guide - Users

Företagsinformation

- **Hur många AGVer har ni?**

Styrning: ☐ MCD ☐ Styrhandtag

Display: ☐ OPT100 ☐ OPT10 ☐ OPT7 ☐ Annan:.................

- **Hur många anställda är ni?**

Användning

- **Vad använder ni AGVn till?**
- **Vilken är den vanligaste interaktionen med AGVn?**
- **Hur många olika personer brukar interagera med AGVn? Vilka är de?**

Displayen

- **Hur använder ni displayen? Hur ofta?**
- **Hur ofta konfigurerar du om displayens innehåll?**
- **Finns det någon typ av information du skulle vilja ha om AGVerna i displayen som inte finns?**

MCD/manuell styrning

- **När brukar AGV'n styras manuellt? Hur ofta?**
- **Kan du styra AGV'en manuellt med den grad av precision som du önskar?**
- **Kan du tänka dig att styra AGV'n utan att ha uppsyn över den? Om nej, varför?**

Allmänt

- **Använder du mjukvaran, t ex app design eller cway?**
- **Skulle du tycka det var användbart med:**
    - **Utförlig information om vad felkoder betyder på en display ?**
    - **Olika säkerhetsnivåer för att få åtkomst till displayen eller för att styra AGVn?**
    - **Kunna se AGVns vy i en bärbar enhet (t ex vid felmeddelande)? T ex stå längre bort och kunna felsöka på långt håll**
    - **En trådlös styrningsenhet?**
    - **En trådlös display?**
    - **En display med touchskärm?**
- **Om du hade en trådlös enhet för att styra AGVn och för att felsöka, hade du kunnat tänka mig att alltid bära med dig den?**
    - **Vilken typ av hårdvara hade du velat använda? Tablet/smartphone/...**

B

Interview Guide - Users (English Version)

Company information

- **How many AGVs do you have?**

Steering: ☐ MCD ☐ Tiller handle

Display: ☐ OPT100 ☐ OPT10 ☐ OPT7 ☐ Other:....................

- **Hur många anställda är ni?**

Use

- **What do you use the AGV for?**
- **What is the most common interaction with the AGV?**
- **How many different people interact with the AGV? Who are they?**

The Operator Terminal

- **How do you use the operator terminal? How often?**
- **How often do you reconfigure the content of the operator terminal?**
- **Is there any information you would like to have about the AGVs that isn't accessible today?**

MCD/Manual steering

- **When do you usually steer the AGV manually? How often?**
- **Can you steer the AGV manually with the level of precision required?**
- **Can you imagine steering the AGV without being able to survey it? If no, why?**

Miscellaneous

- **Do you use the software, for instance AppDesign or Cway ?**
- **Would you find it usable with:**
    - **Extensive information about the error messages ?**
    - **Different levels of security to access the operator terminal?**
    - **Be able to see the view of the AGV (for instance if you get an error)? This would allow you to troubleshoot remotely..**
    - **A wireless manual control?**
    - **A wireless operator terminal?**
    - **A touchscreen as display?**
- **If you would've had a wireless unit with the functions of the MCD and the operator terminal, would you have considered always carrying it with you?**
    - **What kind of hardware would you have wanted to use? Tablet/smart phone/...**

C

Interview Guide - Application Engineer

Allmän information

- **Vad är dina arbetsuppgifter som applikatör?**
- **Vilka är de vanligaste anledningarna till att era kunder vill köpa AGVer?**
- **Har du någon uppfattning om hur viktig interaktion med AGVn är, exempelvis att kunna styra den manuellt eller använda displayen för att kolla info?**

Användning

AGVn

- **Har du någon uppfattning om vem på företagen som brukar ansvara för manuell hantering av AGVn? Kan det vara alla operatörer, eller är det oftare några utvalda?**
- **Hur ofta händer det att ni får komma och hjälpa en kund med något som gått fel på AGVn? Vilka är de vanligaste felen?**
- **Görs en del felsökning på distans? Om ja, finns det info om AGVn ni skulle vilja ha som ni inte kan nå?**

MCD

- **När brukar AGV'n styras manuellt av applikatörerna? (I vilka situationer)**

Operator Terminal / display

- **Vilken display säljer ni?**
- **Hur använder ni displayen? Hur ofta?**
- **Hur ofta konfigurerar ni om displayens innehåll? Kan era kunder göra det själv?**
- **Finns det någon typ av information du skulle vilja ha i displayen som du inte kan lägga in?**

Allmänt

- **Skulle du tycka det var användbart med:**
  - **Utförlig information om vad felkoder betyder på en display ?**
  - **Olika säkerhetsnivåer för att få åtkomst till displayen eller för att styra AGVn?**
  - **Kunna se AGVns vy i en bärbar enhet (t ex vid felmeddelande)? T ex stå längre bort och kunna felsöka på långt håll**
  - **En trådlös styrningsenhet?**
  - **En trådlös display?**
  - **En display med touchskärm?**
- **Vad får ni för feedback från era kunder?**
- **Har du några förslag på förbättringar du skulle vilja se?**

D

Script - User Study

User test: MCD

Välkomna till det här användartestet. Jag kommer börja med att ställa några frågor, sen kommer jag beskriva testet och låta dig utföra uppgiften, sen kommer jag ställa några frågor igen.

Bakgrundsfrågor

Deltagare:

Yrke:

Ålder:

Är du........ ☐ vänsterhänt ☐ högerhänt

Om du har köpt hem en ny teknisk pryl, t ex en ny diskmaskin eller en matberedare, vilken av följande alternativ stämmer bäst överens med hur du lär dig din nya produkt?

Läsa manual / Testa / Ngn annan

När du kommer i kontakt med en teknisk pryl som du inte har haft kontakt med tidgare, t ex en ny telefon, hur bekväm känner du dig med att använda den?

(bekväm) 1 2 3 (obekväm)

Har du vana av följande: *Tycker du det är lätt/svårt att använda en ny sådan?*

- ☐ Touchskärm (smartphone/padda)........................ (lätt) 1 2 3 (svårt)
- ☐ Tv-spels- eller gamerkontroller............................ (lätt) 1 2 3 (svårt)

Om du själv fick välja att köra det här fordonet, hur skulle du vilja göra det? Varför?

Uppgift

Du kommer få i uppgift att använda den manuella kontrollen för att styra AGVn. Jag är intresserad av din förståelse för hur MCDn fungerar mer än att du kör banan på ”rätt sätt”. Under tiden du utför uppgiften får du ställa frågor till mig men jag vill i första hand att du försöker själv.

På marken finns en uppritad bana som du ska följa.

När du har kommit fram till de två strecken vill jag att du följer strecket men kör baklänges tills du når det enkla strecket.

Du får ta hur lång tid på dig som du vill.

Under testet (att anteckna)

Deltagaren förstod

- Hur man svänger med potentiometern framåt...... Direkt   Ganska snart   Efter ett tag
- Hur man väljer att köra FW/BW ....Direkt   Ganska snart   Efter ett tag
- Hur man sätter hastighet .... Direkt   Ganska snart   Efter ett tag
  (att det finns två lägen)
- Hur man svänger när man kör baklänges............... Direkt   Ganska snart   Efter ett tag
- Övrigt....................................

Fick deltagaren någon av dessa ledtrådar?

- ☐ Hur man svänger
- ☐ Hur man kör fram-/baklänges
- ☐ Hur man sätter hastighet
- ☐ Att man måste tänka tvärtom när man svänger baklänges
- ☐ Övrigt....................................

Frågor efter uppgiften

Vad var ditt helhetsintryck, var det lätt eller svårt att köra fordonet längs banan?

(lätt) 1 2 3 (svårt)

Vad tyckte du om följande moment **Om svårt, vad kan förbättras?**

- Att svänga åt rätt håll när du kör framåt (lätt) 1 2 3 (svårt)..

- Att välja om du ska köra FW/BW (lätt) 1 2 3 (svårt)...
- Att veta hur du sätter hastigheten (lätt) 1 2 3 (svårt)...
- Att kör baklänges (lätt) 1 2 3 (svårt)...

Hur tyckte du att handkontrollen var att hålla i handen? Nådde du allt du ville?

Tyckte du att det kändes tryggt och säkert att styra AGVen? Varför/varför inte?

Tycker du om att du kunde styra AGVn med den nivå av precision som du önskar dig?

Skulle du kunna tänka dig styra AGVn med hjälpa av ett annat objekt, t ex en smartphone? Varför/varför inte

Hur många gånger tror du att du skulle behöva köra med den här handkontrollen för att behärska funktionerna?

Om du fick köra banan igen, tror du att det skulle gå bättre?

Frivilligt: kör banan igen.

E

Script - User Study (English version)

User test: MCD

Welcome to this user study. I will start by asking some questions, then I will describe the task I would like you to perform. Then I will let you do the task and I will ask some questions afterwards.

Background questions

Participant:

Profession:

Age:

Are you…. ☐ left-handed ☐ right-handed

If you purchase a new technical item, i.e. a new dishwasher or food processor, which of the following options coincide best with how you learn to use your new product?

Read manual / Test / Ask for help

When you get in contact with a technical gadget you haven't used before, i.e. a new phone, how comfortable do you feel using it?

(comfortable) 1 2 3 (uncomfortable)

Do you have a habit of using: *Is it easy/hard to use a new one:*

- ☐ Touchskärm (smartphone/tablet)........................ (easy) 1 2 3 (hard)
- ☐ Gaming controls.. (easy) 1 2 3 (hard)

If you got the option to steer this vehicle, how would you do it? Why?

Task

Your task will be to use the manual control to steer the AGV. I am interested in your understanding of how the MCD functions more than if you drive the path in “the right way”. During the task you may pose questions but I want you primarily to try yourself.

On the ground there is a drawn path that you shall follow.

When you’ve reached the two lines, I want you to proceed backwards until you reach the single line.

You may take as long time as you want.

During the test (to note)

The participant understood

- How to turn using the potentiometer (FW).......... Directly Quite soon Eventually
- How to choose FW/BW drive .... Directly Quite soon Eventually
- How to choose speed ....Directly Quite soon Eventually
  (that there are two modes)
- How to turn driving BW............... ....Directly Quite soon Eventually
- Other....................................

Did the participant get any of these clues?

- ☐ How to turn
- ☐ How to drive forwards/backwards
- ☐ How to set the speed
- ☐ That you have two think opposite way around when driving backwards
- ☐ Other....................................

Questions post-task

What was your overall experience, how was it driving the whole path (easy) 1 2 3 (hard)

What did you think of the following steps: **If hard, how improve?**

- To turn driving FW (easy) 1 2 3 (hard)..
- Choosing whether to drive FW/BW (easy) 1 2 3 (hard) ....
- To know how to set the speed (easy) 1 2 3 (hard) ....
- To back (easy) 1 2 3 (hard) ....

How did you think it was to hold the manual control? Could you reach everything you wanted?

Did it feel safe and secure to steer the AGV? Why/Why not?

Could you steer the AGV with the level of precision you would have wished for?

Could you imagine steering the AGV with another kind of object, like a smart phone? Why/why not?

How many times do you think you would need to use the manual device to be able to master the different functions?

If you got to drive the same course again, do you think it would go better?

Voluntary: drive the path again.

F

Script - User Study Prototypes

Användartest: tre prototyper

Deltagare:...

Uppgift

Du kommer få i uppgift att använda tre olika appar för att styra AGVn. Jag är intresserad av din förståelse för hur apparna fungerar mer än att du kör banan på ”rätt sätt”. Under tiden du utför uppgiften får du ställa frågor till mig men jag vill i första hand att du försöker själv.

På marken finns en uppritad bana som du ska följa.

När du har kommit fram till de två strecken vill jag att du följer strecket men kör baklänges tills du når det enkla strecket.

Du får ta hur lång tid på dig som du vill.

PÅPEKA:

- Det är inte en färdig modell, endast en princip. Den är under utveckling.
- Det grafiska är inte gjort ännu.
- Det finns flera grejer som kan programmeras annorlunda för att kunna använda appen bättre, t ex kraftigare svängradie. Sådan feedback är väldigt intressant att veta!

Under testet (att anteckna)

Deltagaren förstod

1 = Direkt 2 = Ganska snart 3 = Efter ett tag 4 = ledtråd

Uppgift	**Gyroskop**	**Joystick**	**Seekbars ”Slide”**
Svänga			
Köra framåt/bakåt			
Välja hastighet			
Köra baklänges och svänga			
Tid för att köra banan			
Tittade användaren på displayen innan de började köra?			

Frågor efter uppgiften

Fråga	**Gyroskop**	**Joystick**	**Seekbars ”Slide”**
Var det något moment du tyckte var svårt att utföra? T ex svänga, backa, sätta hastighet			
Var det något moment eller någon funktion du tyckte särskilt mycket om med den här appen?			
Tyckte du att AGVn reagerade som du ville på din styrning?			
Tyckte du att det kändes tryggt och säkert att styra AGVen? Varför/varför inte?			
Tycker du att du kunde styra AGVn med den nivå av precision som du önskar dig?			
Vilka förbättringar skulle du vilja se?			

De kommande frågorna handlar om alla tre appar

Vilket styrningsalternativ tyckte du bäst om? Varför?

Var det något styrningssätt du tycker passar bättre/sämre för någon av följande operationer:

- *Styra i ett trångt utrymme (med behov av precision):*
- *Styra vagnen ett längre avstånd på en öppen yta:*

Skulle du vilja kunna styra AGVn på något annat sätt med hjälp av en app?

Vad tyckte du om att styra AGVn med hjälp av en tablet?

G

Script - User Study Prototypes (English version)

User study: three prototypes

Participant:...

Task

You will be given the task to use three different applications to steer an AGV. I am interested in your understanding of how the apps are working more than if you steer along the lane in the “right way”. During the task you may ask questions but I want you primarily to try yourself.

On the ground there is a drawn path that you shall follow.

When you’ve reached the two lines, I want you to proceed backwards until you reach the end.

You may take as long time as you want.

POINT OUT:

- It is not a final model, only a technical principle. It is under development.
- The graphical interface is not done.
- There are several things that can be programmed differently to be able to use the app in a better way, for instance turning radius. That kind of feedback is thus very interesting!

During the test (to note)

The participant understood

1 = Directly	2 = Quite soon	3 = After a while	4 = Given a hint

Task	Gyroscope	Joystick	Seekbars ”Slide”
Turn			
Drive FW/BW			
Choose speed			
Drive backward and turn			
Time to drive the path			
Did the participant observe the screen before starting			

Questions after the task

Question	Gyroscope	Joystick	Seekbars ”Slide”
Was there any step you thought was difficult to perform using the app? For instance turn, back, set speed			
Was there any part or any function you especially liked?			
Did you feel that the AGV reacted as you wanted when you were steering?			
Did it feel safe and secure to steer the AGV? Why/Why not?			
Could you steer the AGV with the level of precision you would have wished for?			
What modifications would you like to do?			

The following questions concern all the three apps

Which app did you prefer? Why?

Was there any way of steering that would work better or worse for the following scenarios?

- *Steer in a narrow space (where precision is needed) :*
- *Steer the vehicle a longer distance on an open surface:*

Would you like to steer the vehicle in any other way using an app?

What did you think about steering the vehicle with a tablet?

H

Script - Evaluation Drive View

Användarutvärdering

Deltagare:...

Styra ett fordon

Uppgift

Kör runt sick-sack framåt kring koner och kör sedan samma väg tillbaka men backandes.

PÅPEKA:

- Det är inte en färdig modell, endast en princip. Den är under utveckling
- Det grafiska är inte gjort ännu
- Det finns flera grejer som kan programmeras annorlunda för att kunna använda appen bättre, t ex kraftigare svängradie. Sådan feedback är väldigt intressant att veta!

Under testet (att anteckna)

Deltagaren förstod

1 = Direkt 2 = Ganska snart 3 = Efter ett tag 4 = ledtråd

Uppgift	Seekbars ”Slide”
Svänga	
Köra framåt/bakåt	
Välja hastighet	
Köra baklänges och svänga	
Tittade användaren på displayen innan de började köra?	

Frågor efter uppgiften (i egenskap av applikatör)

Fråga	Seekbars "Slide"
Var det något moment du tyckte var svårt att utföra? T ex svänga, backa, sätta hastighet	
Var det något moment eller någon funktion du tyckte särskilt mycket om med den här appen?	
Finns det någon situation där du anser att det inte skulle funka att styra ett fordon med den här appen i stället för med MCDn? (varför?)	
Tyckte du att AGVn reagerade som du ville på din styrning?	
Tyckte du att det kändes tryggt och säkert att styra AGVen? Varför/varför inte?	
Tycker du om att du kunde styra AGVn med den nivå av precision som du önskar dig?	
Vilken info skulle du vilja kunna få medan du kör?	
Vilka förbättringar skulle du vilja se?	

Information & diagnostik

Vad är det första du vill veta om ett fordon som borde synas på en display?

Vad är de vanligaste menyerna du använder på displayen?

Vilken info skulle du vilja kunna se på en display som inte finns där idag?

Hur ställer du dig till att använda en app i en tablet i stället för MCDn och displayen?

I

Script - Evaluation Start View

Utvärdering interface – vyer och navigering

Deltagare:……………………………………………………………….

Visa varje interface var för sig.

Varje app består av flera vyer, det här är startvyn.

	Alt 1	Alt 2	Alt 3	Alt 4
Hur tror du att du navigerar till en annan vy?				
I vilken av de tillgängliga vyerna befinner du dig nu?				
Om du är i en annan vy, hur tror du att du gör för att återvända till startsidan?				

Vilken av de fyra olika interfacen tycker du är lättast att förstå? (Varför?)

Vilken tycker du skulle passa Kollmorgens profil bäst? (Varför?)

Vilken gillar du personligen bäst? (Varför?)

Tycker du generellt att interfacen saknar något?