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User-centered design of an instruction manual for a research vehicle

School of Electrical Engineering
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ABSTRACT OF THE
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Transportation engineering and research remain as focal points in academia and in the industry. The ability to discreetly examine the changing infrastructure and road environment hinges on specialized research tools. The instrumented vehicle of Aalto University caters to this specific research need with an array of sensors and cameras.

Operating complex tools usually requires specific knowledge and expertise. In this project, an instruction manual was developed to allow a larger user base to access the instrumented research vehicle with or without prior expertise. An iterative user-centered design philosophy and cognitive engineering principles were used in creating an intuitive and usable manual.

Keywords: instruction manual, user-centered design, instrumented research vehicle, usability, cognitive engineering

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Liikennetutkimus on akateemisesti ja teollisesti yhä tärkeämpi aihealue ajoneuvojen ja tieinfrastruktuurin jatkuvasti kehittyessä. Liikenteen ja liikenneympäristön tutkiminen muiden tienkäyttäjien huomaamatta vaatii tarkoituksenmukaisia työkaluja. Aalto-yliopiston instrumentoitu tutkimusajoneuvo on rakennettu vastaamaan juuri tähän tarpeeseen. Ajoneuvo on varustettu useilla erilaisilla antureilla ja kameroilla ympäröivän liikennetilanteen tallentamiseksi ja analysoimiseksi.

Perinteisesti instrumentoidun ajoneuvon kaltaisen monimutkaisen työkalun käyttö vaatii erityistietoja ja -taitoja. Tämän projektin tarkoituksena oli kehittää ajoneuvolle ohjekirja käyttäjäkeskeisen suunnittelun menetelmin. Iteratiivisen ja kognitiivisen suunnitteluprosessin avulla tuotettu ohjekirja mahdollistaa instrumentoidun ajoneuvon käytön aloittamisen ilman aiempaa kokemusta ja tietopohjaa.

Avainsanat: käyttöohje, ohjekirja, käyttäjäkeskeinen suunnittelu, tutkimusajoneuvo, käytettävyys, kognitiivinen suunnittelu

Foreword

This thesis is the culmination of my engineering and R&D studies thus far. Through the wide assortment of high quality courses and teaching available in the Aalto University covering human behavior modeling and user-centered design, I have been able to immerse myself to the world of usability and user-experience.

This project would not have been possible without the support and materials of the Transportation and Highway engineering research group. I want to thank all the staff members of our research group for their invaluable input and guidance. Special thanks go to Kari Hintikka for driving the test runs safely and to the 16 fearless persons who participated in the user tests.

Furthermore, I would like to thank D.Sc. Kalevi Kilkki for supervising the thesis and M.Sc. Åsa Enberg for instructing me whenever I needed help and direction.

12.9.2011, in Otaniemi

Aapo Tapio Lumikoivu

Contents

Glossary

Affordance - A quality of an object that allows or affords an action
Cognitive engineering - A study of human cognition to enhance the usability of technical systems and products
Digital divide - A gap between people's ability and access to technical equipment and digital information
Explicit - Precise and easily accessible and reproducible form of something
False positive - An identified problem where there actually was none
Firewire - A serial bus interface for high speed transfer of digital information
Floating vehicle method - A traffic study method for inconspicuously driving along with the study subjects
Focus group - An interactive discussion session for assessing the quality of a product with representative end users or potential customers
Gestalt principles - A collection of laws explaining the automaticity of human from perception
Haptic - The sense of touch
Heuristic - An experience based technique for problem solving or product design
Heuristic of choice - A decision rule for accepting or rejecting read information
Human-computer interaction - A field of study concentrated between human and computer interaction
Instruction manual - A compilation of operational, safety, setup, maintenance and troubleshooting information pertaining to a single device or system
Instrumented research vehicle - A car with an integrated measurement and recording system for studying drivers and roads
Intangible - Virtual or conceptual object or property
Learning - A process of acquiring new or modifying previously learned information
Legacy - Obsoleted methods, technologies and practices still in use
Lidar - An object detection system based on sending and receiving light
Pre-attentive processing - A process performed by the human brain unconsciously to guide the conscious perception
Priming - Altering a person's state of mind in relation to a specific stimulus through preceding experiences
Radar - An object detection system based on sending and receiving radio waves
Scenario-of-use - A user testing session guided by a hypothetical story and setting
Signifiers - An illustration that conveys meaning and significance through mere perception

Tacit - A hidden or directly inaccessible form of something
Tangible - An actual physical object or property
Transportation engineering - Application of scientific and technical principles to study and build transportation networks
Ultrasonic sensor - An object detection sensor based on sending and receiving sound
Usability - Ability to achieve goals with effectiveness, efficiency and satisfaction
User-centered design - Philosophy of designing and optimize products to fit user needs and behavior
User experience - Perceptions and responses that result from using a product

Abbreviations

CAN - Controller area network
CWA - Cognitive work analysis
DVI - Digital visual interface
GPS - Global positioning system
HCI - Human-computer interaction
HFE - Human factors and ergonomics
HTA - Hierarchical task analysis
ICT - Information and communication technologies
LAN - Local area network
PC - Personal computer
R&D - Research and development
ROI – Return on investment
SRS - Supplementary restraint system
SUV - Sport utility vehicle
UCD - User-centered design
UI - User interface

1 Introduction

Traffic safety is a continuous concern among academia and the automotive industry. Public and private research and development focus on creating safe materials and infrastructure, as well as components with integrated intelligence. These new innovations are then used by legislators and executive branches of the government in increasing the throughput and safety of transportation networks.

The Transportation and Highway Engineering Research Group of Aalto University has a long history of monitoring and analyzing traffic flow characteristics and the influence of new road types or safety and performance increasing elements. Gathering empirical data about traffic with numerous sensor types and research methods is essential for accurate model building and scientific analysis. One tool for such data gathering is an instrumented research vehicle. The latest version of Aalto University instrumented vehicle is being finalized and taken into use this year (2011). The purpose of building the vehicle was to enable studies of driver behavior and traffic congestion without interfering or influencing the research targets. Hidden sensors and the method of floating along with the traffic ensure untainted data and reliable results.

The documentation of the devices and systems of this research tool is non-existed, while the vehicle itself is nearly completed for actual usage. This is a common shortcoming in technology driven development projects, where the end-user is forgotten. As a consequence, the usability of the research tool falls severely short and must be addressed before actual studies. User-centered design is a concept of creating new products and services in collaboration with users and other relevant parties. The next step in improving this research vehicle is to create an instruction manual and perform usability testing with actual users. Incorporating users into the development of this tool ensures increased usability and produces an intuitive and comprehensive instruction manual. Additionally, the process of creating the manual provides possibilities to augment the vehicle's systems and start a learning process about the tool for the research group.

This report is a Master's thesis work for a Telecommunications engineering degree in the Aalto University. The purpose of the thesis is to document the process of creating the above mentioned instruction manual and find answers to the following research questions: what is the definition of usability in the case of an instruction manual? How to incorporate users into the development process of a manual? How to ensure the usability of the instruction manual? What benefits does the user-centered approach offer over traditional product development methods? What is a suitable direction for the future development of the manual?

To reach these goals, user testing and heuristic evaluation is conducted at all stages of the development. The tests are carefully documented and organized in a manner based on most recent theories about user-centered design and human behavior modeling. The timeline for the development is May 2011 – June 2011. The development begins by creating explicit content for the manual with task analysis and by generating an initial version of the manual. Heuristic evaluation and cognitive engineering principles are used as the primary starting point for the manual design. A scenario-of-use test with five users is conducted to further improve the manual. A focus group then assesses the usability and quality of the instructions and a second round of scenario tests produce the final release version of the manual.

The user-centered design process of creating an instruction manual was successful. The iterative and participatory nature of the design process allowed early identification of errors and poor design features throughout the project. The end result is an intuitive and comprehensive manual, which facilitates learning through familiar signifiers and consistency. The specialist task analysis method was a suitable way to gather the initial content for the manual and the cognitive design guidelines provided a solid base for the gradual improvement process. The user tests were a reliable and efficient way to assess the usability of the manual and corroborate theoretical design ideas.

The body of this thesis is divided into following chapters: literature and background, methodology, the user-centered design of an instruction manual, results, conclusion and recommendations for future work. In Chapter 2, the instrumented research vehicle, relevant literature and the concept of usability are discussed. Chapter three covers the user-centered design approach and methodology. The fourth chapter reviews the structure and outcomes of the testing. The fifth chapter presents results and discusses the success of the thesis. The sixth chapter is a summary of the project and recommendations for future actions and development are made in chapter seven.

2 Literature and background

The infrastructure of the developed world has reached a state where enhancing performance is difficult without making significant investments in safety as well. Furthermore, automation and imbedded intelligence are commonly used to offer comfort and convenience in using technical devices. The automotive industry is at the forefront of this development and continues to introduce new services and safety increasing features. As the trend of automation suggests, vehicles themselves are becoming more intelligent and several new instrument types are integrated into the vehicles already at the factory level. At the same time, passenger and pedestrian safety is a growing concern and academics, legislators and authorities seek new ways of improving road safety and increasing the capacity of the road network.

Environmental concerns are also driving major modifications and development in both vehicles and the road infrastructure. New road types with special guard rails, speed bumps and safety barriers are becoming common. Hence, the role of *transportation engineering and research* is as important as ever and new ways to gather data and create knowledge are developed continuously, as applicable technology becomes available and affordable.

The *instrumented research vehicle* of the Transportation and Highway Engineering Research Group of Aalto University was developed to cater to the need for research in this rapidly evolving area of society. The vehicle contains multiple sensors and computer systems for monitoring the entire surrounding environment. Special effort has been made to ensure that all sensors and measurement devices are hidden from other road users; thus, allowing studies with minimal influence to study subjects. The *floating vehicle* data gathering method of using an ordinary looking car with hidden sensors provides valuable information about the behavior of drivers in new situations and circumstances. For instance, the effects of a new road type, such as a tunneled highway, or extreme weather conditions can be investigated by using the instrumented research vehicle.

Operating such a vehicle requires expertise, which is often available only through a handful of people. Moreover, this expertise is commonly in *tacit* or silent form and can be completely lost, if those who possess the knowledge leave the organization. Consequently, new research and innovations face a needless hurdle in their path and some ideas are never even discovered as innovative minds, suitable tools and expertise are not brought together. One purpose of this thesis was to tackle the aforementioned hurdle and bridge the gap between research ideas and their execution. Once system specific expertise is no longer needed or becomes accessible through converting tacit knowledge to *explicit* form, innovations should have a smoother path from birth to fruition. In practice, the process of transforming and recording this silent knowledge was done by developing *an instruction manual* for the vehicle. The manual was constructed by utilizing the participatory *user-centered design* (UCD) philosophy. Furthermore, the c*ognitive engineering principles* guided the development from start to finish and *user testing* was conducted at all phases of the process. An additional goal for this research was to assess the *usability* of the measurement system and the manual once it was completed.

The rest of this chapter presents theories, literature and earlier studies concerning: transportation engineering, user-centered design, usability and user-experience, cognitive engineering, economics and instruction manuals. Additionally, a brief description of the vehicle itself is presented.

2.1 Transportation engineering

The globalized world has abated the virtual distances between people, information and services; however, the physical distances naturally remain mostly unchanged. Therefore, transportation and logistics still affect our lives directly and indirectly practically every day. The fluency and efficiency of transportation networks - be it road, rail, water or air – have only grown in importance, since daily commuting and the moving of goods consume significant amounts of our finite energy and time resources. Consequently, the safety, reliability and capacity of these networks remain at the core of transportation research all over the world.

While the average road user perceives fluency and safety in transportation through congestion and accidents, the academic approach is more holistic. The perceivable congestion and conflicts are always assessed in relation to the fundamental characteristics of the traffic. A basic concept of transportation engineering is a *traffic stream*, which is characterized by speed and vehicle density. Traffic *volume* is another commonly used variable, which describes the stream in relation to a discrete time window and a specific place [1 p. 55].

In addition to these exact numerical measurements, transportation research concentrates on human factors as well. Route selection, overtaking and other actions requiring mental decision processes are a subject of continued interest. In this research area, understanding the psychological aspects of driving become increasingly important. For example, the *perception-reaction time* of a human being is a key variable in analyzing driving behavior [1 p. 20]. Additionally, subjective and relative variables such as the *value of time* play central roles in many decision processes. Being able to analyze these variables requires acquiring representative and unbiased data about them. Measuring and recording numerical characteristics of traffic and gathering data about driver behavior are both tasks well suited for an instrumented research vehicle.

2.2 The instrumented research vehicle

The main reason for constructing an instrumented research vehicle is traffic environment monitoring and measuring. While fixed sensors can provide accurate data from a single spatial point, a moving vehicle can provide continuous data from a complete road section or sections. As in all scientific research, data gathering without distracting study subjects is preferable. Therefore, the instrumented research vehicle was designed to move along with the traffic and record driving behavior and conditions discreetly. To further minimize the effect of being present in the research situation, a common passenger car is an ideal platform for the instrumentation. The following subchapters describe in detail the chosen platform, instruments and user interfaces of the new instrumented research vehicle of Aalto University.

2.2.1 The vehicle

The development of a new research vehicle for the transportation and highway research group began in late 2007. A Toyota Land Cruiser 3.0 D-4D SUV (Picture 1) was selected from a group of ten suitable vehicles, since the vehicle has accessible factory sensors for research purposes and provides sufficient elevation for the cameras and direct observations. Additionally, with the vehicle manufacturer's co-operation, a SRS airbag safety system posing hazards to the measurement system operator was deactivated.

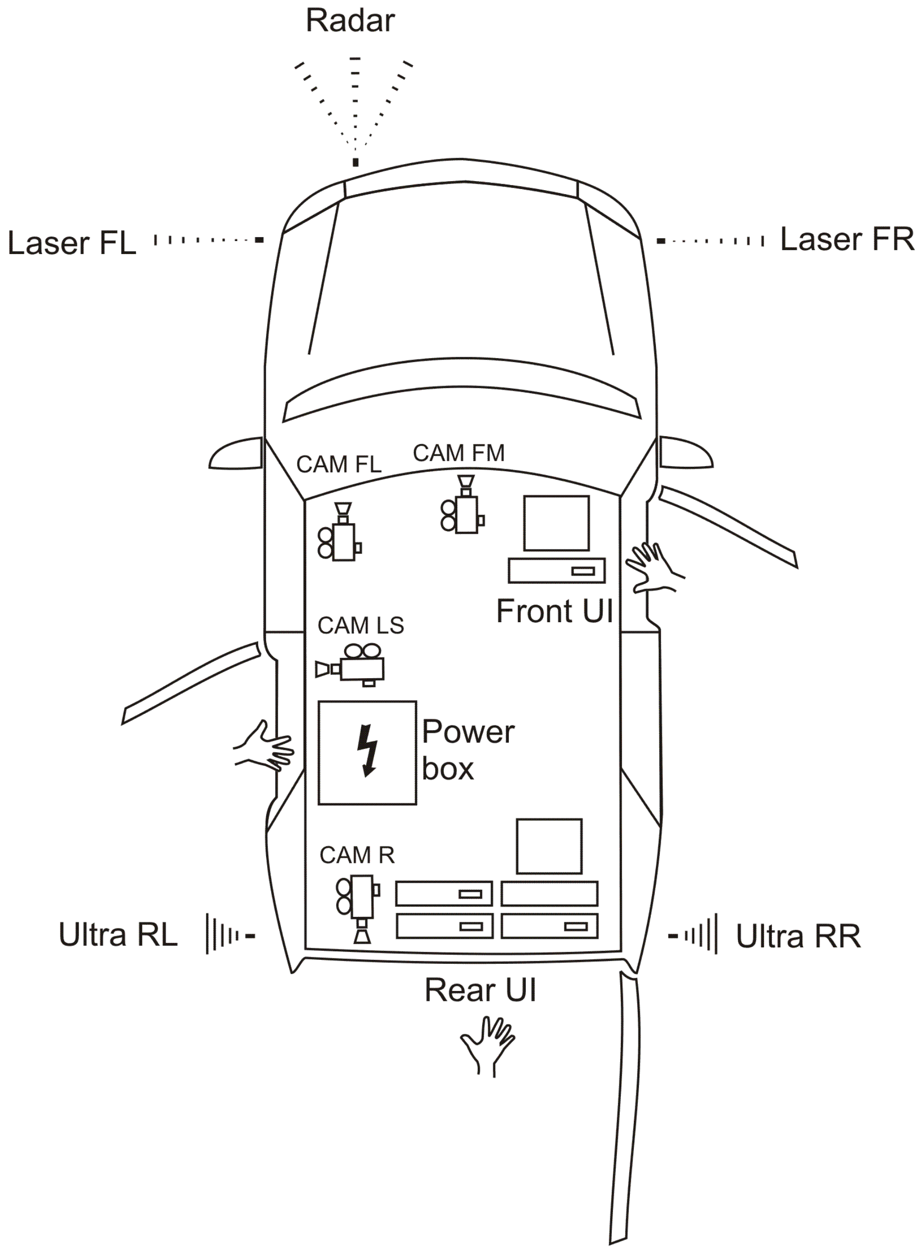
Picture 1: The instrumented research vehicle

A separate electrical system (Picture 2) was added to the vehicle for powering the instruments and their computer cluster. The charger of the vehicle was upgraded to provide increased electrical current for the added devices. An additional 12V battery was installed to enable controlled shutdown of the systems, in case the engine is turned off unexpectedly. The devices can run on the reserve battery for several hours if needed and a separate 230V power source can be used while the vehicle is stationary and a mains supply is available. In order to prevent draining of the vehicle's main batteries, a voltage guard is used to connect the additional electrical system to the charger.

Picture 2: Electrical power for the measurement system

2.2.2 Instrumentation

Primary instruments for mobile traffic research are cameras and radars. The vehicle was equipped with four digital Firewire cameras with changeable optics. Two of the cameras monitor the environment in front of the vehicle, the third monitors the left side with a wide-angle lens and the fourth covers the area behind the vehicle. A basic layout of the vehicle is presented in Picture 3. An option to mount additional cameras and sensors is available.



Picture 3: The layout of the research vehicle

A single radar unit is installed to the left corner of the front bumper. The unit is capable of measuring and following 32 individual objects within 250 meters and has a maximum field of view of 30 degrees. Radar's relative speed measurements are corrected to absolute values with information from the vehicle's driving computer. An external 5Hz GPS-antenna provides additional speed measurements and position data.

The sides of the vehicle are monitored with four integrated distance sensors, two on the left and two on the right. Adjacent to the front wheels are two narrow beam lidars (Laser FL and Laser FR), which provide millimeter accurate distance values to passing vehicles and stationary road-elements. The second side sensor is an ultrasonic wide beam distance sensor, which is located behind the rear wheel. The wider beams of the ultrasonic sensors (Ultra RL and Ultra RR) provide centimeter accurate information about objects that are missed by the narrow lidar beams. An option to mount additional lidar or ultrasonic sensors is available if needed. The side sensors provide fixed point-based data, whereas speed and location of each object in front of the vehicle are measured continuously with the moving beam radar.

Live video feeds from the four or more cameras and the sensory data are recorded to a cluster of computers. The vehicle's rear compartment has been equipped with a rack for four PC-units (Picture 4). In the current version of the vehicle, three of the rack slots are used to house the computer cluster and the fourth is used to store a LAN-switch, DVI-splitter and a DVI-multiplier. Each PC-unit has a bay for removable hard drives.

Picture 4: The computer cluster and rear user interface

2.2.3 User Interfaces

The research vehicle nears completion and the basic instrumentation has been installed. Three physical user interfaces (UIs) have been constructed into the vehicle (Picture 3). The electrical system's UI is accessed from the left side passenger door. While the vehicle is stationary, the research instrumentation and recording systems can be controlled through the rear interface presented in Picture 4. The co-driver's seat on the right front side of the vehicle has the front control interface, which enables control of the systems while the vehicle is on the move. The interfaces are technical by nature, but designed to comply with traffic laws and regulations. An additional LCD-panel with a touchscreen has been installed to the dash-board for providing information to the driver.

As mentioned earlier, the vehicle's measurement system is convoluted and technical by nature. While each individual instrument had at least a crude specification sheet covering basic usage, the combination of these devices, factory installed sensors, hand built components and customized software remained without specifications or an instruction manual. In the following subchapters, the theoretical foundation for creating the manual is presented. The user-centered design stems originally from *ergonomics* and the study of *human factors*. Examining the history of the field offered a starting point for creating a usable manual.

2.3 The origin of user-centered design

Accidents caused by improper usage or poor design increased in numbers, once machines started to become common during the industrial revolution of the 19th century. Operational safety became exceedingly important when new devices and systems were rapidly introduced to everyday use, especially in the military and during armed conflicts. To counter the trend of increased hazards in machine operation and to increase work performance, a field of study called ergonomics started to emerge.

The World Wars in the 20th century were main catalysts for the transformation from the trial-and-error development method to the organized approach of *human factors and ergonomics* or HFE [2 p. 148]. The first published and widely spread practical approaches to HFE were related to labor productivity, but the philosophy and science were gradually adapted to suit other uses as well. Even though the origins of the ergonomic approach are in designing efficient working methods and workforce training, the concept has proved extremely useful in the field of modern engineering and product development.

Currently, the aim of ergonomics is to learn the limitations of human capabilities and barriers set by our natural behavior and to build machines to comply or even take advantage of these attributes. The field has steadily expanded and we now know quite well how humans operate machinery and most importantly, we have learned why people do things in certain ways. Understanding how the human nervous system functions is critical in designing good tools and devices, especially when they are as complex and unique as an instrumented vehicle and its user interfaces. Incorporating cognitive processes and psychology to traditional ergonomics has created a plethora of design methods and concepts for the engineering community. Especially *usability* and *user-experience* are established and widely utilized product development concepts born from the field of ergonomics.

2.4 Usability and user-experience

As is evident from the technological and commercial history of the last century, pure technical excellence does not guarantee success and acceptance of an electrical device or system. Attraction is an intricate psychological process and it can be created or destroyed through a variety of factors and circumstances. Interestingly, once a certain level of technical functionality is met, other aspects begin to dominate the processes of usage selection and attraction forming [3]. For example, excess amount of functions or features can act as a deterrent. Perhaps the most relevant or dominant factors outside the technical domain are the perceived usability and user-experience acquired by using the product. The following paragraphs aim to provide general definitions and descriptions of these key concepts.

According to Jakob Nielsen - a usability engineering veteran - usability is an umbrella term for learnability, efficiency, memorability, satisfaction and the number and quality of errors met during use. Good usability is achieved when learning to use the device is quick and easy. Furthermore, efficiency of use should follow from minimal learning and intermittent usage should not require relearning. Errors should be mostly prevented and recovery from them must be effortless. Finally, the overall pleasantness of the product is pivotal in achieving good usability [4 p. 26].

The International Organization for Standardization (ISO) has defined usability as achieving goals effectively, efficiently and with satisfaction in a specific context of use [5]. More commonly, usability is perceived as the usefulness of a user-interface or a device. Usability is also closely related to the concept of user-experience, which is perhaps the most dominating factor along with the price in the decision making process related to using a device or not.

User-experience is formed not only from the actual usage, but from the anticipation and preconceived notions related to the matter. In essence, user-experience is the perception and responses created through the use and expectations of use of a product in an individual [5]. As mentioned, usability and user-experience are central concepts in the UCD philosophy. The following subchapters concentrate on the user-centered design philosophy, user testing and understanding human behavior.

2.4.1 User-centered design and psychology

User-centered design is fundamentally an iterative process. Gathering knowledge enhances the product, which then again creates new knowledge. Incorporating this iterative loop into the design ensures that the process is cost-effective and prevents permanent adoption of poor solutions. However, enhancing usability on a finished product is usually more challenging and expensive in comparison to building the usability into the product from the beginning. Therefore, moving from the technology driven perspective to the user-centered model can cause friction in some cases. Nevertheless, the positives outweigh the negatives and the UCD practice is becoming more common.

At the core of the user-centered design model is also the notion that because people rarely adjust their behavior, it is the product that must adjust to fit the usage. Furthermore, as the user is capable of learning, so must the device learn and evolve along with the user. Products that require people to change their basic functioning will surely fail.

The human brain is the center of the nervous system, which controls and enables the actions of a human being. UCD focuses on gaining an understanding of the user and usage of a device and in incorporating the knowledge into the design process. Two approaches can be identified for gaining knowledge about the user: direct physical measurements and indirect analysis based on observations.

Direct observation of the brain is possible yet limited with the relatively new method of *Functional magnetic resonance imaging* or FMRI, which is based on monitoring changes in cerebral blood flow [6]. Furthermore, the shortcomings caused by limited technology continue in the problems of linking brain activity and actions together. Therefore, physical measurements are not sufficient by themselves for UCD purposes. Further information about decision making and rationalization are needed in creating good usability.

The other approach for knowledge acquisition is indirect and also an older field of science. *Psychology* is the study of the human mind and considerable advances in human behavior analysis have been made in the usability field during the last 50 years. The revolution of electric devices has brought along numerous different interfaces between the user and the machine. Keyboards, pointing devices and screens have replaced handles and levers. The direct mechanical force of the past is now usually generated by indirect electrical forces and an intermediary user interface layer. The tasks that were intuitive and straightforward have been replaced by tasks that require mental concentration over physical control. Even many basic services are usually accessed only through electronic devices [7 p. 293]. As a result, many reactions to our actions happen hidden from our eyes and other direct neural inputs such as the *haptic* sense of touching an object.

Nowadays, we must often rely on the delayed or indirect information to assess the effect of our actions. The human brain has a remarkable talent to adapt to this new situation, but with certain limitations. Therefore, the need to understand what happens in our mind is sorely needed in interpreting the usage of these devices and naturally in designing the devices in the first place. Furthermore, this knowledge about the brain can help us to design tools beyond avoiding conflicts with our mental processes. In fact, these machines and tools can be designed to utilize and take advantage of our mind, once we know how it works.

Psychology and cognitive engineering can provide tools to further incorporate the user into the product development, well beyond simple usability testing with a finished product. In this project, the process of designing user tests benefited significantly from the theories and knowledge about the human mind.

2.4.2 User testing and sample sizes

The purpose or motivation for the usage guides everything the user does. User actions may sometimes seem unreasonable or even counterproductive, but there is always a reason for acting. Therefore, understanding the underlying purpose and knowing the user are prerequisites for analyzing the user's reasoning and actions. Each user is unique as is the situation where the usage happens. Since uniqueness restricts generalization of the test results, it is commonly countered by increasing the sample size and reporting results as statistic probabilities and error margins. Minimizing the variation in the sample base and testing situation are also needed to ensure the accuracy of the analysis.

In usability engineering, an ongoing debate exists about user testing sample size. Nielsen suggested that using five participants in testing reveals 85% of the often occurring usability issues in the product [8]. This was later elaborated by Jeff Sauro to apply only, if the five users are testing the same product in the same situation with the same tasks [9]. Additionally, the likelihood of discovering a usability problem is not necessarily correlated to the severity of the problem [10]. The occurrence rate of a usability problem is in a pivotal role in mathematically obtaining optimal sample sizes [11]; however, practical considerations often set limits to the eventual sample sizes. In this project, a testing sample size ranging between five and ten was used.

Testing the usability of a product can be subjective or objective. Objective testing can be based on *heuristic evaluation*, where the user interface is inspected by comparing its characteristics to previously set principles or heuristics. This method requires good knowledge about testing principles and is performed by usability specialists. Objectivity is achieved by finding answers to simple questions, for example whether or not a task can be completed. By performing the test with adequate number of repetitions, a quantitative analysis can be used to provide statistical results.

Testing with real users can also be done by using heuristics, but additional instructions for the tests are also needed. A scenario test describes a situation and a task for the test participant [4 p. 100], after which the users receive no further instructions and try to complete the scenario on their own. Monitoring the actions of the user is done with minimal contact and the process is recorded in one form or another. Subjectivity arises from the user's unique actions and from the interpretation of those actions and encountered problems.

As outlined, user-centered design can be done analytically with the user in mind or by introducing real users into a participatory development process. A combination of both is in most cases the best method; thus, some consideration must be given to the privacy and comfort of the human participants. Testing has to be based on volunteers and compensations for their time should be provided if needed. The storage and use of personal information and recordings of people are subject to privacy laws and common courtesy. Creating a trusting and safe environment can be crucial for the success of the tests and can advance the willingness to participate in further user studies.

Acquiring sufficient samples for a quantitative analysis is in many cases impractical, but qualitative analysis can usually be used successfully with a small sample. In the development of the instruction manual for the research vehicle, a balance between objective and subjective analysis was the targeted outcome. A detailed description of the usability testing methods chosen for the project is presented in Chapter 3.

2.4.3 Understanding human behavior

Human behavior is driven by hardwired physiological and psychological needs. Maslow famously divided these needs into five categories: physiological, safety, belonging, esteem and self-actualization [12]. In all research and development projects, safety is an important concern. In UCD, special emphasis can be put on esteem and self-actualization related needs. The process of designing the user-experience can greatly benefit from understanding what users expect to gain from the product. A differentiated product can also be designed to meet the needs and feelings of belonging, by acting as a common denominator for a group of individuals.

Esteem needs, such as respect from other people, are closely related to the holistic usability of a device. Successful operation of complex devices is connected to personal skills and abilities. Poor usability and the need for respect from others can lead to a situation, where the device is not used at all to prevent loosing face or fame. Furthermore, repeated failures or usage problems can become synonymous with the name of the device in street language, which is something each developer and engineer hopes to avoid. Understanding esteem needs is critical in analyzing the actions of a user in problematic situations. The testing situation must promote persisting with the problem and ensure that the testee does not feel humiliated by adversity.

A high degree of the basic functioning of a human being is unconscious and automated. These functions are also quite fast in comparison to conscious actions [13]. Therefore, building the user-interface to take advantage of these automatic functions promotes proficiency, while the contrary causes real hurdles or even hazards for the usage. Forcing the user to use conscious effort for functions that normally are unconscious is synonymous with poor usability.

One specific aspect of the automated functioning is the ability to perceive form. A theory of perception was developed by the German psychologist Max Wertheimer in 1923. The theory was used as a base to create a set of principles to explain certain aspects of visual perception. According to these Gestalt (shape) principles or laws, the human visual system perceives shapes and patterns through proximity, similarity, continuation and closure of objects [14]. These principles offer valuable insight about how to use color and form to facilitate fast and automated perception and learning.

Since human behavior is built on basic needs and automation, understanding these factors about human psychology is crucial for designing a good user-experience. A product that functions, learns and evolves in collaboration with the user will ensure success; thus, resulting in filling the esteem and self-actualization needs driving the usage. Failing to meet these needs leads to negative user-experiences and diminished or even forced usage. The engineer’s approach of incorporating psychology to the domain of technical product development is called cognitive engineering.

2.5 Cognitive engineering

Research and development (R&D) is traditionally technology oriented. Research generates new materials, methods or principles, which are further refined and then utilized in designing commercial products. Often a company has specialized people designing, manufacturing and marketing. The development can be described with a conveyer-belt analogy, where one part of the process begins when preceding parts are completed or near completion.

This process binds the whole organization from the very first stage forwards and leaves little to no room for improvements down the line. Even blatant design errors are occasionally deemed acceptable, since correcting them would be too costly.

A significant source for these design errors is the *technology first* -perspective. The user-centered design philosophy aims to address specifically problems created by the technology oriented R&D. Furthermore, the reactive UCD methods can be used proactively, if c*ognitive engineering principles* are incorporated to the process. Cognitive engineering is a design philosophy, which aims to improve efficiency and usability of technical products through understanding the cognitive processes of users [15].

The purpose of participatory user-centered design and user testing is to incorporate end-users into all stages of the development, so that errors and deficiencies are caught early on and throughout the process. Usability of the product should increase substantially through user testing, since the technology perspective is balanced against human needs. Ironically, the user testing methods themselves are not very usable and can be costly to implement. Moreover, an average engineer usually doesn't have the necessary skills for the testing and another separate entity is used to perform the testing. This results in yet another artificial barrier in the compartmental design process that is widespread nowadays.

The process of designing instruction manuals can also suffer from the conveyer-belt design orthodoxy described above. The manual may be the last piece of the development process and pressure to release the product can significantly affect the design [16 p. 414]. Furthermore, very little general research has been done about the usability of instruction manuals and widely accepted design principles are not easily available or at all in existence. However, the UCD approach complemented with cognitive engineering principles provides a solid base for practically any technical R&D project. The following sections present central concepts of cognitive engineering.

2.5.1 Delays, closure and the digital divide

Even though accessing computer systems and other electrical devices through keyboards and pointing devices come naturally for the ICT-oriented people, there are also those, who have no experience or limited access to the digital world. The gap between computer savvy and the rest of the community is called the *digital divide*.

The divide has three dimensions: a global divide between industrialized and developing countries, a social divide depending on a person's income level and a democratic divide caused by skill and involvement differences [17 p. 4].

In the academia, the gap is quite small and computer skills are a prerequisite for participating in most studies and equipment is provided for by the establishment. However, acknowledging the divide in general is a valuable and relevant position in UCD and even in this project. Especially the democratic gap had to be taken into consideration, since the computer system of the instrumented vehicle has grown increasingly convoluted.

As the world moves from the physical to the virtual, some people have difficulties in adapting to the new situation. The complexity and un-natural structure of user interfaces can deter rather than encourage interaction with the device. The human neural system is accustomed to a near instant action-reaction correlation and any delay lasting longer than two seconds can break the natural feel of correlation. In fact, the natural response time for an action such as pushing a button is just one tenth of a second [18].

The psychological term for the need to receive a reaction within seconds is called *closure*. Delays are more tolerable once this sense of completion has been achieved by closing the action-reaction sequence with a special indicator, but a delay of 10 seconds or more may severely interfere concentrating to the task at hand [4 p. 134]. Addressing the democratic divide, action-reaction closure and delays were exceedingly important in designing the instruction manual for the research vehicle.

2.5.2 Affordance, signifiers and instructional legacy

Delays and the resulting lack of complete closure are common in using computer systems and a great hindrance to those who are entering the digital world. Adjusting to the world of delays needs guidance, at least in cases where delays can't be removed. A progress indicator can mitigate the effect of delays and facilitate patience. Additionally, learning new skills by utilizing the knowledge related to existing skills can be most beneficial.

Once a person is familiar with the concept of pushing a button, adapting to new devices with similar buttons becomes easier. Furthermore, the physical form of the interface can also mimic other existing familiar interfaces. For example, the handle of a regular door is so familiar that even a picture of a handle is associated with the act of opening. This relationship between the ability to operate the handle and the perception of the handle itself is called *affordance* [19 p. 127]. The handle or even an image of a handle affords the act of opening. The UCD process can benefit significantly from the concept of affordance in designing interfaces to elaborate and abstract systems. By introducing new systems and devices with the help of familiar affordances, the transition to the new environment becomes natural and efficient.

Efficiency in operating and making choices based on visual affordances is well documented, but the actual psychological mechanism is not agreed upon. For instance, in the process of climbing stairs, affordances of choice and execution are perceived to be different from those perceived during only evaluating object properties [20]. Furthermore, while objects afford *tangible* action, the significance of the action and available options can be *intangible*. Incorporating affordance with significance produced a theory of *signifiers*. A person encountering a new situation or a device constructs responses and actions by trying to understand the significance of the perceived environment and information [21]. Providing explicit signs and cues for the user to work as signifiers is one of the main responsibilities of a user-centered designer.

The documentation of an electrical device - be it on paper or in digital form - is a user interface in itself. Therefore, many of the general principles and heuristics of user interfaces can and should be utilized in documenting the devices and systems. Adhering to these *rules-of-thumb* will enable the reader to start learning quickly and adopting new information can happen in a familiar context. Additionally, the structure and format of an instruction manual should conform and follow existing manual design at least to a degree.

The concept of *legacy* or backwards compatibility is not relevant only in the technical domain. The concept has meaning beyond the original usage of the term and can be valuable in introducing new systems. Taking advantage of the user's existing knowledge should facilitate faster learning and adoption of the new system. However, adhering to poor practice only because it conforms to instructional legacy should be avoided. Best learning results are achieved by integrating the new knowledge with both familiar and intuitive instruction formats and designs.

2.5.3 Human perception and learning

Even a paper interface can be constructed to present visual affordances or signifiers and the usage of color and form is especially powerful. The human eye has cells specialized in the detection of color, depth and motion and the brain can interpret this basic information very quickly. Object recognition and analyzing movement beyond the first observation also happen in specialized parts of the brain [22 p. 1].

Processing information with these specialized capabilities is fast and effortless and this information can be utilized to build efficiency into the process of reading an instruction manual. Since the human perception system looks for certain visual cues naturally, the concentration of the reader can be targeted to specific knowledge on purpose. However, the human perception system has a limited conscious capacity in relation to time and the available sensorial information and is dependent on both the observed content and the observer [23 p. 48]. Therefore, the structure and amount of information in the instruction manual should be subjected to specific visual user tests in addition to other testing.

The human brain counters this capacity limit by pre-attentively processing images; thus, allowing our conscious perception to concentrate to areas that are perceived as most informative. One way for the pre-attentive process to analyze the image is to look for order in the chaos. Another is to look for anomalies in the organized. This way, a single colored dot is always consciously observed first in a group of black dots and it is possible to perceive the hidden number in the polychromatic test for color blindness. By breaking the structure with color of form, the instruction manual can be designed to guide the readers gaze in a beneficial way. If the way to break the structure is used consecutively, it will become a recognizable pattern and the reader will eventually learn to look for it pre-attentively. The fast and parallel pre-attentive processing is based on perceiving form and structure without consciously accessing memory. [24]

Learning is a process of adopting new information. Commonly, learning from books and manuals happens only in one direction, since there is only one sentient participant present in the situation. From the UCD point of view, it would be most beneficial if learning and transfer of knowledge could happen in both directions. As the user learns and gains skills and efficiency, the system or device should also learn to know the user and adapt accordingly as the user evolves. This would enable the system to actively change the depth and width of information available to the user, for instance by offering shortcuts to the advanced and step-by-step instructions to the beginner. Introducing such adaptive features to a paper guide is quite challenging, but the premise and principle can still be utilized. Nevertheless, while creating a paper manual capable of learning may be impractical; some form of feedback gathering and revision procedure should be implemented.

2.5.4 The psychology of choice

Making a decision about what devices to acquire or use can be a complicated mental process. The user interface (UI) is in a pivotal role in this selection process, since the physical UI is the first feature that is available for inspection upon encountering the device or system. The decision process has both rational and emotional aspects and both affect the choice and the subsequent use of the device. In the case of an unfamiliar product, the selection process begins when a *first impression* is formed.

The first impression of a product forms in a matter of seconds and can be very lasting [25]. The impression is often acquired automatically and unconsciously before actually operating the device in such a short time that the impression is mostly based on pure aesthetics. Consequently, aesthetical aspects dominate the initial evaluation process over technical usability factors. However, once the choice to use is made, content usability becomes equally important as the visual factors of the device [26]. Creating a balance between aesthetics and other usability factors was a key goal in the development of the instruction manual in this project.

The psychology of choice is a subject for ongoing scientific study. Even when a study uncovers dominating decision making processes and identifiable selection rules, it is found that they are not consistently followed. The existence of a coherent set of selection criteria does not guarantee reaching the same decision every time a choice is made, since the decision process of a human is not always rational [27]. Furthermore, the selection process is guided by personal experience and knowledge, which are not always consciously recognized.

A skilled and knowledgeable operator makes choices and judgments unawares of the cues and signs being accessed and evaluated. For a user with less skill, the decision process can be even more unconscious, since the amount of available information doesn't promote rational decision making [28]. The intuitive nature of choice processes hinders studying them and incorporating research findings into product development projects. However, utilizing the available knowledge is sensible, even if the desired effect is achieved only in some use-cases.

Acknowledging the unconsciousness of choice further promotes using UCD over traditional technology and feature driven development. In the case of testing the instruction manual, understanding the psychology of choice was critical and provided a sufficient foundation for analyzing user actions accurately. Since decision making often revolves around monetary issues, it is prudent to widen the perspective from technical and human considerations to cover the economic aspects as well.

2.6 Engineering and economics

While safety, efficiency and usability remain among the main issues for engineers developing new products, another equally powerful motive exists behind corporate research and development. These new tools and devices need to be economically viable to produce and attractive to the potential user base. Therefore, the connection between engineering and economics is strong and exists nowadays even in the academia. Consequently, a holistic view about *technology*, *economics* and *the user* is needed in building successful and usable products. Acquiring this all-encompassing view requires quantifiable inputs from all of the three areas. A good design passes technical inspections, economic considerations and usability testing. If these factors are incorporated into the design process early on, the end product will have a higher probability to succeed commercially and perform the way it was designed.

Quantifiable values can also be assigned to the development process itself, in order to better understand the actual monetary value of an additional feature or a round of user testing. In practice, a usability return on investment (ROI) can be calculated by measuring factors such as saved development time, increases in revenues and even brand popularity [29]. Adding the economical dimension to engineering should increase the efficiency of the process itself and guarantee long-term viability and prosperity for the company and people performing the work.

Engineering an instruction manual is not an exception to this rule and the economic aspects of the development need to be considered carefully. Creating a schedule for the work ensures staying within the development budget and providing compensation for user contribution promotes willingness to participate in future projects. Additionally, highly valuable theories and scientific practices for analyzing user actions have been developed by economists for marketing purposes.

Observing, recording and quantifying human behavior is at the core of user-centered design and understanding selection methods and decision making processes of the customer are crucial. Choosing whether or not to buy or use a product is potentially an abstruse behavioral process and achieving reliable results and analysis can be difficult. One possible methodical approach is to assign a numerical value for time, which is a key parameter in rational decision making. Specifically, a quantifiable *opportunity cost* numeric can be used to replace the user's subjective *value of time*.

Opportunity costs can be derived from the loss of *utility* or satisfaction by choosing one opportunity over another. Maximizing utility is the primary factor in the decision making of a rational person [30 p. 10]; however, not all decisions are rational and some problematic situations are resolved by taking a chance. The relevance of understanding decision making processes is paramount in user-centered design projects, as mentioned before. For example, finding information from the instruction manual requires problem solving and decision making with incomplete information. The ability to analyze users' actions in relation to their satisfaction provided useful information for enhancing the manual structure and design. This chapter is concluded by discussing the core substance of the development project - the instruction manual.

2.7 Instruction manuals

Complex tools are often accompanied by cryptic user instructions or none at all. This has contributed to the birth of a user base, which is unwilling to even open the manual before starting to operate the device. Even those who take the time to read the manual usually suffer from the poor design of the instructions; thus, the usage is in-efficient or even erroneous. Usually these tools are built to improve efficiency or remove tedious work, but often they actually cause new obstacles and add frustration to the work performance. In some instances, operating modern machinery can be hazardous to the health of the operator or other people. This increases the need for using machinery and related systems in a proper way well beyond the original efficiency purpose.

The goal of an instruction manual is to minimize situations where usage choices have to be made without relevant knowledge. The ideal manual would; therefore, provide instruction for each possible situation. Since this is clearly impractical, the second best result is to provide guidance in overcoming problems by offering information essentials complemented with troubleshooting methods. Pages and pages of specifics and step-by-step instructions are more likely to turn the user away from the manual, than to encourage reading further.

The instructions should comply with the basic heuristics of choice: representativeness, availability and adjusting the initial choice [31]. Firstly, the instructions must represent the issue they are covering in a way which is recognized by the reader. Secondly, the action or answer suggested by the manual must be actually available and accessible for it to be selected. Finally, the representation must be rational and convincing enough to overcome the resistance caused by any previous choices.

The concept of minimalistic manual design promotes doing and learning at the same time, when the user's attention is not monopolized by complex instructions. Additionally, minimalism facilitates the fulfillment of the natural need to act and physically operate the device when learning is happening [32]. To complement legacy based page numbers and section markers, it is beneficial to provide additional information about the location of the opened page in the manual. Showing the state of the system, even though the system is printed on paper in this case, adheres to experience based design rules. Furthermore, the behavioral need to quantify observations in relation to the whole is addressed by showing progress in comparison to the length of the document [33].

As mentioned before, aesthetics play a key role in encountering new devices or information. The layout and use of form and color must be carefully considered and subjected to user testing. Although this particular manual was designed to suit a certain user group, the general design offers good usability to all potential users. For instance, while the manual is in full color, it is also usable if viewed in gray-scale for some reason. The next chapter presents the methodological guidelines and practices for the iterative UCD process in detail.

3 Methodology

Behavioral and social science have made significant strides in understanding the human psyche and brain functions during the past decades, as discussed in Chapter 2 of this report. The human ability to automate actions and responses has enabled focusing on long term survival and goals. Knowledge about the humane tendency to automate basic responses and prefer certain ways of operating presents new challenges and opportunities for research and the development of technology. User-centered design is a product development concept that surfaced in the 1950s, but has only recently become main stream along with the popularity of the terms usability and user-experience. Combining cognitive engineering principles and UCD with technical R&D promises a new generation of devices, which capitalize on our inherent automation capabilities as well as on certain other inbuilt preferences of the human brain.

With the wide academic arsenal of usability theory and human behavior modeling, it is possible to create devices and interfaces that feel natural when used for the first time and evolve as the user's experience and skills develop. *Human computer interaction* or HCI is another name for this area of engineering science, which seeks to create sophisticated interfaces between the human and computer domains. In the case of a modern car, the interfaces also have to promote safe operation and take into consideration the hazardousness of the operating environment. Information must be available with a quick glance and demanding tasks should require stopping or slowing down the vehicle, also in the case of the user interface of an instruction manual.

In this chapter, the development methods and guidelines used in creating the instruction manual are described comprehensively. Building the development process on the theories presented in Chapter 2 and on practical UCD methods ensured a highly usable end product. The process started by defining tangible goals and motivation for the development.

3.1 Motivation and goals of the development

The aim of this work was to analyze and augment the usability of the interfaces in the instrumented research vehicle. In order to allow easier initiation to the new research tool, a user manual for the onboard systems was constructed with the help of real end-users. The process of developing the manual of the scientific measurement systems was user-centered and included heuristic evaluation as well as scenario and focus group testing. The end result is an intuitive instruction manual, which provides essentials easily and comprehensively. The usability of the research vehicle has a substantial effect in the long term success of several research projects involving the car now and in the future.

In the beginning of this project, the vehicle was available for use, but only the developing team had the necessary expertise to operate the vehicle. By converting their tacit knowledge to explicit form, the instrumented research vehicle became available to the whole research team and other relevant parties. Furthermore, a process of learning the system commenced, when the researchers were incorporated into the participatory development project.

The UCD process is fundamentally iterative and a plethora of guidelines and methods exist for actual testing. In this project, the manual was created through an initial round of specialist testing and three iterations of user-testing. The methods used in this project are described in subchapter 3.3 and the usability guidelines for the development are discussed below.

3.2 Development guidelines

User interface design became a popular topic for engineers when computer displays and graphical operating systems were developed. However, designing interfaces with good usability proved to be difficult, since the physical layer available for implementation and evaluation controls abstract and complex systems indirectly. Consequently, a complete analysis of an UI is often problematic and impractical.

The gap in skills and aptitude between developers and potential end-users was and remains considerable, even though graphical user interfaces are becoming predominant in commercial products. Therefore, the basic usability of a graphical interface is often inherently quite poor for the average user. The unavailability of complete and exhaustive analysis tools has led to a situation, where literally thousands of guidelines exist for user interface development [34]. Adhering to all these guidelines would be impossible; thus, designers are forced to produce their own design codecs or choose a subset of the available material.

In this development project, three such subsets formed the foundation of the design. The sets were: Nielsen's usability heuristics, Lund's usability maxims and Gerhardt-Powals cognitive engineering principles. The guideline choice was based on the popularity and applicability of the sets. Nielsen's experience based *heuristics* are among the most popular and accepted guidelines for producing good usability.

3.2.1 Nielsen's heuristics

A heuristic is a design principle generated by the experience and knowledge of successes and failures in design. A set of these heuristics allows analysis and approaching the complexity of UI design in an organized way. The supposition is that when a user interface is in accordance with accepted heuristics, a good level of usability is achieved.

Jakob Nielsen was one of the first to offer a widely accepted list of heuristics for interface design and evaluation. The list was originally developed for web site improvement, but it is general enough to be useful in most UI development processes. Nielsen's ten heuristics [4 p. 20] are:

- use simple and natural dialogue
- speak the user's language
- minimize the user's memory load
- be consistent in the use of words, symbols, pictures and structuring
- provide feedback and reports of progress
- exiting from the UI must always be available and visible
- cater to all skill levels by providing guided progress for novices and shortcuts for experts
- error messages must be clear and offer information to the user
- error prevention must be built into the design
- help documentation must be provided in a minimal step-by-step format within the context of use.

Although some of the heuristics are not applicable to a paper interface, many of them offer valuable approaches. The use of dialogue and language is critical in conveying abstract information. The principle of minimizing memory load can be used to decide content ordering and structure in the manual. Consistency in the use of colors, pictures and text should help the user to quickly learn what to expect and look for. The skill level differences of the users were taken into account in the manual design and a process for giving and receiving feedback was implemented. A help section for the use of the manual itself is also available as the heuristics suggest.

While Nielsen's heuristics are among the most popular, they are only a fraction of the design guidelines created during past two decades. Lund's usability maxims were collected for the precise purpose of identifying the most pertinent guidelines from the thousands available.

3.2.2 Lund's usability maxims

One of the main problems of user-centered design is the poor usability of the development methods and theories themselves. Likewise, the sheer amount of usability guidelines hinders adopting the design philosophy. Arnold Lund opted to remedy this problem by surveying UCD experts and creating a list of usability maxims by arranging the guidelines in order of their perceived value. Seven of the most valuable guidelines [34] form the core of Lund's usability maxims:

- know the user; and you are not the user
- uniform objects should act consistently
- information for decision making should be available in the context where decisions are made
- error messages should mean something to the user and propose corrective measures
- every action should have a reaction
- usage mistakes are inevitable; so corrective measures should always exist
- user's memory capacity should not be strained to the limit.

While the error and action maxims are related to operating electrical devices, they offer value for the manual design as well. Addressing error messages and action-reaction deficiencies in the instruction manual is vital as a general rule. However, covering these issues was increasingly important in this project, since correcting inconsistencies in the instrumented vehicle itself was outside the scope of the development project. Furthermore, even the partially applicable maxims were used to assess the usability of the measurement system as a whole for future development.

Maxims about knowing the user, uniform objects, information contexts and memory capacity were utilized to their full extent in the manual development. Selecting users to the participatory tests was based on acquiring knowledge about real end-users. Consistency and memory load minimization formed the core of the design as suggested and information context helped in defining suitable ordering for the instructions. To further build on the accepted design guidelines, a set of cognitive engineering principles was also utilized.

3.2.3 Cognitive engineering principles

Nielsen's heuristics for website design inspired other researchers to create models for systematically approaching the field of usability. Gerhardt-Powals created a set of cognitive engineering principles from earlier work in the field done by Murphy and Mitchell in 1986 and Taylor in 1989. The Gerhardt-Powals set [15] comprises of ten principles for user-centered design:

- automate unwanted workload by reducing calculations and comparisons
- reduce uncertainty by displaying data in a clear and familiar way
- fuse data from different levels of accuracy into one level to reduce cognitive load
- present information in a meaningful context and provide interpretation
- improve recall and recognition by using contextually relevant labels
- group data and information consistently throughout the whole system
- reduce contact with raw data by generating and displaying representative graphics
- display only information relevant to the task at hand
- allow customizing of formats and levels of detail based on preference
- avoid repetition and incorporate only minimal information redundancy into the design.

Contrary to usability heuristics and maxims, the cognitive principles are not experience but theory based. Therefore, they offered a second approach for developing the manual and are more or less generally applicable. Automating unwanted workload can be done by taking advantage of pre-attentive processing. Displaying information in clear and familiar ways can be done with affordances or signifiers and once again the consistency of information is emphasized in the design guidelines. Memory load issues can be tackled by analyzing recall and recognition processes and information grouping. Allowing customizing should increase the user's feeling of being in control and avoiding repetition facilitates efficiency.

The experience based heuristics and theory based principles were used throughout the development. In addition to these general guidelines, several specific usability testing methods were used in the actual iterative design process. The chosen testing methods are presented in detail in the following sub-chapter.

3.3 Development methods

The testing methodology of UCD can be roughly divided into two groups. Expert methods utilize usability specialists, who are able to review product characteristics and features analytically from the user's point of view. The other method group consists of participatory tests with real users. This user testing forms the fundamental basis of user-centered design. Commonly, test participants are chosen randomly from a group of potential end-users and they are given tasks to complete or products to play with. Preferably, the user's aptitude should range from novice to expert in relation to the test product. It should be noted that testing with an expert user is not the same as testing with a usability expert. Furthermore, even a novice user can be experienced in user testing in general, which can affect the testing procedure and results. Consequently, information about the user's background, skill level and previous experiences in user testing are vital for the success of analyzing test data.

The choice of testing methods is dependent on the current state of the development. Specialists can be used to gain understanding of the usability level quickly and early on. Even an initial design, a paper prototype or a mere design draft can be subjected to expert reviews. Contrarily, user testing usually requires significant time and resource investments and is harder to implement in the beginning of the development. Even though two groups of testing methods exist, a combination of tests from both categories generally yields best results. Furthermore, it would be optimal to be able to design the testing program to cover the whole development and not start from the first prototype or a nearly finished product.

In the development of the instruction manual for the research vehicle, usability testing was conducted throughout the project. Additionally, both specialist methods and user testing were used, for achieving reliable and usable results. The project started with an expert review and continued to participatory tests. Usability guidelines and cognitive engineering principles acted as a framework for the entire development. The first phase of the project was content gathering, which was done with the help of a *task analysis*. The material from the analysis was converted into an initial manual design with the help of heuristics of choice and other suitable design tools and concepts discussed in Chapter 2. The manual was then subjected to an iterative and participatory user testing program of usage *scenarios* and *focus group discussion*. The following subchapters present the chosen methods in depth.

3.3.1 Task analysis

The goal of a task analysis is to identify usability problems by dividing user actions to their most basic components and cognitive processes. A mere description of the task is not sufficient, but an analysis about causes and solutions for problems is needed. In the analysis, tasks are considered to be goal oriented and not only a sum of independent actions. The method was originally created for assessing work and training performance [35], but has since been adapted to usability testing purposes.

The goal governing a task is a preferred state of affairs in comparison to the current state. A goal may be active or latent, a condition which will define a plan of actions and contingencies [36 p. 19]. Task analysis is an invaluable tool, for the UCD process of creating an instruction manual. By systematically evaluating actions and their goals, problems in the current design become evident and a better solution may present itself in the process. In practice, the tasks are decomposed to events in a hierarchy of goals and subgoals. An event is a series of operations - a fundamental of task analysis - which comprises of goals, inputs of the environment, user actions and criteria for evaluating success or failure [36 p. 20]. The decomposition of events and operations continues until the most basic operation is reached [37 p. 73].

For example, a task analysis could start from the goal of turning a computer on for the purpose of controlling a sensory device. By decomposing the events and operations required in achieving the goal, the lowest level of the hierarchy could be identified as using a finger to apply pressure to the ON-switch of the computer. The level of detail needed for successful analysis is dependent on the task and complexity of the system. While examining a push of a button may seem excessive, in some cases the depth of understanding acquired by evaluating even the most basic operations is necessary.

Independent of the level of detail, the created hierarchy of fundamental operations is then evaluated. The outcome of a successful analysis is a detailed decomposition of the task containing descriptions of problems, efficiency evaluation of the applied operational path and solutions for future development. The hierarchical form of the method is referred to as hierarchical task analysis or HTA. Naturally, task analysis is not the only existing method for decomposing tasks. Cognitive work analysis (CWA) is a similar tool for deriving design implications and analytically assessing user performance [38 p. 13]. However, HTA is the most popular decomposition tool in design projects and in problem solving [39]; thus, it seemed suitable for this project as well.

In developing the instruction manual, an HTA was used to acquire the initial information content for the manual. Event decompositions were used to select information essentials and identify problematic tasks. Additionally, the analysis provided information about increasing efficiency of use and remedies for correcting usability problems in the measurement system in the future. After the first manual version was completed, it was subjected to scenario testing.

3.3.2 Scenario testing

UCD promotes and requires incorporating real end users to the development process. A systematic approach and guidelines are needed to retain control and objectivity of the tests with human participants. The participatory user testing method chosen for this study is called *a scenario-of-use*. A scenario study can be done with low costs and resources, once a prototype or an initial version of the product is available. Therefore, the method is a natural choice to follow after the specialist testing is completed.

The process of creating a test scenario begins by identifying intended users and the tasks they most commonly perform with the device [40 p. 45]. Additionally, the context of use needs to be carefully evaluated and defined. The second step is the decomposition of the chosen tasks by utilizing a method such as HTA or CWA. The third phase is to determine the roles of all agents present in the test. The user needs to know beforehand how to act towards the tester and other persons present in the situation. Ensuring the accuracy and objectiveness of the results is a key concern and successfulness should be evaluated after the test is over. The fourth step is to generate the scenario description and guide for the user's actions. A high degree of flexibility should be fused into the test, in order to allow the user to make decisions and not just choose from a list of predetermined options. Recording the test on video is required to enable detailed analysis and a draft of expected outcomes and execution times will further ensure the objectivity of the evaluation. [41]

A finished scenario test must always be subjected to *pilot testing*. The pilot will ensure that the scenario can in fact be performed and provides a learning opportunity to the test organizer. The pilot test should use exactly same material and happen in comparable circumstances as the real tests. If the scenario content or circumstances are adjusted significantly after the pilot, a second pre-test may be appropriate before proceeding to actual user tests. Once a successful pilot test has been achieved, the real scenarios-of-use should be smoothly executable.

A user in a scenario test is not the study subject, as is the case in clinical trials for example. Even though the user's actions are recorded and mental models analyzed, the subject of the study is the interaction happening between the product and the user. Therefore, the main focus in analyzing scenario tests is identifying problematic situations, erroneous results and causes for user frustration. Using human participants in testing requires addressing ethical consideration along with technical ones. The pressure to perform and succeed in the test situation can be a real strain to the user [4 p. 181]. Furthermore, the recorded material can contain personal information and is subject to privacy protection laws and common courtesy.

The user's frustration or other negative feelings have implications beyond research ethics. The quality of the test data may be affected by the user's distress or the test may even be interrupted prematurely. Therefore, the tester must be able to recognize and separate harmful situations from normal problem solving difficulties. Encouraging the user to continue in the face of adversity or fatigue may be needed, even though it may have an effect on the test data reliability. Consequently, the scenario must be designed in a way that needless sources of frustration are removed and difficult parts of the test can be omitted if necessary. Additionally, knowing or getting to know the user before the test should help to address the issue. Fortunately, the hands-on theme of scenarios can mitigate the effect of being studied, since the user needs to concentrate on tangible objects and actions. As mentioned, piloting the test should also help lessen the user's anxiety and frustration.

Since scenarios are structured and limited in scope, they provide information about specific features and usability problems. This allows the test organizer to validate first impressions immediately after the test is over. In this project, each scenario ended with a questionnaire and a short discussion about the test and initial findings. The recorded usability problems and feedback about design solutions were used in the iterative development process to create an enhanced version of the manual. A more exhaustive discussion about the manual was conducted in a *focus group*.

3.3.3 Focus group discussion

User testing with a single participating individual provides information pertaining to a particular user type and usage situation. Additionally, traditional user tests do not promote free debate, since the test is often task oriented. Contrarily, a focus group discussion presents the developers a chance to inquire opinions and usability information from multiple users in a single session. Furthermore, a more holistic view of the usability state of the product becomes available, if the discussion is directed to areas left uncovered by other tests. A focus group is suitable tool for confirming feedback and findings from earlier tests and also for drafting design solutions for implementation and further testing.

Even though focus groups were originally a marketing research tool, the method has been adapted to be applicable also in usability testing. These groups offer an opportunity to gather information about subjects unknown to the designers. The group should comprise of six or more carefully chosen participants, who have an open yet slightly moderated discussion about the product in question [42]. For a product with a mass audience, sufficient sample representation requires numerous group sessions, while a system with a specific user base can benefit even from a single event. The interactive and open nature of a focus group discussion requires recording for accurate analysis. The role of the moderator is limited to keeping the discussion going by providing an inspiring atmosphere and eliciting full and equal participation from all debaters.

In developing the instruction manual, a focus group session was organized to evaluate the second version of the manual. Special emphasis was given to aesthetics, vocabulary and the use of language in the manual. Using language familiar to the users is vital for the success and readability of the instructions. Additionally, contradictory or unreliable findings from previous tests and competing design solutions were subjected to further scrutiny during the discussion. As in the case of scenario testing, formal information about the test partakers and their impressions about the session were acquired through a questionnaire. This chapter is concluded by discussing issues related to choosing participants for user testing.

3.4 Choosing participants

UCD revolves around user testing and choosing representative participants for the tests is a prerequisite for reliable test results. Naturally, the representativeness can only follow from gaining an understanding of the potential user base and choosing comparable testees. Accurate personal information about individual participants is also needed, since interpreting test results reliably requires sufficient background information.

The skill level of a testee is a significant variable in user testing. *Content expertise* and prior knowledge about the product enables users to identify more problems as they have an expectation how the device should work. Conversely, an expert user may be able to overcome more obstacles than a novice by using compensatory strategies acquired through experience. Even though an inexperienced user may find fewer problems, they are usually more severe [43].

An expert user has the tendency to concentrate on issues of efficiency and functionality, especially in the early stages of the development. Since there is a significant difference in both the number and severity of found usability issues depending on user aptitude, the user sample must have sufficient skill variation. Having fresh eyes and seeing something for the first time often provides different reactions to the stimulus in comparison to seeing something familiar. Therefore, content novices are needed especially for testing aesthetic features of the product. In extreme cases, experienced testees may prevent accurate testing and should not participate in certain tests.

Context expertise or experience is another important factor in usability testing. A person participating to a user test for the first time can act differently in comparison to a testing veteran. Generally, it would preferable to have only context novices in usability testing, since accounting for data artifacts caused by prior testing experiences can be difficult. However, context expertise rarely prevents user testing completely.

In this study, the scenario tests used five users as instructed by Nielsen [8] and confirmed by Sauro [9]. The users were all potential operators of the instrumented vehicle and their prior knowledge about the vehicle varied from novices to experts. The focus group session happened between ten debaters. All test participants were recruited from the working staff of Aalto University research groups and their customers or related third parties.

The personal skill levels relevant to the tests were evaluated before recruiting. This ensured sufficient variation in the users and produced material about a score of usability issues. The participation was based on volunteers and small compensation when needed. Users were selected evenly from Finnish and English speaking groups. Another selection factor was the availability of the participant on the following day for further reflection and discussion. The following chapter describes the iterative UCD process for creating an instruction manual in more detail.

4 User-centered design of the instruction manual

Operating the measurement system of the research vehicle is a demanding task, as mentioned before. Since the vehicle is primarily a platform for a variety of instruments, it would be impractical to create an instruction manual to cover all possible configurations. Furthermore, the current setup is designed for a single purpose measurement task of monitoring traffic with cameras and distance sensors. Therefore, a natural direction for developing the instruction manual was to draft a likely research scenario to match the present equipment status of the vehicle.

Conflicts and driving behavior in a multilane tunnel were chosen as a subject theme for the scenario, since tunnels are a relatively new and distinct element in Finnish road infrastructure. The scenario was primarily designed to serve this development project, but the collected sensor and video data remains available for future research as well. Additionally, the participatory UCD process presented an opportunity to monitor the reliability and stability of the measurement system during numerous repetitions.

The outcome of user-centered design hinges on the successfulness of user testing. Even though a cast of usability tests for experts exists, gathering enough reliable data with only specialist methods can be challenging and ineffective. Combining cognitive design principles, expert testing and actual user tests with real end-users should provide a sound foundation for any R&D project.

This chapter describes the user-centered design of the instruction manual comprehensively. Firstly, a usability definition for an instruction manual is presented. Secondly, design targets for the manual and the project are discussed. Finally, the actual iterative design process is reviewed.

4.1 Defining good usability

Although user interfaces have a standard definition for usability [5] and the UCD community follows commonly agreed criteria for producing good user-experiences, special usability implications caused by the context of use should also be addressed. Therefore, defining usability of an instruction manual in the case of a research vehicle was the first step in producing desirable results later on. The definition acted as a foundation for evaluation criteria and user tests [44]. Additionally, the definition was used to choose between conflicting designs.

The standard usability guidelines of effectiveness, efficiency and satisfaction remain at the core of even this specific definition; however, an effort to substantiate them seemed reasonable. Usability stems from effectiveness, which in turn is synonymous with achieving results. Essentially, the information content and structure of the manual must facilitate positive and expected outcomes of the usage. Each occasion when the manual is accessed without finding an answer, can be considered as a failure in effectiveness.

The efficiency of use is subject to the effectiveness of use. The required investment in time and effort to search information from the manual must be negligible compared to the time required to perform the actual task. Thus, content ordering should minimize needed page flips and information format should be clear and comprehensible. Using language and layout formats familiar to the reader promotes both conscious and subconscious proficiency. While efficiency is a secondary objective in comparison to effectiveness, proficiency often correlates with the third satisfaction criteria.

Best usability is achieved when the usage produces results easily and gives the user a feeling of satisfaction. This third key element of subjective judgment is in a pivotal role, when further decisions about using the manual are made. Satisfaction originates from feelings of aptitude and being in control. The intuitive feel of well-designed instructions can be engineered by using the cognitive design principles presented in previous chapters. Capitalizing on the user's pre-attentive processing and other automated functions promotes feelings of satisfaction and results in positive user-experiences. Unfortunately, meeting this third usability criterion can be a daunting task. The chosen development process for designing the manual is presented below.

4.2 The user-centered development process

The development project was designed to be iterative right from the beginning. In the first phase, an initial design solution was produced based on the contextualized definition of usability, design guidelines and cognitive engineering principles. This solution was then utilized to specify targets and procedures for a specialist UCD method, which was used to produce content for version one of the manual.

From the first phase onwards, real end-users were incorporated into the participatory design process. A scenario-of-use test was conducted with the initial manual version. The material from the scenario test set the direction for the first design iteration round and version two of the instruction manual. Additionally, a collection of competing design solutions was drafted based on the findings of user test round 1. The enhanced manual along with the competing designs was then subjected to a focus group discussion between ten people. The development project is outlined in Table 1.

Table 1: Development process dissection

Subject	Description
Direction	Sketching expected results and design progression
Guidelines	Drafting initial design guidelines for the process
Content	Acquiring content through hierarchical task analysis
Initial design	Production of the first manual version
User test 1	Subjecting the manual to scenario-of-use testing
Iteration 1	Production of the second manual version
User test 2	Evaluating the enhanced manual in a focus group
Iteration 2	Production of the third manual version
User test 3	Subjecting the manual to scenario-of-use testing
Iteration 3	Production of the final manual version
Outcome	Release of the manual and future development suggestions

The second iteration round further improved the manual design based on user feedback and through implementing corroborated design alternatives. A third user test ended the participatory phase by generating material and enabling decision making for the third and last iteration round. A closing review of the success of the project and chosen methods provided a direction for future development of the manual. The rest of this chapter covers the actual design process.

4.3 Iterative development

The development project was scheduled for the period of May - June in 2011. The first step was the choice of direction and drafting an expected outcome of the process. The direction for the development was formulated in the following way:

> *The instruction manual will cover the essentials of operating the system in detail. A section of general troubleshooting instructions covers the rest of the identified issues. The manual will be produced in accordance to UCD design guidelines and complies with cognitive engineering principles and instruction manual legacy. In contradictory cases, cognitive principles and guidelines trump instructional legacy. Users are incorporated to the process as early as possible and throughout the process. Only minimal information redundancy is allowed and the length of the instructions should not be excessive.*

A summary of the design principles is presented in Table 2.

Table 2: Design principles

Topic	Description
Cognitive principles	Learning through familiar affordances and signifiers
Gestalt principles	Highlighting important issues and facilitating fast perception
Heuristics of choice	Availability and attractiveness of the information content
Lund's maxims	Knowing the users and presenting the information consistently
Nielsen's heuristics	Information in the user's own language and aptitude level
Minimalism	Facilitating learning through physical action
Participatory design	Identifying and addressing the needs of the users
User reflection	Time for processing the new experience and information
Usability	Contextualized effectiveness, efficiency and satisfaction of use

The initial content for the manual was gathered through an HTA specialist method. The theoretical tunnel research theme provided boundaries for the analysis. After the first manual version was completed, the following detailed scenario was used to design the first user test:

- locate the instruction manual and familiarize yourself with the vehicle
- activate the power distribution system
- activate sensors and computers
- prepare cameras and sensor recording for a research run
- perform two measurement legs through a road section with a tunnel
- verify the success of the data recording and return the vehicle to its original state.

The same scenario outline was later used in designing the third and final user test. Between the scenario-of-use tests, a focus group discussion was arranged to answer specific questions about user preference. All test participants were recruited from potential end-users. The following set of decision criteria was used in user selection:

- only voluntary participation
- possibility to reflect for one night and give feedback on the following workday
- minimal prior knowledge about the design project

- sufficient background information about the user is available or achievable

- representativeness in terms of skills and language

- willingness to be recorded.

The following sub-chapters cover the UCD process thoroughly.

4.3.1 Gathering content and building the manual

After an outline for the scenario was completed and shortly peer-reviewed by a transportation researcher and the thesis instructor, a hierarchical task analysis was performed based on the scenario. Each identified action, problem and stage of the analysis was written down and arranged into a hierarchy of actions and choices. This content then acted as a starting point for the actual development of the manual. The content was streamlined for efficient use and in order to comply with the minimalistic design philosophy. Several design alternatives were mapped and the content and layout was built based on the cognitive design principles.

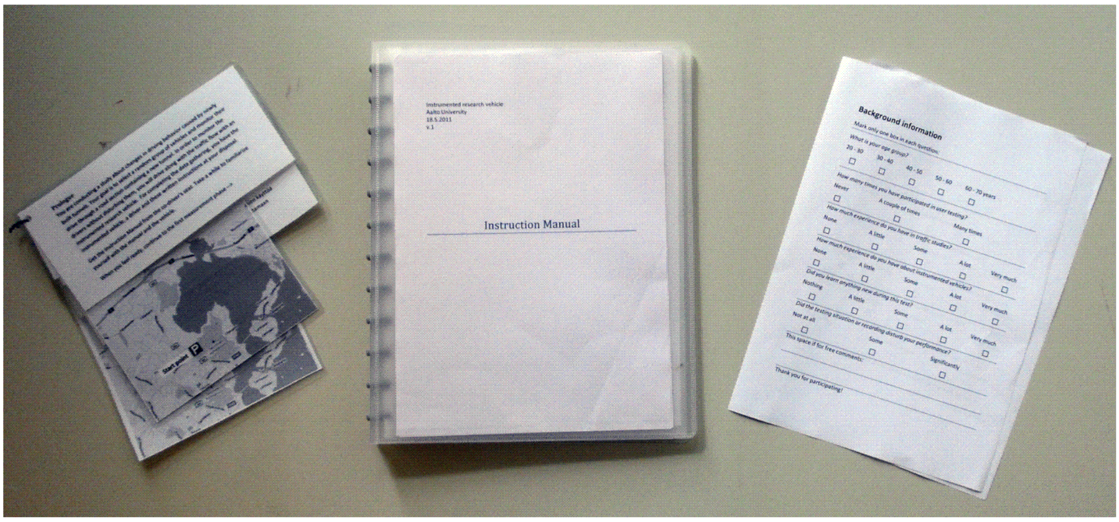
The implemented features were selected based on their compliance with the design guidelines; additionally, an artificial length barrier of 20 pages was set, based on the perceived amount of relevant information. The initial version of the manual was then printed on paper and combined into a hardcover booklet. The manual was first compiled in English and then translated into Finnish. Table 3 lists the major design features selected for the first version of the manual.

Table 3: Design features for manual version 1

Feature
Consistent use of color and icons to facilitate fast learning
Common vocabulary throughout the manual
Critical information presented with the help of signifiers
Information essentials in 20 pages for minimalism
Introduction to the manual itself in the beginning
Page numbers in the x / X format for showing system state
Quick start procedure for advanced users
Summary in the beginning of each topic for efficiency
Support and author information included
Table of Contents and Index to ease navigation
Troubleshooting section to help overcoming problems
Visual consistency in use of pictures and drawings

4.3.2 User test 1

Based on the theoretical research scenario, an actual scenario-of-use was drafted. The identified tasks were elaborated into readable text and worded into an assignment (Appendix A). This assignment and the first version of the instruction manual (Picture 5) allowed the first round of user testing with real end-users to take place. Four testees were recruited from within the research group and the fifth participant was chosen from a customer organization.



Picture 5: The assignment, instruction manual and questionnaire of test 1

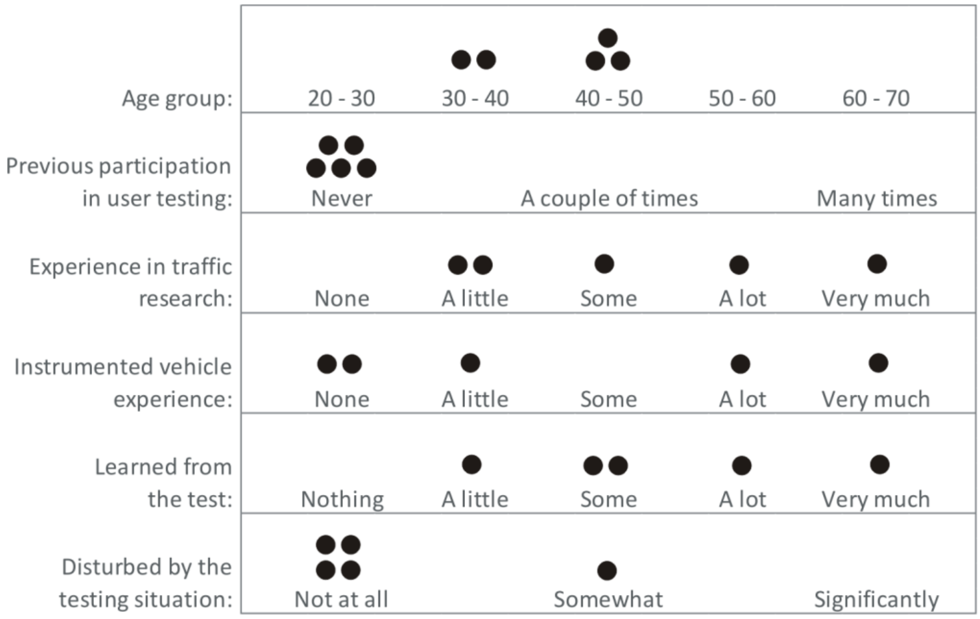
The scenario-of-use was subjected to a pilot test before actual testing. The pilot test was performed by a person affiliated with the construction of the vehicle. The purpose of the pilot was to test the feasibility of the scenario and allow the test organizer to practice recording and acting in the real test situation. The knowledge gained from the pilot was used to modify the manual and scenario slightly and a decision to proceed further with the real test was made.

The actual tests were held during three days in a way, where one participant took the test in the morning and one in the afternoon. The tests were held on Tuesday, Wednesday and Thursday; thus, enabling each user to reflect on the test for one night and give further feedback on the following workday. A request was made to the participants that they would not disclose the content and structure of the test within the research group during those three days.

In the test, the user assumed the role of a research system operator and a separate person drove the vehicle. The tests utilized an experienced research driver, who was instructed to refrain from helping the users during the test even if asked to help. The driver participated only through direct physical input, such as turning the engine on and driving to a specific target. Additionally, the driving safety and obeying traffic rules was the driver's responsibility, regardless of what the user might ask or do. A test organizer (the writer of this thesis) was also present in the testing situation, in order to record the actions of the user to video. The tester's role was primarily to observe and record the progress, but in cases of growing frustration or direct feedback about the test or manual, minimal contact through discussion was allowed.

All tests started by introducing the user to the vehicle, driver and scenario testing in general. After the short briefing, the permission to record the session was confirmed. The user was given the assignment and instructed to try to complete the task independently. The test material was prepared both in Finnish and in English. Native Finnish speakers used the Finnish material and everyone else used the English assignment and manual. Each user succeeded in completing the assignment. The longest test session lasted two and a half hours and the fastest lasted a little over one hour. The session times are not comparable, since traffic conditions were drastically different during the tests. In any case, the performance speed is not a relevant variable in this type of testing and all times were in the expected range.

After the test run was over, each user was asked to fill out a short questionnaire about the session (Appendix B). The questions were designed to reveal some background information about the skill levels of the users and their previous knowledge about the vehicle. Furthermore, a question about the test situation itself was asked to help in designing the future testing rounds. The user's personal impressions about each test were immediately written down and confirmation for organizer's interpretations was sought through open discussion with the tester and driver. Picture 6 presents the answers of the users.



Picture 6: Answers to background questionnaire in test 1

In test 1, two participants were aged between 30-40 and three between 40-50 years. None had participated in any user testing in the past. As intended, experience in traffic studies ranged evenly from little experience to very much experience. Similarly, two users had never done anything with an instrumented research vehicle, while the other three had some, a lot or very much experience.

As mentioned before, a secondary objective of the user-centered development was to initiate a learning process for the research staff. Test 1 revealed that learning had happened; though, some seemed to have learned more than others. The users rated their learning results evenly from learning a little to learning very much during the test. Feedback about the test itself is crucial for successful continuation of user testing, since testing is based on volunteers. For this reason, all tests contained a direct question about the test and also space for free comments. Four users reported that the testing situation did not disturb their actions at all, but the fifth felt somewhat disturbed by the presence of the test organizer.

4.3.3 Iteration 1

Based on the five user tests with the first scenario-of-use [45], a list of immediate and possible changes was drafted. Most of the changes were based on identifying problematic situations and concepts during the test sessions and screening the video recordings. For example, several testees were reluctant to search information from multiple parts of the manual to solve a single problem. Therefore, reordering of the content was necessary. The rest of the proposed changes came directly from the participants either during the test or after they had reflected on the test for some time.

The choice to categorize a change to immediate or possible improvement was made based on the rate of occurrence, severity of the consequences and practicality of implementation. For example, many proposals and improvements to the layout and physical form of the manual were postponed to the last iteration phase. Some proposed changes were conflicting with each other or with the design principles. Convincing but interfering proposals were used to create material for further user testing. Major reworking of the order of content was done based on the frequency and number of needed page flips in achieving a specific task. Some topics were elaborated with more detail and some topics were trimmed by erasing excess content.

A visual topic navigation bar was added to the manual at this stage of the development. The bar was an initial design feature, but it was not implemented to the first version; thus, reducing the number of needed modifications to the layout and content after the first round of testing. Interestingly, even some of the basic operations - for example operating a wireless keyboard - proved to require detailed guidance. Instructions about the use of a keyboard were deemed unnecessary in the task analysis phase; however, the user tests clearly demonstrated the necessity of specific instructions. A comprehensive list of key changes and added content concerning iteration 1 is presented in Table 4.

Table 4: Major design revisions in iteration 1

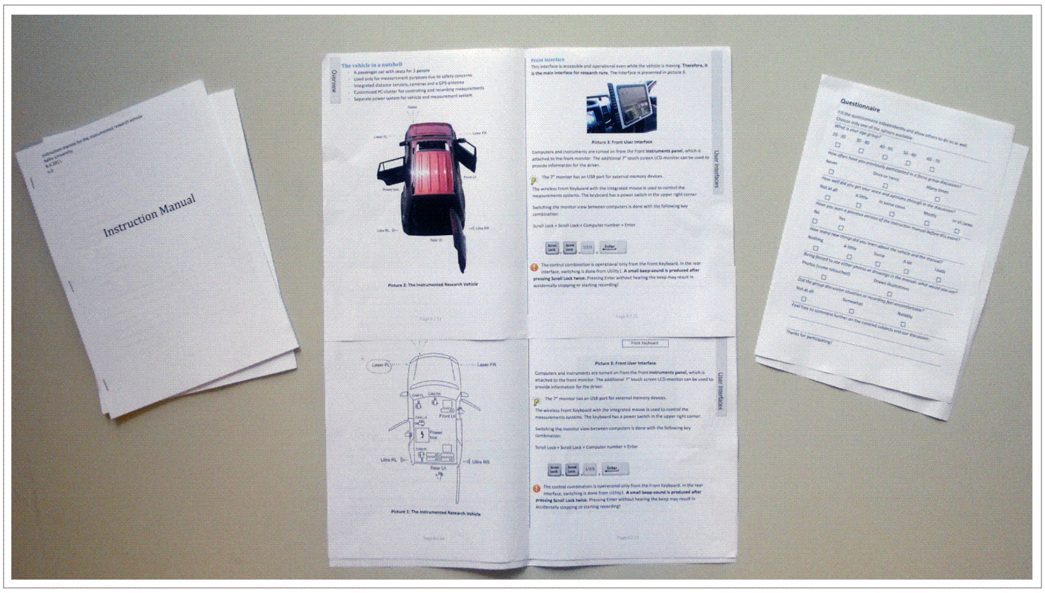
Modification
A separate section added detailing the correct use of wireless keyboards
A visual navigation bar was introduced to help switching between topics
Added information about the simultaneous use of the two user interfaces
Details added to software usage and camera operations
Re-organized topic structure and content placement to minimize needed page flips
The content of the Troubleshooting topic was significantly revised
The Index was completely reorganized and drastically extended
The power system instructions were redesigned and augmented
The step-by-step procedure for video recording was extended

4.3.4 User test 2

Even though testing with five users is an efficient way to uncover most usability problems, it is also beneficial to apply other testing methods in addition to the individual tests. A focus group discussion will allow the tester to get direct answers to direct questions without interfering or influencing the outcome of a single test. A group of at least six users is needed for fruitful discussion and the upper limit of the number of participants should be evaluated separately in each case [4 p. 215]. A too large group may require excessive moderation, which can affect the discussion in a negative way.

The second version of the instruction manual and several pages of alternative manual configurations (Picture 7) were subjected to a focus group discussion between ten people. The session was arranged on a Thursday to once again allow the participants to give additional feedback after sleeping one night. The participants were recruited from the potential user base and a moderator (the writer of this thesis) in an active role conducted the test. Each participant received the manual and material in either Finnish or English based on their preference.

The discussion was initiated by introducing the UCD philosophy and by describing the state of the development project. A permission to record the session was acquired from everyone and a small prize was promised for participation. Each person was encouraged to participate in either Finnish or English and the moderator acted as an interpreter when needed. Additionally, pencils were provided for each participant and they were requested to mark and comment the manual and material candidly and independently.

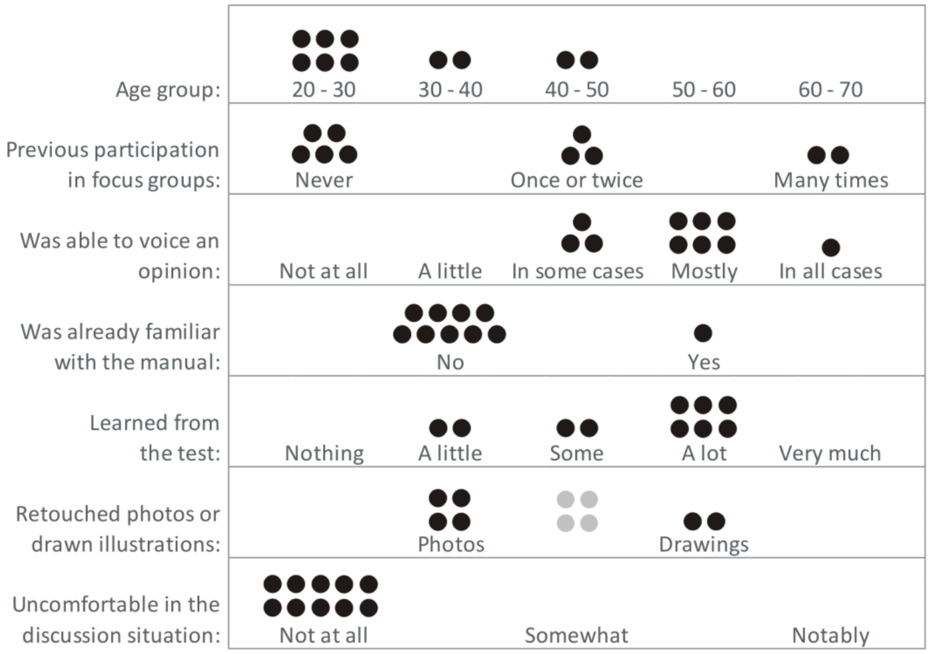


Picture 7: The manual, competing designs and questionnaire of test 2

The discussion was designed to flow freely, but with a topic skeleton to ensure sufficient coverage of the manual. The role of the moderator was to keep the debate moving and encourage input from everyone. Confirmation for first impressions and interpretations was also sought out by posing direct questions and actively participating in the discussion when deemed appropriate. The discussion begun with an eye-concentration test, where each participant was asked to mark the three places, which caught their attention at a first glimpse.

The concentration test was followed by assessing the merits and flaws of different design styles of the manual. For example, the usage of drawn illustrations or retouched photographs was discussed by providing each person two double pages with photographs on one and drawings on the other. Another main subject for the discussion was the language and wordings used in the manual. Unfamiliar words, poorly described concepts and misleading phrases were marked directly to the manual and spoken comments were written down by the moderator.

Numerous proposals were made regarding the layout and format of the manual. After the discussion was over, each participant was asked to fill out a questionnaire containing background questions and space for impressions about the test session (Appendix C). A small prize was given to each participant and a hands-on presentation of the vehicle was offered to those who were interested. Picture 8 lists information about the participants based on their questionnaire answers.



Picture 8: Answers to questionnaire in test 2

Six of the participants were aged between 20-30 years, whereas the four remaining were between 30-40 and 40-50 years. The group had some experienced focus group participants, but the majority had little or no experience of such situations. An open discussion can have a tendency to revolve around the most vocal talkers. A key task of the moderator is to prevent these individuals from monopolizing the discussion and gently force everyone to participate. Based on the responses to the questionnaire, this goal was achieved with satisfactory success. A clear majority was able to voice an opinion in most cases and only three participants felt that some of their opinions were left unheard.

Nine out of ten users had not seen any versions of the manual beforehand; thus, they were able to give valuable first impression feedback about the material. Particularly the success of the eye-concentration test hinges on fresh eyes and minds. If the material is already familiar to the viewers, their eyes and concentration are guided not only by pre-attentive processes, but also by their memories and conscious mind. As mentioned, the aim for this part of the test was to tap into the pre-attentive process and utilize the results in designing the manual to guide the eyes of a new reader to the most pertinent information.

The results of the eye-concentration test were almost completely unanimous. The largest picture on the double page caught the attention of all participants almost immediately. After the picture, their concentration had shifted to other pictures or colored objects on the double page. This type of testing would benefit significantly from a larger sample size, but since the results were so unanimous, they were accepted as such to guide the design process further. Since all participants had answered independently and in silence, the reliability of the answers was not questioned, even though the unanimity was notable. Furthermore, the results were in accordance of the predicted outcome based on the theory of pre-attentive processing.

Another main talking point during the test was the choice between using retouched photographs or drawn illustrations in the manual. The participants were asked to compare designs with photos to designs with drawings and mark their preference directly to the material. Once all had marked a preference, the subject was discussed in detail. Unfortunately, opinions and arguments in the group divided between the two designs and many could not even choose a clear preference. This was later confirmed by the questionnaire, where four users were unable to choose one over the other even if being forced to (Grey answers in Picture 8: Answers to questionnaire in test 2).

In the end, a preference towards photographs gained majority in votes, but the quality of the photos and drawings was deemed to play a more important role. All in all, the debate over illustrations raised more questions than it answered. The final decision in this matter was postponed to the last iteration, since the group's preferred choice of using both photographs and drawings was in contradiction to the design philosophy. Consequently, a preliminary combination of retouched photos and drawn illustrations was chosen to be subjected to user testing in test 3.

The participants indicated that the discussion had been informative and most had learned significantly from the session. Once again the last question posed to the users was about the test itself. As a testament to the success of the discussion, none of the participants had felt uncomfortable being recorded or part of a test group. Even the long length of the discussion (approx. 1 hour and 10 minutes) had not felt tiring to anyone, since the free flowing structure allowed the debate to concentrate on interesting subjects.

On the following day, many participants wanted spontaneously to review the discussion once more. Feedback about the test situation and manual content gained from these individual sessions were written down and incorporated to the recorded material of the focus group debate.

4.3.5 Iteration 2

The material gathered from the focus group was used to draft out a list of immediate and possible modifications to the manual. The decision of implementing a change or a proposal immediately was made by assessing the implications of the change in relation to the design principles and upcoming user tests. Since only a single round of user testing remained, all changes with potentially major effects to the usability of the manual needed to be implemented in this phase.

The opinions of the focus group participants were consistent in most issues, but unanimous views were rare [46]. Proposals with a simple majority were accepted, if they did not conflict with the cognitive principles. Unanimous proposals were implemented even if they were conflicting with the design philosophy. A number of visual changes and layout proposals were postponed to the final iteration phase. As mentioned before, the final choice of using photographs or drawings was postponed and a combination of the two was implemented for manual version 3.

Each specific decision to use a photo or a drawing was based on majority votes from the focus group discussion. Unfortunately, the votes reflected the quality of the chosen picture and not the format. Even though this procedure of mixing photos and drawings significantly altered the continuity and congruency of the manual contents, it improved the information value of the content. A re-evaluation of the compromise between information content and design philosophy was incorporated to test 3 and the subsequent final iteration.

Based on the focus group discussion, the manual was again significantly modified. Especially the language and sentence structure saw heavy changes. A glossary was drafted to explain the critical unfamiliar words; however, the glossary would not address the actual vocabulary problem. Therefore, incorporating the glossary to the manual would be done only as a last resort. Based on the eye-concentration test, the position and size of the notification icons were adjusted. Additionally, the topic summary was emphasized in comparison to the rest of the page by increasing contrast with a background box.

A fourth signifier icon was added to the manual and the content revised accordingly. Safety information concerning the power system was augmented and a step-by-step procedure was added for operating the measurement software. Pictures and tables were repositioned to appear on the same page where they are first referenced. Key changes are listed in the following Table 5.

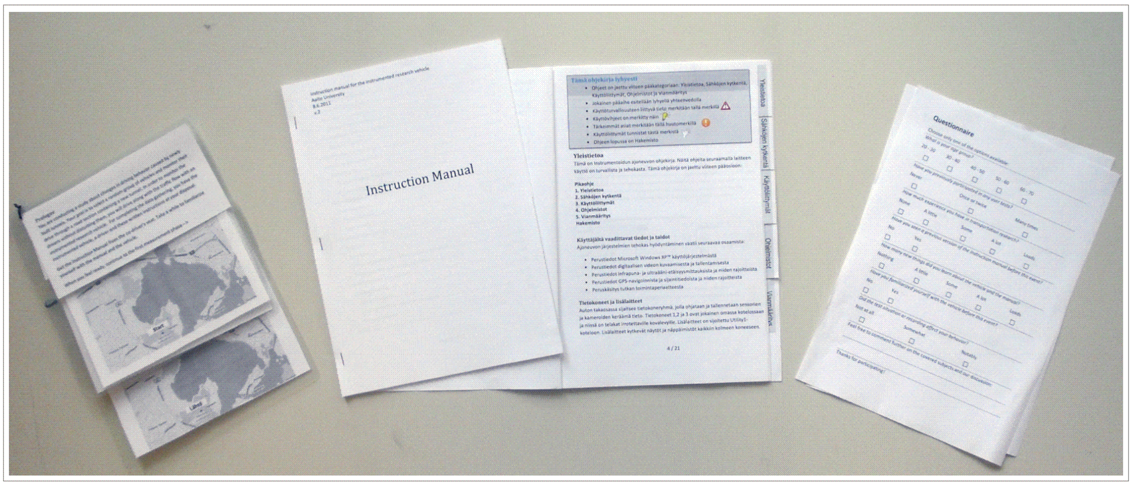
Table 5: Major design revisions in iteration 2

Improvement
Change of location and size of signifier icons
Enhanced structural clarity through contrast creating backgrounds
Introduction of a fourth signifier icon to represent user action
Introduction of retouched photographs to the manual
Modified software guidance to step-by-step form
Power system safety information augmented
Significant content addition and structure changes to UI topic
Tables and pictures forced to the page where they are referenced
Visual changes to step-by-step operations

4.3.6 User test 3

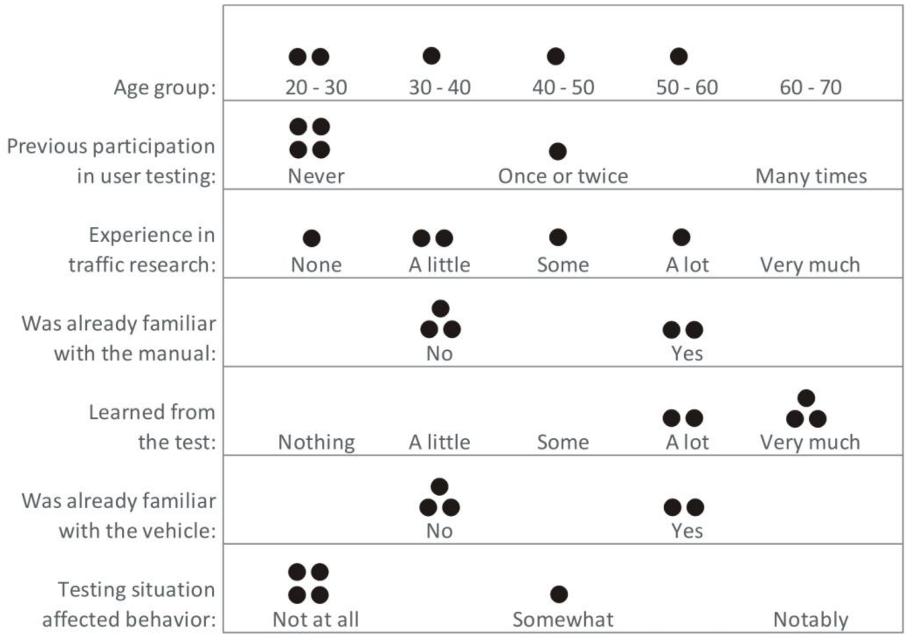
A third user test was arranged to conclude the participatory phase of the design project. Manual version 3 was printed on paper and compiled to a booklet in both English and Finnish. All major design features were implemented for the final user review. The theoretical research scenario assignment of test 1 was used as a basis for user test 3. The assignment was modified slightly with the acquired experience of scenario testing and to answer the most pertinent design questions raised by the focus group discussion (Appendix D).

The tests were again arranged on a period of three days followed by a work day. The first test was in the morning of a Tuesday and the last in the afternoon of a Thursday. The possibility to reflect for one night and give feedback on the following day had proven to be a valuable part of testing. All five users were recruited from within the transportation and highway research group. At this stage, most of the group was aware of the design project in general terms, but the specifics of the actual user tests were not commonly known. The tests were conducted with five new users. Picture 9 contains the material of user test 3.



Picture 9: The scenario, instruction manual and questionnaire of test 3

While the assignment was slightly altered from test 1, the testing round followed the original pattern. Thus, tests were conducted as described in the earlier scenario test section and each session was video recorded. The driver and test organizer were the same in both test 1 and test 3. The tester concentrated specially on open key design issues and situations that were problematic in earlier testing. Each test ended with a questionnaire (Appendix E) and the answers are summarized in Picture 10.



Picture 10: Answers to questionnaire in test 3

The test participants were distributed quite evenly between 20-30 and 50-60 age groups. Most of them had never taken part in any user testing and three out of five had not seen any previous versions of the manual. This group of testers was slightly less experienced in traffic research in comparison to the first group, but sufficient aptitude distribution existed to provide data from different skill levels. The learning results were as good as expected and the test situation only minimally disturbing.

All users were able to reach the goals set by the assignment. The test times ranged from less than an hour to little over one and a half hours. As mentioned before, the performance times are not comparable due to different traffic conditions. Furthermore, comparison between test 1 and 3 is not reasonable, since the test scenarios were not identical. A separate shorter test about test times would be needed with a significantly bigger sample size to provide quantitative information about enhances in usability between design iterations.

Written notes and videos about the tests provided the bulk of design solutions for iteration 3. However, the casual and voluntary reflection sessions once more produced interesting design suggestions. Some of them were implemented to the release version of the manual and the rest were used to sketch a continuation for the development project.

4.3.7 Iteration 3

The third round of user testing was successful in answering most open design questions [47]. The success of the tests seemed to indicate that the manual was in good condition content wise, as to be expected in this phase [48 p. 410]. Therefore, most of the changes in iteration 3 concerned layout and structuring of the information. Table 6 lists major design changes performed in this iteration.

Table 6: Final design revision in iteration 3

Improvement
Added a visual navigation bar to help moving inside a topic
An after-measurement check list included
Enhanced structural clarity further with contrast backgrounds
Feedback form included
Information about using the manual completely revised
Layout finalized and streamlined
Photographs replaced by drawings
Pre-measurement check list included
The amount of signifier icons reduced for added effectiveness

In order to meet the design principles, a consistency choice of using either retouched photographs or drawn illustrations needed to be made. The user tests showed a clear preference related to the quality of the illustration, but the choice of format divided opinions evenly. Achieving sufficiently good photographs about the vehicle turned out to be impossible within the scope of this development; thus, a decision to only use drawings and screen captures was made.

Following the good reviews about the visual navigation bar, a secondary navigation illustration was added to the manual. Navigating inside an individual topic posed problems for some users in stressful situations; hence, a second bar representing progress within a topic was introduced. The layout of the manual saw other changes as well. The information content and structure were streamlined to suit a double paged layout and contrast was added with additional background boxes.

One goal for the development was to try to find a way to incorporate interaction into the manual. A first attempt to achieve this was done by adding a check-box sheet with additional space for feedback into the manual (Appendix F). Whether or not the users are willing to use the form remains to be seen; however, the chosen method was directly suggested by multiple users.

The use of signifier icons in the manual was significantly altered in the last iteration. The number of these icons was reduced and the effectiveness of the remaining ones was emphasized with contrast adding backgrounds. According to the eye-concentration test [46], the icons readily caught the user’s attention, but the significance of the icon itself was not self-evident. Unfortunately, testing a wide array of icons was not possible in this development project. The finished release version of the instruction manual is presented in Appendix G.

5 Results and discussion

The English language version of the instruction manual for the instrumented research vehicle of Aalto University is presented in Appendix G. The Finnish version of the manual is a direct translation of the English one. The manual was developed in accordance with the user-centered design philosophy and cognitive engineering principles. An iterative and participatory user testing process was conducted to guarantee a high level of usability for the manual. Table 7 presents development milestones from May - July period in 2011.

Table 7: Development milestones

Date	Milestone	Description
2.5.2011	Beginning	Project timeline and testing structure finalized
9.5	Task analysis	Hierarchical task analysis begins
12.5	Version 1	Initial content and structure completed for the manual
13.5	Pilot test	A pilot test for scenario-of-use testing
17 - 19.5	User testing	First round of scenario tests using manual version 1
30.5	Version 2	First iteration of the manual completed
9.6	Focus group	Focus group discussion using manual version 2
13.6	Version 3	Second iteration of the manual completed
14 - 16.6	User testing	Second round of scenario tests using manual version 3
7.7.2011	Release version	Final iteration of the manual completed

5.1 Answers to research questions

An exhaustive description and documentation of the development project is presented in Chapter 4. The process and outcome of defining usability in the case of an instruction manual is discussed in subchapter 4.1. Essentially, the usability of a manual hinges on the three general principles of effectiveness, efficiency and satisfaction in the specific context of use. Furthermore, abiding by the heuristics of choice and capitalizing on cognitive engineering principles produce good user-experiences and usability for an instruction manual.

User-centered design methods open an excellent possibility to move from the technology first -principle to a more holistic design doctrine. Specialist tools and participatory user testing complement each other and the iterative process identifies usability problems early on and throughout the development. Voluntary participants and thematic scenarios produce accurate and reliable information about the usage and a focus group allows testing the product efficiently on a larger sample of users. The UCD philosophy promotes a balance between technology, economics and the user, which is commonly a shortcoming of the traditional R&D.

The participatory process provided material also for future development and tangent projects. The videos and sensory data of the measurement runs remain available for transportation research. User suggestions requiring collaboration and other unimplemented design features are presented in chapter 7. The successes and failures of the development are discussed further below.

5.2 Analysis of the development process

As expected, the UCD methods and user testing were a suitable and fruitful approach to developing an instruction manual. The hierarchical task analysis provided content for the initial construction and also to later additions. The original streamlining of the content was wanting in some cases, but addressing deficiencies revealed by user testing was effortless, since the necessary content was already available in HTA form. In the end, the applied depth of analysis detail proved to be nearly optimal.

The chosen user testing methods were efficient and easy to use. A combination of video and sound recordings and hand written notes provided a good foundation for the iterative development process. The focus group discussion answered most of the open design questions and provided a chance to test the manual on a large user group in a single session. Recruiting users was effortless and the background questionnaire helped in interpreting the data. Spontaneous feedback sessions after the tests provided a significant amount of usable suggestions and design improvements. Therefore, scheduling time for personal reflection was a successful design feature.

The scenarios-of-use based on a realistic research theme were a success. Piloting the test and using the same driver and organizer in all tests facilitated smooth and uninterrupted sessions. All testees reported positive learning results and a willingness to take part in future user testing. The effect of being recorded was insignificant to a clear majority of the users. Additionally, the vehicle and measurement system proved to be technically reliable and suitable for the research purpose.

The short development period and limited number of iterations kept the cost of the development in control. The time invested in the development could have been cut approximately in half, if the participatory phase would have been left out. However, the usability of the manual version 1 was quite poor in comparison to the iterated end product. Additionally, the time investment of an individual test participant was kept minimal and the value of learning should easily match the value of the used time. Using voluntary participants with a flexible schedule kept the opportunity costs down for each person and compensation was available when needed. Consequently, the monetary investment into the development project can be justified by the results.

The user tests clearly showed the importance of an iterative development process. Although the design principles mentioned in subchapter 4.3 are on a solid theoretical base, implementing them straightforwardly proved to be difficult. The first version of the manual was lacking in content and structurally deficient as well. Only through several iterations, the content and context have begun to fulfill the initial cognitive and usability design principles.

The whole development process was highly dependent on a single individual. A single designer may have problems in abandoning original design concepts even when user tests clearly demonstrate their inadequacy. A team of designers is probably less likely to anchor themselves to a single approach. However, a single designer can produce good usability by setting strict guidelines and unambiguous targets for the process. In this project, the usability heuristics, cognitive engineering guidelines and usability maxims were used extensively to facilitate decision making between conflicting designs and to justify abandoning earlier design solutions.

6 Conclusions

Transportation engineering and research continues to be an active field of science. New road types, vehicles and related infrastructure as well as services are developed constantly. One contribution to the field is the new instrumented research vehicle of Aalto University. The vehicle contains an extensive sensory and camera selection for measuring and analyzing road conditions and driver behavior reliably and discreetly.

The vehicle was equipped with the measurement system in a technology driven development project by three Aalto University staff members (including the author of this thesis) during the years 2007 – 2011. Unfortunately, little thought was given to the actual end-users and the overall usability of the tool. The process of creating an instruction manual for the measurement system aimed to address these issues. The selected user-centered design philosophy acted as a guideline for the design process. In most R&D projects, a team of designers usually achieves superior results. However, using a team is naturally not possible, when the development is done as a thesis work. The participatory UCD approach and 16 individual testees compensated for the lack of a designer team.

This report presented the iterative and participatory development process used to create an instruction manual for the research vehicle. Furthermore, the validity and applicability of the chosen UCD methods was assessed by finding answers to the research questions. As mentioned earlier, the process was a success and the chosen methods fully suitable for the project. The roles of the focus group moderator and the test organizer were performed by the author of this thesis; thus, the analysis of the videos and voice recordings was effortless during the development.

The project started with the process of defining usability in the case of an instruction manual and the drafting of design guidelines. The guidelines were based on cognitive engineering and usability theories. One of the main goals of the development was to design the product to comply with and even capitalize on the user's inherent capabilities and characteristics.

By incorporating users into the design process from the very beginning, problems were identified early on and poor design solutions abandoned consistently. Through interpreting the causes of the usage problems, enhancing the manual was efficient and effective. The end result is an instruction manual, which should contain the essentials-of-use in a detailed and usable form. The readers gaze is guided to important information pre-attentively and the consistency of the structure facilitates quick learning. To further improve the product, interactivity was infused to the manual with the feedback form suggested by the users. The effectiveness of that particular implementation method remains yet to be seen.

The main motivation for the UCD approach came from the notion that even technical superiority does not guarantee success and acceptance of the product. Furthermore, technical complexity can deter users or lead to erroneous and hazardous use. By introducing new products in familiar ways, the user can learn quickly and gain proficiency despite the intricateness of the system. The approach required getting to know the users and setting their needs to the center of the development. Seeking an understanding of the psychology of choice, limits of human perception and the need for action-reaction correlation enabled usability issues to be addressed systematically.

The specialist methods and participatory user tests used to create the manual also started a learning process in the potential end-users. The participants reported that they had learned to use the system during the process and future operation would be significantly easier. An iterative development process allowed constant adoption of new design solutions and augmentation of the instructions content. By creating a progressive structure for the design project, minimal time and effort investments were lost in abandoning poor design implementations. The whole staff of the research group was reached and utilized in the development, by developing and releasing the manual both in English and in Finnish.

In conclusion, the UCD methods and principles served as a reliable and effective development philosophy. These methods were easy to use and widely applicable, as demonstrated by the success of this project. The presented process of task analysis, scenarios and a focus group should be applicable to most if not all instruction manual development projects. The cognitive engineering theories and experience based heuristics open a path to understanding the actions and thought patterns of the users. A good level of usability can be achieved by designing the product to capitalize on the user’s characteristics. Usability in the form of efficiency, effectiveness and satisfaction leads to pleasant user-experiences and continued use; even in the case of an instruction manual.

7 Recommendations for future work

The first release version of the manual is completed. However, some design features and user suggestions fell outside of the scope of this project. Additionally, some of the implemented cognitive design solutions failed to fully capitalize on inherent user capabilities. Table 8 lists proposals for future user-centered development of the instruction manual.

Table 8: Proposals for future development

Suggestion
Acquiring professional studio grade photographs of the system
Another eye-concentration test with enhanced signifiers
Another preference test between retouched photos and drawings
Development and study of effective signifiers
Development of a video tutorial to complement the paper manual
Tests covering the use of the Troubleshooting section
Tests evaluating the quality of the feedback form

One of the key conflicts in the design process was the question of using either retouched photographs or drawn illustrations. Due to the lack of good quality photos, a decision to use drawings was made. The use of both formats could also be considered at the cost of consistency. Another important issue was the use of signifiers and affordances. A specific test covering the use of signifier icons could be informative, since the specific process of recollection and recognition of images is not yet fully understood [49 p. 251]. Furthermore, another eye-concentration test with a larger sample would be justified.

A suggestion to produce a video tutorial to complement the instruction manual was made by multiple users. The video could be used to illustrate the correct and safe use of the system more efficiently than a paper guide. In this development project, the Troubleshooting section saw quite little use. Designing a test containing deliberately problematic situations might give valuable information about the problem solving section of the manual. Additionally, the next phase of developing the manual would benefit from a team of designers instead of a single designer. The effectiveness and quality of the feedback form should also be tested as soon as possible.

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9 Appendices

A Scenario Assignment 1

Prologue

You are conducting a study about changes in driving behavior caused by newly built tunnels. Your goal is to select a random group of vehicles and monitor their drive through a road section containing a new tunnel. In order to monitor the drivers without disturbing them, you will drive along with the traffic flow with an instrumented research vehicle. For completing the data gathering, you have the instrumented vehicle, a driver and these written instructions at your disposal.

Get the Instruction Manual from the co-driver's seat. Take a while to familiarize yourself with the manual and the vehicle.

When you feel ready, continue to the first measurement phase -->

Phase 1 – Preparing the vehicle for measurements

With the help of the manual, power the computers and instruments. Turn on computers 1 - 3, prepare cameras CAM R, CAM FM and CAM LS and sensors LASER FL, LASER FR, ULTRA RL and ULTRA RR for measurement and recording.

When the system is ready, go to phase 2 -->

Phase 2 – Measurement 1 / 2

Instruct the driver to proceed to the starting point and follow the cameras and sensors on the way. Choose a group of target vehicles and begin recording. Follow the targets through the tunnel while maintaining a suitable distance and stop at the designated end point. End recording and prepare for the second measurement leg.

Move to phase 3 -->

Phase 3 – Measurement 2 / 2

Choose a new group of vehicles and record their behavior as you head back to the starting point. Once again, stop recording after you have passed the target road section.

Proceed to phase 4 -->

Phase 4 – Examining the recorded data

Go through the recordings and make sure you have successfully gathered both video and sensory data. You may repeat measurement legs 1 and 2 if you are unhappy with the material. After a successful measurement run, instruct the driver to return to the garage.

Move to the last phase -->

Phase 5 – Finishing the measurement session

Return the vehicle to its original state by powering off computers and electrics. You have now completed your data gathering part of the study.

The test ends. Please fill the background questionnaire.

B Questionnaire 1

Background information

Mark only one box in each question:

What is your age group?

20 - 30	30 - 40	40 - 50	50 - 60	60 - 70 years
☐	☐	☐	☐	☐

How many times you have participated in user testing?

Never	A couple of times	Many times
☐	☐	☐

How much experience do you have in traffic studies?

None	A little	Some	A lot	Very much
☐	☐	☐	☐	☐

How much experience do you have about instrumented vehicles?

None	A little	Some	A lot	Very much
☐	☐	☐	☐	☐

Did you learn anything new during this test?

Nothing	A little	Some	A lot	Very much
☐	☐	☐	☐	☐

Did the testing situation or recording disturb your performance?

Not at all	Some	Significantly
☐	☐	☐

This space if for free comments:

Thank you for participating!

C Questionnaire 2

Questionnaire

Fill the questionnaire independently and allow others to do so as well.
Choose only one of the options available:

What is your age group?

20 - 30 ☐ 30 - 40 ☐ 40 - 50 ☐ 50 - 60 ☐ 60 - 70 ☐

How often have you previously participated in a focus group discussion?

Never ☐ Once or twice ☐ Many times ☐

How well did you get your voice and opinions through in the discussion?

Not at all ☐ A little ☐ In some cases ☐ Mostly ☐ In all cases ☐

Have you seen a previous version of the instruction manual before this event?

No ☐ Yes ☐

How many new things did you learn about the vehicle and the manual?

Nothing ☐ A little ☐ Some ☐ A lot ☐ Loads ☐

Being forced to use either photos or drawings in the manual, what would you use?

Photos (some retouched) ☐ Drawn illustrations ☐

Did the group discussion situation or recording feel uncomfortable?

Not at all ☐ Somewhat ☐ Notably ☐

Feel free to comment further on the covered subjects and our discussion:

Thanks for participating!

D Scenario Assignment 2

Prologue

You are conducting a study about changes in driving behavior caused by newly built tunnels. Your goal is to select a random group of vehicles and monitor their drive through a road section containing a new tunnel. In order to monitor the drivers without disturbing them, you will drive along with the traffic flow with an instrumented research vehicle. For completing the data gathering, you have the instrumented vehicle, a driver and these written instructions at your disposal.

Get the Instruction Manual from the co-driver's seat. Take a while to familiarize yourself with the manual and the vehicle.

When you feel ready, continue to the first measurement phase -->

Phase 1 – Preparing the vehicle for measurements

With the help of the manual, turn on electrics and instruments. Turn on computers 1-3, prepare cameras CAM R, CAM FM and CAM LS and sensors LASER FL, LASER FR, ULTRA RL and ULTRA RR for measurement and recording.

Use the rear UI for turning the computers and sensors on and the front UI to prepare the cameras. Use the numbered hard disks for video recording. Start recording before leaving the starting place.

When the system is ready, go to phase 2 -->

Phase 2 – Measurement 1 / 2

Instruct the driver to drive through the newly built tunnel marked on the provided map. Choose a group of target vehicles for your study. Follow the targets through the tunnel while maintaining a suitable distance and stop to a safe location. End recording and prepare for the second measurement leg. Once again, start recording while standing still.

Move to phase 3 -->

Phase 3 – Measurement 2 / 2 and examining the recorded data

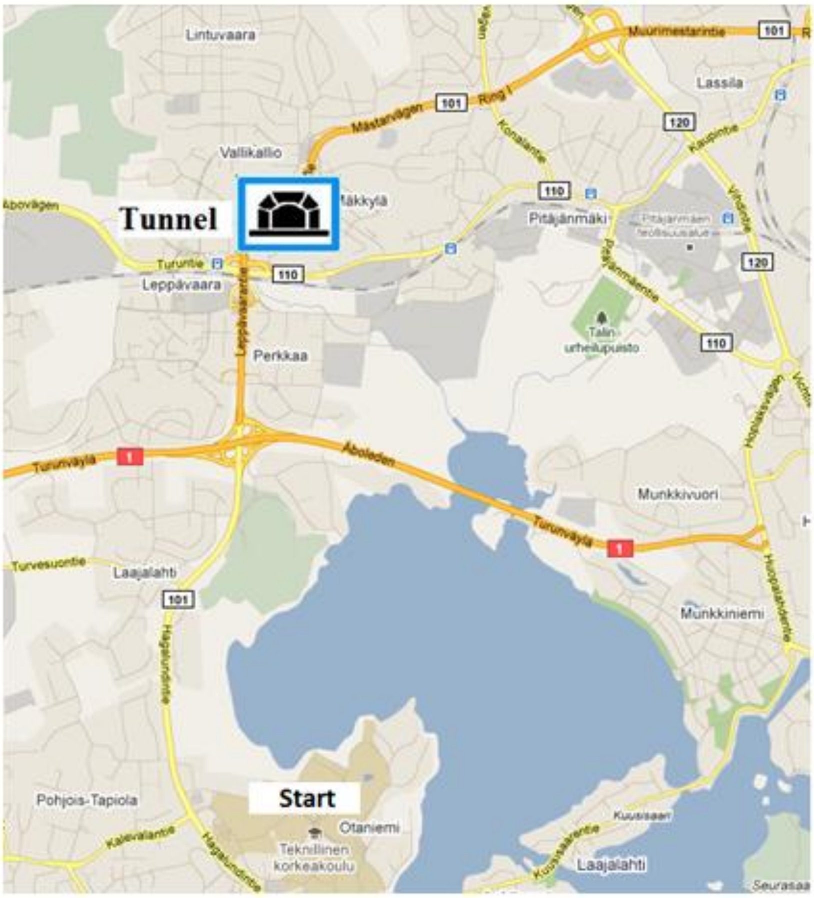
Instruct the driver to drive back to the starting point. Once there, stop recording and go through the data to make sure you have successfully gathered both video and sensory data. You may repeat measurement legs 1 and 2 if you are unhappy with the material.

After a successful measurement run, move to the last phase -->

Phase 4 – Finishing the measurement session

Return the vehicle to its original state by powering off computers and electrics. You have now completed your data gathering part of the study.

The test ends



E Questionnaire 3

Questionnaire

Choose only one of the options available:

What is your age group?

20 - 30 ☐ 30 - 40 ☐ 40 - 50 ☐ 50 - 60 ☐ 60 - 70 ☐

Have you previously participated in any user tests?

Never ☐ Once or twice ☐ Many times ☐

How much experience you have in transportation research?

None ☐ A little ☐ Some ☐ A lot ☐ Loads ☐

Have you seen a previous version of the instruction manual before this event?

No ☐ Yes ☐

How many new things did you learn about the vehicle and the manual?

Nothing ☐ A little ☐ Some ☐ A lot ☐ Loads ☐

Have you familiarized yourself with the vehicle before this event?

No ☐ Yes ☐

Did the test situation or recording affect your behavior?

Not at all ☐ Somewhat ☐ Notably ☐

Feel free to comment further on the covered subjects and our discussion:

Thanks for participating!

F Checklist and Feedback form

Pre-measurement checklist

Prepare the measurement system for use by completing the steps below:

- ☐ Rubber covers removed
- ☐ Car Power ON
- ☐ Master Power ON
- ☐ Computer, Instrument and Utility fuses ON
- ☐ Computers ON
- ☐ Sensors ON
- ☐ Sensors active
- ☐ Keyboard ON
- ☐ Monitor ON
- ☐ Cameras in Live-mode and prepped for recording
- ☐ Sensor recording ON
- ☐ Computer clocks synchronized
- ☐ Sufficient space on hard drives

→

After measurement checklist

Return the system to the original state by completing the steps below:

- ☐ Video and data files accessible
- ☐ Interlaced clock on video files is not frozen
- ☐ Computers OFF
- ☐ Keyboard OFF
- ☐ Sensors OFF
- ☐ Computer, Instrument and Utility fuses OFF
- ☐ Master Power OFF
- ☐ Car Power OFF
- ☐ Rubber covers in place

Feedback

Report problems, malfunctions and suggestions related to the manual or vehicle:

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Reported by: ______________________________ Date: ___________

G Instruction manual

Instruction manual for the instrumented research vehicle
Aalto University
Aapo Lumikoivu
7.7.2011

Instruction Manual

Table of Contents

Quick start procedure for advanced users

1. Remove rubber covers from the Radar and Laser/Ultra side sensors (page 6)

2. Power Up the electrical system including computers 1-3, utilities 1-2 and instruments 3-4 from the Power box (pages 7-9)

3. Turn computers and instruments ON either from the rear or front User Interface (pages10-13)

4. Control and record cameras (pages 14-17)

5. Activate sensor monitoring and recording (pages 18-19)

6. Fill the pre-measurement checklist

7. Perform the measurements

8. Return the system and vehicle to their original state

9. Fill the feedback form and after measurement checklist

Overview

This manual in a nutshell

- Information is divided into five main parts: Overview, Powering Up, User Interfaces, Programs and Troubleshooting
- Each main concept is introduced with a summary of key points
- There is an Index at the end of the manual
- Information about operational safety hazards is marked with a
- Tips are marked with a
- Particularly important information is marked with a note like this
- Possibility for user actions can be recognized from this mark

This is an Instruction Manual for the Instrumented Research Vehicle. By following these instructions, you will be able to operate the devices safely and efficiently. This manual is divided into five main parts:

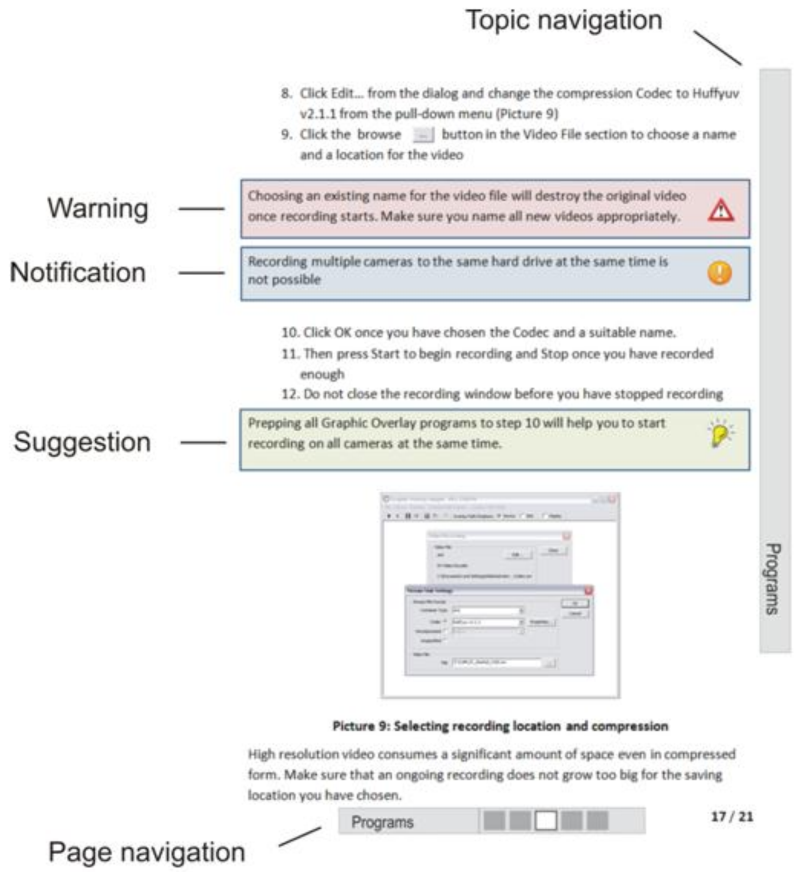
Quick start procedure for advanced users
1. Overview
2.Powering Up
3. User Interfaces
4. Programs
5. Troubleshooting
Index

Operator requirements

Operating the systems in this vehicle requires following skills and knowledge:

- Basic user skills and knowledge about Microsoft Windows XP™ operating system
- Basic understanding of live video acquisition and compression
- Basic understanding of infrared and ultrasonic distance measurements and their limitations
- Basic understanding of GPS navigation and positioning and their limitations
- Basic understanding of the concept of radar

The layout of the manual is illustrated in Picture 1. Topic navigation bars mark the section boundaries and the page navigation bar shows progress within a topic. Operational hazards are marked with red triangles and notifications with orange balls. Tips and suggestions are marked with the light bulb icon.



Picture 1: The layout of this manual

The vehicle

The instrumented research vehicle is a passenger car with seats for three people. A driver and a research operator are both required for safe operation. The vehicle may be used only for research purposes due to safety concerns. The vehicle houses an integrated computer cluster, power source, cameras and distance sensors.

Computer units and utilities

A specialized cluster of computers is used to control, record and monitor all equipment. Computers 1, 2 and 3 are all in separate cases and have removable hard-drives. The Utility1 case stores the KVM (Keyboard, Mouse and Video) switches, which provide control and image to the two user interfaces. All computers are connected to both interfaces, but they can be controlled only one at a time.

Sensory instruments

This vehicle is equipped with the following measurement devices:

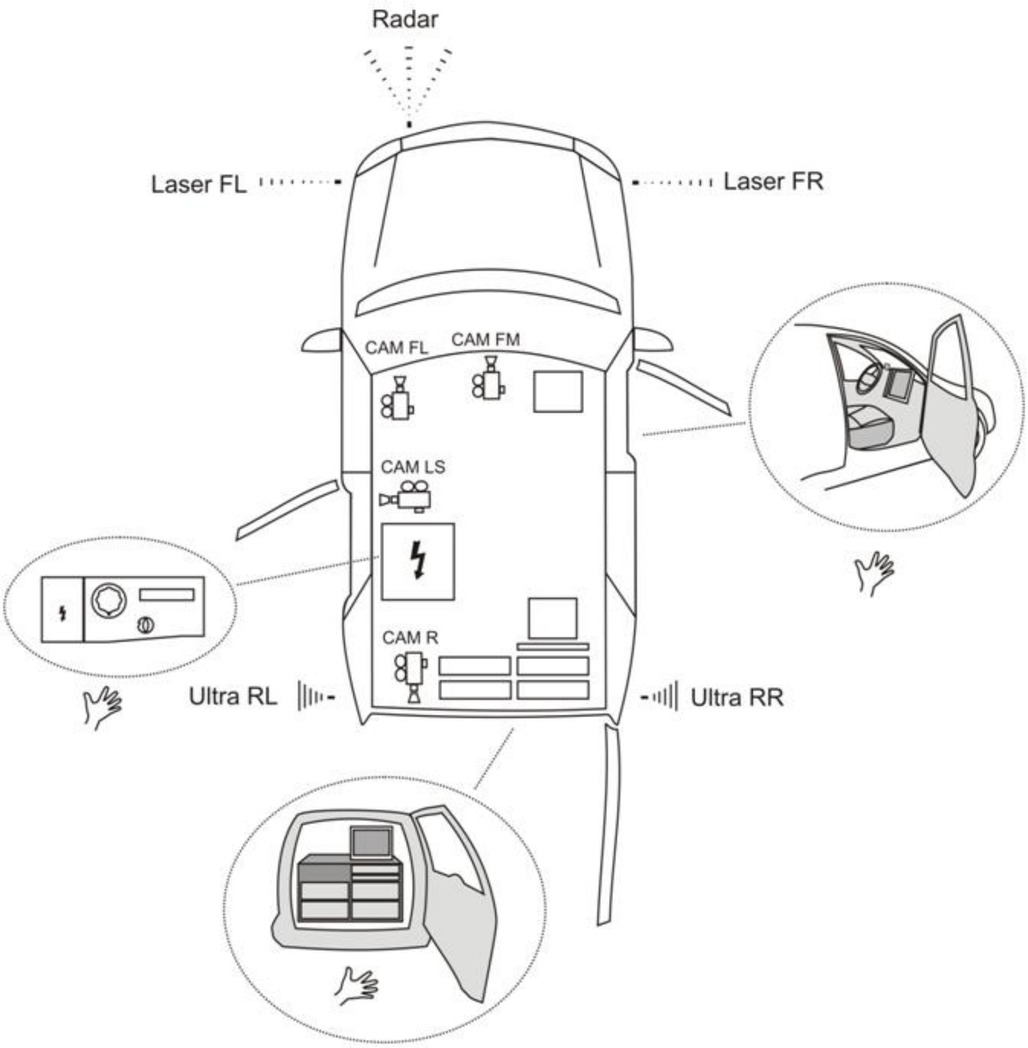
- 1 x Bosch LRR3 radar unit
- 2 x Noptel CM3 infrared laser distance sensors
- 2 x Sick UM30 ultrasonic distance sensors
- 4 x TIS Firewire CCD color cameras
- 1 x Garmin GPS18-5Hz positioning device

The radar unit is located next to the left driving light of the vehicle and is facing forwards. The unit can independently follow up to 32 objects and measures speed in addition to their location. The two laser sensors are located in the front left and right corners facing left and right respectively. The two ultrasonic sensors are located in the rear left and right in a similar way as the lasers. The GPS unit is connected to Computer 1 and measures the position and speed of the vehicle 5 times in second. Table 1lists distance sensor details.

Table 1: Sensor beams and radii

Sensor	**Beam**	**Radius**
Radar	30 degrees	250m
Laser FL, Laser FR	Pinpoint	20m
Ultra RL, Ultra RR	10 degrees	6m

Radar, Laser and Ultra sensors have **rubber covers**, which need to be removed before measurements. Locate them with the help of Picture 2.



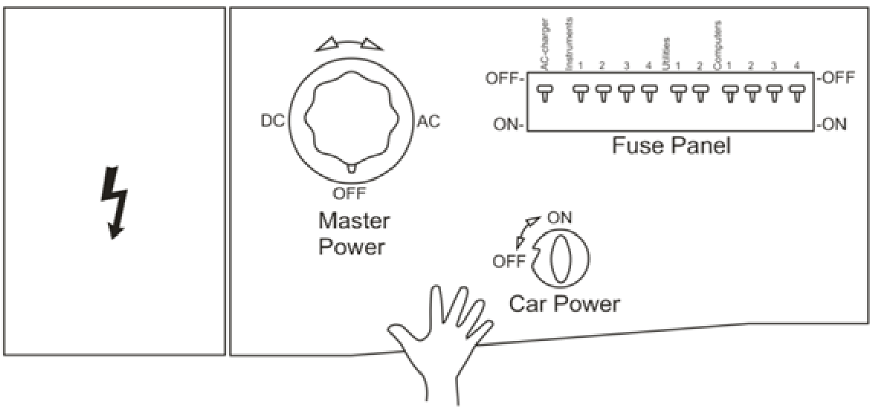
Picture 2: The Instrumented Research Vehicle

Powering Up

Powering Up in a nutshell

- The measurement system runs on 12V direct current, which is provided by the Power box located behind the driver's seat
- The Power box can run the system for several hours without external power if needed
- The vehicle can provide power, when the engine is running
- External mains power can be used when the vehicle is stationary

The Power box of the measurement system is accessible from the rear left door. A picture of the power user interface is below:



Picture 3: The Power box interface

The Master Power switch has three modes: OFF, AC-power and DC-power. The DC-power is the primary option and provides power to the system even if the vehicle's engine is turned off. AC-power option is for diagnostics and maintenance and available only when the vehicle is stationary and plugged into a mains outlet.

The Car Power switch is used to separate the vehicle's own power from the measurement power system. The Fuse Panel divides Master Power to all electrical measurement devices and computers in the car. The panel has four instrument power fuses, two utility fuses and four computer fuses. Additionally, the switch for the AC-charger is in the Fuse Panel.

DC-power is the main option for all measurements. DC and AC power options are mutually exclusive.

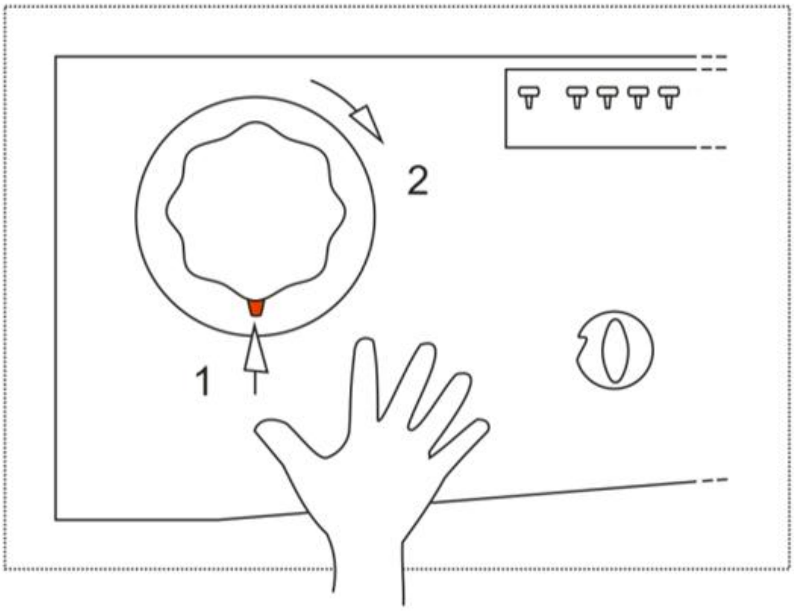
Choose DC or AC

DC-powering up sequence

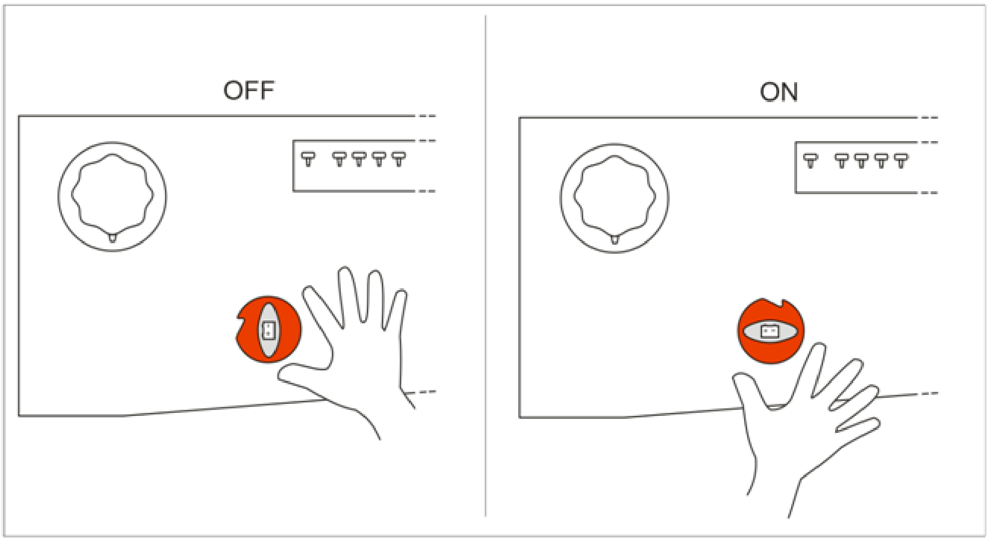
1. Select DC from Master Power (Picture 4)
2. .Switch Car Power to ON (Picture 5)
3. Switch on instruments fuses 3-4, utilities fuses 1-2 and computer fuses1-3
4. Turn on computers and sensors

AC-powering up sequence

1. Connect the power system to AC mains
2. Switch Car Power to OFF
3. Select AC from Master Power
4. Switch on instruments fuses 3-4, utilities fuses 1-2 and computer fuses 1-3
5. Switch on the AC-power source
6. Turn on computers and sensors



Picture 4: The Master Power switch – Choosing DC-power



Picture 5: The Car Power switch - OFF / ON

When the power system is on, computers and sensors can be turned ON either from the rear interface or from the front user interface.

The Power Box houses a regular 12V-car battery, which contains sulfuric acid. The battery is sealed and bolted to the vehicle's frame to ensure safe usage.

User Interfaces

User Interfaces in a nutshell

- Computers are controlled either from the Front UI or from the Rear UI
- Instruments and cameras are controlled from computers
- A push-button panel is used to power instruments and computers
- A control interface for the electrical system is accessible through the rear left door

The devices and cameras are controlled through two separate, but connected user interfaces. One interface is located in the rear of the vehicle and one in front of the co-driver's seat. Both interfaces consist of:

- A 1280*1024 LCD-monitor
- A wireless keyboard with integrated mouse
- A push-button panel for devices

Because the user interfaces are connected, you can perform one task from the rear and the next from the front if you want. Switching between control interfaces is possible during most operations without any extra procedures.

The front UI is your main operating station, even though it doesn't allow full control of all functions and systems.

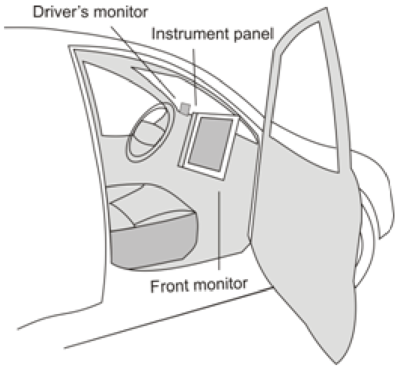
The LCD-monitor shows the desktop of a single computer at a time. All computers are connected to the monitor and switching between desktop-views is done from the Front Keyboard or from the Utility1 case. Table 2 summarizes the vehicle's user interfaces.

Table 2: Functional differences of the User Interfaces

User Interface	Turn ON/OFF computers	Turn ON/OFF sensors	Operate Computers	Change Hard disk drives	Access Utility 1
Front UI	X	X	X	-	-
Rear UI	X	X	X	X	X

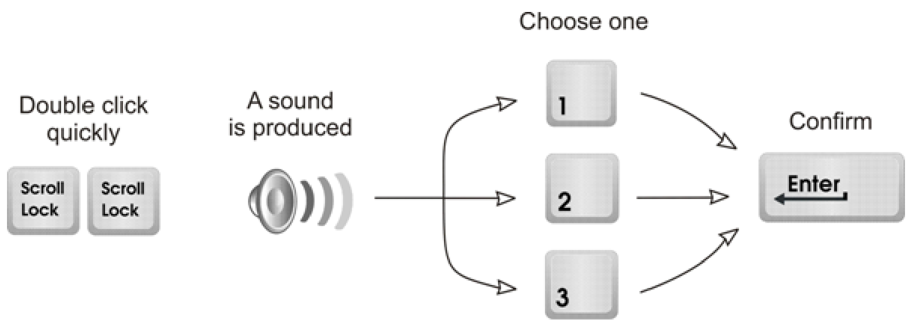
Front User Interface

This interface is accessible and operational even while the vehicle is moving. **Therefore, it is the main interface for research runs.** The interface is presented in Picture 6.



Picture 6: Front User Interface

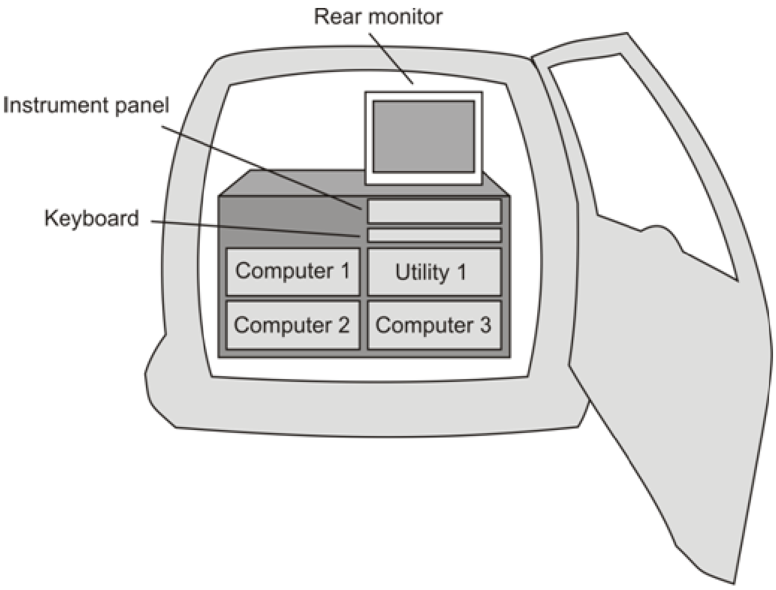
Computers and instruments are turned on from the front **Instruments panel,** which is attached to the front monitor. An additional 7" touch screen LCD-monitor with an USB port can be used to provide information for the driver and connectivity for external memory drives. The wireless Front Keyboard with the integrated mouse is used to control the measurements systems. The keyboard has a power switch in the upper right corner. **Switching the monitor view between computers is done with the following key combination:**



This control combination is operational only from the Front Keyboard. **A small sound is produced after double clicking Scroll Lock.** Pressing Enter without hearing the sound may result in stopping or starting recording!

Rear User Interface

This control interface can be used to operate the systems when the vehicle is stationary. The interface is presented in Picture 7.



Picture 7: Rear User Interface

Computers are turned on by opening their metal front panels and pushing the revealed power switches. Close the front panels once the computers are on. Measurement instruments Laser FL, Laser FR, Ultra RL and Ultra RR are turned on from their respective push-buttons in the **Instruments panel** above Utility1.

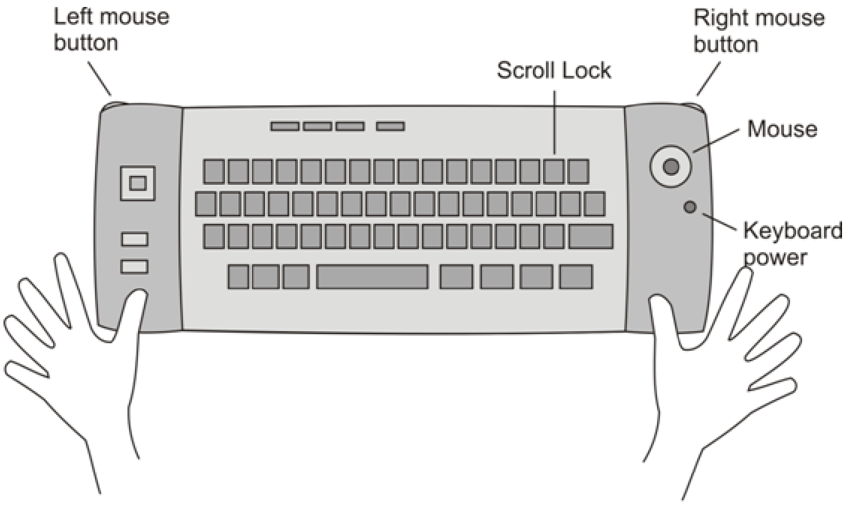
The LED-switch can be used to turn of the LEDs during measurements. This way the green lights won't attract attention from other road users.

The rear monitor is located behind the instrument power panel and can be turned into an upright position from the handle in the right upper corner of the cluster. The monitor view is controlled by opening Utility1 and pushing the desired computer button.

Remember to lower the rear monitor to its downright position before allowing the driver to move the vehicle.

The wireless Rear Keyboard is located under the rear monitor. The keyboard is turned on from the keyboard Power button. The keyboard has an integrated ball mouse and two mouse buttons, which are located in left and right upper corners.

The keyboard requires two hands for successful operation. Left mouse button and Right mouse button are integrated to the upper corners of the keyboard. Picture 8illustrates the two handed operation.



Picture 8: Wireless keyboard with an integrated mouse

Programs

Programs in a nutshell

- The computers run on Microsoft Windows XP™ operating system
- The username is Operator and there is no password
- The sensors are controlled and recorded with Instruments
- The cameras are controlled and recorded with Graphic Overlay

All computers run on the Windows XP operating system in English. The Desktop contains all necessary icons for operating the measurement system. Synchronize the system time for each computer before starting measurements.

Username for the computers is Operator and there is no password. All cameras are accessible and controllable only from their respective computers.

Cameras

The four cameras are located inside the vehicle and are pointed towards the front, left and rear. Table 3 lists the details for the cameras:

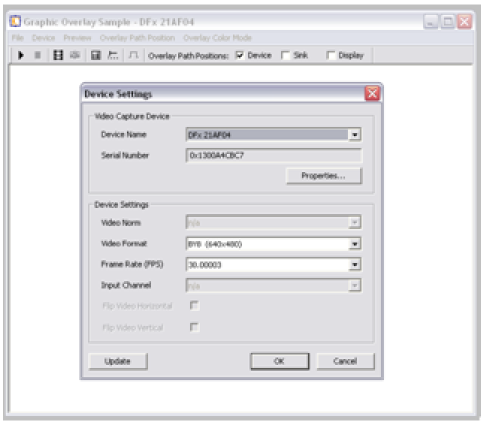
Table 3: Camera information

Camera	Resolution	FPS	Device name	Connection
CAM FM (Front Middle)	1024*786	1-30	DFx 31BF03	Computer 3
CAM FL (Front Left)	640*480	1-60	DFx 21AF04	Computer 1
CAM LS (Left Side)	640*480	1-60	DFx 21AF04	Computer 2
CAM R (Rear)	640*480	1-60	DFx 21AF04	Computer 2

Video recording and camera control software

The four cameras listed in table 2 are controlled and recorded with a program called **Graphic Overlay**, each from their respective computers. Each computer has shortcut to the recording program on their desktops. Double clicking the desktop shortcut will open the program and enable changing camera and recording settings. The following procedure will enable video recording with minimal actions.

1. Change keyboard control and monitor image to the computer, which has the camera you are going to activate
2. Open the recording program by double clicking the shortcut: **Graphic Overlay**
3. Click Select... from the Device menu
4. Choose a camera from the Device Name pull-down menu and set Video Format to BY8 and Frame Rate to 30, if they are not already selected. Then click OK (Picture 9)



Picture 9: Camera selection and options

If the computer is connected to multiple identical cameras, the device name will have a sequential number in the end to separate the cameras. Be sure to remember which cameras you have already activated, if you activate multiple cameras on a single computer.

> You must open another copy of the Graphic Overlay program, if you want to record with multiple cameras on a single computer.

5. Once you have chosen a camera, press the black arrow shaped Play-button in the top left corner
6. You should now see a live feed from the selected camera

Following the next steps allows you to record the live camera feed.

7. Select Record Video... from File menu

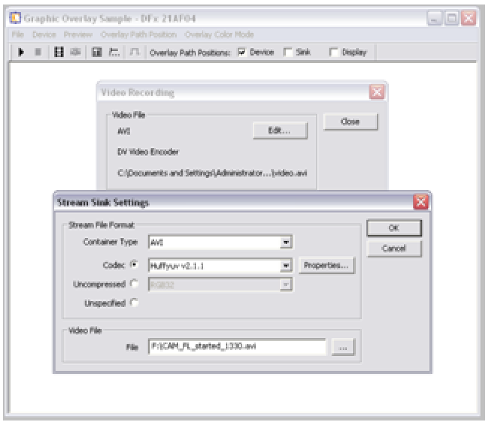
8. Click Edit... from the dialog and change the compression Codec to Huffyuv v2.1.1 from the pull-down menu (Picture 10)
9. Click the browse [...] button in the Video File section to choose a name and a location for the video

Choosing an existing name for the video file will destroy the original video once recording starts. Make sure you name all new videos appropriately.

Recording multiple cameras to the same hard drive at the same time is not possible

10. Click OK once you have chosen the Codec and a suitable name.
11. Then press Start to begin recording and Stop once you have recorded enough
12. Do not close the recording window before you have stopped recording

Prepping all Graphic Overlay programs to step 10 will help you to start recording on all cameras at the same time.



Picture 10: Selecting recording location and compression

High resolution video consumes a significant amount of space even in compressed form. Make sure that an ongoing recording does not grow too big for the saving location you have chosen.

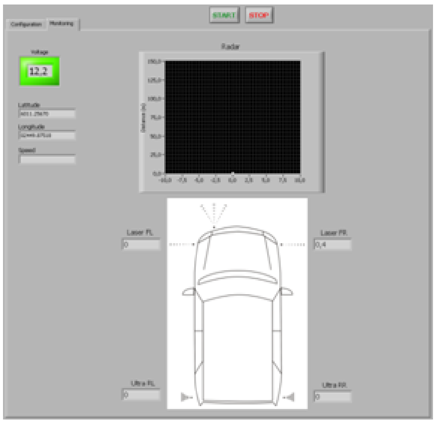
Sensor control and recording software

The distance sensors and the GPS are all connected to Computer1 and can only be accessed and controlled from that computer. The control and recording program is called **Instruments** and it has a shortcut on the desktop. The following operation allows you to monitor and record sensor data.

1. Double click the Instruments-shortcut icon. A window will open to the configuration tab (Picture 11)

Picture 11: Sensor configuration tab

2. Here it is possible to change the Radar sensitivity and filenames even before the measurements are running. Select Monitoring tab to proceed (Picture 12)



Picture 12: Sensor monitoring tab

3. Click the Start-button to begin measuring and recording. The program will ask you to choose a saving location and names for the distance measurement data and GPS positioning data.

Instruct the driver to walk around the vehicle. This way you can see, if the sensors are working. Reboot them from the Instruments-panel if necessary.

4. End recording by pressing the Stop-button

Once you have pressed Stop, you cannot record again before pressing the small arrow-button in the left upper corner of the window.

Index

Troubleshooting

Troubleshooting in a nutshell

- Be systematic and trace your steps with this manual to find if you missed a step or two
- Resetting power and trying again at least once is reasonable
- Look for loose cables, there shouldn't be any. All cables and their ports are marked
- Contact information for product support is provided at the end this manual

Known issues and procedures for resolving unknown problems are listed below

Known issues

- Bosch radar calibration and positioning incomplete
- Replacing an existing video recording by accidence is common
- Interlaced time on video files freezes
- AC-power option requires constant power load to remain operational. The AC-power source will shut down automatically, if there is no load for several minutes. The power source will come back online after a cooling down period.
- Neglecting to turn On the car power will eventually result in an uncontrolled shutdown of all systems without warning
- Failed attempt to change computer view from the Front UI, may result in unintended starting or stopping of recording.

Troubleshooting unknown problems

- Check that all stages of startup procedure are completed -> Resolved?
- Reset and redo stages one by one -> Resolved?
- Perform a hard boot by shutting down all computers and electrics-> Resolved?
- Check that all cables are connected to their respective ports -> Resolved?
- Contact product support if you are unable to resolve problems yourself

Product support

Aapo Lumikoivu, Jukka Turtiainen, Kari Hintikka