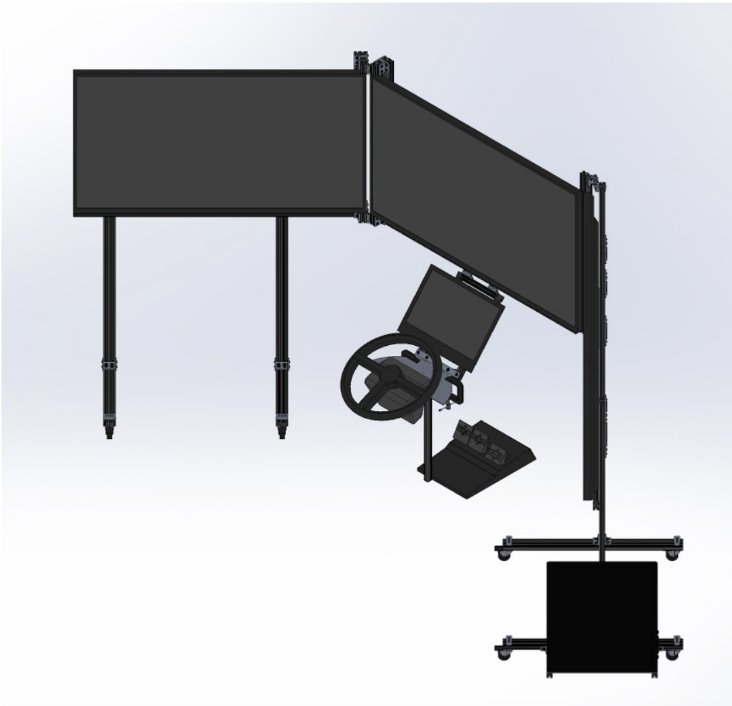

Driving Simulator Interfaces for Intelligent Vehicle Evaluations on Heavy Duty Vehicles

Bachelor's Thesis number 2016:05

Bachelor's Thesis in Applied Mechanics

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Gothenburg, Sweden 2016

Bachelor's thesis

Driving Simulator for Evaluation of Driver Interfaces for Intelligent Heavy Duty Vehicles

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Cover: Isometric view over the final concept.

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Executive Summary

More and more autonomous driving solutions are implemented in vehicles today. These are used as a support in traffic to reduce environmental impact, congestion and accidents. For autonomous vehicles to become a reality, all systems and the driver's reactions to these has to be tested thoroughly before the vehicles are safe enough to drive on public roads.

The main objective of the project was to develop the hardware of a desktop simulator for Heavy Duty Vehicles, more specifically long haul trucks. The sponsor is Volvo Trucks North America and the project group consists of students from Chalmers University of Technology and Pennsylvania State University. An additional objective was to offer the students an opportunity to experience working in a global environment.

The customer needs considered of most importance was ease of use, flexibility, and portability. From these needs, six possible concepts of different simulators was generated. These concepts were compared against each other in a Pugh-matrix, with the help of the customer needs. The concept chosen for further development was a three-screen setup with two different additions; a modified gaming steering wheel and a rack holding the screens (estimated cost $8,100, 65 700 SEK). The group at Chalmers University of Technology focused on the construction of the steering wheel and the group at Pennsylvania State University built the rack. It is possible to combine both additions to one working simulator.

Before building the prototype, a material selection was done with emphasis placed on sustainability and environmentally friendly materials.

Since some parts of the simulator are modified and specially manufactured for this project, instructions and drawings have been made. This, in combination with simple symmetries and manufacturing processes, make the parts easy to recreate.

The simulator have many possible areas of usage depending on the additions, for example autonomous systems or HMI evaluations. There is also a possibility to add a Head Mounted Display to increase the driving experience, but this requires improvement of graphics and other things.

In conclusion, the simulator hardware mainly consist of COTS-parts, with some modified additions which are easy to recreate. Since the rack is foldable and placed on wheels, it is to a high degree portable, even though it does not fulfill the requirement of a desktop simulator.

Sammanfattning

Idag implementeras allt fler autonoma lösningar i fordon. De skall användas som hjälpmedel i trafiken för att bland annat minska miljöpåverkan, trängsel och olyckor. För att autonoma fordon skall bli verklighet måste alla system samt förarens reaktioner till dessa testas grundligt innan fordonen kan framföras på allmän väg.

Huvudsyftet med detta projekt var att utveckla hårdvaran till en skrivbordssimulator anpassningsbar till tunga fordon, mer specifikt lastbilar med släp. Projektets sponsor är Volvo Trucks North America och projektgruppen består av studenter från både Chalmers tekniska högskola och Pennsylvania State University. Ytterligare ett mål var att utveckla studenternas förmåga att arbeta i ett globalt team.

De kundkrav som ansågs vara av störst vikt var användarvänlighet, flexibilitet och portabilitet. Utifrån dessa krav har sex möjliga koncept på simulatorer genererats. Dessa koncept evaluerades i en Pugh-matris, där de viktades mot varandra med hjälp av kundkraven. Konceptet som valdes för vidareutveckling består av tre skämar samt två olika tillägg; en modifierad spelratt och en ställning för skärmarna (uppskattat pris $8100, 65 700 SEK). Gruppen på Chalmers tekniska högskola har fokuserat på tillverkandet av den modifierade ratten, medan gruppen på Pennsylvania State University har byggt ställningen. De två tilläggen kombineras och bildar ett koncept av en fungerande simulator.

För att kunna tillverka prototypen gjordes ett materialval för en hållbar konstruktion med hög grad av miljövänlighet.

Då några delar är modifierade och har specialtillverkats för projektet, har tydliga instruktioner och ritningar gjorts för att kunna återskapa dessa. Enkla symmetrier och tillverkningsmetoder har använts för att minimera kostnad och tid för produktion.

Simulatorn kan ha många olika användningsområden beroende på vilka funktioner som adderas. Till exempel så skulle autonoma funktioner eller HMI kunna utvärderas. Det finns även en möjlighet att implementera en så kallad Head Mounted Display i simulatorn för att förbättra körupplevelsen, dock behöver vissa förbättringar i bland annat grafik göras innan detta är möjligt.

Sammanfattningsvis består simulatorns hårdvara till största delen av kommersiella delar med några få modifierade tillägg som är lätta att återskapa. Då ställningen för skärmarna är hopfällbar samt har hjul och är lätt att demontera så är simulatorn till stor det portabel, trots att den inte uppfyller kravet om att vara en skrivbordssimulator.

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Erika Danielsson, Julia Eugensson, Victoria Johansson. Gothenburg, May 2016

List of Abbreviations

ACC	Adaptive Cruise Control
AHP	Analytical Hierarchy Process
AV	Autonomous Vehicle
BOM	Bill Of Material
COTS	Commercial Of-The-Shelf
FOV	Field of View
HMD	Head-Mounted Display
HMI	Human Machine Interface
LCD	Liquid Crystal Displays
LKA	Lane Keep Assist
NHTSA	National Highway Traffic Safety Administration
PLA	Polylactide
ReVeRe	Resource for Vehicle Research
RITA	Research and Innovative Technology Administration
ROS	Robotic Operating System
SMS	Simulator Motion Sickness
U.S DOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure communication
V2V	Vehicle-to-Vehicle communication
VEAS	Vehicle Engineering and Autonomous Systems
VR	Virtual Reality

Descriptions

Learning factory	The engineering workshop at Pennsylvania State University.
Prototype lab	The engineering workshop at Chalmers University of Technology.
ReVeRe	A research lab with focus on vehicles, where Chalmers University of technology is one of the partners.
VEAS	The division of Vehicle Engineering and Autonomous Systems at Chalmers University of Technology with focus on engineering within systems in the applications of vehicles and robots.

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1 Introduction

Technology is heading towards more autonomous driving solutions, and the prospect of intelligent and autonomous vehicles is becoming a reality. As long as the autonomous driving functions requires a driver to intervene, there is a need to evaluate Human Machine Interface (HMI). Autonomous driving creates new risks in the HMI, which increases responsibility to predict how the driver will react to the driver warning systems in the vehicle. The more variations of HMI the driver is exposed to, the easier it gets for the driver to misinterpret the signals. A simulator is the most cost efficient and safe way to test delivery of proper and vital information to the driver. The simulator makes it possible to test a wide range of vehicle platforms and the interaction between different road users.

1.1 Initial Problem Statement

Since testing of autonomous systems requires many test subjects and a large volume of data, the tests have to be easy to set up and recreate. This demands a simulator which is portable and easy to build of Commercial Off-The-Shelf (COTS) parts. The simulators available today at Volvo Trucks North America are either too big and consists of an entire cab of a truck, or not detailed enough with only one screen.

1.2 Objectives

The objective is to create the hardware setup with compatible software for a desktop simulator. The simulator has to be portable and easy to recreate with COTS parts, but should also create a driving experience as close to reality as possible. The desired use of the simulator is to evaluate driver behaviour in a heavy duty truck environment before the driver operates the real vehicle, and hereby reduce the risk of accident during development.

1.2.1 Scope

The simulator will be adjustable to two different truck platforms; the FH (Volvo Trucks Europe) and the VNL (Volvo Trucks North America). The project will only focus on adapting the simulator to a rigid truck without trailer to avoid simulating the movement of joints. The trucks simulated will have an automatic gearbox.

The simulator is a desktop simulator and will not have a motion based platform. The definition of a desktop simulator is a portable simulator hardware setup, small enough to fit on a desk.

The road surface conditions during simulations will be dry with no precipitation and the driving will take place on highways.

The Volvo FH simulated is a FH16 6x2 Rigid with rear air suspension with a wheelbase of 6000mm (236in) and an overall length of 12160mm (479in). The Volvo

VNL that is simulated has a rear air suspension with a 3200mm (126in) wheelbase and an overall length of 6855mm (270in).

The functions of the softwares that will be used in the project is considered a limitation, as well as the budget.

1.2.2 Deliverables

This project will mainly have four deliverables:

- A description of the chosen design with dimensions, constraints, design methodology, COTS options and pricing.
- CAD design layout of the driving simulator and basic I/O schematic of the system.
- A functional desktop simulator prototype with the chosen concept.
- Videos of the working prototype that shows how the driver interacts with the simulator.

2 Team and Project Management

The project will give students the possibility to gain experience of working with a global development team by having conference call meetings, handling time difference and cultural differences.

2.1 Preliminary Economic Analyses - Budget and Vendor Purchase Information

Students of Pennsylvania State University have a budget of $1,000 (8 040 SEK), which will cover the parts used to construct the simulator.

Students of Chalmers University of Technology have a given budget of $230 (2 000 SEK). This will be used for purchase of additional hardware for the simulator.

A detailed list of Budget and Bill of Materials for all concepts can be seen in Appendix A and Appendix B.

2.2 Project Management

Project management consisted of creating a Gantt-chart, a deliverables agreement and a group contract.

A schedule given by the universities was used as the foundation for the Gantt-chart, found in Appendix F, where deadlines and deliverables were defined. The chart shows during which period of time the deliverables will be worked on and it will be updated frequently as work continues during the semester. Responsibilities are divided between the two universities and thereafter delegated to an individual.

The deliverables agreement is used as an overview of the deadlines and to ensure that students, mentors and sponsors agree on what will be delivered from the project. This is found in Appendix D. A group contract was established to ensure that the project group has the same level of ambitions and how a potential disagreement is handled. The group contract is found in Appendix E. Other subsections in this contract includes meetings, communication and decision making.

2.3 Risk Plan and Safety

A major risk in the project is identified as lack of competence, and this could therefore affect the outcome of the final product. Another big risk is problems with communication between the group members, since there is a time difference between the two countries and the major part of the communication is handled through an internet based group communication. Other risks are named and leveled in Appendix C.

2.4 Ethics Statement

The simulator will make testing with humans necessary early in the process and this will minimize the risk of putting unreliable systems on the road. Safety and comfort is taken into consideration when developing the simulator. This includes discomfortable situation when experiencing too realistic accidents, motion sickness and possibility of being hurt by a component of the simulator.

One of the biggest problems with driving simulators is identified as motion sickness, and this will be closely investigated with the help of a study made by Volvo Trucks. If the simulator creates motion sickness for many of the test subjects, the tests will be hard to perform and not enough data will be received.

2.5 Environmental Statement

The prototype is going to reduce the time needed to test the systems on the road, which reduces the emissions and fuel consumption during the testing. A desktop simulator is cheaper to produce than a prototype of an entire truck since it contains less components. However, the environmental impact of the materials and components used in the desktop simulator will be taken into consideration during material selection process.

2.6 Communication and Coordination with Sponsor

In the beginning of the project, a time was set for the weekly conference calls with sponsor, Tuesday at 9:00 (US EST) and 15:00 (CET). The communication will mainly take place through this meeting, but will be complemented with communication through e-mail. Three presentations will be held for the sponsor; a project proposal-, midterm- and a final presentation.

3 Customer Needs Assessment

The customer in this project is Volvo Trucks North America.

3.1 Gathering Customer Input

Customer needs were gathered from the project description and from conference calls with the customer.

3.2 Customer Needs

3.2.1 Ease of Use

The simulator must be designed to make it easy to use for all customers, not only Volvo Truck drivers. No time should have to be spent understanding how the systems works, ideally a user would be seated and immediately start the simulation.

3.2.2 Flexible

The driving simulator needs to be flexible to provide a realistic driving experience for Volvo North American trucks and Volvo European trucks. The software of the simulator will be able to run a model of the North American trucks with the extended hood and engine as well as the European trucks with the cab-over front end. It is very important for the customer to get a realistic experience driving both truck models.

3.2.3 Cost

The cost of the simulator is an important factor in the concept selection. The cost has to be satisfying for Volvo to make it possible to produce many simulators and therefore ensure that enough data can be collected.

3.2.4 Ease of Implementation

It is of importance that both softwares are easily implemented in the driving simulator and are easy to install. The steering wheel, pedals and screens have to be compatible with the different software systems that the team will utilize. The simulator should also be made mainly out of COTS-parts to make it easy to set up in different locations. Any modified parts should be easy to recreate because of simple shape and manufacturing methods, and all drawings and instructions has to be easy to follow for customer.

3.2.5 Reliable

The driving simulator has to be reliable to ensure that no data is lost in the test drives and also to make the driving experience as comfortable as possible for the test subject. Lagging and simulation crashes can cause nausea, which results in an uncompleted test.

3.2.6 Portable

Volvo Trucks North America has requested a desktop simulator, which means a simulator that is portable without compromising the realistic experience.

3.3 Weighting of Customer Needs

To analyze areas of prioritization in the development of the product, weighting customer needs is of importance. This is performed to ensure that the distribution of resources and time is allocated properly during the project.

After gathering information regarding customer needs, these were weighted in an Analytical Hierarchy Process (AHP), Table 1. Each row represents a judgment of the importance of one need, relative to the other needs. Score 1 means equal important, score 2 means twice as important, and so on. A total score is summed up and calculated into a percentage.

Table 1: Analytical Hierarchy Process (AHP) pairwise comparison chart to determine weighting for main needs

	Ease of Use	Flexible	Cost	Ease of Implementation	Reliable	Portable	Sum	Weight
Ease of Use	1.00	1.00	2.00	1.00	2.00	1.00	8.00	0.19
Flexible	1.00	1.00	2.00	2.00	2.00	1.00	9.00	0.22
Cost	0.50	0.50	1.00	0.50	1.00	0.50	4.00	0.10
Ease of Implementation	1.00	0.50	2.00	1.00	2.00	0.50	7.00	0.17
Reliable	0.50	0.50	1.00	0.50	1.00	0.50	4.00	0.10
Portable	1.00	1.00	2.00	2.00	2.00	1.00	9.00	0.22

As seen in Table 1, the two customer needs considered most important are flexible and portable.

4 External Search

A Heavy Duty Truck (HDT) is defined as a gross weight vehicle of more than 3.5 tonnes (European Commission 2014). The European long haul platform investigated in the project is the Volvo FH truck (Volvo Trucks Sweden 2016). The USA long haul platform investigated in the project is the Volvo VNL.

If vehicles were to be equipped with autonomous technology, this could reduce crashes, energy consumption, pollution and congestion. National Highway Traffic

Safety Administration (NHTSA) has developed a five level scale of grading for Autonomous Vehicles (AV), from Level 0 where the driver is in complete control of all functions of the vehicle, to Level 4 where the vehicle can drive itself without a human driver. AVs' on level 3, which means the driving functions are sufficiently automated and the driver can safely engage in other activities, will be on public roads in a few years. Companies such as Google, Toyota and Volvo Cars have come a long way in this development.(The RAND Corporation 2014)

Vehicle-to-Vehicle (V2V) communication allows vehicles to continuously communicate and be aware of each other. If something happens to one car, for example a sudden braking, cars several meters behind can get a safe warning to prevent a crash from occurring.(NHTSA 2016) A visualization of V2V is found in Figure 1.

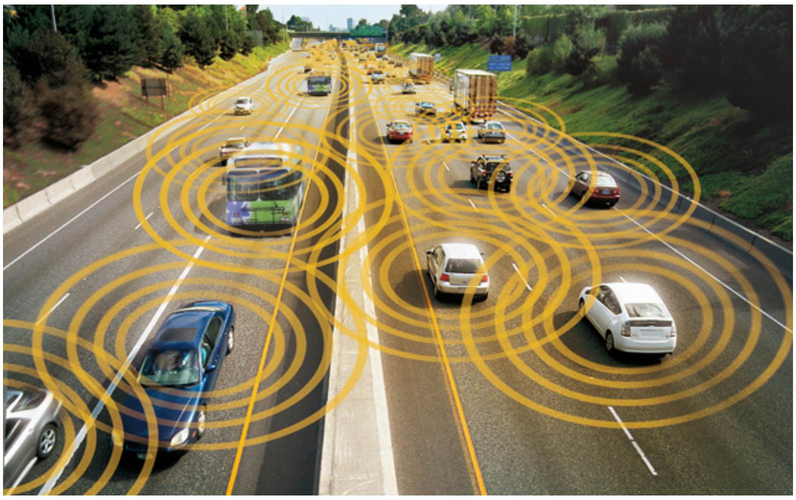

Figure 1: A visualization of V2V-communication (John Coyle 2015)

Vehicle-to-Infrastructure (V2I) communication is a wireless exchange of information between vehicles and roadway infrastructure. The information could be critical safety and operational data, and intend to reduce crashes. This is a key research program within the U.S. Department of Transportation's (U.S. DOT) Research and Innovative Technology Administration (RITA). (United States Department of Transportation 2015)

HMI means Human-Machine Interface and can represent both physical and/or virtually user interfaces.

Simulator Motion Sickness (SMS) is a very common outcome in simulators. This is a serious problem with simulators and can vary in severity. Symptoms of SMS can be nausea, sweating, headache and fatigue. The main cause for SMS is inconsistent information about body orientation and motion received by different senses. SMS seems to be most common in stationary simulators, but also occurs with motion based platforms. Factors such as flicker, field of view, time lag and update rate can affect the experience of motion sickness. (United States Department of Transportation 2015)

4.1 Patents

A patent search was performed to examine existing designs for driving simulators. This research has shown that desktop simulators have many different designs and applications that are patented. This allows analysis of different mechanisms and design specifications that can be implemented in the prototype. Table 2 contains the art-function matrix which portrays the patents used for the concept generation of the simulator. For example screen, steering wheel, pedal and rack setup was taken into consideration.

Static desktop driving simulator technology and patents, found in patent US4196528 A, is the focus for this project (Foerst 1980). This patent involves displaying different views to the driver in a realistic driving environment.

Table 2: Art-function matrix

Art / Function	Animated Visual Display	Realistic Customer Interaction	Gaming Steering Wheel/Pedals
Ease of Implementation	US20120157198A1		US20090319459A1
Ease of Use		US7775884B1	US7775884B1
Flexibility	US20090319459A1	US7775884B1	US7775884B1

4.2 Existing Products

4.2.1 Different Categories of Simulators

There are many different kinds of simulators, everything from basic game simulators and desktop simulators to very advanced motion-based platform simulators. There are simulators in many professions which requires testing before execution for a safe usage, for example medical operations and construction equipment. Simulators will hereafter refer to driving simulators.

Motion-based platform simulators provide the most realistic driving experience compared to stationary simulators due to the constant motion and feedback the driver experiences. The motion-based platform simulator Hexatech, manufactured by the company Cruden, is accessible at Chalmers University of Technology. This simulator uses Cruden's software which makes it possible to change parameters and give the driver a realistic experience when testing.

4.2.2 Software

The two software packages used are predefined and chosen due to different knowledge, expertise and access at the universities. Both softwares will be compatible with the hardware.

4.2.2.1 Cruden Software

Cruden's software is known for being used in motion-based platform simulators (Cruden 2016), but have recently proceeded into working with desktop based simulators as well. The software is called Panthera and is compatible with both Simulink and Matlab which makes it useful for many universities and technology based companies. Panthera is easy to use since the changes in the script immediately can be implemented into the program. Panthera visually shows the characteristics that is defined in the script as well as the selected environment. Any graphical errors are easily visualised by appearing in a different color.

4.2.2.2 Robotic Operating System Software

Robotic Operating System (ROS) is an open source software package that allows users to view and modify the source code of the software. This provides the user with a wider range of applications than a closed source software which promotes the sharing of resources between users. The simulator software and its graphics has been in development for over a year by a third party at Pennsylvania State University. Photographs and measurements for interior and exterior has been provided for the development of the software.

4.2.3 Head-Mounted Display

A Head-Mounted Display (HMD) is available in different embodiments such as helmets or goggles and it consists of a screen mounted on the head in front of the eyes. The screen usually consists of a Liquid Crystal Display (LCD) because of the light weight. The two biggest competitors on the market today are Oculus Rift and HTC Vive (HTC 2015) (Oculus VR, LLC 2016). The HMD ensures that the user always has an updated picture of the surroundings in front of the eyes when changing the direction of the head, because of a tracking device. A majority of HMD's are connected to the processor with cables since the wireless systems are not reliable enough to prevent lagging or latency issues. An excessive amount of lagging can cause SMS. There are several techniques that can be added to the HMD to enhance the experience, and an example of this is Virtual Reality Gloves. The gloves makes it possible for the user to interact with what is seen on the screen.

5 Engineering Specification

5.1 Establishing Target Specification

The objective of this project is to develop a desktop driving simulator which promotes a realistic driving experience for the Volvo Trucks. The target specifications related to these customer needs are discussed in 3.3.

5.2 Relating Specifications of Customer Needs

The Needs-Metrics Matrix, shown in Table 3, uses the categories from the AHP matrix (section 3.3) to compare with objectives established in the project description. The matrix describes which customer needs can potentially be fulfilled by the different objectives.

Table 3: Needs-Metrics Matrix

	Built out of COTS-parts	Realistic driving experience	Compatible with both software packages	Evaluate driver behaviour safely
Ease of Use		X		X
Flexible	X	X	X	
Cost	X	X	X	X
Ease of Implementation	X		X	
Reliable		X		X
Portable	X			X

The result of the matrix is that all customer needs should be able to be accomplished.

6 Concept Generation and Selection

6.1 Problem Clarification

The simulator will need to accept user input, which for example includes pedal- and steering wheel position. This information has to be imported into the driving simulator software. The simulator returns visual, audial and possibly tactile feedback to the user. The Table 4 shows the black box diagram of the problem, displaying what input (left) the device requires to be able to provide the output (right). HMI is not taken into considerations for analysis in this project but is still an input and feedback possible from a driving simulator.

Table 4: Black-Box

User input		Driving simulator	Device Feedback	Solution
Throttle	$\Rightarrow$		$\Rightarrow$ Visual	Screens
Brake	$\Rightarrow$		$\Rightarrow$ HMI	
Steering	$\Rightarrow$		$\Rightarrow$ Audio	Surround Sound
HMI's	$\Rightarrow$		$\Rightarrow$ Tactile	Force Feedback

6.2 Concept Generation

The concept generation was performed with multiple methods. Brainstorming was performed based on the patent search (Foerst 1980), photos and existing simulators. This acted as a foundation for the generated concepts and includes angles and placement of screens, pedals and steering wheel. The next step in the generation process was to elaborate how to create a realistic experience with the help of additions and modifications based on customer needs. Mind mapping was also a method used to give an overview of what components possibly could be put into, or removed from concepts. Mutual for all generated concepts is that the simulator has a gaming steering wheel, pedals, a computer and a chair. The steering wheel and pedals have force feedback which can be adjusted. All setups can be rearranged as needed for various vehicles.

6.2.1 Concept 1 - Five-screen Setup

The Five-screen setup concept uses five displays, shown in Figure 2. This concept gives a one-to-one ratio of the interior cab dimensions to simulator dimension. The three front screens displays the front window and the two side screens displays the driver and passenger windows. These are set up on a table and are easy to reconfigure.

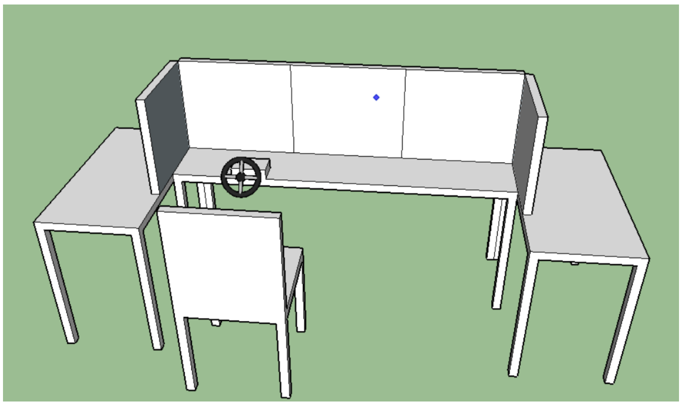

Figure 2: Concept 1 - Five-screen Setup

6.2.2 Concept 2 - Projector Based Setup

This concept utilizes a single mid-sized projector, Figure 3, which displays the entire field of view with a curved screen. The projector covers the front windshield and some of the right and left windows. The projector is set up behind the user and adjusted to emit the viewable area necessary.

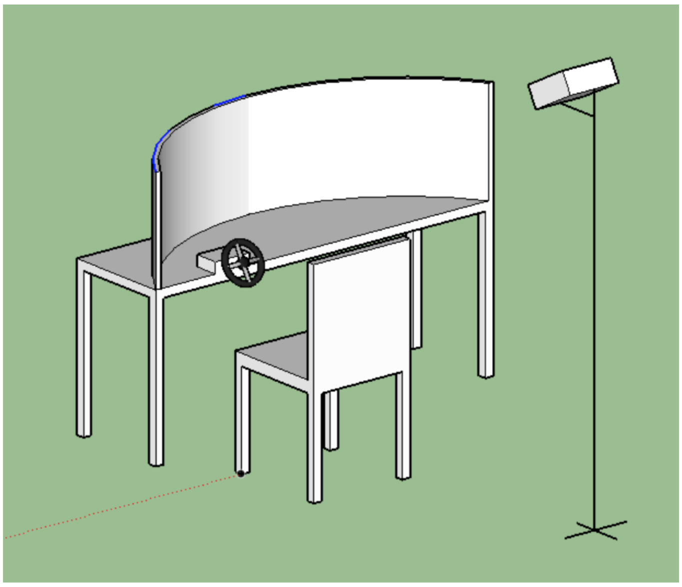

Figure 3: Concept 2 - Projector Based Setup

6.2.3 Concept 3 - Three-screen Setup with Truck Steering Wheel

The three-screen setup, Figure 4, is based on three screens that are placed to show the entire field-of-view (FOV) in the truck. The FOV stretches from the left side window to the left A-pillar (left screen), from left A-pillar to the center of windscreen (center screen) and from rest of the windscreen to the right side window (right screen). This concept is easy to implement mainly with COTS parts. This concept will enhance the driving experience with the truck steering wheel and truck pedals.

Figure 4: Concept 3 - Three-screen Setup with Truck Steering Wheel

6.2.4 Concept 4 - Head-Mounted Display

The fourth concept consists of a HMD, Figure 5, and its tracking device, as well as at least one screen. This allows the driver of the simulator to get a view of the entire cab of the truck, in comparison to a screen setup where only a predefined FOV is visible. More information on the technique behind HMD can be read in Section 4.2.3.

Figure 5: Head-mounted display by Oculus Rift, (Oculus VR, LLC 2016)

6.2.5 Concept 5 - Three-screen Setup with Rack and Gauge Monitor

This setup has three 55" screens to cover the entire FOV, with a fourth screen for the gauges of the truck, see Figure 6. The FOV for this concept is the same as in Section 4.2.3. The fourth screen is placed underneath the front screen at an angle to match that of the gauge cluster inside the cab of the truck.

All screens will be held and positioned by a rack which allows adjustment of angles of the screens. The steering wheel will be mounted on the rack in front of the gauge screen.

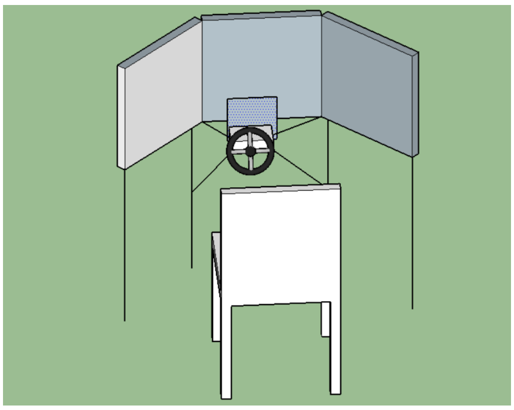

Figure 6: Concept 5 - Three-screen Setup with Rack and Gauge Monitor

6.2.6 Concept 6 - Four-screen Setup with Rack and Gauge Monitor

Concept 6, shown in Figure 7, consist of the same setup as the concept in Section 6.2.5 with one additional screen. This additional screen increases the amount of details when looking out the windscreen. The gauge monitor will provide the same information to the driver as in concept 5.

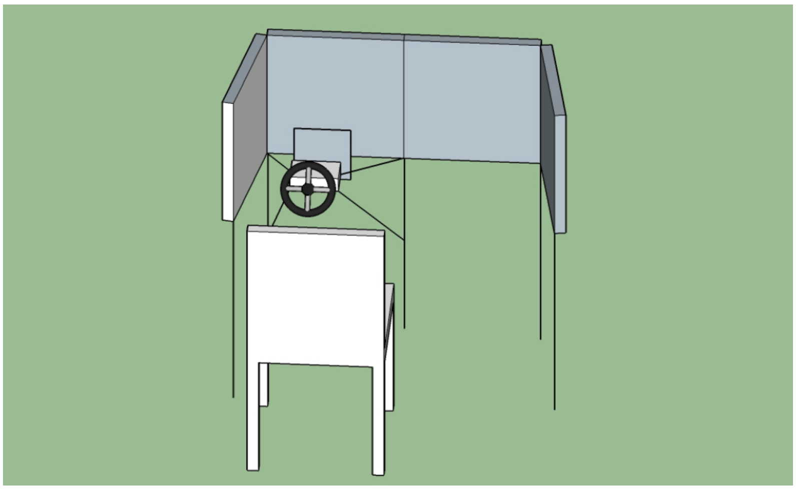

Figure 7: Concept 6 - Four-screen Setup with Rack and Gauge Monitor

6.3 Concept Selection

The concept selection process used is the Pugh-matrix, Table 5, which is a globally known process for concept selection which allows an easy comparison between the different concepts and how well they fulfill the customer needs. Pros and cons for all concepts were established before performing matrix.

6.3.1 Pros and Cons of concepts

This section will shortly describe the pros and cons regarding the different concepts that were taken into consideration. The Pugh-matrix is based on these pros and cons as well as the concept descriptions.

- Five-screen Setup
  - \+ High number of screens gives a wide FOV.
  - − Expensive and not portable because of the number of screens and needs an expensive computer to be able to run simulations.
- Projector Based Setup
  - \+ Affordable and portable.

  - Can not be made entirely out of COTS parts, difficult to angle the screen which means that the FOV is limited and not realistic.

- Three-screen Setup with Truck Steering Wheel
  + Gives a good FOV and gives the user a realistic test drive with actual part from truck.
  - Can not be made entirely out of COTS-parts, some viewing angles will be lost due to the size of the screens.

- Head-Mounted Display
  + Very portable, only requires one screen, covers all viewing angles.
  - Can lag because of resolution requirements which can lead to nausea.

- Three-screen Setup with Rack and Gauge Monitor
  + Gives a good FOV with three larger screens and has a gauge screen that the driver can interact with.
  - Can not be made entirely out of COTS parts, expensive computer needed to run the simulator and high cost of larger screens.

- Four-screen Setup with Rack and Gauge Monitor.
  + Gives a good FOV with four large screens and has a gauge screen that the driver can interact with.
  - Can not be made entirely out of COTS parts, expensive computer needed to run the simulator and high cost of larger screens.

6.3.2 Pugh-Matrix

The projector concept was chosen as a reference in the Pugh-matrix.

Table 5: Pugh-matrix and ranking

		Concepts											
		Concept 1		Concept 2		Concept 3		Concept 4		Concept 5		Concept 6	
Selection Criteria	Weight	Rating	Weigthed Score	R	W S	R	W S	R	W S	R	W S	R	W S
Ease of Use	0.19	3	0.57	3	0.57	4	0.76	4	0.76	4	0.76	3	0.57
Flexible	0.22	3	0.66	3	0.66	3	0.66	3	0.66	3	0.66	3	0.66
Cost	0.10	1	0.10	3	0.30	2	0.20	2	0.20	1	0.10	1	0.10
Ease of Implementation	0.17	3	0.51	3	0.51	3	0.51	3	0.51	3	0.51	3	0.51
Reliable	0.10	1	0.10	3	0.30	5	0.50	2	0.20	2	0.20	1	0.10
Portable	0.22	1	0.22	3	0.66	3	0.66	4	0.88	2	0.44	1	0.22
	Total Score		2.16		3.00		3.29		3.21		2.67		2.16
	Rank		5		3		1		2		4		5
	Continue		No		No		Yes		No		Yes[a]		No

Relative Performance	Rating
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

[a]Requirement from sponsor.

The concept with the best score in the matrix was the three-screen setup with truck steering wheel with 3.29 (concept 3) closely followed by the head-mounted display concept with 3.21 (concept 4). On Volvo Trucks North America's request, concept three and five will be combined to one concept with a three screen setup with a truck steering wheel, rack and a gauge monitor. These two concepts are similar, and therefore compatible and easy to combine. The components of the simulator can be divided into two sections, which can be designed and manufactured independently of each other. The components can be combined, but also work separately. The students at Chalmers University of Technology will implement the truck steering wheel and pedals and the Pennsylvania State University students will implement the gauge monitor and build a rack.

7 System Level Design

Since knowledge and resources at the two universities differ, the system level design is divided to get a better insight of the different hardware and software setups.

7.1 System Level Design - Chalmers University of Technology

7.1.1 Hardware Setup

The hardware setup consists of a computer, three 24" screens, a truck steering wheel and pedals. The angles between the screens are decided by the FOV and will be the same as for the bigger 55" screens. The gaming steering wheel and pedals will be used as inputs to the system. The main differences between a truck and a car steering wheel are the tilting angle and the size of the steering wheel. To get a simulation as close to reality as possible, the gaming steering wheel will be replaced by a truck steering wheel which will be attached to the gaming steering engine with the help of an adapter. The gaming steering wheel used has a lock-to-lock steering angle of 900°, which is the maximum angle available for gaming steering wheels. This is as close to the 1800° steering angle in a real truck possible to simulate with COTS-parts. The wheel torque will be adjusted to imitate a steering wheel in a truck, and the force feedback of the pedals will also be adjusted to mimic a truck's. The tilting angle of the steering wheel will not be adjustable for the driver of the simulator. However, the angle will be set to suit as many drivers as possible. The distance between the driver and the steering wheel will be in a predetermined range measured from the lower edge of the steering wheel to the outer edge of the chair both horizontally and vertically. The distance between the steering wheel and the pedals will also be measured in a truck, from the lower edge of the steering wheel to the outer edge of the pedal.

Two modified plates will replace the current plates of the pedals, which will adjust the angle and size to resemble pedals from a truck.

An adjustable office chair with a high backboard will be used to gain a more realistic feeling of a truck seat.

7.1.2 Software Setup

Graphics of the FH16 exterior was received from the Department of Vehicle Engineering and Autonomous Systems (VEAS) at Chalmers University of Technology. The sketches given were not complete and work has been done to improve the details of the graphics in the program SketchUp. The 3D-model is done with polygonal modeling which consists of triangle-shaped areas that creates a surface.

The 3D-models (.3ds format) were then converted into the correct format for Panthera. The main objective regarding graphics was to give the user a realistic feel of being seated in a truck. Ideally, this would include more detailed interior from a FH16 and complete visual parts of the exterior. Figure 8 shows the view from the front seat and 9 shows the exterior of the truck, more pictures are found in Appendix G.

Figure 8: Front view from driver position

Figure 9: The FH16 implemented in Panthera

The Panthera software uses C++ as programming language. The project has used a script (.ini format) for a Scania truck found in 3D-warehouse as a foundation where dynamics and measurements has been changed to fit the FH16 model mentioned in Section 1.2.1.

Synchronization has been done between graphics and programing in Panthera. The rigid truck is graphic models that are implemented into the software.

7.2 System Level Design - Pennsylvania State University

7.2.1 Hardware Setup

The hardware consists of three 55" screens, a gaming steering wheel with pedals and a smaller 19" screen to display the gauge cluster. The screens will be oriented to display an accurate view using the simulator program and will be mounted on the rack with the use of the mounting holes on the rear of the screens. The gaming steering wheel will be in a fixed position relative to the gauge cluster screen, and the pedals will be placed on the floor mimicking the position of the pedals relative to the steering wheel in an actual truck. Also, an adjustable office chair will be implemented so that drivers can align themselves in their normal driving position.

7.2.2 Software Setup

The software used in the simulator has been in development for the past year in the ROS software by a graduate student at Pennsylvania State University.

7.3 System Level Design - Combined

The two setups will be compatible to each other in terms of hardware but software will be vary depending on location. To run the three 55" screens with the simulator software, a high powered computer is needed. The truck steering wheel will be mounted on a plate below the gauge screen.

8 Detailed Design

8.1 Component and Component Selection Process

This process has been divided into two sections for each addition; COTS-parts and modified parts. COTS-parts can be purchased and added to the prototype without any modifications and the modified parts are designed and manufactured for the project.

8.1.1 Component and Component Selection Process - Steering Wheel

8.1.1.1 COTS-parts

The computer which is needed to run three 24” screens in a simulation is available at Chalmers University of Technology. The gaming steering wheel chosen has the largest lock-to-lock angle (900°) available among gaming equipment, which is the closest to a truck steering wheel with an angle of 1800°. The pedals are included in the price for the gaming steering wheel. The truck steering wheel is provided by Volvo Trucks and is a standard Volvo Truck spare part.

8.1.1.2 Modified Parts

A gaming steering wheel is smaller than a steering wheel from a truck. To be able to combine the gaming steering wheel engine and the truck steering wheel, an adapter has to be manufactured. To get the right angle of the steering wheel, the steering wheel engine will be turned 180° on the table and 90° up towards the driver. To achieve this, a new mount to attach the steering wheel engine to the table, has to be manufactured. The design for the stand will be a shaped steel sheet with holes for bolts located to correspond with the existing holes in the steering wheel engine, and will be attached to the table with clamps. The stand will also include a circuit board sustainer to hold one of the two circuit boards from the gaming steering wheel engine. The sustainer will be made out of the existing gaming steering wheel hub.

The gaming pedals have to be adjusted since the angle and size differs compared to a truck. Measurements and pictures taken at the Resource for Vehicle Research (ReVeRe) at Chalmers University of Technology are used to make CAD-drawings for the pedal plates and thereafter 3D-printed. The printed parts will be attached to the existing pedal stand.

8.1.2 Component and Component Selection Process - Rack

8.1.2.1 COTS-Parts

Three 55” screens, a 19” screen and a computer are available at Pennsylvania State University. The computer can run the four screens needed for the prototype.

The gaming steering wheel was chosen because of its high lock-to-lock angle, as mentioned before.

8.1.2.2 Modified Parts

A plate will be fabricated for the steering wheel, which will be designed to enable mounting with the rest of rack. This will make maneuvering and positioning the rack easier if the simulator needs to be moved. The 19" screen, which displays the gauge cluster, will be mounted on the rack underneath the middle 55" screen. Therefore, an adjustable mount will be manufactured in order to simulate the angle and positioning of the gauge cluster for different truck models. The chair will be adjustable in order for the user to be able to get in the proper driving position to reach the pedals comfortably.

8.2 Material and Material Selection Process

The material selection process for the simulator was an important aspect in the development of the prototype. Cost, weight, machinability, environmental impact, sustainability and strength were mainly taken into account when deciding which material to use.

8.2.1 Material and Material Selection Process - Steering Wheel

After consulting with the Prototype lab, a 3mm (0,118in) steel sheet was recommended to use for the stand of the steering wheel. This material will be used because of its low price, durability and is easy to work with. Steel is one of the more environmental friendly metals at a reasonable price, with high availability and the appropriate properties. Rubber was used because of its material properties which enables to shape into right size which is useful for the surface in contact with the table of the stand and to prevent sliding. Polylactide (PLA) will be used for the 3D-printed parts.

8.2.2 Material and Material Selection Process - Rack

Aluminum is chosen for the structural components of the simulators since it is easy to machine and inexpensive. The prototype will use extruded aluminum which is light. This is an important property for a structure of this size. For the simulator to support the three 55" screens, weighing approximately 18kg (40lb), and still be portable, extruded aluminum is the most viable option. The driving simulator will not be exposed to harsh environmental conditions which can lead to an accelerated corrosion process. Therefore, the thermal properties and high corrosion resistance properties of stainless steel are not needed. The total cost of the construction is approximately $500 (4 010 SEK).

8.3 Manufacturing Process Plan

This section shows in detail the manufacturing process plan of the simulator. These following sections have been divided into steering wheel and rack to elucidate the differences.

8.3.1 Manufacturing Process Plan - Steering Wheel

All operations will take place at the Prototype lab with help from staff members. A sheet of steel will be water jet cut according to the CAD-drawings of the four parts (Appendix H) of the stand. These parts will be welded together at a 90 degrees angle and all sharp edges will be removed. Two holes will be drilled in the stand for attachment of the steering wheel engine and two holes for attachment of the circuit board sustainer. This enables usage of the existing threads on the back of the engine and the steering wheel hub, which uses M6 bolts and M4 screws respectively. The attachment points between the stand and steering wheel engine will give extra support because of additional fixed points. To avoid scratching any mounting surface, rubber will be cut and glued onto the stand.

To attach the truck steering wheel to the steering wheel engine, an adapter will be constructed. This will be 3D-printed out of PLA from a CAD-drawing. The adapter will be fastened by threaded holes, screws, bolts and nuts. The pedal plates will also be 3D-printed out of PLA from a CAD-drawing. These will adjust the angle and size to make them similar to the pedals in a truck. Before attaching them, excess material from the manufacturing must be removed with a knife. To attach the pedal plates, M4 bolts will be used together with plates to allocate the pressure.

The stand will mounted to the rack with clamps. The entire manufacturing process plan can be seen in Table 6.

Table 6: Manufacturing Process Plan - Steering wheel

ASSEMBLY NAME	MATERIAL TYPE	RAW STOCK SIZE	OPERATIONS
Stand	Sheet of steel	3mm (0.12in)	Cut to size on waterjet
			Weld parts together in a 90 degree angle
			Drill holes
			Remove sharp edges
Rubber mat	Rubber	3mm (0.12in)	Cut to size with knife
			Glue mat to contact area of stand
Adapter	PLA		3D-print from CAD-model
			Remove spill material from manufacturing
Pedal Plates	PLA		3D print from CAD model
			Remove spill material from manufacturing
Pedal assembly			Remove original shims and pedal plates from pedal stand
			Attach new pedal plates to pedal stand with bolts and plates
Steering wheel assembly			Remove gaming steering wheel from engine and detach steering wheel hub with circuit board
			Truncate the wire between the two circuit boards and remove cable from Steering column
			Solder wires and attach steering wheel hub with circuit board to stand
			Attach adapter to steering wheel engine with screws
			Attach truck steering wheel to adapter with bolts and nuts
Complete assembly			Attach Stand to table with clamps
			Attach engine of steering wheel to stand with the integrated mounting and with bolts and plates

8.3.2 Manufacturing Process Plan - Rack

Detailed drawings of the manufactured parts for the rack can be viewed in Appendix H. In order to ease any reproduction of the prototype, the Manufacturing Process Plan, Table 7, outlines the processes needed in fabricating and assembling the prototype.

To manufacture the rack, the aluminum T-slotted framing will need to be cut to the dimensions required by the process plan and then assembled according to the CAD-models using various mounting hardware. The screens will be mounted to the rack using existing mounting brackets.

Table 7: Manufacturing Process Plan - Rack

ASSEMBLY NAME	MATERIAL TYPE	RAW STOCK SIZE	OPERATIONS
Rack	Aluminum T-Slotted Framing	25.4 x 25.4 x 254mm (1"x1"x10")	Cut to the appropriate length based on drawings
			Deburr cut material
	Assorted hardware		Assemble the cut aluminum frame and hardware into rack structure
	55" Screens		Mount the screens to rack
	19" Screen		Mount the screen to rack

8.4 Analysis

The truck dynamics in the software are mainly made with the help of information about the trucks found at Volvo Trucks' website, complemented with measurements taken in real trucks. This include, for example, measurements of height, width, length, center of gravity and distance between wheel bases, as well as settings for engine, gearbox, pedals and steering.

8.4.1 Analysis - Steering Wheel

Since the modified gaming steering wheel with rack does not have any variable load, no further calculations or analysis of the durability of this part is needed. All other parts of the simulator are COTS-parts with no modification, which also makes calculations unnecessary.

Some of the parameters found at Volvo Trucks' website have been modified to get the correct truck characteristics in the simulator. These values have also been complemented with measurements from the cab of a truck. Car points in Figure 10 shows the characteristics such as center of gravity and other parameters of importance for vehicle dynamics.

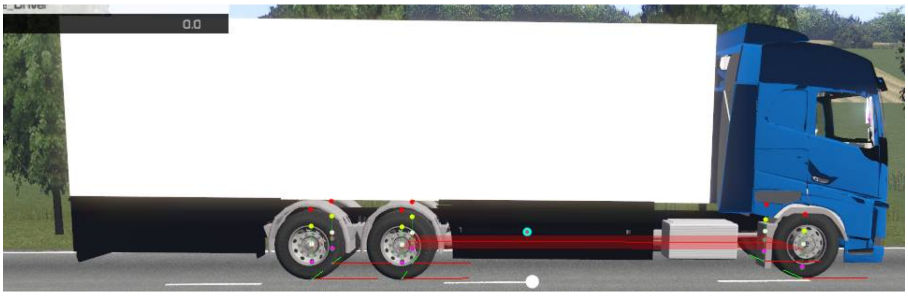

Figure 10: Vehicle with car points

8.4.2 Analysis - Rack

Since the rack is supporting the entire weight of the screens, analysis is required to ensure that the rack will not deform. Finite Element Analysis (FEA) would have been ideal for running stress tests, but the computers on Pennsylvania State University could not handle running a full FEA. Therefore, a simple deflection test was done in the Learning Factory involving a 0.3m (1ft) piece of scrap extruded aluminum. The 0.3m (1ft) piece of extruded aluminum was loaded up to 36kg (80lb) at 4kg (10lb) intervals. The deflection was measured after each 4kg (10lb) weight was added. After the 36kg (80lb) test there was no measurable deformation of the piece. 36kg (80lb) was chosen as the cutoff weight since this is more than the weight of the screens.

Also, the truck steering wheel setup weighs more and has a larger radius than the gaming steering wheel and will put extra stress on the wheel mounting plate. Therefore, due to the weight of the truck steering wheel, an extra leg will be added to support the the excess weight and decrease the risk of failure.

8.5 CAD Drawings

8.5.1 CAD Drawings - Steering Wheel

Figure 11 shows the stand by itself without the steering wheel engine mounted to it, the drawing is available in Appendix H. Figure 12 shows the full assembly with the four main components; steering wheel, steering wheel engine, stand and C-clamps but without the circuit board sustainer. Pictures of the circuit board sustainer and all the manufactured parts mentioned in this section are available in Appendix G

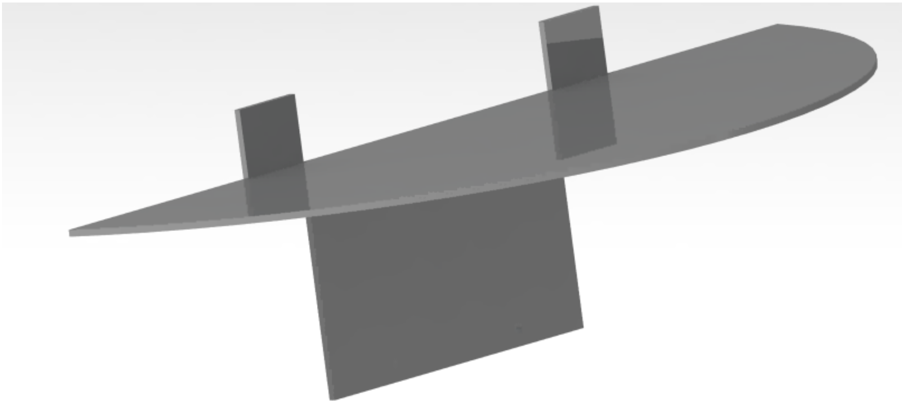

Figure 11: Stand

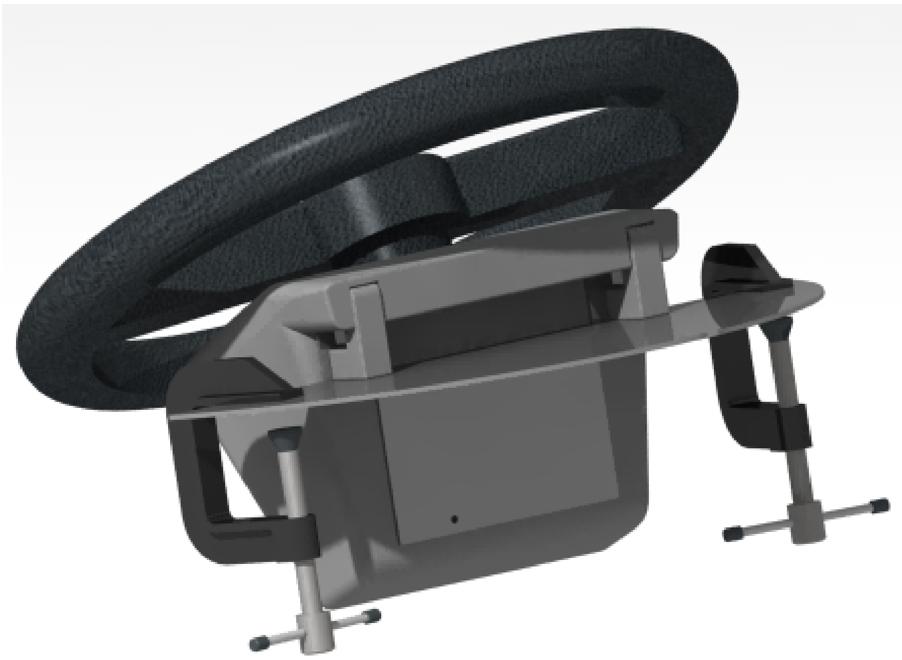

Figure 12: Stand with steering wheel

Figure 13 and 14 shows the trottle pedal plate and brake pedal plate separately. Figure 15 shows the pedal plates mounted to the pedal stand. The drawing is available in Appendix H.

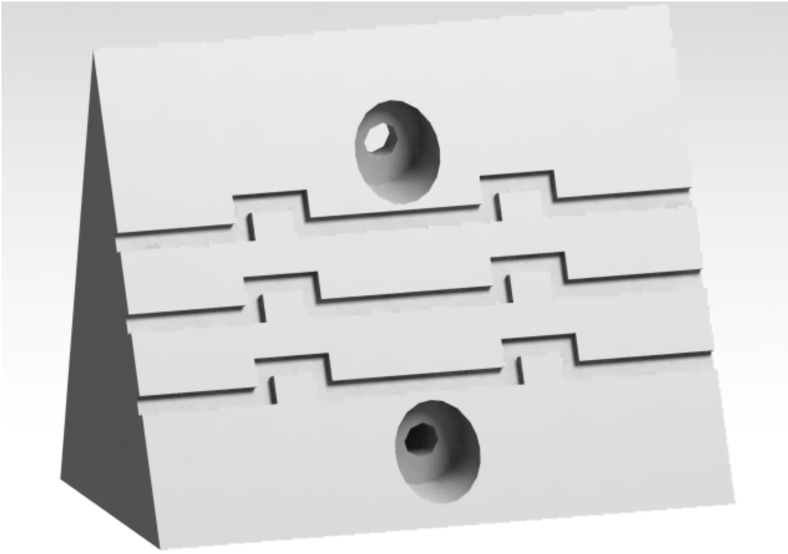

Figure 13: Pedal plate of throttle pedal

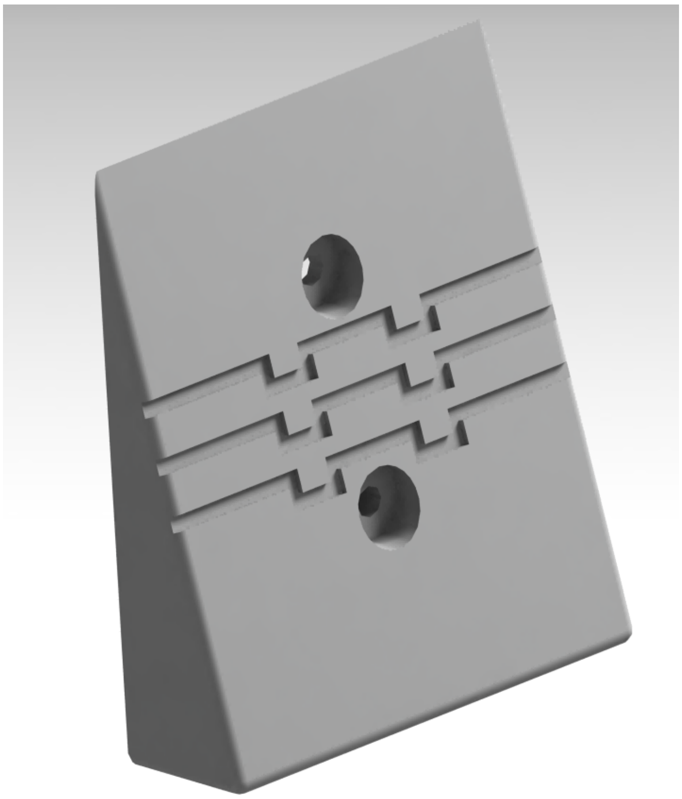

Figure 14: Pedal plate of brake pedal

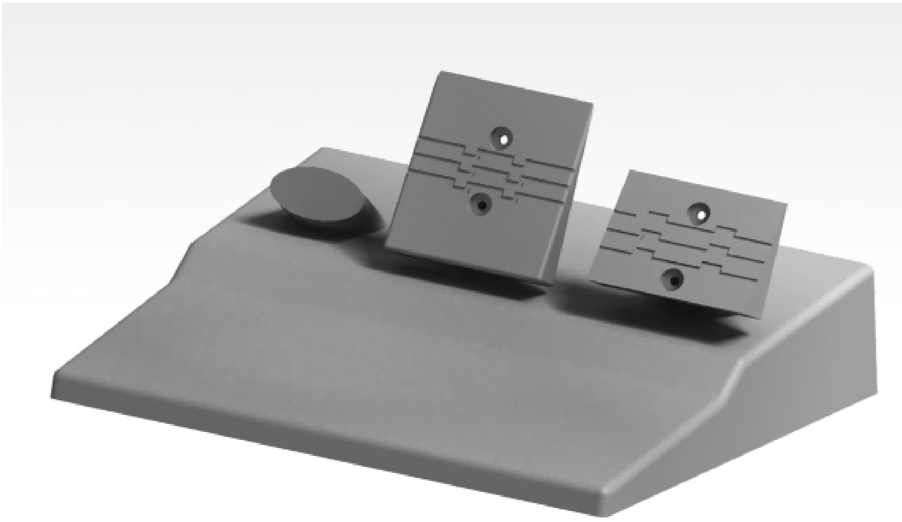

Figure 15: Pedals mounted to pedal stand

Figure 16 shows the adapter from both sides. The sides differ because of diverse attachment points. The drawing is available in Appendix H.

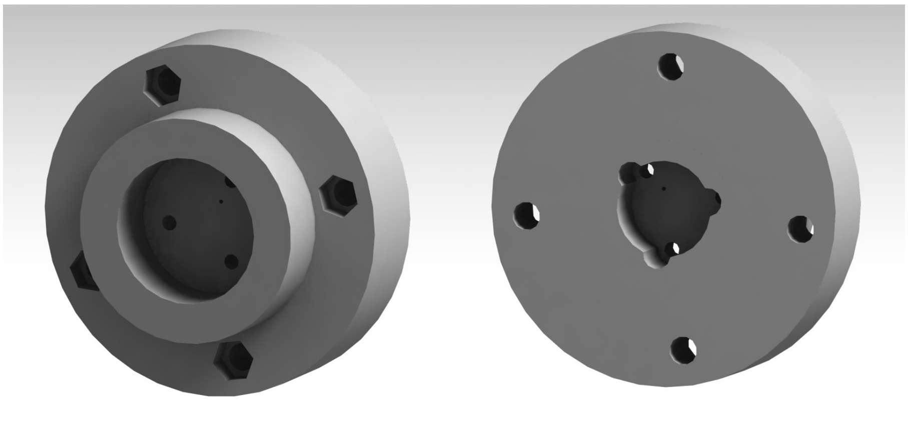

Figure 16: Both sides of the adapter

8.5.2 CAD Drawings - Rack

Figure 17 shows the rack of its own. Figure 18 and 19 shows the rack with the three 55" screens and the gauge cluster from a front and back view. Figure 20 shows the rack isometric and folded.

Figure 17: Isometric front view of rack

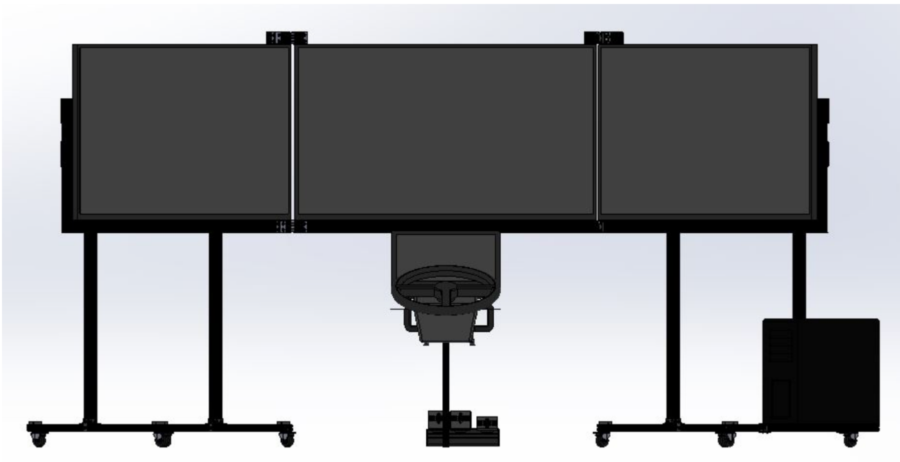

Figure 18: Front view

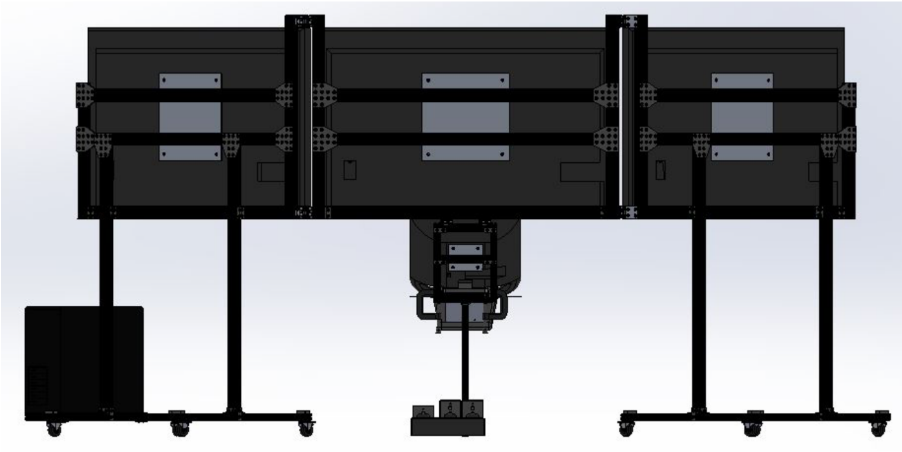

Figure 19: Back view

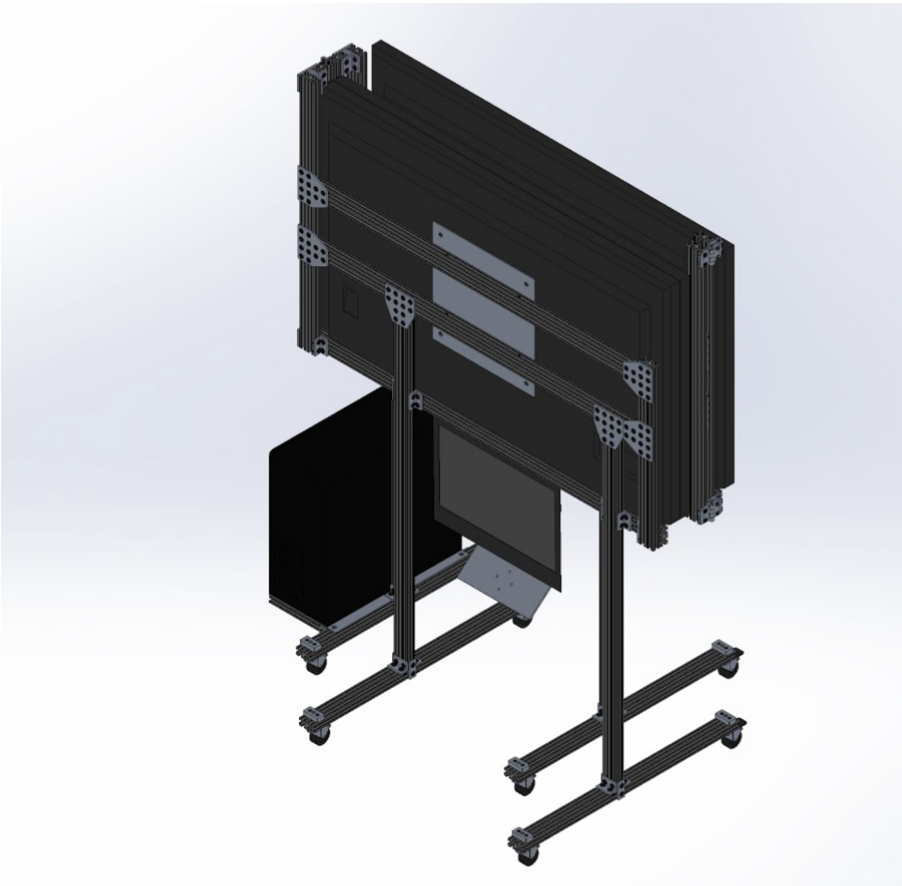

Figure 20: Isometric folded

8.5.3 CAD Drawings - Combined

Figure 21 shows an isometric view of the concept with all additions.

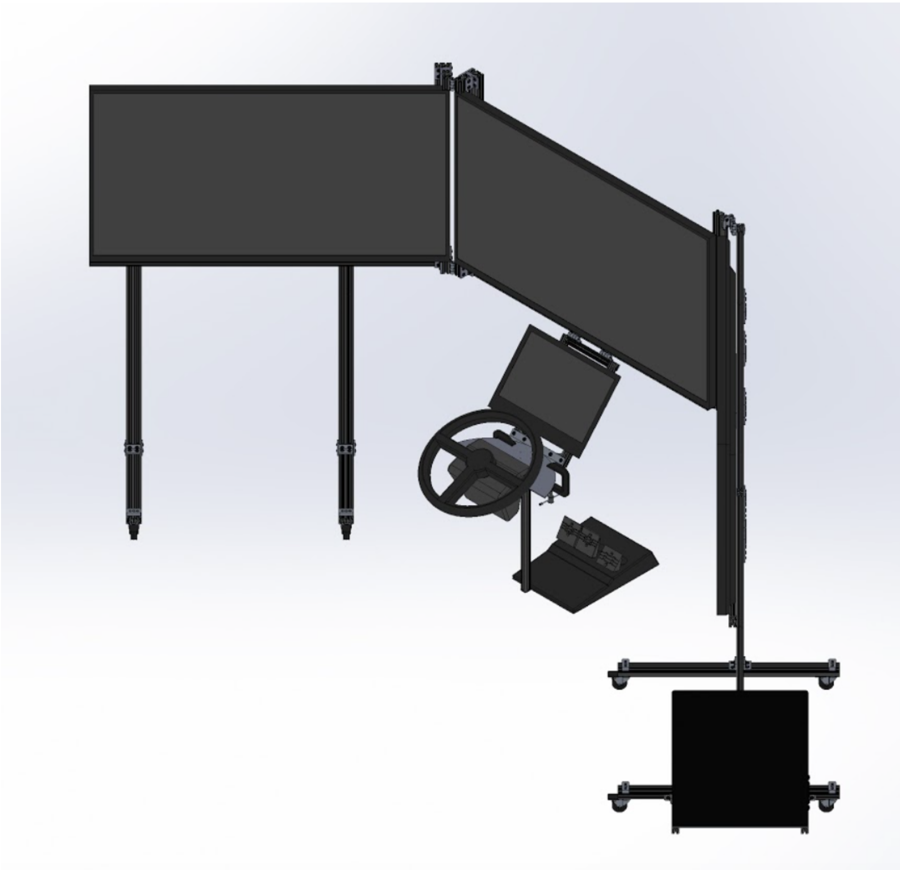

Figure 21: Combined isometric view

8.6 Test Procedure

Since the students have no truck experience, a truck test drive on Volvo's test track will be performed to get the right settings for the simulator. This will help with getting as correct settings as possible for the steering wheel, pedals, seat, sound and FOV. These settings will also be tested by letting a few test subjects with truck driving experience try the simulator in an early stage of the development.

8.7 Economic Analyses - Budget and Vendor Purchase Information

The BOM in Appendix A has been updated with information regarding material cost for the adapter and mounting. Updates regarding what computer used in the different concepts has also been done.

9 Construction Process

9.1 Construction Process - Steering Wheel

The contours of the four parts for the stand was water jet cut according to the drawing in Appendix H. All the sharp edges were removed with a bench grinder, and the parts were welded together according to the drawings. The holes for attaching the steering wheel engine were thereafter drilled with a 7mm (0.28in) drill according to the existing holes in the steering wheel engine and right after the holes for the circuit board sustainer was drilled with a 4mm (0.16in) drill according to the holes in the steering wheel hub. To avoid scratching any mounting surface, rubber was cut and glued onto the stand. Pictures of all the different parts manufactured are available in Appendix G

The pedal plates were 3D-printed from the CAD-drawings (see Appendix H). The preparatory work before printing was made in the software MakerBot, where all the material characteristics were defined. By adding both pedal plates to the same file, it is possible to print both at the same time. All corners of the pedal plates are sharp to make the printing easier. Since holes are included in the drawings and therefore made during printing, no additional drilling is required. The only processing needed is the removal of all spill material. Before attaching the printed pedal plates to the pedal stand, the existing pedal plates and shims are removed. M4 screws are used together with plates to attach the new pedal plates according to the Figure 22.

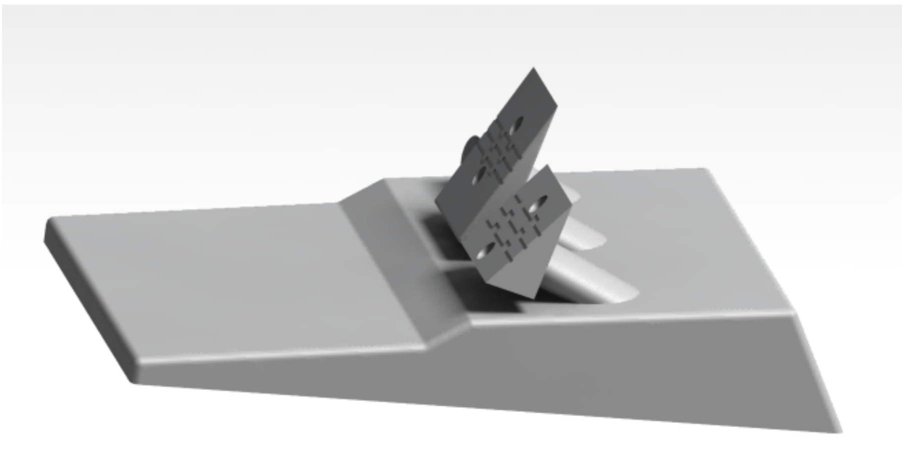

Figure 22: Mounted pedal plates

The adapter between the truck steering wheel and steering wheel engine was also 3D-printed from a CAD-drawing, (see Appendix H) and the preparatory work and processing was made the same way as for the pedals. The first time the adapter was printed it did not fit the truck steering wheel since exact measurements were hard to get. New measurements were taken and implemented in the CAD-drawings, and a new adapter was printed. The gaming steering wheel and the steering wheel hub and with the circuit board was removed. The wire between the two circuit boards were cut and lead away from the steering column. The wires were soldered and the steering wheel hub with circuit board was attach to the stand. The adapter was then attached to the steering wheel engine with M4 screws. Thereafter, the truck steering wheel was attached using M8 bolts, nuts and plates. Pictures from the work is available in Appendix G.

9.2 Construction Process - Rack

All extruded aluminum, hinges, nuts, bolts and plates were ordered through McMaster-Carr using CAD-drawings with dimensions to show how much of each of the pieces that were needed. The extruded aluminum was cut at the Learning Factory. Approximately thirty brackets, shown in the CAD-drawings, were cut and drilled from the ordered plates using the water-jet or by hand. Placement of the different parts and materials are described below.

First, the upper part of the left rack, was constructed using CAD drawings to specified dimensions. Once the upper part of the rack was complete, the two legs were attached to the two brackets already bolted to the upper portion. Two wheels were then bolted to the bottom of each foot of the legs, using two angle brackets each. Construction of the right part of the rack is identical and a mirror image of the left part, with the addition of the computer rack.

The middle rack is symmetric and constructed with five pieces of extruded aluminum bolted together using brackets and a back plate for the screen. The three rack sections were connected together by eight hinges and four pieces of two 50.8mm (2in) pieces of extruded aluminum. Two hinges were bolted on opposite sides of the 50.8mm (2in) extruded aluminum, creating four of these pieces. The hinges were fastened to the corners of the center part of the rack, and bolted to the corresponding corners of the right and left parts of the rack.

The smaller screen, displaying the gauge cluster, is bolted to a mounting setup constructed with four pieces of extruded aluminum. The upper bar is mounted to the bottom bar of the center screen using two hinges, and the back plate for the gauge screen is mounted on the bottom bar. Four holes are drilled in the back plate in the same bolt pattern as the screen which allows the screen to be mounted to it using screws. While in use, the screen is held in the desirexd position using a removable mechanical stop. Finally, the steering wheel mount is bolted to the bottom bar of smaller screen mount.

Any alignment issues that may arise when bolting the rack together or fastening the screens can be managed by loosening the bolts to allow the rear ties to slide along the tracks of the extruded aluminum.

10 Final Discussion

10.1 Results and Discussion

The hardware setup together with the software and graphics fulfill the needs for a operating simulator. During a simulation, the test driver experiences driving with a real truck steering wheel with a torque similar to a truck's. The simulations are realistic and easy to run. When the track has been loaded, the test subject is placed in the driver's position and can start driving immediately. This fulfills the customer need of the simulator being easy to implement.

The simulator constructed in the project consists mainly of COTS-parts which fulfills the objective to make it easy to recreate. The modified parts are developed in a way which uses minimal material for a first prototype and a simple manufacturing process, which satisfies one of the objectives. The simulator is easy to move since the computer, steering wheel and screens are placed on the rack, which in itself has lockable wheels. By rotating the steering wheel engine, the truck steering wheel received an angle very close to a real truck's. This was an easier solution compared to making an adapter that would modify the angle as well as fit the truck steering wheel to the steering wheel engine.

The ability to evaluate HMI has been a parallel focus throughout the project when generating and selecting concept. Focus regarding this did change from a sponsor perspective and this subject will be evaluated more thoroughly in Section 11.

At Chalmers the given budget of \$247 (2 000 SEK) was exceeded by \$494 (4 000 SEK) for purchases of screens, material and a gaming steering wheel. This money was provided by the program of mechanical engineering. The expensive gaming steering wheel in the project is the only steering wheel on the market with the needed lock-to-lock angle and it has been disassembled and modified, which requires it to be bought especially for this project. To be able to have a setup of three screens which is not moved or unplugged between usages, two additional screens have been purchased.

On the Pennsylvania State side the given \$1,000 (8 106 SEK) budget was exceeded by approximately \$800 (6 484 SEK) for the purchasing of all the materials, and the cost of machining and using the water-jet in the learning factory. However, approximately \$500 (4 053 SEK) was saved when the students decided to cut and drill their own brackets and plates instead of having them special ordered. The excess money needed is being provided by Volvo Group to ensure that the student's' project is completed.

The level of development of the simulator has been limited by several factors. The two main limitations has, as predicted, been knowledge and time. Graphics and vehicle dynamics have been defined and adjusted in the software Panthera at Chalmers University of Technology and in ROS by a third part at Pennsylvania State University. The knowledge of the softwares used is limited, both from students and instructors. Getting all graphical parts to work together with software has also shown to be an issue. The details as well as the quality of the graphics could have been improved if the project group had gotten access to better 3D-models, but this was not established within the time limit. The option would have been for the project group to make the 3D-models which would have required more time than the project allowed.

The software used at Chalmers, Panthera, is still in development with new features and improvement of existing functions. Some of the functions wanted from the software, such as autonomous systems, are very hard or impossible to implement in the software at this stage. There is also limited documentation about how to implement some of the wanted features which would have improved the realistic experience of the simulator, for example rear view mirrors. Figure 23 shows the interior together with the dysfunctional rear view mirrors on the right side.

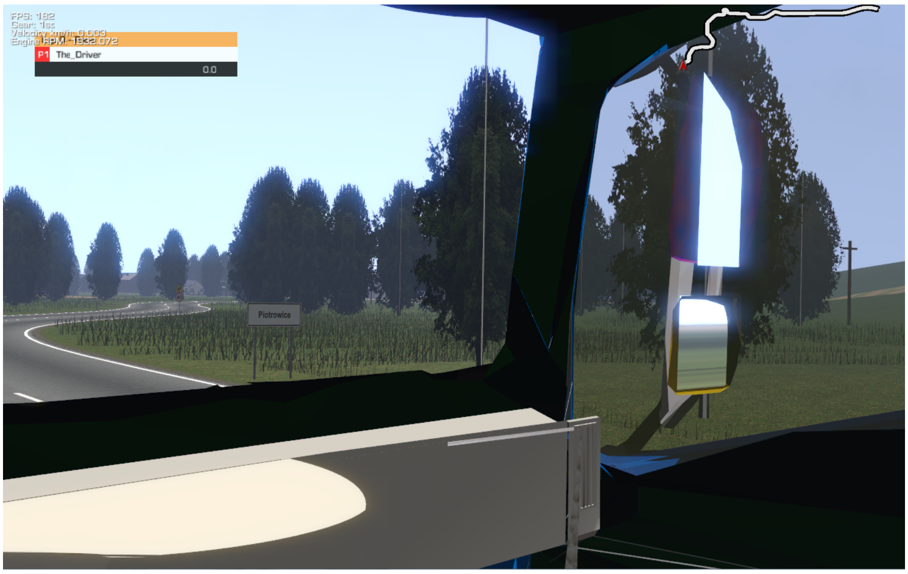

Figure 23: Right side of windshield and window

The exterior graphics of the FH16 is as good as required since it is not the primary focus for a simulation driving a truck. However, the exterior is of importance when simulating traffic situations such as V2V communication or platooning. The interior consists of the main parts in the FOV, seen in Figure 24 such as seats, dashboard and A-pillars. These are not as detailed as needed but could easily be improved with better graphical models. To run more detailed models, a more powerful computer is required because of their high amount of data. If these models would have been implemented and driven by the computer available today, lagging during the simulation would probably have occurred. It was decided that realistic graphics was not prioritized because of the risk of SMS caused by lagging.

Figure 24: FOV in the simulator

Also as a result of limited time, the planned test drive was not performed. This means that the force feedback of the steering wheel and pedals has not been calibrated according to how the truck was experienced, but from values found reasonable. The FOV could also have been improved after a test drive, but is now approximated with the help of pictures and experience from the inside of a truck standing still.

One of the main objectives has been to learn how to work in a global team. This has sometimes been a challenge because of cultural- and time differences, but also since the project has different structure and requirements at the two universities. Another aspect has been level of knowledge in different areas which can lead to a gap in understanding each other. Exchanging material has also been a difficulty because of the distance which makes it hard to quickly transport a part from one country to another and at the same time stay within the given budget and time limit. This led to the conclusion that the two countries will design and manufacture separate parts.

11 Conclusion and Recommendations

11.1 Conclusion

In conclusion, the hardware of the simulator consists of COTS-parts and a few modified additions which are easy to recreate. The hardware is compatible with the software and is easy to implement. Since the rack is foldable, has wheels and is easy to demount, the simulator is to a certain degree portable, even though it does not fulfill the demands of a desktop simulator. A more realistic driving experience could have been achieved if the limitations regarding time, knowledge, graphical models and budget would not have existed.

11.2 Future Development and Recommendation

Depending on what functions that are added to the simulator, many different aspects of the driving can be tested. If for example buttons on the steering wheel or a touch screen is added, HMI can be tested. It could also be a possibility to add autonomous functions and active safety systems for evaluation of driving behaviour in different traffic situations.

The graphics should be improved by better models of the interior of a truck and continued work with implementing mirrors. This would potentially enhance the driver's experience of being inside a real truck. By adding more realistic textures to the present model this could also increase the experience. Adding a gauge cluster both in graphics and software would also increase the driving experience since the driver can visually see information such as the speed of the vehicle.

To give a more realistic driving experience, it would be beneficial to run the simulation with a HMD and possibly additional gloves. This gives the driver a possibility to move the focus point and no viewing angles are lost. The technology is relatively new, and is continuously developing. Because of the high demand, problems such as lagging (which can cause SMS) are of high priority to improve. A HMD demands a highly detailed graphics to provide a realistic experience and the interior of the cab should therefore be improved before starting tests with this type of device in the simulator.

Further development with the adapter to make it slimmer and give it a better fit between the adjacent parts would be beneficial. Less material would be needed and the structure would be more durable. Looking into the possibility to 3D-print in metal would also make the adapter more lasting.

Possibility to place speakers underneath the seat of the chair to mimic the engine sound in a European truck has been discussed. This has not been implemented in the prototype due to lack of money and time. This is something that possibly can add another dimension to the driving experience in the simulator, and is recommended to add in the future. Also, the quality of the sound should be improved for a more realistic experience. The sound in the simulator today is developed as far as the team's knowledge and time limit allows.

A seat together with a seat belt could be added to ensure that the driver of the simulator is in the right position during all time of test session.

12 Self-Assessment - Design Criteria Satisfaction

12.1 Customer Needs Assessment

To self-assess and show how customer needs were fulfilled, Table 8 shows a score between 1-10 for each need, where 10 is the highest score.

- Ease of Use: It is not difficult for the user to interact with the simulator because of its realistic feel and simplicity. This means that it is easy to use for all drivers with any kind of vehicle experience, both in real life and in simulators. It is also easy to select roads, vehicles and controls in the software for the test leader.

- Flexible: There has not been enough time within the project to be able to implement all vehicle models in one software, but this should not be a problem if the right format of vehicles are provided to both parts.

Table 8: Score for Customer Need

Customer Needs	Score
Ease of Use	10
Flexible	4
Cost	5
Ease of Implementation	8
Reliable	9
Portable	4

- Cost: The total cost for the simulator was higher than first expected. The score is still relatively high since no cost requirement from sponsor was expressed.
- Ease of Implementation: Some parts of the hardware for the prototype have been modified, but the instructions to recreate these are easy to follow and the complexity level is low. The simulation setup is compatible with both softwares.
- Reliable: A powerful computer minimizes risk for lagging and software failure. The project has not experienced any issues regarding reliability and therefore this customer need receives a high score.
- Portable: The original demand from customer was a desktop simulator. This demand has changed during the project, and Volvo requested the concept with three 55" screens, which no longer makes it possible to fit the simulator on a desk. However, the simulator with its rack is easy to fold and move because of the wheels. It is also possible to easily disassemble the screens and the steering wheel from the rack, which makes it easier to transport.

12.2 Global and Societal Needs Assessment

To be able to evaluate if the the final product satisfies global and societal needs, the primary needs regarding the simulator were taken into consideration. The scale used is between 1 and 10, where 10 is the highest score. A short explanation of the scores is followed by Table 9 .

- Production of material: No material used in the product is hazardous for the environment or for people producing or being in contact with it. The production for each material is considered safe.
- Quantity of material needed for manufacturing: The material used for the prototype is a small in comparison to construction of a real size truck. Since the pedals and adapter to steering wheel are based on CAD-drawings, material usage for these components will be the exact amount needed.

Table 9: Scale for Global and Societal Needs

Need	Score
Production of material	8
Quantity of material needed for manufacturing	8
Recyclability	8
Sustainability of material	9
Safe to use	10
Ethics	10

- Recyclability: The materials used for manufacturing of the modified parts, steel and aluminum, are easy to recycle. The pedals and the adapter are constructed with the plastic PLA, which is a biodegradable thermoplastic. Rubber is possible to granulate and use in low-grade products. The COTS-parts, for example screens and computers, can either be reused or disassembled and parts of it reused or recycled.

- Sustainability of material: The only parts of the simulator in risk of problems due to fatigue is the rack. The strength analysis performed shows that this will not be a problem within the lifetime of the simulator. The screens and computers will however have to be updated to newer versions as the technique moves forward.

- Safe to use: The majority of users do not experience any symptoms of SMS during a test period within 1-10 minutes. It is also safe to move around in the simulator since it does not contain any sharp edges or any other objects that can be hurtful for the user.

- Ethics: Testing with humans is required in an early stage of the development of the simulator, but all test subjects have been voluntary and has only tested the prototype for a short time. The simulation environments has intentionally not been made too realistic with special effects such as crashes and blood to avoid any trauma for the test subjects.

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Appendix

A BOM

A.1 Concept 1 - Five-Screen Setup

Part Number	Description	Vendor	Qty	Cost
B00NUS8QQY	VIZIO E500i-B1 55-Inch 1080p Smart LED TV	Planet73 (Via Amazon)	5	$2,280 (18 556 SEK)
B001NT9TK4	Logitech G27 Racing Wheel	Amazon	1	$400 (3 256 SEK)
B003L1ZYYW	10ft HDMI	Amazon	5	$35 (285 SEK)
749942	4'Folding Table, Cream Top and Mocha Legs	Staples	3	$180 (1 465 SEK)
	Computer		1	$6,000 (48 833 SEK)
			Total	$8895 (72 395 SEK)

A.2 Concept 2 - Projector Based Setup

Part Number	Description	Vendor	Qty	Cost
B010YZTOSO	Abdtech 130" Mini LED Projector	Amazon	1	$80 (651 SEK)
B001NT9TK4	Logitech G27 Racing Wheel	Amazon	1	$400 (3 256 SEK)
B003L1ZYYW	10ft HDMI	Amazon	1	$7 (57 SEK)
B00KK9481I	Logitech Speakers 2.1	Amazon	1	$26 (212 SEK)
B00005113L	Power Cable	Amazon	1	$6 (49 SEK)
315412	1x2 8ft Pressure treated Board	Lowe's	2	$2 (16 SEK)
334961	Board 40x60 White	Office Depot	1	$13 (106 SEK)
	Computer		1	$6,000 (48 833 SEK)
			Total	$6,534 (52 680 SEK)

A.3 Concept 3-Three-screen Setup with Truck Steering Wheel

Part Number	Description	Vendor	Qty	Cost
	Computer		1	$6,000 (48 833 SEK)
	Philips 24” with HDMI	Computime Electronics AB	3	$405 (3 297 SEK)
5010620181	Deltaco HDMI-1080F	Dustin	3	$107 (867 SEK)
5010875920	Logitech G920 Driving Force	Dustin	1	$405 (3 295 SEK)
	Material from workshop	XP		$13 (100 SEK)
			Total	$6,973 (56 724 SEK)

A.4 Concept 4 - Head-Mounted Display

Part Number	Description	Vendor	Qty	Cost
	Computer		1	$6,000 (48 833 SEK)
	Philips 24” with HDMI	Computime Electronics AB	1	$135 (1 099 SEK)
5010620181	Deltaco HDMI-1080F	Dustin	1	$32 (294 SEK)
5010875920	Logitech G920 Driving Force	Dustin	1	$405 (3 297 SEK)
5010776904	Creative T3150 Wireless	Dustin	1	$43 (349 SEK)
	Oculus Rift	Oculus	1	$599 (4 875 SEK)
	Material from workshop	XP		$13 (100 SEK)
			Total	$7,231 (58 840 SEK)

A.5 Concept 5 - Three-screen Setup with Rack and Gauge Monitor

Part Number	Description	Vendor	Qty	Cost
B001NT9TK4	Logitech G27 Racing Wheel	Amazon	1	$400 (3 216 SEK)
B00NUS8QQY	VIZIO E500i-B1 50-Inch 1080p Smart LED TV	Planet73(Via Amazon)	3	$1,386 (11 281 SEK)
B003L1ZYYW	10ft HDMI	Amazon	4	$28 (228 SEK)
B003D59FEQ	Acer V223W EJBD 22-Inch Wide LCD Display	Accurate IT Services(Via Amazon)	1	$95 (774 SEK)
47065T101	Clear Anodized Aluminium Single Profile Extrusions	McMaster-Carr	20'	$63 (513 SEK)
	Misc. hardware for Extruded Aluminium	McMaster-Carr		$100 (814 SEK)
	Computer		1	$6,000 (48 833 SEK)
			Total	$8,072 (65 699 SEK)

A.6 Concept 6 - Four-screen Setup with Rack and Gauge Monitor

Part Number	Description	Vendor	Qty	Cost
B001NT9TK4	Logitech G27 Racing Wheel	Amazon	1	$400 (3 256 SEK)
B00NUS8QQY	VIZIO E500i-B1 50-Inch 1080p Smart LED TV	Planet73(Via Amazon)	4	$1824 (14 845 SEK)
B003L1ZYYW	10ft HDMI	Amazon	4	$28 (228 SEK)
B003D59FEQ	Acer V223W EJBD 22-Inch Wide LCD Display	Accurate IT Services(Via Amazon)	1	$95 (773 SEK)
47065T101	Clear Anodized Aluminium Single Profile Extrusions	McMaster-Carr	20'	$63 (513 SEK)
	Misc. hardware for Extruded Aluminium	McMaster-Carr		$100 (814 SEK)
	Computer		1	$6000 (48 833 SEK)
			Total	$8510 (69 262 SEK)

A.7 Three-screen Setup with Rack, Gauge Monitor and Truck Steering Wheel

Part Number	Description	Vendor	Qty	Cost
B001NT9TK4	Logitech G27 Racing Wheel	Amazon	1	$400 (3 216 SEK)
B00NUS8QQY	VIZIO E500i-B1 50-Inch 1080p Smart LED TV	Planet73(Via Amazon)	3	$1,386 (11 281 SEK)
B003L1ZYYW	10ft HDMI	Amazon	4	$28 (228 SEK)
B003D59FEQ	Acer V223W EJBD 22-Inch Wide LCD Display	Accurate IT Services(Via Amazon)	1	$95 (774 SEK)
47065T101	Clear Anodized Aluminium Single Profile Extrusions	McMaster-Carr	20’	$63 (513 SEK)
	Misc. hardware for Extruded Aluminium	McMaster-Carr		$100 (814 SEK)
	Computer		1	$6,000 (48 833 SEK)
	Hardware	Material from workshop		$13 (100 SEK)
			Total	$8,085 (65 799 SEK)

B Budget

B.1 Concept 1 - Five-screen Setup

Categories	CAPSTONE	Dr. Brennan	Combined
Travel	$125	0	$125
Material Cost	$500	$2100	$2600
Poster	$30	0	$30
Cost Contingency	$345	0	$345
Total	$1000	$2100	$3100

B.2 Concept 2 - Projector Based Setup

Categories	CAPSTONE	Dr. Brennan	Combined
Travel	$125	0	$125
Material Cost	$500	$80	$580
Poster	$30	0	$30
Cost Contingency	$345	0	$345
Total	$1000	$80	$1080

B.3 Concept 3 - Three-Screen Setup with Truck Steering Wheel

Categories	CAPSTONE	Dr. Brennan	Combined
Travel	$125	0	$125
Material Cost	$500	$1500	$2000
Poster	$30	0	$30
Cost Contingency	$345	0	$345
Total	$1000	$1500	$2500

B.4 Concept 4 - Head-Mounted Display

Categories	CAPSTONE	Dr. Brennan	Combined
Travel	$125	0	$125
Material Cost	$500	$620	$1120
Poster	$30	0	$30
Cost Contingency	$345	0	$345
Total	$1000	$620	$1620

B.5 Concept 5 - Three-screen Setup with Rack and Gauge Monitor

Categories	CAPSTONE	Dr. Brennan	Combined
Travel	$125	0	$125
Material Cost	$700	$1600	$2300
Poster	$30	0	$30
Cost Contingency	$145	0	$145
Total	$1000	$1600	$2600

B.6 Concept 6 - Four-screen Setup with Rack and Gauge Monitor

Categories	CAPSTONE	Dr. Brennan	Combined
Travel	$125	0	$125
Material Cost	$700	$2100	$2800
Poster	$30	0	$30
Cost Contingency	$145	0	$145
Total	$1000	$2100	$3100

C Risk Plan

Risk	Level	Actions to Minimize	Fall back Strategy
Change in customer specification	Moderate	- Involve customer in process of refining specifications - Work with customer to estimate time and cost penalties of changes	- Add time to schedule for that particular task
Schedule delays	Moderate	- Constantly track project progress - Look for ways to accelerate activities	- Re-allocate resources or staff - More frequent check-up
Product does not function as desired	High	- Test early and often - Consult instructor regularly	- Simplify goal
Customer not satisfied	Moderate	- Understand the customer's needs (voiced and non-voiced) - Deliverables agreement	- Discuss ways to fix the problem
Problems with project group communication	High	- Schedule regular meeting - Well documented progress - Group contract	- Discuss ways to fix the problem
Problems with communication between project group and sponsor/ instructor	Moderate	- Schedule regular meeting - Well documented progress	- Well prepared meetings
Lack of compentence	High	- Thorough background research	- Awareness of limitations - Use help from mentor or other expert
Budget is too limited	Low	- Make a spending plan	- Lower other expenses
Problems with storage of documents	Low	- Save documents often - Use well known and safe document storage	- Saving deliverables on several places
Final report not finished	Moderate	- Follow Gantt-chart - Start in time	- Communication with instructors - Push deadline

D Deliverables Agreement

Learning Factory Industry Project-Deliverables Agreement

Date 03/02/16

Project Title **Driving Simulator Interfaces for Intelligent Vehicle Evaluations**
Sponsor Company **Volvo**

Company Contact **Deborah Thompson** Email Deborah.thompson@volvo.com
Company Contact **Samuel McLaughlin** Email Samuel.mclaughlin@volvo.com
Faculty Coach **Jason Moore** Email jzm14@engr.psu.edu
Faculty Coach **Håkan Richardsson** Email rhakan@student.chalmers.se
Examiner **Bengt Jacobson** Email bengt.jacobson@chalmers.se

Team Name **Volvo 2 - Simulator**
Student Team (primary contact) **Erika Danielsson** erikad@student.chalmers.se
Victoria Johansson vicjo@student.chalmers.se
Julia Eugensson **juliaeu@student.chalmers.se**
Christopher Cinti **ccc5296@psu.edu**
Nicholas Parsons **nap5151@psu.edu**
Matias Rojas **mvr5392@psu.edu**

Problem Statement:

The integration of autonomous systems in heavy duty vehicles and how the drivers will interact in abnormal situations requires investigation before actualization, for example how does the driver react to the warning systems and how does the driver gain control of the situation when being warned.

Deliverables:	Delivery Date
1) Final Report (copies to sponsor, instructor and Learning Factory)	**PSU: 02/05/16** **Chalmers: 17/05/16**
2) Weekly update memos (status reports); delivery method: e-mailed to instructors (Fauculty Coach), examiner and sponsor.	
3) Statement of Work (Project Proposal)	**14/02/16**
4) Detailed Design Specification Report	**28/03/16**
5) Final Project Report (PSU)	**02/05/16**
6) Final Project Report (CTH)	17/05/16

Check below if this project involves:

☐ Non-Disclosure Agreement (attach copy of agreement to this form)
☐ Loan of equipment, materials, documents (see next page)

Signatures: We agree to the deliverables listed above:

Project Sponsor date

Faculty Coach: date

Team Members:

date

date

date

date

date

Deliverables Agreement **– page 2**

Sponsor Supplied Items

In support of this project, we (project sponsor) agree to provide the following equipment, materials, or apparatus by the date listed.

The student team is responsible for returning all loaned items. The instructor reserves the right to withhold a final grade if loaned items are not returned, or if a copy of the final report is not delivered to the sponsor.

Item	Delivery Date	Check one	If Loan, Return Instructions
		☐ donation ☐ loan	
		☐ donation ☐ loan	
		☐ donation ☐ loan	
		☐ donation ☐ loan	

E Group Contract

Team Name: Volvo Driving Simulator

1. Team Members and Contact Info

Christopher Cinti	ccc5296@psu.edu	+1 (570) 592-7466
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Nicholas Parsons	nap5151@psu.edu	+1 (814) 251-4843
Matias Rojas	mvr5392@psu.edu	+1 (412) 518-2384

2. Team Mission Statement
As a team, we plan on solving the problem at hand within the given parameters and in a professional manner. Along the way, we will continue to improve our team skills as well as our overall communication and engineering skills so that we may work even better on any future projects. We plan on making a project with aspiration to receive a higher grade.

3. Meetings
    - Web Meetings over Adobe connect
    - Time: Tuesdays @ 9:00am (US) @15:00 (SWE)
    - Agenda: will be predetermined before each meeting
    - Attendance: mandatory, unless family illness, personal illness, job interview and transportation issue
    - A group member must notify the group of any absence as soon as possible.
    - Information Storage: Google Drive will be the preferred method to store and share information
    - Every meeting should have a note taker, one in each country. These notes shall be uploaded to google drive after the meeting
    - Professionality should be obtained during meetings (no pranks, no swearing, no cell phone)

4. Communication
    - Group chat is prefered over emails or calls
    - Adobe connect or Skype

5. Performance Expectations
    - There must be equal distribution of workload at meetings

- Work must be completed in a timely manner
- Work will be reviewed by entire team before submission

6. Decision Making

   - All decisions will be made as a team during team meetings
   - If a decision is urgent, the team will communicate via skype/adobe connect, group chat and email to determine the outcome
   - If a prior decision needs to be reconsidered it will discussed at team meetings

7. Consequences and Accountability

   - 3 or more unexcused absences at meetings will be reflected on peer evaluation
   - Failure to submit work on a timely manner or contribute equally to the team will also be reflected on the team evaluation

8. Conflict Resolution

   - If a conflict arises, a meeting will take place with the entire team to discuss the matter
   - If the conflict continues to prove to be an issue even after the meeting has taken place, the group will consult our faculty advisor for further assistance

F Gantt Chart

Driving Simulator Interfaces for Intelligent Vehicle Evaluations on Heavy Duty Vehicles

Group: Volvo 2		2016-03-23	
Erika Danielsson			
Victoria Johansson			
Julia Eugensson	Responsibility:	CTH	Chalmers University of Technology
Christopher Cinti		PSU	Pennsylvania State Univeristy
Matias Rojas			
Nicholas Parsons			

Color explanation: Due dates | Meetings | Exam weeks/breaks | Presentations | Working on assignment | Meeting minutes

Dates	11/1 - 17/1	18/1-24/1	25/1-31/1	1/2-7/2	8/2-14/2	15/2-21/2	22/2-28/9	29/2-6/3	7/3-13/3	14/3-20/3
Project week number	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9	week 10
Chalmers students exam week/breaks										
Penn State spring break										
Introduction to project										
Group contract			Tuesday 26/1							
Prepare for first Volvo meeting			Tuesday 26/1							
Deliverables defined					Monday 8/2 (PSU,CTH)					
Proposal outline					Monday 8/2 (PSU,CTH)					
Gantt Chart					Monday 8/2 (PSU,CTH)					
Project proposal/planning report (to intsructors)					Sunday 14/2 (PSU,CTH)					
Arrangements for Proposal presentation to sponsor						Tuesday 16/2				
Project proposal/planning report (to sponsors)							Monday 22/2			
Project proposal presentation to sponsor							Thursday 25/2			
Team Peer evaluation								Monday 29/2		
Deliverables agreement								Tuesday 1/3		
Arrangements for Design specifcation Report/Mid term presentation										
Design specifcation/Mid term report submission to instructors										
Arrangements for Design Specifcation presentation to sponsor										
Design Specification/Mid Term Report Submission to Volvo										
Design Specification/Mid Term Report Presentations										
Final Project presentation										
Penn State Project Showcase										
Project deliverables submission (PENN STATE STUDENTS FINISHED)										
Exit Cross Cultural assesment										
Final project report hand in (Chalmers)										
Opposition hand in (Chalmers)										
Chalmers Final project presentation										
Weekly Reports (due Fridays)		PSU	CTH	PSU	CTH	PSU	CTH	PSU	CTH	PSU
Weelky instructor-students meetings (Tuesdays)										
Meeting minutes			CTH	PSU	CTH	PSU	CTH	PSU	CTH	PSU

Dates	21/3-27/3	28/3-3/4	4/4-10/4	11/4-17/4	18/4-24/4	25/4-1/5	2/5-8/5	9/5-15/5	16/5-22/5	23/5-29/5
Project week number	week 11	week 12	week 13	week 14	week 15	week 16	week 17	week 18	week 19	week 20
Chalmers students exam week/breaks										
Penn State spring break										
Introduction to project										
Group contract										
Prepare for first Volvo meeting										
Deliverables defined										
Proposal outline										
Gantt Chart										
Project proposal/planning report (to intsructors)										
Arrangements for Proposal presentation to sponsor										
Project proposal/planning report (to sponsors)										
Project proposal presentation to sponsor										
Team Peer evaluation										
Deliverables agreement										
Arrangements for Design specifcation Report/Mid term presentation	Tuesday 22/3									
Design specifcation/Mid term report submission to instructors	Wednesday 23/3									
Arrangements for Design Specifcation presentation to sponsor	Thursday 24/3									
Design Specification/Mid Term Report Submission to Volvo		Monday 28/3								
Design Specification/Mid Term Report Presentations		Thursday 31/3								
Final Project presentation						Tuesday 26/4				
Penn State Project Showcase						Thursday 28/4				
Project deliverables submission (PENN STATE STUDENTS FINISHED)							Monday 2/5			
Exit Cross Cultural assesment							Tuesday 3/5			
Final project report hand in (Chalmers)									Tuesday 17/5	
Opposition hand in (Chalmers)										Tuesday 24/5
Chalmers Final project presentation										Thursday 26/5
Weekly Reports (due Fridays)	CTH			CTH	CTH	PSU				
Weelky instructor-students meetings (Tuesdays)										
Meeting minutes	CTH									

G Pictures

Figure 25: Picture of Front.

Figure 26: Picture of front side with part of the rigid.

Figure 27: Picture of the three-screen setup

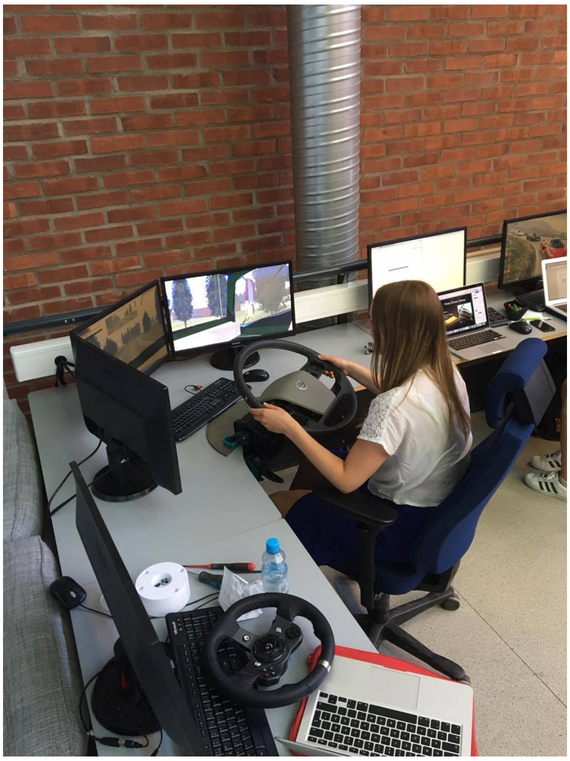


Figure 28: Picture of test person driving the simulator

Figure 29: Picture of the pedals in use

Figure 30: Picture of the steering wheel setup mounted to a table

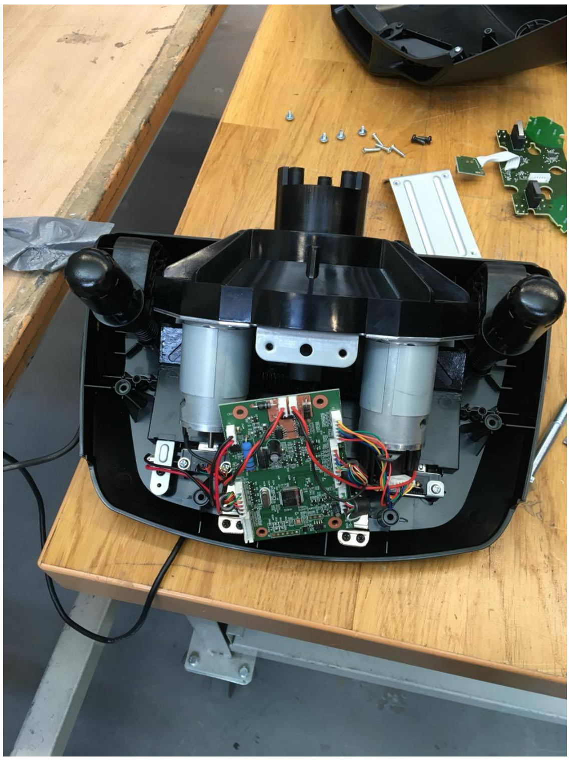


Figure 31: The steering wheel engine case opened. The circuit board in the top right corner was located in the gaming steering wheel and had to be connected to the circuit board in the engine.

Figure 32: Picture of removal of wires.

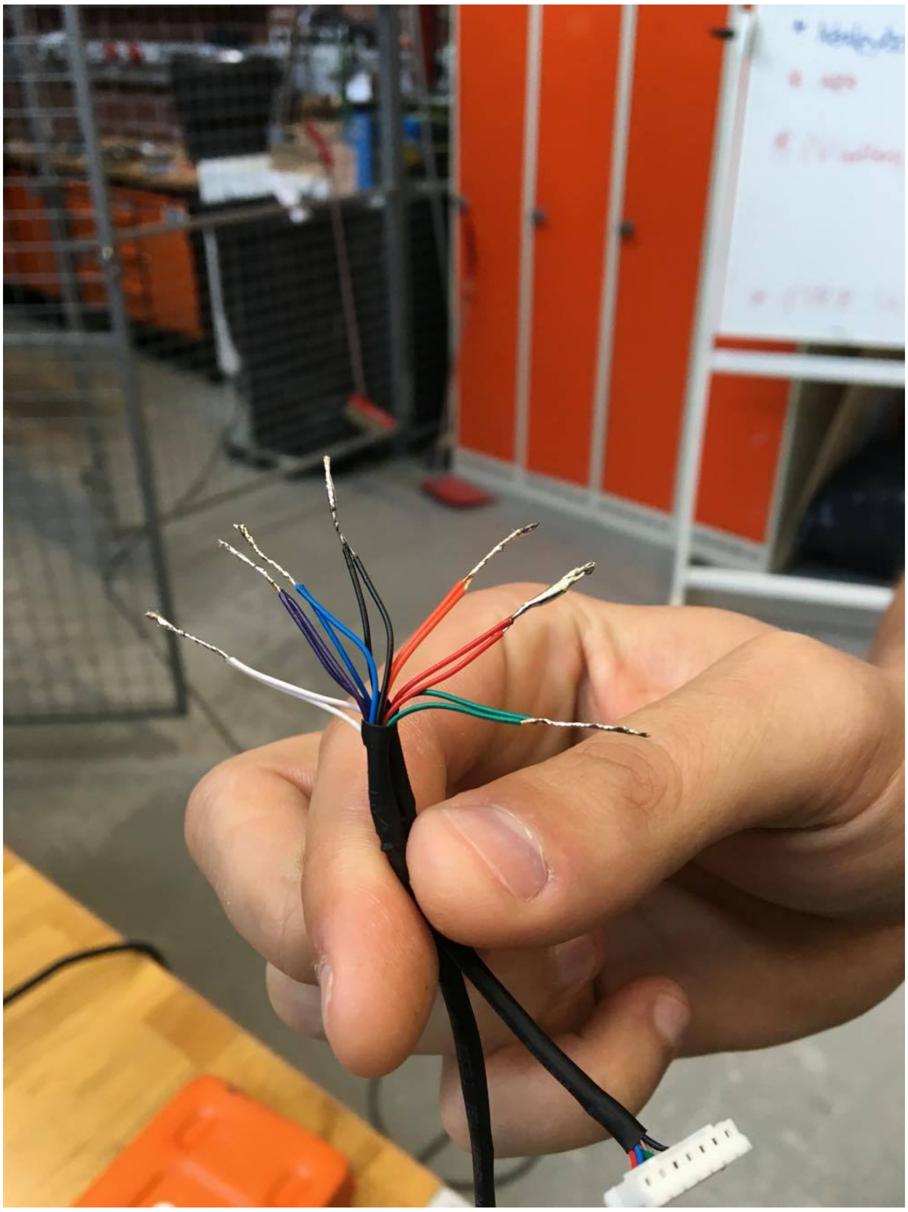
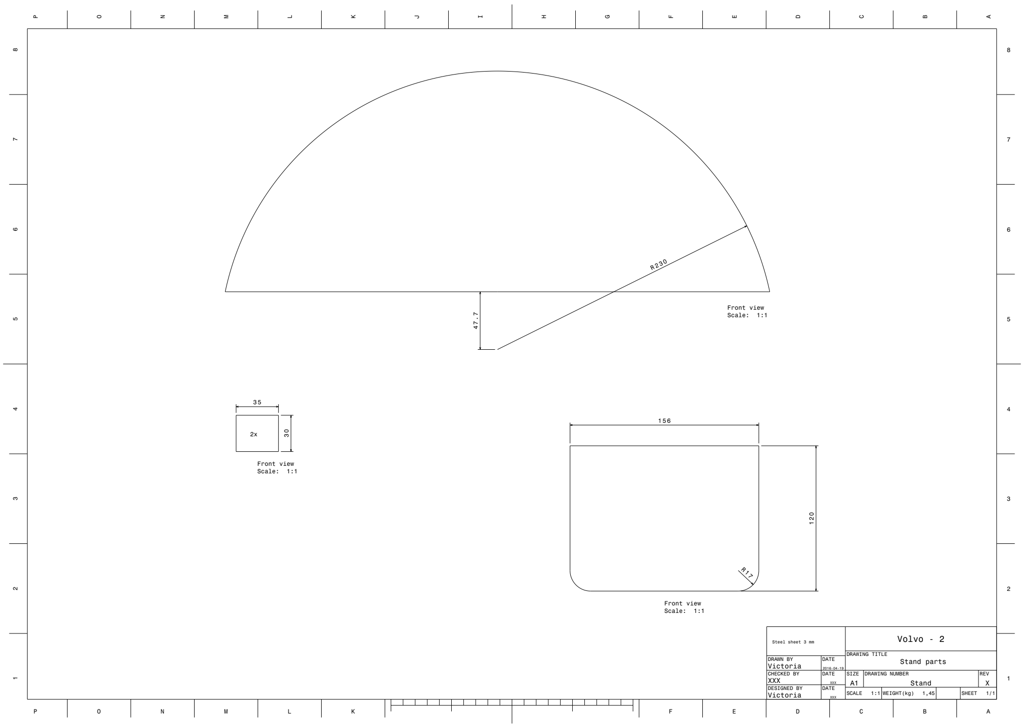
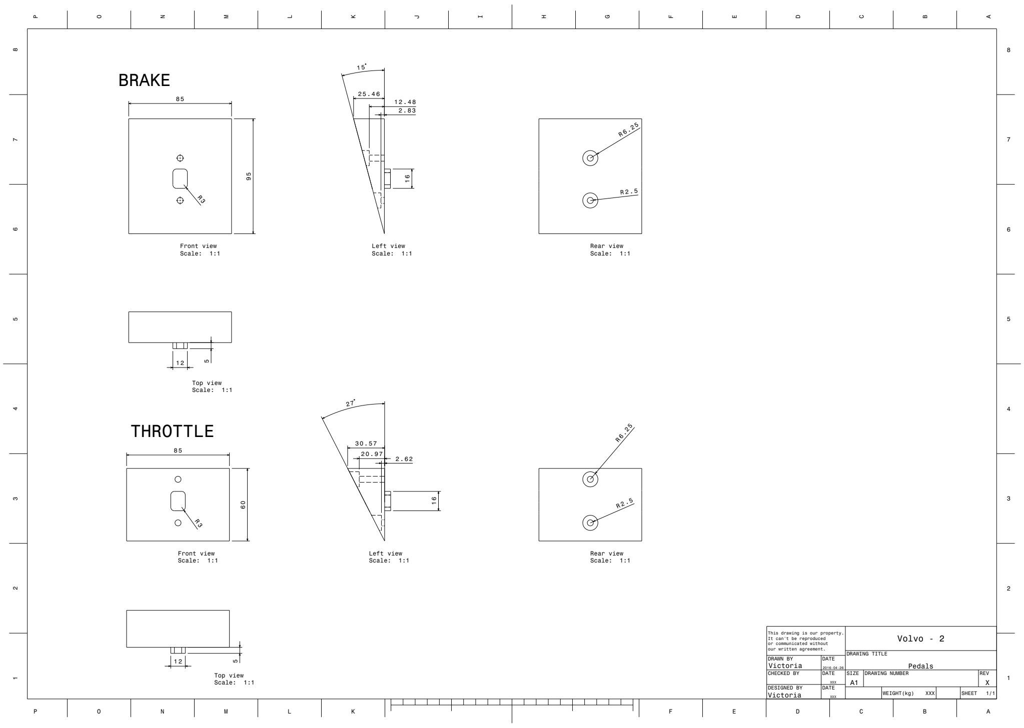


Figure 33: The wires soldered together

Figure 34: Picture of the mounted circuit board sustainer in different angles

H Drawings


R230
47.7
Front view
Scale: 1:1
35
30
2x
Front view
Scale: 1:1
156
120
R17
Front view
Scale: 1:1
Steel sheet 3 mm
Volvo - 2
DRAWING TITLE
Stand parts
DRAWN BY
Victoria
DATE
2016-04-19
CHECKED BY
XXX
DESIGNED BY
Victoria
SIZE
A1
DRAWING NUMBER
Stand
REV
X
SCALE 1:1
WEIGHT(kg) 1,45
SHEET 1/1


BRAKE
85
95
Front view
Scale: 1:1
15°
25.46
12.48
2.83
16
Left view
Scale: 1:1
R6.25
R2.5
Rear view
Scale: 1:1
12
5
Top view
Scale: 1:1
THROTTLE
85
60
Front view
Scale: 1:1
27°
30.57
20.97
2.62
16
Left view
Scale: 1:1
R6.25
R2.5
Rear view
Scale: 1:1
12
5
Top view
Scale: 1:1
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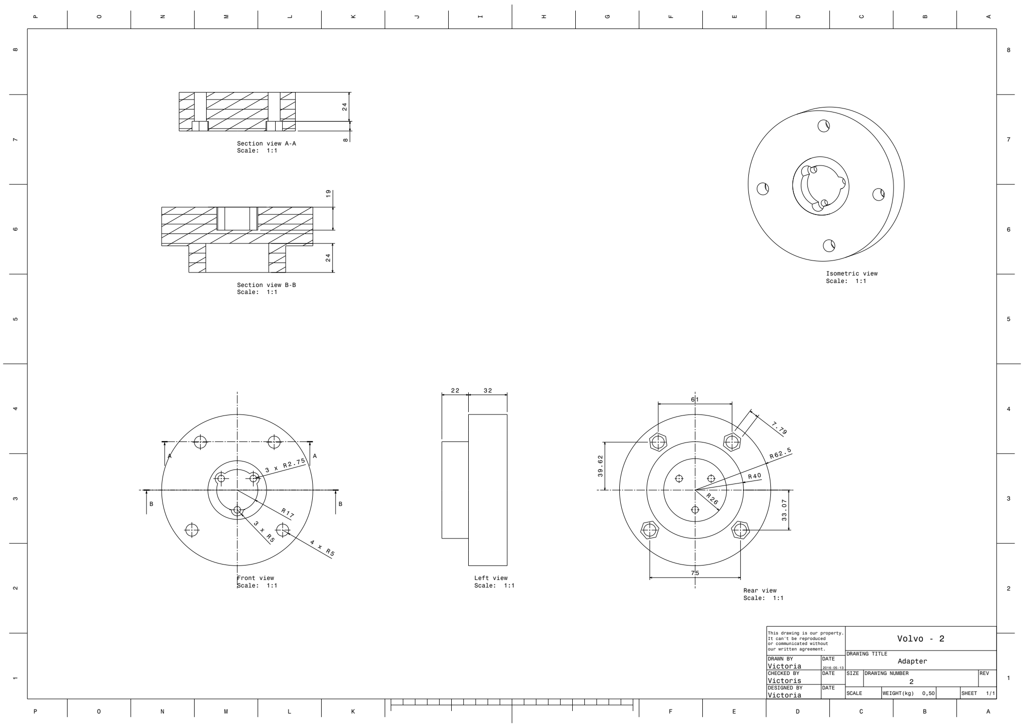
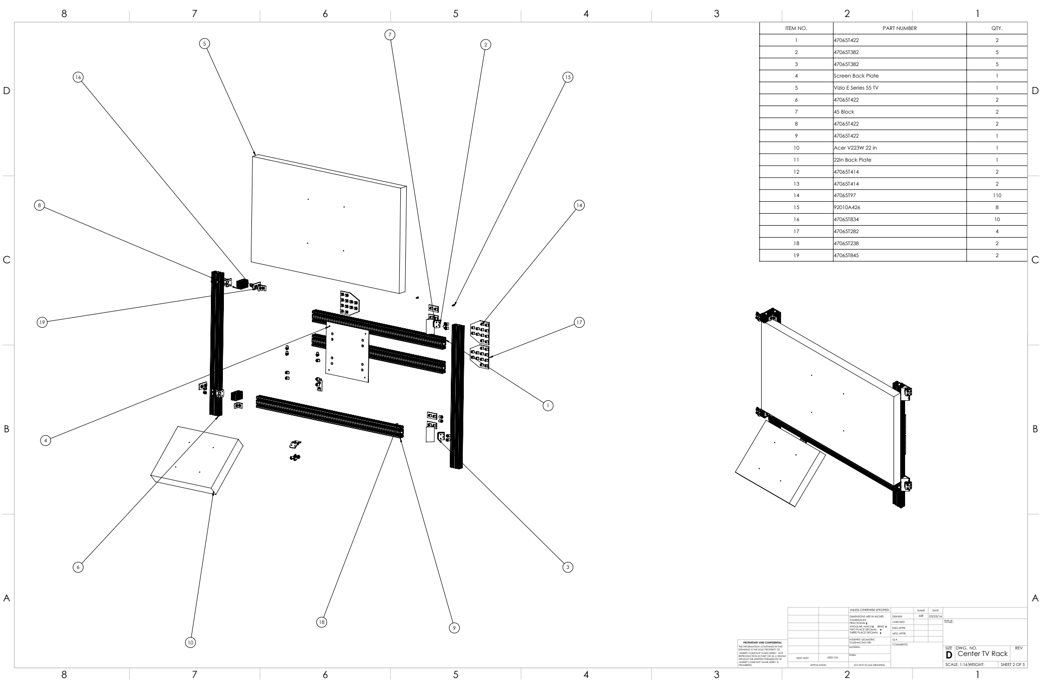
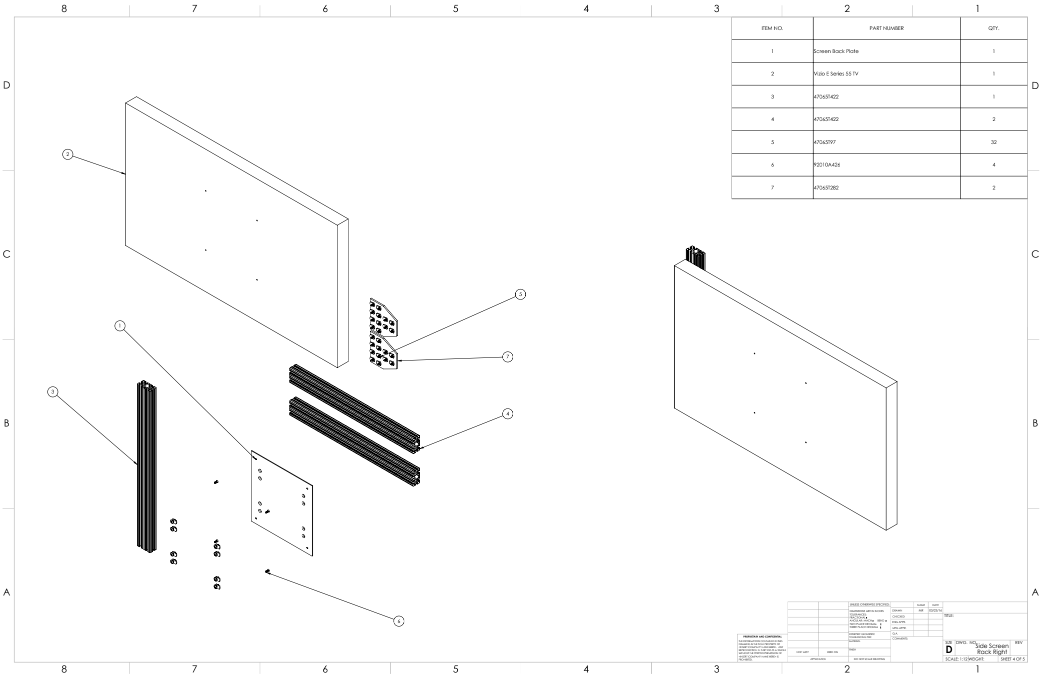
or communicated without
our written agreement.
Volvo - 2
DRAWING TITLE
Pedals
DRAWN BY
Victoria
DATE
2016-04-26
CHECKED BY
DESIGNED BY
Victoria
SIZE
A1
DRAWING NUMBER
REV
X
WEIGHT(kg) XXX
SHEET 1/1

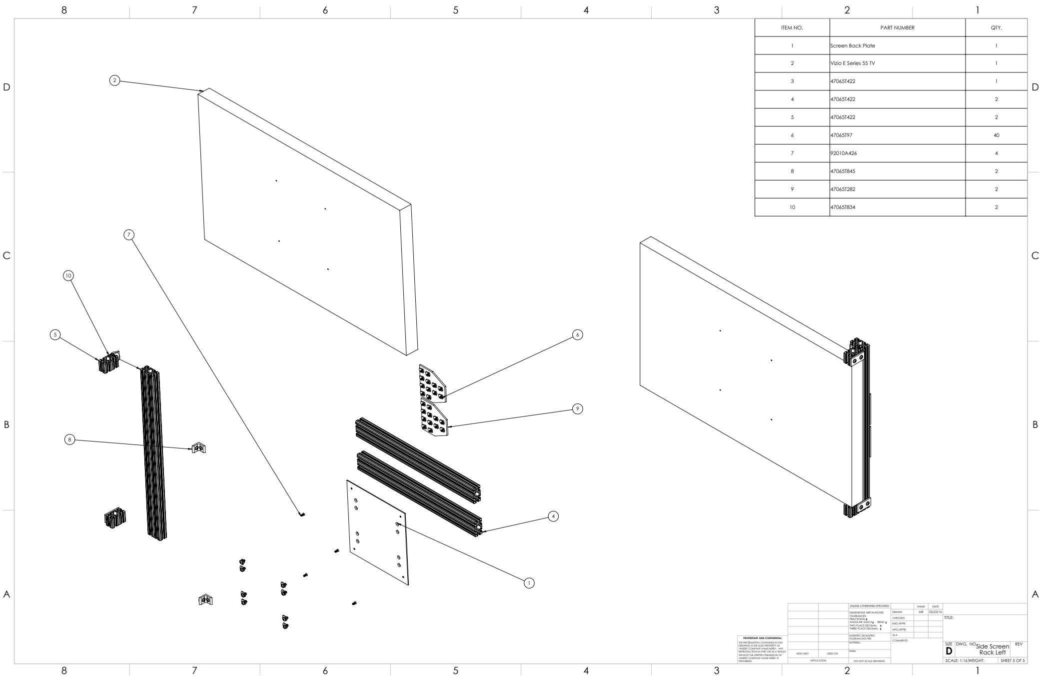




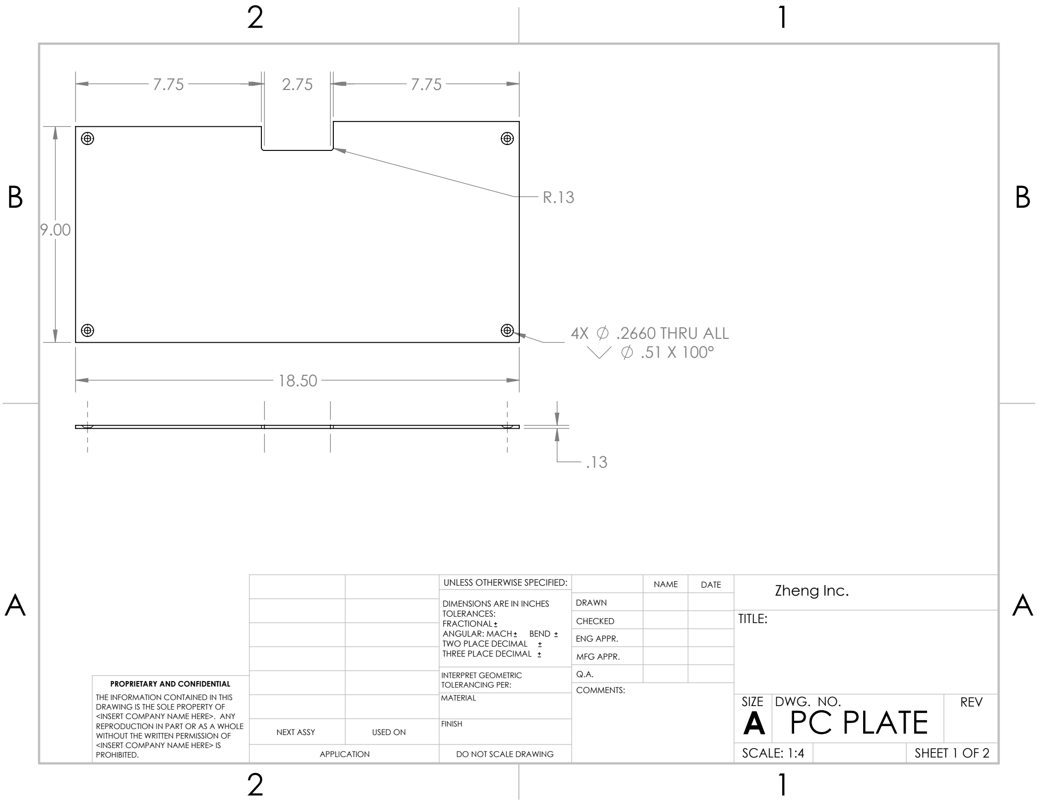
ITEM NO.	PART NUMBER	QTY.
1	47065T422	2
2	47065T382	5
3	47065T382	5
4	Screen Back Plate	1
5	Vizio E Series 55 TV	1
6	47065T422	2
7	45 Block	2
8	47065T422	2
9	47065T422	1
10	Acer V223W 22 in	1
11	22in Back Plate	1
12	47065T414	2
13	47065T414	2
14	47065T97	110
15	92010A426	8
16	47065T834	10
17	47065T282	4
18	47065T238	2
19	47065T845	2



ITEM NO.	PART NUMBER	QTY.
1	Screen Back Plate	1
2	Vizio E Series 55 TV	1
3	47065T422	1
4	47065T422	2
5	47065T97	32
6	92010A426	4
7	47065T282	2



ITEM NO.	PART NUMBER	QTY.
1	Screen Back Plate	1
2	Vizio E Series 55 TV	1
3	47065T422	1
4	47065T422	2
5	47065T422	2
6	47065T97	40
7	92010A426	4
8	47065T845	2
9	47065T282	2
10	47065T834	2


7.75
2.75
7.75
R.13
9.00
4X ∅ .2660 THRU ALL
∅ .51 X 100°
18.50
.13
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Zheng Inc.
TITLE:
SIZE
A
DWG. NO.
PC PLATE
REV
SCALE: 1:4
SHEET 1 OF 2
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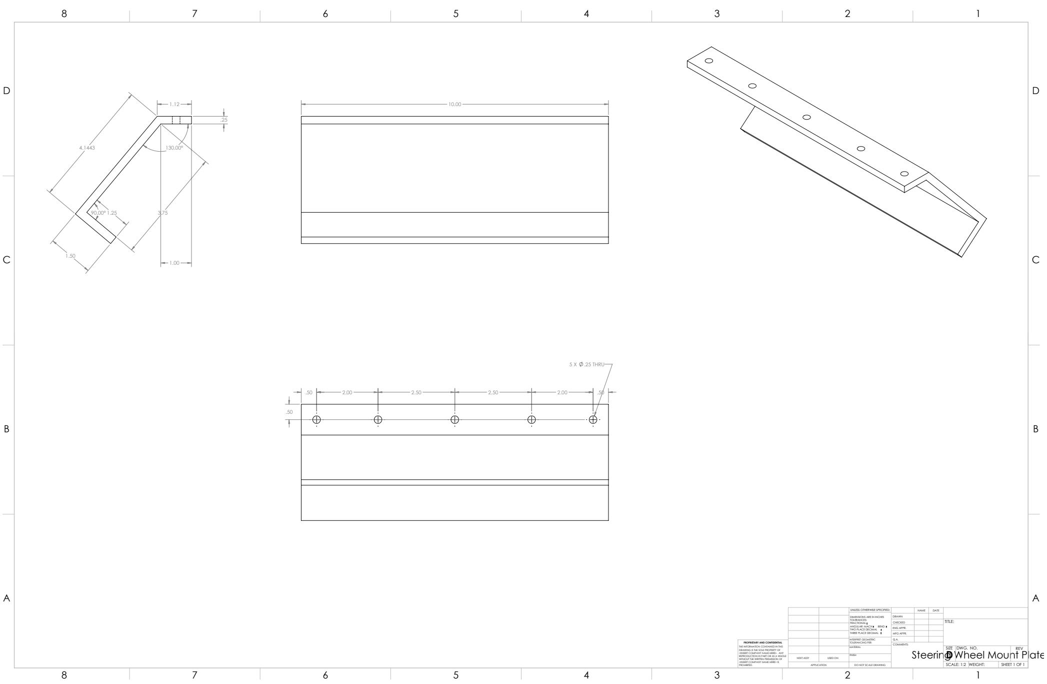
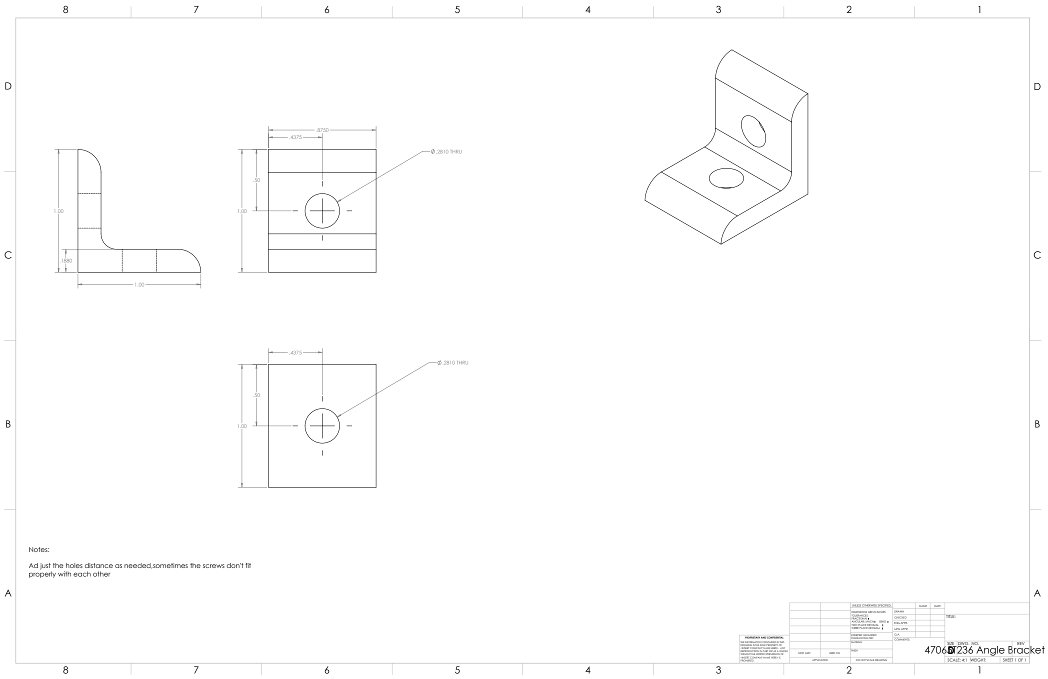
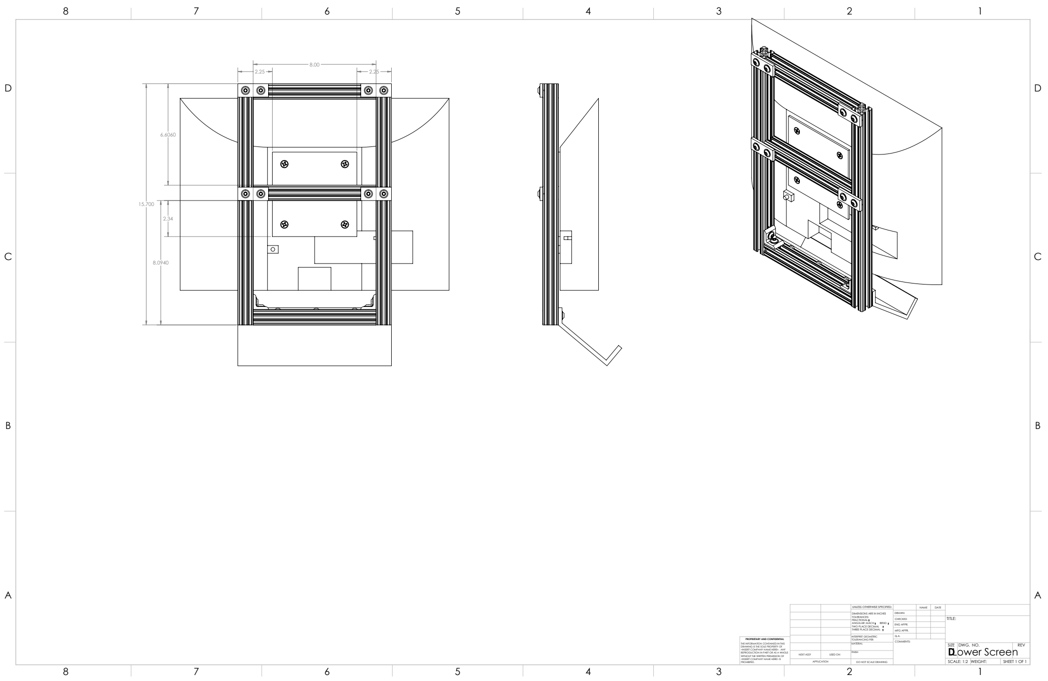
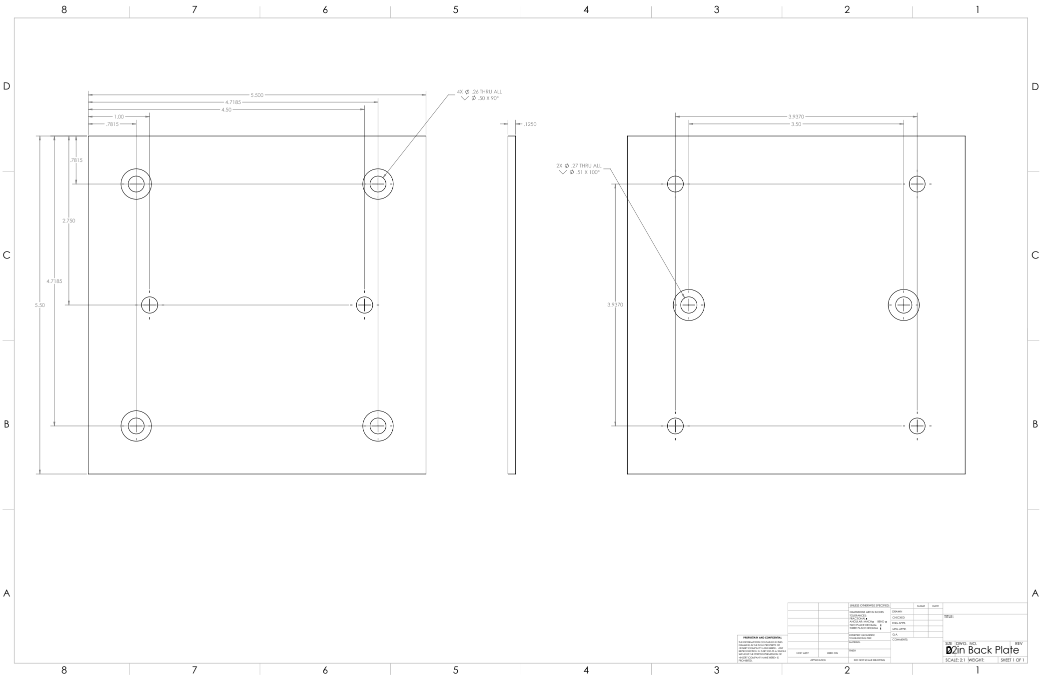

Steering Wheel Mount Plate


Notes:
Ad just the holes distance as needed,sometimes the screws don't fit properly with each other
Ø .2810 THRU
SIZE D
DWG. NO.
47065T236 Angle Bracket
SCALE: 4:1
SHEET 1 OF 1


SIZE D
DWG. NO.
Lower Screen
SCALE: 1:2
SHEET 1 OF 1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NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
DWG. NO.
REV
D
2in Back Plate
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1