



# Design Test Rig for Trailer Connections

A Structured Approach to Developing a  
Customizable Test Rig for Trailer Connector  
Verification in Heavy Vehicle Production.

Master's thesis in Industrial and Materials Science

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Master's thesis 2025

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*In collaboration with Volvo Group*

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# Abstract

Reliable connections between truck and trailer are crucial for maintaining quality and safety standards within truck production. However, the current testing equipment is simplistic and lacks reliability especially when testing nonstandard trucks. This can result in potential production delays and quality issues. This thesis conducted in collaboration with Volvo Trucks, aims to address these issues by developing a specialized, modular test rig specifically for verifying trailer and bodybuilder connectors within Volvo's Customer Adaptations.

To identify user needs and market requirements. Stakeholder analyses, structured interviews and observations were performed. The gathered information from these segments formed a basis for requirements and a detailed development phase. Multiple design concepts were evaluated using elimination and Pugh matrices. Finally resulting in the selection of a modular and flexible solution utilizing Siemens PLC and HMI technology. The developed test rig incorporates robust electrical components and effectively supports all connector types such as VBG, NATO 12-pin, and ISO 12098. The rig also has additional capacity for future integration of pneumatic and hydraulic testing modules. The outcome is a well-documented, scalable concept designed for widespread implementation across Volvo's production facilities, significantly enhancing operational efficiency and overall product quality.

## **Key words**

Test rig, trailer connections, PLC, Siemens, HMI, modular design

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Axel Malmberg



Yan Gu



# List of Acronyms

<b>PLC</b>	Programmable Logic Controller
<b>HMI</b>	Human Machine Interface
<b>CA</b>	Customer Adaptation
<b>DC</b>	Direct Current
<b>TIA Portal</b>	Totally Integrated Automation Portal
<b>IP</b>	Ingress Protection
<b>ISO</b>	International Organization for Standardization.
<b>NATO</b>	North Atlantic Treaty Organization
<b>ST</b>	Structured Text
<b>LD</b>	Ladder Diagram
<b>FBD</b>	Function Block Diagram
<b>PDS</b>	Product Design Specification
<b>REBA</b>	Rapid Entire Body Assessment



# Table of Contents

- 1. INTRODUCTION .....1**
  - 1.1. BACKGROUND.....2
  - 1.2. AIM.....2
  - 1.3. LIMITATIONS .....3
  - 1.4. RESEARCH QUESTIONS.....3
  - 1.5. COMPANY DESCRIPTION .....4
    - 1.5.1. Volvo Group .....4
    - 1.5.2. Customer Adaptation (CA) .....4
- 2. THEORETICAL FRAMEWORK.....5**
  - 2.1. CONTROL SYSTEMS .....6
    - 2.1.1. PLC.....6
    - 2.1.2. HMI.....6
    - 2.1.3. PROFINET .....7
    - 2.1.4. Siemens TIA Portal.....7
    - 2.1.5. PLC Programming Languages & IEC 61131-3 Standard .....8
  - 2.2. ELECTRONICS .....9
    - 2.2.1. DC/DC Converter .....9
    - 2.2.2. Galvanic Isolation.....9
    - 2.2.3. Optocoupler.....10
    - 2.2.4. Power Resistor .....10
  - 2.3. MAINTENANCE .....11
    - 2.3.1. Preventive Maintenance.....11
    - 2.3.2. Corrective Maintenance.....11
  - 2.4. TRAILER CONNECTORS .....12
    - 2.4.1. VBG 14/17/22 .....12
    - 2.4.2. ISO 12098 15-Pin Connector .....13
    - 2.4.3. NATO 12-Pin Connector.....14
    - 2.4.4. ISO 1185 / ISO 3731 Connector .....15
  - 2.5. ERGONOMICS .....16
    - 2.5.1. Physical Ergonomics .....16
    - 2.5.2. Cognitive Ergonomics.....16
    - 2.5.3. REBA.....16
  - 2.6. USER INTERFACE DESIGN PRINCIPLE.....17
  - 2.7. M5 STACK.....18
- 3. METHODOLOGY .....19**
  - 3.1. PRODUCT DEVELOPMENT PROCESS.....20
  - 3.2. RESEARCH APPROACH .....22
    - 3.2.1. Literature Search.....23
    - 3.2.2. Stakeholder Identification .....23
    - 3.2.3. Observations.....24
    - 3.2.4. Interviews .....25
  - 3.3. MARKET ANALYSIS .....26
    - 3.3.1. Bench Marking .....26
  - 3.4. REQUIREMENTS IDENTIFICATION .....27
    - 3.4.1. Customer Needs List .....27
    - 3.4.2. Technical Requirements List .....27
  - 3.5. CONCEPT GENERATION .....28
    - 3.5.1. Idea Generation.....28

3.6.	CONCEPT EVALUATION .....	29
3.6.1.	Elimination Matrix.....	29
3.6.2.	Pugh Matrix .....	30
3.6.3.	Low Fidelity Prototype.....	30
<b>4.</b>	<b>IDENTIFICATION .....</b>	<b>31</b>
4.1.	MARKET RESEARCH .....	32
4.1.1.	Trailer Connectors.....	32
4.1.2.	Benchmarking Within Volvos Assortment .....	34
4.1.3.	Benchmarking Outside Volvos Assortment .....	36
4.2.	IDENTIFIED STAKEHOLDERS & REQUIREMENTS .....	38
4.2.1.	Stakeholder Identification.....	38
4.2.2.	Requirements .....	39
4.3.	INTERVIEWS & OBSERVATIONS.....	41
<b>5.</b>	<b>CONCEPT DEVELOPMENT.....</b>	<b>43</b>
5.1.	BRAINSTORMING .....	44
5.2.	ELIMINATION MATRIX .....	45
5.2.1.	Vagnen .....	46
5.2.2.	Bärbar.....	47
5.2.3.	Trådlös.....	48
5.2.4.	Tunnkabel .....	48
5.3.	PUGH MATRIX .....	49
<b>6.</b>	<b>TECHNICAL SOLUTIONS.....</b>	<b>51</b>
6.1.	SYSTEM SOLUTION .....	52
6.2.	COMPONENT SELECTION .....	56
6.2.1.	PLC.....	56
6.2.2.	HMI.....	58
6.2.3.	Optocoupler.....	59
6.2.4.	Power Supply .....	60
6.2.5.	Fuse Holder .....	60
6.2.6.	Load Resistor .....	60
6.3.	PLC PROGRAMMING.....	61
6.4.	HMI DESIGN – INTERACTION.....	62
6.4.1.	Home Screen .....	62
6.4.2.	Signal Screen .....	63
6.4.3.	Chanel Screen.....	65
6.4.4.	Non-User-Focused Screens .....	66
6.5.	LOW FIDELITY PROTOTYPE .....	69
6.6.	MAINTENANCE .....	71
<b>7.</b>	<b>FINAL PRODUCT.....</b>	<b>72</b>
7.1.	DESCRIPTION .....	73
7.2.	PRELIMINARY TESTING .....	76
7.2.1.	Functional Verification.....	76
7.2.2.	Load and Stress Test.....	76
7.2.3.	Field Test with VBG 14 In Real Environment .....	76
7.2.4.	REBA.....	77
<b>8.</b>	<b>DISCUSSION.....</b>	<b>78</b>
8.1.	INTERPRETATION OF RESULTS .....	79
8.2.	FEEDBACK FROM USERS .....	80
8.3.	WEAKNESSES AND UNCERTAINTIES.....	81
8.4.	FURTHER WORK .....	82
8.4.1.	Integration of Hydraulic and Pneumatic Testing .....	82
8.4.2.	Wireless or Remote Interface .....	82

8.4.3.	Logging of Results and Traceability of Data .....	82
8.4.4.	Extended Load Tests and Environmental Durability .....	82
<b>9.</b>	<b>CONCLUSION .....</b>	<b>83</b>
<b>10.</b>	<b>REFERENCES .....</b>	<b>86</b>



# 1. Introduction

This chapter describes the premise of this thesis and presents the context, problems and motives for creating a new trailer coupling test rig. It lays the groundwork by describing the priority of the problem within Volvo Trucks' customization division and defines the scope and purpose of this project.

# 1.1. Background

Ensuring reliable connections between a truck and its trailer is essential for both quality and safety at the end of producing a truck. However, keeping full-size trailers in the factory for testing is space-inefficient and time-consuming. Moreover, trailers vary widely due to the different functions and customizations requested by customers, making in-line testing even more complex. To address challenges, a more efficient approach is needed one that simulates the functions of a trailer without requiring the physical presence of an actual trailer. This thesis project focuses on designing a test rig to verify the functionality of trailer and body builder connectors in Volvo Trucks before delivery, with particular attention to the Customer Adaptations area. This section of the manufacturing process requires a tool capable of handling a broad range of specialized features. While a tool already exists at the end of the line, it cannot accommodate the verification of extra functions often demanded in Customer Adaptations. Therefore, a separate test rig is needed to meet these specialized requirements. The goal is to enhance product quality and streamline the verification process by developing a flexible, accurate, and user-friendly testing solution suitable for the diverse range of heavy trucks produced at the plant.

# 1.2. Aim

The aim of the project will include the following key steps: identifying users' stakeholders to gather their requirements, defining detailed product specifications and applying a structured concept selection methodology to design the test rig. Following the design phase a prototype of the test rig will be built and its functionality verified in collaboration with stakeholders. To make the project possible the work will involve the use of PLCs. This includes programming of PLCs and HMIs. The project will also require prototyping, ideation, and analysis of the existing production and test environment. To further achieve a thorough understanding there will be discussions with stakeholders. Finally, the complete design will be documented in Volvo's database to support future implementation and potential scaling.

## 1.3. Limitations

The project is constrained by several factors that must be effectively managed to ensure project completion. These factors include, for example, the allocated budget where it requires balancing cost efficiency with high quality design and performance. Furthermore, the project is constrained by the delivery time which depends on lead times for components and equipment from external suppliers.

The overall project timeline should be kept, which means that strict deadlines must be followed for the design, prototype, and implementation phases. Finally, the project must consider limitations in data sharing protocols and follow cybersecurity measures when integrating with existing production systems.

## 1.4. Research Questions

This project addresses the challenge of designing a test rig that aligns with the aims outlined in Section 1.2. To refine the focus, the following questions and hypotheses will guide the investigation:

- Which electrical components should the test rig verify and what is the optimal number of components to be tested simultaneously to balance efficiency and accuracy?
- Should the test rig verify all key systems, including electrical, hydraulic, and pneumatic systems? And in what ways can the test rig enhance daily production efficiency?
- How should the test rig interface with Volvo's existing production systems to ensure seamless integration? And how can the test rig embody Industry 4.0 principles, such as smart manufacturing?
- What design elements will ensure the test rig is as user friendly as possible for technicians and operators? And how can the rig accommodate different user groups (e.g., technicians, operators, and maintenance engineers)?
- What are the optimal design parameters to guarantee high-quality verification of truck components? And can the design be standardized for scalability across various Volvo plants and workshops?

## **1.5. Company Description**

This section introduces the industrial partner, and the specific division involved in the project.

### **1.5.1. Volvo Group**

The project is conducted in collaboration with Volvo Trucks in Gothenburg, Sweden. Volvo Trucks is part of the larger company Volvo Group. The Volvo Group's core areas include trucks, buses, construction equipment, and marine & industrial engines. Volvo trucks focuses is on delivering innovative transportation solutions that emphasize safety, quality, and environmental care [1].

Traditionally, Volvo Trucks has catered to the long-haul and heavy-duty trucking sector. In recent years, however, they have been investigating how their technology and expertise can be applied to new applications and industries.

### **1.5.2. Customer Adaptation (CA)**

Customer Adaptation (CA) is a section within Volvo Tuve's factory that will be the focus for our project. This part of the plant focuses on constructing trucks with special demands and additions that cannot be integrated into the regular production line. These may include extra functions or parts that are not common enough for standard assembly. Customers requiring CA support range from military and firefighting services with specialized features to private buyers seeking unique additions. This part of the manufacturing plant typically handles lower production volumes and has longer lead times. Up to 12 stations can be allocated for different customer projects simultaneously, although not all stations are always in use.



## 2. Theoretical Framework

*This section reviews the main theories, technological advances and standards that are the basis for test rig design. It covers control systems, communication protocols, electrical components, ergonomics and maintenance. All the necessary technical groundwork to make informed design decisions.*

## **2.1. Control Systems**

Modern test rigs rely on stable and responsive control systems to handle inputs, perform tests and provide accurate data output. This section describes the main components and standards used in the rig control system.

### **2.1.1. PLC**

A programmable logic controller (PLC) is a computer system specially designed for the automation and control of industrial processes. PLC takes inputs from for example sensors and switches and executes the predefined program for the control of the outputs like the motor etc. Every PLC system has main components like the central processing unit (CPU) responsible for executing the program, the memory system where the data and the program is storages and the input/output modules known as the I/O and serves the purpose of being the interface for the control system and the environment. PLC is programmed by using the standard languages under the guidelines provided by the IEC-61131-3 standard and is very flexible as the programs can easily be modified. PLC is also reliable, being designed for the tough environment of industries and possessing good real-time capability for the control of the processes without the loss of even one cycle. Modern PLCs typically support network communication via Ethernet connections, enabling cloud connectivity, remote monitoring, and real-time data analytics. These capabilities enhance their effectiveness in optimizing industrial processes [2].

### **2.1.2. HMI**

The HMI (Human-Machine Interface) is one of the basic components of industrial automation and forms the bridge between machines or systems and the operator. It allows the operator to easily monitor, control and communicate with PLCs and other computerized equipment. HMIs typically consist of graphical and touch screens that process digital and analog input signals and deliver them as visualizations that the operator can understand easily [3].

HMI systems support various functions such as displaying real-time data, alarm management, logging of operational data and diagnostics of the system. They communicate via various communication protocols such as Modbus, Profibus and Ethernet/IP for data exchange with PLCs and other equipment. By improving usability, minimizing operator errors, and providing feedback on system performance, HMIs make a significant contribution to optimizing industrial automation [3].

### 2.1.3. PROFINET

PROFINET is the industrial communication standard over Ethernet for real-time data exchange between field devices, controllers and other industrial devices such as sensors, drives, and robots. It builds on the existing Ethernet infrastructure and addresses the need for deterministic communication at field level and greater connectivity at enterprise level. Unlike standard office Ethernet, PROFINET is designed to handle real-time data exchange, device diagnostics and robust security features which allow PROFINET to operate reliably in the harsh industrial environment while delivering high-speed operation and minimal latency [4].

### 2.1.4. Siemens TIA Portal

The Totally Integrated Automation (TIA) Portal is Siemens engineering software for the configuration and programming of the automation systems. TIA Portal integrates the PLCs, the HMIs, motor drives, and the network setups into one environment. TIA Portal has the features like the seamless engineering, the intuitive interface, and the data handling from one place. TIA Portal allows the configuration of the hardware, the logic programming, the screen design for the HMI, and the handling of the networks easily. TIA Portal supports the drag-and-drop operation, the real-time diagnostics, and the handling of the massive libraries, thus automating the engineering faster and easier. TIA Portal is heavily utilized for the industrial automation as shown in Figure 1. TIA Portal improves the efficiency by reducing the engineering time and delivering the best possible integration for the systems [5].

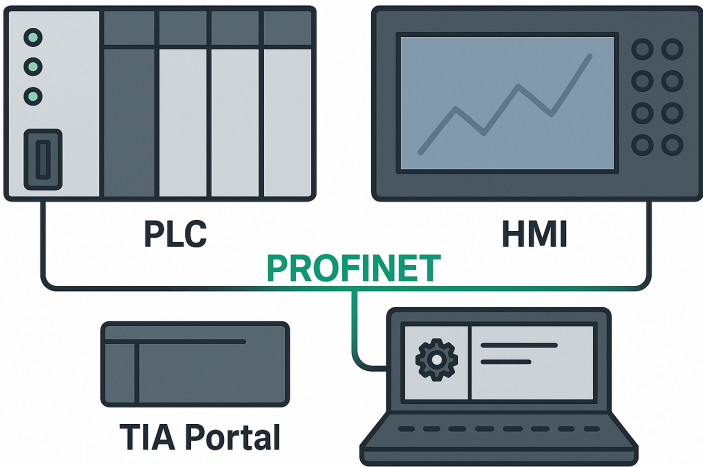


Figure 1 Plc. Hmi, Tia Portal.

### 2.1.5. PLC Programming Languages & IEC 61131-3 Standard

The IEC 61131-3 standard defines five programming languages for PLCs, categorized into textual and graphical (see Figure 2). The textual languages include Instruction List (IL) which is an outdated and low-level assembler-like language, and Structured Text (ST) which is a high-level language suitable for complex control algorithms. Graphical languages include Ladder Diagram (LD) which is an electrical relay logic-like language widely used because it is intuitive, and Function Block Diagram (FBD) which represents logic through connected blocks and is suitable for modular and reusable programming. The Sequential Function Chart (SFC) is also a structured method for representing sequences of actions and operations. The IEC 61131-3 standard also identifies a programming model with predefined and user-defined types, Program Organization Units (POUs) such as functions, function blocks and programs, and execution control elements such as tasks and configurations [6].

## PLC Programming Languages

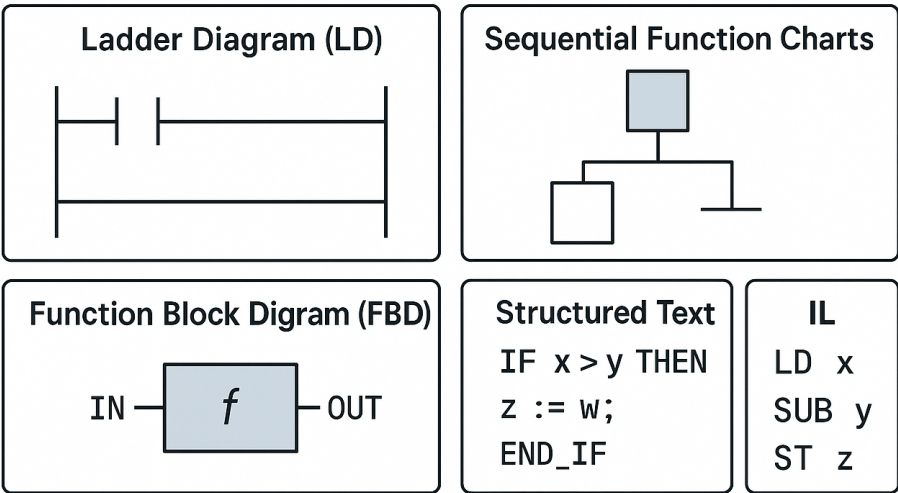


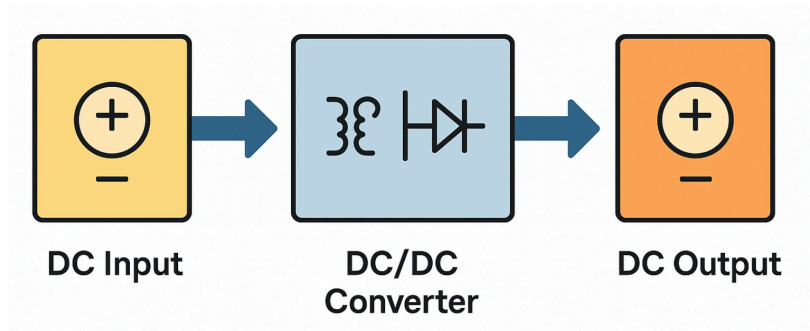
Figure 2 PLC Programming Languages.

## 2.2. Electronics

This section describes the core electronic components critical for signal processing, isolation and voltage conversion in the test rig

### 2.2.1. DC/DC Converter

A DC-DC converter often referred to as a switched regulator or simply converter, is a device that takes direct current (DC) as input and provides regulated direct current as output (see Figure 3). The output voltage can be higher than, lower than or isolated from the input voltage depending on the type of converter used. DC-DC converters are used in applications where different voltages are required for different components of an electrical circuit/system [7].



*Figure 3 DC/DC Converter*

### 2.2.2. Galvanic Isolation

Galvanic isolation is a technique that prevents electrical current from passing between different sections of an electrical system while still allowing the transfer of energy and information. Galvanic isolation is necessary for safety, noise elimination and to avoid ground loops in circuits. There are several techniques for galvanic isolation, capacitance, utilizing class Y capacitors that block DC current and allow AC signals to pass through. Induction, using electromagnetic fields to transfer energy without physical contact Also light using optoisolators with LEDs and photodetectors to let signals through without electrical contact. Some key applications are DC-DC converters using induction for isolation and voltage step-up, relays for controlling circuits without direct contact, opto-isolators for isolating low-voltage circuits, and isolated CAN transceivers for safe transmission of data between high- and low-voltage subsystems [8].

### 2.2.3. Optocoupler

An optocoupler is also known as an optoisolator or photocoupler. It is an electrical component that provides electrical isolation of different sections of a circuit but with transmission of the signal by light. It consists of a light-emitting diode as input and a light-sensitive component such as a phototransistor, photodiode or photoresistor as output (see Figure 4). The light from the LED stimulates the photosensitive component so that current flows through it, but with the input and output circuits electrically isolated [7].

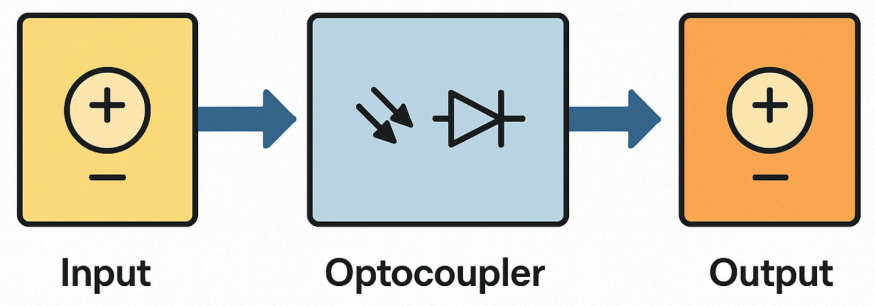


Figure 4 Optocoupler

### 2.2.4. Power Resistor

A power resistor as shown in Figure 5 is a type of resistor designed to handle and dissipate quite large amounts of electrical power. Power resistors tend to be larger so that they can dissipate heat more easily. Power resistors can use materials and construction techniques that increase their resistance to thermal stress. To facilitate better heat management, power resistors may be provided with cement coatings, aluminum housings or heat sink mounting structures [7].

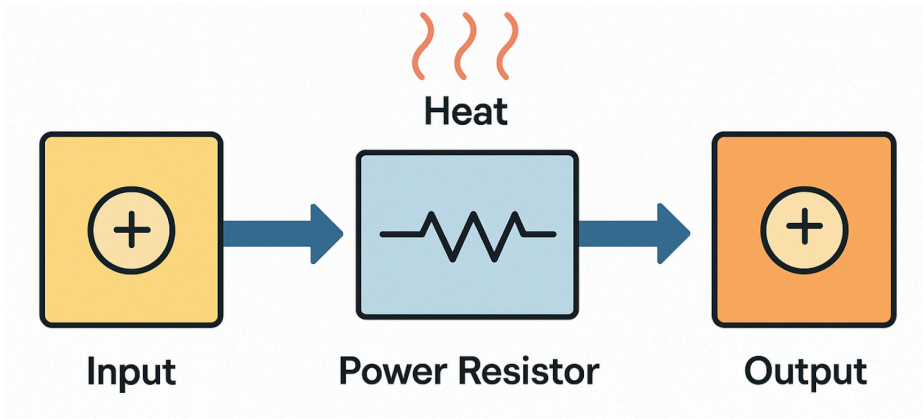


Figure 5 Power Resistor

## **2.3. Maintenance**

Maintenance strategies for test equipment are important to ensure the long-term functioning and reliability of the equipment. This section discusses both preventive and corrective maintenance strategies applicable to the rig.

### **2.3.1. Preventive Maintenance**

Preventive maintenance is a proactive maintenance process for equipment and systems where regular inspections, servicing, and repairs are carried out at regular intervals. As opposed to waiting for equipment to break down, preventive maintenance aims to prevent unexpected failures and extend the life of the equipment. Preventive maintenance is usually time-based, and the work is carried out based on fixed time intervals or the number of operating hours. Preventive maintenance can include lubrication, adjustments and inspections, and scheduled replacement of parts. It focuses on the reliability of the equipment and avoiding costly downtime or unexpected repairs [9].

A disadvantage of preventive maintenance is that it uses assumed failure intervals that do not necessarily correlate with the condition of the equipment. This leads to unnecessary maintenance or surprise failures if the schedule is not optimized for the actual conditions of the equipment [9].

### **2.3.2. Corrective Maintenance**

Corrective maintenance is a reactive maintenance strategy that takes action to repair systems and equipment when they malfunction or break down. It is performed to restore operations, either as an emergency response to unplanned failures or as planned for non-critical failures during regular inspections. Emergency corrective maintenance requires immediate action with high costs due to downtime and working hours. Planned corrective maintenance schedules the repair at an appropriate time to avoid disruption. Although corrective maintenance cannot be avoided, it is inefficient and costly when carried out [9].

## 2.4. Trailer Connectors

To be compatible with a wide range of trailers, the test rig must be able to test several different connector types. The most applicable standards and connector types used in Volvo applications are described in this section.

### 2.4.1. VBG 14/17/22

VBG connectors as shown in Figure are robust electrical connectors designed for use in heavy vehicles and equipment powered by 24-volt systems. For multiple connections to auxiliary equipment, they are available in 14-, 17- and 22-pin configurations. The double cable entries in both the socket and plug, as well as the large brass pin contacts, ensure secure grounding as well as efficient power transmission, reducing voltage drop and oxidation to a minimum [10].

The housing is made of glass fiber reinforced polyamide with excellent impact resistance. A lever mechanism allows for smooth connection and automatic release, protecting against accidental damage. A sealed and locked (SAL) variant is also available, providing enhanced protection against moisture, dirt and salt and achieving an IP54 protection class [10].

From a technical standpoint, pins 1 and 12 are designed for grounding and charging, using 9.5 mm contacts rated up to 25 A. Additional pins include single (6.5 mm, 15 A) and double (6.5 mm, 10 A) types for signal transmission. Self-cleaning contact surfaces help to maintain the performance by reducing buildup and ensuring reliable connections over time [10].



*Figure 6 VBG Power Plug Standard.*

## 2.4.2. ISO 12098 15-Pin Connector

ISO 12098:2020 defined 15-pin connector as shown in Figure 7. It is a standardized interface for electrical connections between towed and towing vehicles with 24 V systems. It facilitates power transmission, lighting signals, auxiliary controls and CAN bus data transmission, for the exchange of modern vehicle functions except brakes and running gear. The connector is a solid plug-in connector system with floating contacts for secure connection, closes automatically by cover and supports cable connections with cross-sections of 1.5 mm<sup>2</sup> to 2.5 mm<sup>2</sup>. ISO compliant adapters allow easy converting to older 7-pole systems. It is well designed to ensure high reliability, ease of use and compliance with ISO 4091 test requirements [11].



*Figure 7 Spiral cable 15/15-poles.*

### 2.4.3. NATO 12-Pin Connector

The 12-pin NATO connector STANAG 4007 is a standardized electrical connection intended for use between towed and towing vehicles (prime movers) in all NATO member countries with a voltage of 24 volts (see Figure 8) . With a circular 12-pin interface (see Figure 9) , it provides compatibility for lighting and signage systems including taillights, blackout lights, turn signals and fog lights. The design includes both socket and pin sockets, as well as double or single plugs, all engineered to exacting mechanical and electrical specifications for ruggedness, water resistance and consistent field use in tactical environments [12].



Figure 8 Nato 12-PIN connector.

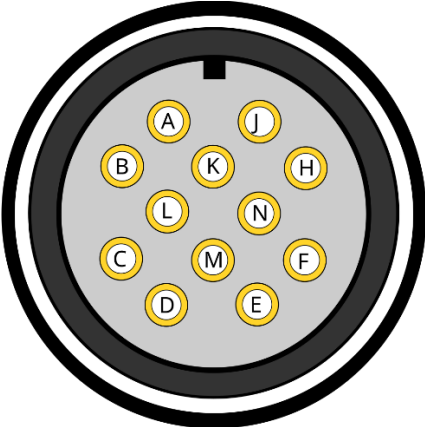


Figure 9 Interface NATO connector [13].

**2.4.4. ISO 1185 / ISO 3731 Connector**

ISO 1185 and ISO 3731 both describe two variants of 7-pin, 24V commercial vehicle trailer connectors. ISO 1185 (Type N) shown in Figure 10 was introduced back in 1975 to manage simple trailer lighting functions such as brake lights and turn signals. It has a black casing and is well suited for simple trailers, but it doesn't cover features such as reversing or rear fog light functionality. ISO 3731 (Type S) shown in Figure 11 was then introduced in 1980 to cover these other functions. It is also a 7-pin, 24V device but is paired with the Type N connector. It has a white casing and supports the use of additional lights and power for trailer devices (such as refrigeration units) [14] [15].



*Figure 10 Spiral cable 7/7-poles 24S.*



*Figure 11 Spiral cable 7/7-poles 24N.*

## **2.5. Ergonomics**

The usability and safety of the operator is the highest priority in production. The following section discusses ergonomic principles related to the design and use of the trailer test rig.

### **2.5.1. Physical Ergonomics**

Physical ergonomics is about how the body interacts with the physical environment of a workplace. It involves designing tasks, workstations and equipment in a way that is compatible with the anatomical, physiological and biomechanical properties of the human body. The aim is to prevent the risk of injury, discomfort and fatigue by taking into account factors such as posture, repetition, effort and physical stress. With an optimal physical environment, physical ergonomics enables safer, more efficient and more comfortable working environments, improving both workers' wellbeing and overall productivity [16].

### **2.5.2. Cognitive Ergonomics**

Cognitive ergonomics deals with the mental activities involved in work, including perception, memory, attention and decision-making. It is concerned with how individuals process information and how systems can best support these mental activities. In industrial settings, cognitive ergonomics aims to reduce mental load, eliminate errors and increase clarity through deliberate planning of instructions, interfaces and task organization. Standardized work procedures, visual aids and error proofing (poka-yoke) are some of the typical tools used to enable workers to perform cognitive activities in a more reliable and efficient way [16].

### **2.5.3. REBA**

The Rapid Entire Body Assessment (REBA) is an ergonomic assessment tool used to evaluate the risk of musculoskeletal disorders (MSDs) in work tasks involving the whole body. The tool helps identify risky work postures by analyzing key body areas such as the neck, trunk, legs, arms and wrists, along with factors such as force, repetition and coupling. Using a simple worksheet, assessors assign scores to different postures observed during work, which are then combined to give a final score indicating the level of MSD risk [17].

## 2.6. User Interface Design Principle

User interface design plays a crucial role in ensuring that interaction between users and systems is efficient, intuitive, and resistant to errors. Two theoretical frameworks that inform good UI design are Donald Norman's *psychology of artifacts* [18] and Patrick Jordan's usability principles [19].

### **Key concepts from Norman's psychology of artifacts:**

**Mental models** – Users form expectations about how a system works based on experience. Interfaces should align with these expectations to feel intuitive and reduce the learning curve.

**Signifiers** – Visual or interactive cues that indicate how a component should be used (e.g., buttons, icons, or highlights).

**Mapping** – The logical and spatial relationship between interface elements and their functions. Good mapping helps users understand what actions will result from their inputs.

Relevant usability principles from Patrick Jordan:

**Consistency** – The design should solve similar problems in similar ways to reinforce user understanding and predictability.

**Feedback** – The system should clearly indicate that user actions have been registered and show the result of those actions.

**Visual clarity** – Information and controls should be easy to read, recognize, and understand without ambiguity.

**User control** – Users should feel in control of the system and be able to navigate, undo, or correct actions without frustration.

These selected principles provide a practical foundation for designing interfaces that support smooth interaction, reduce user errors, and accommodate both novice and experienced users in technical environments like HMI systems.

## **2.7. M5 Stack**

M5Stack CoreS3 is the M5Stack series third-generation development core, which is driven by the ESP32-S3 dual-core processor. It has a 2.0-inch capacitive touchscreen, camera, loudspeaker, two microphones, as well as some sensors such as a proximity sensor, a six-axis movement sensor, and a magnetometer. Onboard WiFi, 16MB Flash, and 8MB PSRAM enable both Arduino and UiFlow2 programming environments to run on it [20].



# 3. Methodology

*The methodology describes the formalized process followed to investigate, define and establish the test rig. It describes how information was collected through interviews, observations and benchmarking, and how product development models were used to ensure that the final design meets stakeholder and technical needs.*

# 3.1. Product Development Process

Through this thesis project, a structured and iterative product development approach was followed (see Figure 12). The process began by gathering information about the product, its users, and other stakeholders through observations and interviews. This helped clarify the product’s purpose, operator requirements, and overall constraints.

Next, in the Identification Phase, we summarized the collected data, defined technical requirements, and set boundaries for the project. With these foundations in place, multiple concepts were generated and evaluated against user needs using tools such as the Pugh matrix and elimination matrix.

In parallel, suitable components for a test rig were investigated, procured, and assessed for both cost-effectiveness and integration feasibility. Finally, the most promising concepts were validated with test-rig operators, ensuring that user needs, technical requirements, and project goals were all met in a viable and beneficial solution.

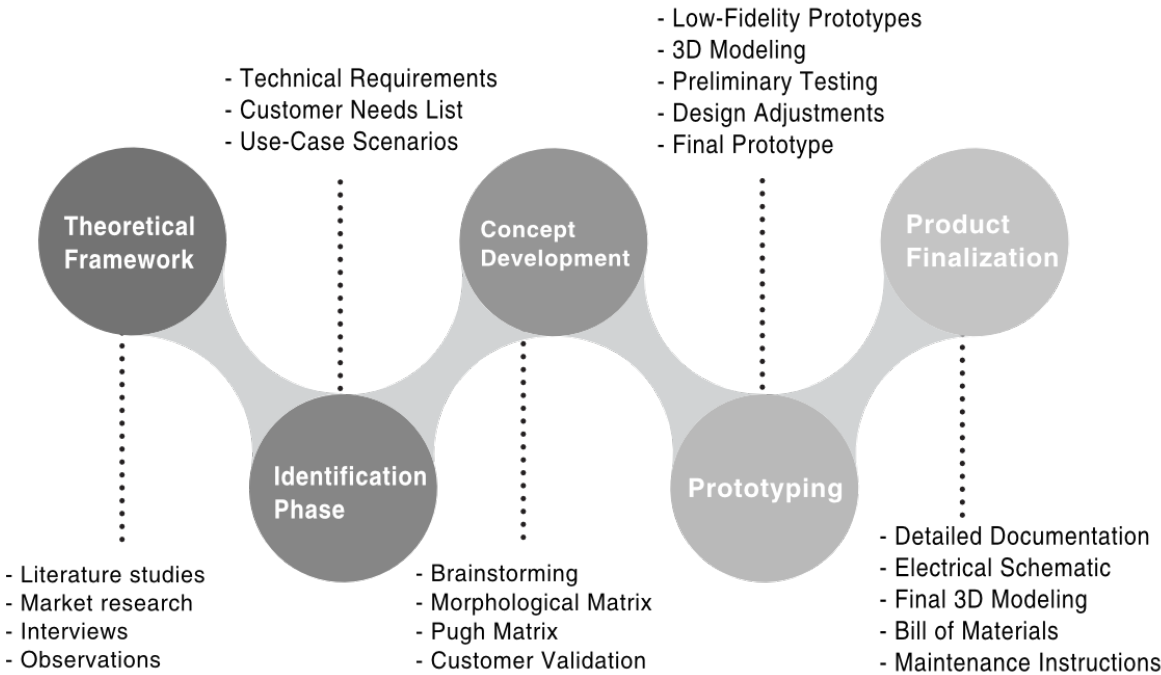


Figure 12 Product development process used throughout the project

The methodology used in this project is rooted in the stage gate model by Robert G. Cooper (see Figure 13), which is a systematic approach where you continue to the next stage once you are done with the one before, and then you can iterate between the different stages. It is, however, rooted in the fact that interviews, observation, and requirements both technical and

customer-based are more or less already defined, which is not the case in this project. Therefore, it also becomes a kind of mixture with the design thinking process. The reason for the use of the stage gate model is that it is adaptable and can be used on many different types of projects. Where this is not a classic product development project since it is very production engineering–focused regarding where the product is set. This model is very structured, focusing on minimizing the risk of moving forward without support from decisions. It serves as a checklist ensuring that steps have not been missed and creates a well-documented structure where the traceability of decisions becomes very clear. This is good since we, as master’s thesis students, come to the company as newcomers. Our decisions and choices can be traced and understood from a third-party perspective, since we come with another mindset and set of thoughts than those within the company.

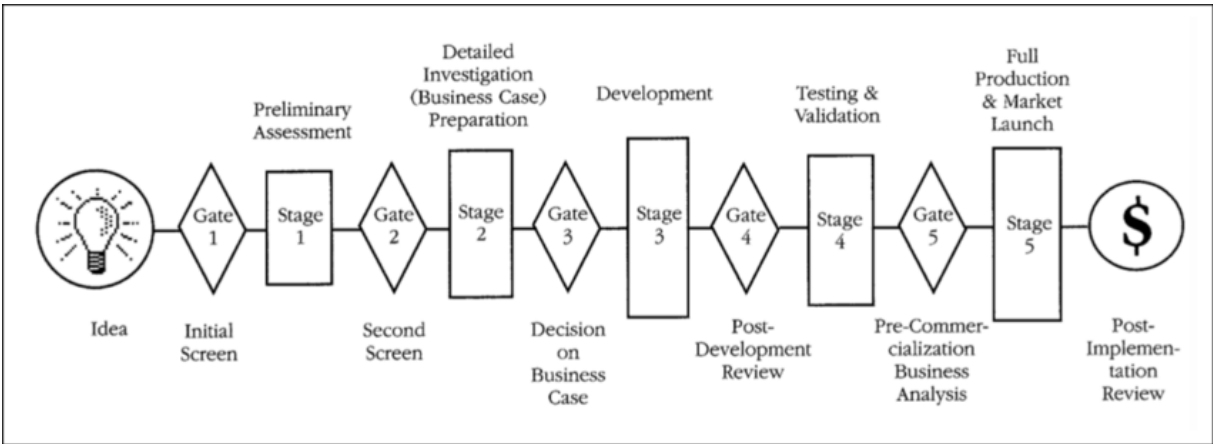


Figure 13 stage gate model by Robert G. Cooper [21].

The Stage-Gate model consists of five key phases, each separated by a decision gate to ensure project viability before proceeding [21]. The first phase, scoping, involves evaluating the project idea based on market and technical feasibility, as well as creating a timeframe for the project. Next is business case development, where concepts are developed, iterated, and assessed through feasibility studies and project planning. The third phase, development, focuses on detailed product design and system-level planning, describing how the concept should function in its intended setting or system, such as the customer adaptation part of Tuve's manufacturing. This is followed by testing and validation, where prototypes are iterated, refined, and tested internally and in the market. Finally, the launch phase involves full-scale production, commercialization, and the finalization of all necessary documentation for manufacturing and market entry

## 3.2. Research Approach

This section outlines the methodology used for data collection and analysis to obtain a comprehensive understanding of the test rig that is being developed and the factors influencing the product. This methodology includes tasks such as initially conducting a literature search to see what connectors the trucks have and what voltage they use. This provided an initial overview of the system. Then, methods such as observations and interviews were used to gain a deeper understanding of the existing product and its problems.

When conducting research, there are multiple approaches. Two common ways are either to do qualitative or quantitative research. As noted in *User-Friendly Handbook for Project Evaluation*, quantitative research is usually used when you want to count or measure something, or when you want to generate data that can be generalized [22]. Qualitative research is more common when you need a deeper understanding of how and why something occurs, and to uncover potential unexpected scenarios. Therefore, qualitative research was deemed most suitable for the project task, where the goal of the research was to get a deeper understanding of what the technicians wanted to test, what they could currently test, and the potential errors that occur with the existing test rig, which they could not identify themselves. Based on these insights, interviews and observations were selected as the primary research methods.

### **3.2.1. Literature Search**

The initial phase of the literature search focused on analyzing the existing test rig, its operational context, and the relevant technical systems, as well as identifying its key components. This research involved examining the truck voltage systems, the required connectors, and conducting a detailed study of the hydraulic and pneumatic systems.

Additionally, the literature search aimed to identify part IDs for existing test equipment used in the factory to gain insight into proper documentation practices. The feasibility of implementing the test rig beyond Cab Assembly (CA) was also explored. While similar tests were conducted at the end of the production line, these tests were designed for standard trucks, resulting in a significantly different testing scenario and user requirements. However, during this investigation, it was discovered that an ongoing project was already addressing this area.

As a result, the focus shifted to systematically analyzing the key stakeholders involved in this project and establishing a priority framework to ensure an effective and structured approach to their involvement.

### **3.2.2. Stakeholder Identification**

Based on the findings from the literature search, conducting a stakeholder identification mapping can be a logical next step. This process involves ranking stakeholders hierarchically and prioritizing them based on their level of involvement and impact. This approach not only provides a clear overview of priorities but also ensures that all individuals and groups affected by the product's development are considered and included. By taking all relevant stakeholders into account, this process helps ensure that the product integrates well into its intended environment.

Regarding the test rig, this process was carried out by gathering information from the literature search to identify key stakeholders for interviews and determine relevant situations for observation. The goal was to ensure that the product fulfilled its intended purpose while also considering opportunities for future expansion.

### **3.2.3. Observations**

Observations can be performed in various ways, primarily categorized into structured and unstructured methods. Structured observations focus on gathering quantitative data by following a detailed plan that specifies how the observation should be conducted and what behaviors to monitor. In contrast, unstructured observations are often employed in the early stages of a project to collect extensive qualitative data. They do not rely on a predetermined framework but instead consider the context and surroundings of behaviors. Furthermore, there is the Observer-as-participant technique, where the people being observed are informed about the observation. However, the observer does not actively engage in the activity being observed. This technique poses the challenge of influencing the observer. The opposite of this is Complete observation, where the researcher does not take part in the activity and the individuals involved are unaware, they are being observed. This poses challenges but minimizes observer biases.

In this project, the method used was structured observation combined with observer-as-participant observation. The method was carried out by informing the technicians that the task was to use the already existing test rig as usual. While they were using it, questions and thoughts were asked.

The reason for this approach was that the information needed was qualitative, as the environment and case were predefined. The focus relied on identifying behaviors that the technicians could not define or express in an interview. The choice to use observer-as-participant observation was mainly because the technicians were already aware of the task of improving and developing a new test rig. If questions and thoughts had not been expressed during the observation, it would have been less beneficial.

### 3.2.4. Interviews

An interview is a research method where one asks open-ended questions to gather information from a user. The aim is to collect experiences, needs, behaviors, and challenges that the interviewed person encounters. Interviews are primarily a qualitative research approach, focusing on in-depth, narrative insights rather than numerical data. To perform a successful interview as effectively as possible, several factors need consideration. One important point is to have a clear goal for the interview, what kind of information do you want to uncover? As S. Portigal notes, defining this objective ensures the conversation stays purposeful and yields actionable findings. Furthermore, the importance of open-ended questions cannot be overstated. Open-ended questions allow the interviewee to share their experiences freely [23]. Similarly to observations, there are structured and unstructured interviews. Unstructured interviews are quite free-flowing and open, resembling a casual conversation with no prior preparation and no specific topic to discuss. This approach allows flexibility to explore user perspectives in depth but may lack focus. In contrast, structured interviews adhere to a predetermined list of questions, including follow-up questions, and focus on a specific topic. These interviews ensure consistency across responses, making it easier to compare findings systematically. Research highlights that structured interviews reduce bias and improve reliability, while unstructured ones can uncover richer, unexpected insights, though they risk inconsistency [24]

During the project, the method primarily used was structured interviews, conducted with multiple different users to obtain a variety of answers and to gain a broad perspective on the test situation. This approach ensured that the interviews remained focused on the project's goals while capturing diverse user experiences.

## **3.3. Market Analysis**

Doing market analysis has multiple benefits, including gaining a broad perspective on the products available on the market. This involves examining both competitors and potential products to use as inspiration two factors that can enhance productivity. The method used was benchmarking, serving as both a source of inspiration and a means of identifying possible solutions.

### **3.3.1. Bench Marking**

Benchmarking is the process of measuring your product or services against another. This can be done through various comparable aspects. By using this method, you can compare your approach, evaluate outcomes, and, in the process, gather information on best practices. The aim is to improve your product or business performance. here are different types of benchmarking, primarily external benchmarking and internal benchmarking. External benchmarking involves comparing your performance or products to those of competitors with the goal of gaining knowledge and insights into new products or processes. Internal benchmarking, on the other hand, is when you compare your product or performance within the company to another product or process that already exists. Benchmarking offers many benefits, especially in product development. It allows you to rank your product against competitors or the market, creating a structured way to compare it with existing products. Additionally, it increases awareness of what the market offers. This, in turn, shortens the innovation process and may reduce the need for extensive trial and error, making product development more efficient [25].

Benchmarking in this project was not approached as a means of analyzing competitors but rather as an exploration of existing market solutions to draw inspiration from Therese's approach. Additionally, we examined available components, assessed potential suppliers, and evaluated the functions these components could offer.

## **3.4. Requirements Identification**

This section describes the methodologies used to identify the project requirements. It includes a customer needs list and a technical requirements list, both of which were used to systematically outline and summarize the customer's expectations and the technical constraints. By combining these methods, a comprehensive view was achieved, ensuring alignment between what the customer wanted and what was technically feasible.

### **3.4.1. Customer Needs List**

A customer needs list comprises raw statements that identify customer requirements. The process begins by collecting data on user or customer's needs and preferences. This data is then interpreted and compiled into a list. Typically, these needs are organized hierarchically into categories such as primary, secondary, and tertiary. Additionally, it's essential to determine which requirements are critical to customers to prioritize them effectively. Additionally, the list is evaluated and refined by eliminating redundant needs and grouping similar ones in a structured manner [26].

### **3.4.2. Technical Requirements List**

A technical requirement list, often called a product design specification (PDS), is a compiled, structured document that details all the technical requirements a product must meet. It captures the necessary functions, performance criteria, and constraints that must be included when proposing a design. It outlines what the product should be able to achieve under defined conditions, but without specifying how. This document often serves as a fundamental guide or reference during the development process. Although it can be outlined in various ways, common requirements typically include factors such as material, weight, and size [27].

In this project, the technical requirements list was developed mainly through interviews and observations with the stakeholders. This list served as a guideline to keep the project within a reasonable design space and to achieve a product that would satisfy the customer while also being technically feasible.

## **3.5. Concept Generation**

This part of the report outlines the concept generation methods that were used. The main method employed was brainstorming. This was carried out in a number of ways, and the brainstormed ideas were developed in an iterative manner, where further brainstorming took place after concept selections to continue refining and developing the concepts.

### **3.5.1. Idea Generation**

Idea generation is a short, structured, and crucial process meant to generate creative ideas. A common method is brainstorming. Brainstorming is a technique where a group generates a wide variety of solution concepts without evaluation in between, aiming to produce as high a quantity as possible. This encourages creativity and helps explore a vast amount of the design space. Structured brainstorming is another method that can be used, where prompts or guidelines are often applied to maximize the number of ideas, though within a more specific and detailed area [26].

In the project, both methods were used. First, brainstorming was applied to explore the whole design space. However, through concept evaluation, it became clear that many of the ideas were not technically or time-wise feasible. Therefore, a structured brainstorming method was also applied, this time with a more narrowed scope.

## **3.6. Concept Evaluation**

The concept evaluation phase is where the concepts generated during the ideation phase are assessed based on their feasibility. Different evaluation methods can be used, depending on the project's needs. Evaluation can be focused on identifying which concepts require further development or improvement or determining which ideas may need to be changed or discarded entirely.

### **3.6.1. Elimination Matrix**

An elimination matrix, often referred to as a selection matrix, is used to evaluate each concept against key requirements such as time, budget, or technical feasibility. Unlike comparative methods, this matrix checks whether a concept meets defined criteria or customer needs. It is used to quickly narrow down the number of concepts by identifying which ones fail to meet critical constraints. This allows the team to focus on further development on the most viable and realistic options maximizing resources [26].

The matrix format is made by listing product concepts in rows and the evaluation criteria in columns, providing a structured framework for the comparison of concepts and an effective way to get an overview. When performed, some criteria are deemed more important than others. An example is that, one key factor during this project was time and the technical possibility of building a functioning product. The requirements are therefore often weighted to reflect their relative importance, ensuring that the matrix helps narrow down the concepts to the most promising ones. This supports decision-making in line with the project scope and increases the likelihood of delivering a feasible and successful outcome.

### **3.6.2. Pugh Matrix**

A Pugh Matrix, also known as a concept selection matrix, is a method distinct from an elimination matrix for selecting product concepts. It involves comparing various product concepts against a chosen reference concept to provide a consistent baseline for evaluation. The primary objective is to narrow down the number of concepts by collaboratively assessing how well each satisfies predefined selection criteria. This approach is notably visual and begins with selecting a reference concept, followed by identifying evaluation criteria that are crucial for the concept's relevance and utility. These criteria are then weighted based on their importance. Once the criteria are established, each concept is evaluated relative to the reference: if a concept performs better, it receives a '+1'; if worse, a '-1'; and if equal, a '0'. These scores are then multiplied by the criteria's weights and summed to provide an objective performance score for each concept, serving as a solid foundation for selection. If initial evaluations yield concepts with similar scores, the process can be iterated using different reference concepts to achieve a more definitive selection.

### **3.6.3. Low Fidelity Prototype**

According to Ali and Lande [28], low-fidelity prototypes are simplified representations of a product. Low-fidelity prototypes are Created with minimal resources with intention of exploring and communicating core ideas early in the engineering design process. These prototypes are not focused on fine details or final functionality but instead aim to externalize thinking, support rapid iterations, and enable early feedback. In engineering context low-fidelity prototypes can include rough physical models, simplified electrical systems, or basic functional assemblies that help validate critical design assumptions without committing significant time or cost. The purpose of using low-fidelity prototypes is to quickly test technical feasibility, uncover usability issues and support communication within the development team.



# 4. Identification

*This chapter is about defining the key factors driving the project, including stakeholder requirements, technical requirements and market conditions. It sets the stage for the idea development phase by defining a clear problem area and outlining key constraints.*

## **4.1. Market Research**

This section outlines the findings from the market analysis regarding similar products available on the market. These products have served as inspiration for the development of the proposed solution. The analysis covers both software and hardware solutions. Furthermore, it highlights products commonly used in the context for which the product is being developed, such as trailer connectors.

### **4.1.1. Trailer Connectors**

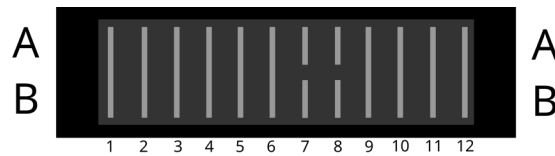
Different trailers have different connectors depending on their user needs. There are standard connectors for trailers, but there are also connectors for military trailers, as well as trailers with extra functions. Furthermore, there are connectors for cabinet lighting. All these different connectors are not equally common, but they do occur depending on the situation and the type of truck.

#### **ISO 12098, 15 - Pin Connector**

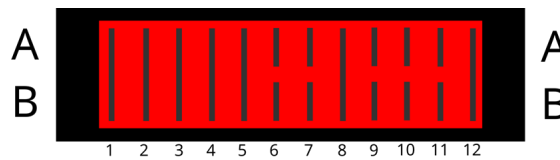
ISO 12098 defines the most common electrical connector used for trucks without additional or special functions. It is a 24-volt connector featuring 15 pins, each with a predefined and standardized function that cannot be changed.

## VBG

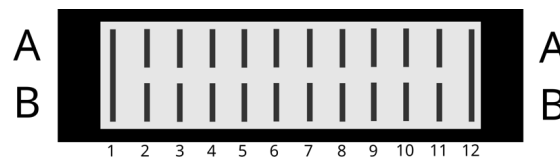
The VBG connector is the main connector used when there are extra functions on the truck, such as tilting the trailer. The VBG connector has different layouts depending on how many extra functions the truck has. It consists of a 14-pin setup (see Figure 14), a 17-pin setup (see Figure 15), and a 22-pin setup (Figure 16). The 14-pin and 17-pin setups are the most common.



*Figure 14 VBG 14-pin [29]*



*Figure 15 VBG 17-PIN [30]*



*Figure 16 VBG 22-PIN [31]*

## 12-pin NATO Trailer Socket

The 12-pin NATO connector is the preliminary connector for military vehicles. Like the VBG connector, it comes in different setups. However, this contact differs based on country. The number of pins remains the same, but the function assigned to each pin differs. There are several versions, including STANAG 4007 (NATO Standard), USA, DUE, GRB, and SWE. The Swedish version is the most common for us, since we are based in Sweden

## ISO 1185, 7 - Pin Connector

This is the least common connector as is mainly used for inside trailer light. This contact has 7 pins and is rarely seen at the customer adaptation trucks

### 4.1.2. Benchmarking Within Volvos Assortment

Benchmarking was conducted by investigating the different test carriages currently used at Volvo Tuve and analysing how they are constructed. The goal of this benchmarking was to identify a standard to follow, which would simplify future spare part ordering and ensure that the new test rig design aligns with Volvo’s safety and supplier requirements.

In addition to the physical structure, benchmarking was performed to gain an understanding of the testing systems Volvo currently uses for trailer electrical connections. Two main rigs are in operation: one in the Customer Adaptation (CA) department and one at the end-of-line.

The test rig used in the CA department see Figure 17, operates using four segmented lamps, each manually labelled to indicate different trailer pin functions. Each segment of the lamp is wired to a specific pin on the trailer connector and as a function is activated the corresponding lamp section lights up. While this solution provides a basic visual indication it has several limitations. The system relies on a simple electrical setup. This increases the risk of fuse failures or general electrical faults. This creates uncertainty around testing reliability. Furthermore, the use of manually marked lamps makes it unclear which pin corresponds to which function, which can lead to misinterpretation, delays in troubleshooting, and longer lead times overall.



Figure 17 Test rig used in the CA department.

To gain a broader perspective, the test rig used in the end-of-line environment was also analysed see Figure 18. This rig is more standardized and is primarily used to test ISO 12098 (15-pin) connections. It features a more compact and structured design and integrates both pneumatic and electrical testing into a single unit. Additionally, it is connected to Volvo’s internal system, allowing automated registration of test results. However, this rig is only intended for standardized trucks and is not adaptable for customer-specific configurations. This rig also lack some of the features talked about earlier having a simple electrical system and an interface that can be difficult to interpret.



*Figure 18 End-of-line test rig.*

### 4.1.3. Benchmarking Outside Volvos Assortment

Benchmarking was not only conducted within Volvo but also extended to external products. This external benchmarking mainly focused on identifying existing market solutions that address the problem of analyzing signals between a truck and a trailer.

One of the first products reviewed was a widely available commercial solution: a standard test connector used between cars and trailers (see Figure 19). This is a common product designed to test standard signal functions on a car. However, it lacks customizability and adaptability, making it less suitable for more advanced or specific testing scenarios.



Figure 19 Standard trailer connector tester for car [32].

Similar products exist for trucks (see Figure 20). This product also faces the issue of being designed primarily for customer use, which limits its adaptability and makes it less suitable for production environments where modifications, durability, and integration are important.



Figure 20 Trailer connector tester for trucks [33].

Similar products exist, but in other formats such products are for example the JALTEST PTE (Portable Trailer e-Supply) (see Figure 21) which work in a similar fashion, but seems to be more a robust systems, but also lacks the adaptability that a production tool should have.



Figure 21 Portable trailer e-Supply [34].

Another more fitting product, designed for production use, is the NATO MUTT® (Mobile Universal Trailer Tester) (see Figure 22). This product is capable of testing both electrical signals for the NATO connector and pneumatic systems. However, it is designed to simulate a truck rather than a trailer, meaning it works in the opposite direction compared to our use case. The MUTT® is also available for 15-pin connectors. While this solution is more industry-ready and robust than consumer-grade products, it still lacks customizability. As a result, it may not be adaptable to future needs or more complex test scenarios.



Figure 22 The Mobile Universal Trailer Tester.

# 4.2. Identified Stakeholders & Requirements

In this part, the key stakeholders and their specific requirements for the product are outlined. Understanding the needs of different stakeholders is essential to ensure that the final design fulfills both functional and operational expectations. The requirements were gathered through interviews, observations, and benchmarking activities.

## 4.2.1. Stakeholder Identification

Based on the findings from the literature search and benchmarking, a stakeholder identification mapping was conducted (see Table 1). This mapping outlined not only where the test rig could be implemented but also identify individuals and groups who are directly or indirectly involved. Additionally, it considered possible use case scenarios that could present challenges. The identification of these different groups was essential, as they were key parties we engaged with during interviews and observations.

*Table 1 Stakeholder identification*

Users	Examples
Primary Users	Technicians at Customer Adaptation (CA)
Secondary Users	Operators at the end of the line (slussen)
Tertiary Users	Technical mechanics works on heavy adjustments
Customers	Volvo trucks, GTO
Extreme Users	Trucks with many additional functions Trucks with non-standard connectors Trucks requiring hydraulic tests End of shifts when workers are tired
Maintenance	Service technicians, maintenance engineers, Equipment Engineers
Indirect Stakeholders	Safety managers, Manufacturing engineers, Plant Coordinator

## 4.2.2. Requirements

Requirements were initially divided into customer requirements and technical requirements but were later combined and categorized into a final list (see Table 2). The requirements are based on observations and interviews, as well as technical limitations due to time constraints. The requirement list includes mandatory requirements, which must be fulfilled for the project to be successful, and optional requirements. These optional requirements are weighted based on their importance. Where a high value means more importance while a lesser value means less importance. The importance is determined by customer needs as well as observations made during the use of existing equipment. The requirements have been iterated multiple times with feedback from both technicians and engineers in CA.

*Table 2 Requirements list*

No.		Type (R/O)	Weight	Comment
<b>1. Electrical Functions</b>				
1.1	Compatible with 24V electrical systems	R	–	For trucks and trailers
1.2	Support for IO-Link sensors	O	1	Ability to connect modern sensors
1.3	Verifies functions for Volvo coupling systems	O	1	Functional testing of Volvo systems
1.4	Support for multiple connector standards	R	–	Includes 7/7-pin lighting
1.5	Handles repeated restarts	O	3	Important for recurring tests
1.6	Built-in protection against short-circuit, overload, and fire	R	–	Safety critical
1.7	Marking and wiring per Volvo standards	R	–	For unified documentation and service
1.8	Minimum 20 digital 24V inputs	R	–	Required for parallel test signals
1.9	Dust/IP-rated construction	R	–	Suited for demanding environments
<b>2. Mechanical/Physical Functions</b>				
2.1	Compact design	O	1	Dimensions should be specified
2.2	Portable and easy to transport	R	–	Easy to move between locations
2.3	Durable in workshop environments	R	–	Resistant to impact, dirt, moisture
2.4	Support for hydraulic testing	O	2	May be implemented as a separate module
2.5	Support for pneumatic testing	O	1	Compressed air already available in CA
2.6	Protection against paint damage	R	–	Equipment must not damage the vehicle
2.7	Modularity for future expansion	O	2	Enables easy further development
<b>3. Usability/Ergonomics</b>				
3.1	Simple and durable connectors	R	–	Must withstand frequent use
3.2	Operable by one person	O	2	Easy to handle by a single operator
3.3	Clear and readable measurement values	R	–	Prevents misinterpretation

3.4	Ergonomic design	O	3	Reduces physical and mental strain
<b>4. Environment and Materials</b>				
4.1	Sustainable materials	O	2	Recyclable and low environmental impact
4.2	Uses Volvo's existing component stock	O	1	Reduces cost and increases availability
4.3	Materials withstand industrial environments	R	–	Withstands external impacts
4.4	Material selection supports future scalability	R	–	Important for series production
<b>5. Performance and Durability</b>				
5.1	Minimum 10-year operational life	O	4	With planned maintenance
5.2	Operates continuously for a full workday	O	4	At least 8 hours without interruption
5.3	Handles 30 test cycles/day, max 1 maintenance/year	O	2	Robust for daily use
5.4	Space-efficient design	O	3	Fits into existing work areas
<b>6. Control and Automation</b>				
6.1	Compatible with Volvo's automation systems	R	–	Must integrate with current infrastructure
6.2	Separate power for control system and lights	R	–	Minimizes interference
6.3	Computer-based control system	R	–	Enables monitoring and operation
<b>7. Production and Cost</b>				
7.1	Ready within thesis timeframe	R	–	Prototype completed within project duration
7.2	Scalable manufacturing cost	O	1	Adaptable to different production volumes
7.3	Manufacturable by third-party suppliers	R	–	Not dependent on internal production
<b>8. Scalability and Development</b>				
8.1	Compatible with other test systems	O	3	Enables future integration
8.2	Prepared for future sensor integration	O	3	E.g. pressure and force measurement

Some requirements are highly important, but currently have a sustainable solution through external factors, meaning that the test rig does not need to implement these features immediately. One example is the requirement to test pneumatic systems. Currently, the technicians only check whether there is air present, not how much, which is what the engineers would prefer. However, testing for the presence of air can still be performed without the test rig.

## 4.3. Interviews & Observations

Interviews were conducted both individually and in groups. Initially, a group interview was held to gather general background information. This was followed by individual interviews with two technicians to gain deeper insights into specific challenges and working methods. During one of these sessions, we observed the complete testing procedure using the old test rig and had the opportunity to try out the current rig ourselves. These sessions provided valuable perspectives on the main difficulties technicians face in their daily work.

Through the interviews, we also discovered that similar testing equipment was being used at the end of the production line, where trucks are assembled. To explore this further, we conducted informal interviews with the process technicians responsible for that part of the line. One technician explained the testing procedures used there, which led us to spend a full day at the Slussen area, observing operations and conducting additional spontaneous interviews with technicians operating the equipment.

As part of this visit, we also conducted a process mapping exercise to better understand the workflow (see Appendix B). We documented the technicians' activities, outlined each step of the testing process, and noted the tools in use. This mapping revealed that some needs and routines differed or even conflicted between the CA department and the end-of-line environment. For example, CA handles non-standardized trucks, while the end-of-line process focuses solely on standardized vehicles, resulting in different demands on the test equipment. Additionally, we learned of an ongoing project at Volvo Lundby, where an engineering team is developing a compact handheld test rig capable of testing both pneumatic and electrical signals. Since that project was already underway and outside the scope of our work, we decided to concentrate our efforts entirely on the CA department.

However, the observations at end-of-line offered valuable insights into features that could also benefit CA. One example is the inclusion of built-in paint protection in the test rig a small but practical feature that could be smart to include in our own concept.

With these insights in mind, we shifted focus to a more detailed and structured observation of how test equipment is used specifically within the Customer Adaptation environment. This included another observation mapping exercise (see Appendix C), where we tracked the full testing process, interviewed technicians, and took detailed notes. From this combined data, we identified several key problem areas (see Table 3), along with their root causes (see Table 4).

Table 3 *Observed problems when using the existing test rig*

Problems #	Problem Areas Identified
1	Difficult to see values on the test rig, especially for extra functions
2	No registration or logging of test results
3	The test rig is large and difficult to fit into tight spaces
4	Cables are bulky, easily damaged, and lack proper cable management
5	Ergonomic issues when trying to look into the rearview mirror during testing
6	Adapters are placed in non-ergonomic positions
7	Difficult to connect adapters to the test rig due to poor connector design

Table 4 *Root causes from observed problems*

Cause #	Root Cause Description
1	Lamps and/or numbers are too small or unclear to read
2	The test rig does not support easy result logging, reducing the incentive to record data
3	The overall size of the test rig is too large for certain truck configurations
4	Cables are heavy-duty but have no designated storage or protection
5	Mirror angles make it difficult to clearly see indicators
6	Lack of space and dedicated holders for adapters
7	Connector design is not optimized for quick, repeatable use



# 5. Concept Development

*This chapter explains the creative process used to develop and evaluate potential test rig solutions. Concepts were developed through brainstorming, run through formal evaluation frameworks and refined following stakeholder feedback. The result is a selection of clearly defined concepts that are ready to be prototyped and validated.*

# 5.1. Brainstorming

Based on the requirements gathered from interviews and observations, as seen in Chapter 4, two brainstorming sessions were conducted. The concepts generated during these sessions were developed to fulfill the identified requirements. Each concept was created with the same level of detail to ensure that later evaluations could be made as objectively and unbiased as possible.

At this stage, the concepts were not developed with technical feasibility or economic aspects in mind. While these are important factors, they were intentionally excluded during brainstorming, as they can act as limiting factors that may restrict creativity and prevent the generation of potentially valuable or innovative solutions. An overview of the generated concepts from the second iteration can be seen in Figure 23.

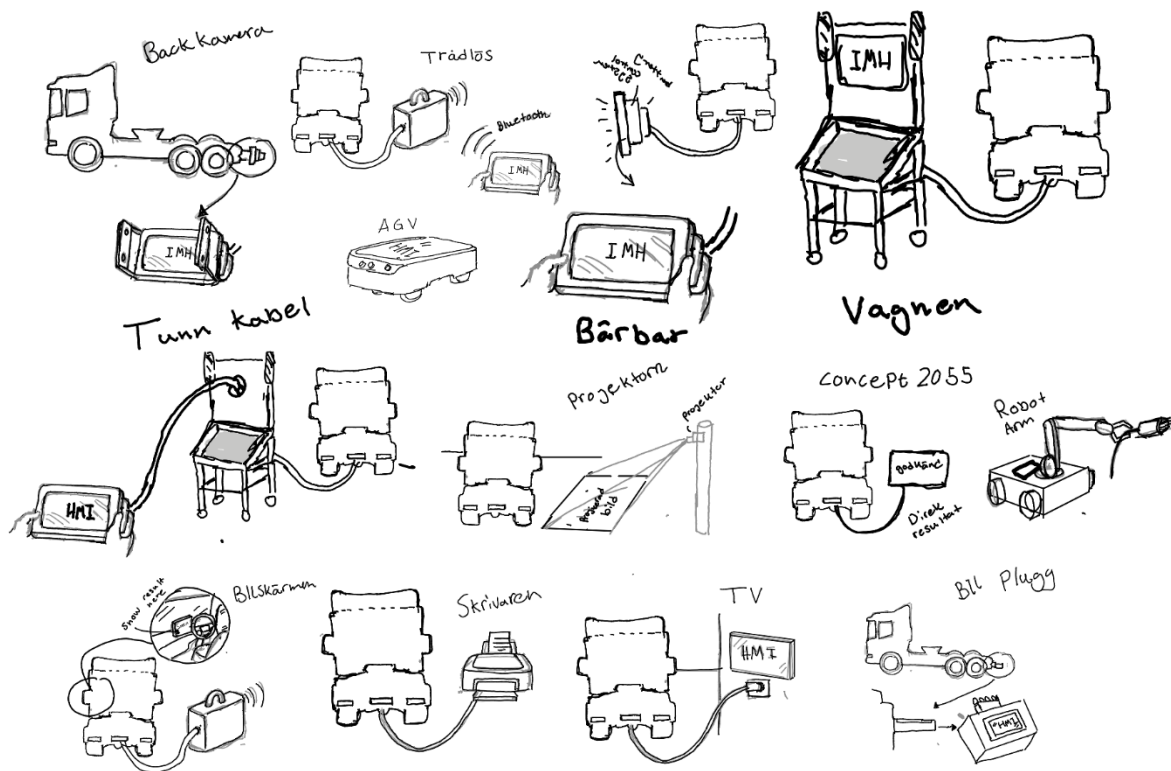


Figure 23 Brainstorming session second iteration.

## 5.2. Elimination Matrix

The number of concepts generated during the brainstorming sessions was very high, and it was not feasible to investigate all of them in detail, as that would have taken too much time. To narrow down the concepts in a fast and structured way, an elimination matrix was used (see Table 5). In this matrix, the concepts were evaluated based on the following criteria: solves the main task, fulfills the requirements, is technically feasible, fits within a reasonable budget, and could be developed within the available time frame. These criteria were chosen not only with the intention of inventing a good product but also to ensure that the selected concept could realistically be developed into a final, production-ready solution.

The budget aspect was somewhat unclear, as no specific numbers had been disclosed. Therefore, this criterion was assessed based on whether the cost of the solution seemed justifiable in relation to the value it could provide.

*Table 5 Elimination matrix*

Concept	Solves main task	Fulfills requirements	Technically feasible	Within a reasonable budget	Could be developed in timeframe
Vagnen	+	+	+	+	+
Bärbar	+	+	+	+	+
Ttrådlös	+	+	+	+	+
Backkameran	-	-	+	+	+
Tunnkabeln	+	+	+	+	+
Pojektorn	+	-	+	-	+
Bilskärmen	+	+	-	-	-
Skrivaren	+	-	+	+	+
Concept 2055 robotarm	+	+	+	?	-
AGV	+	+	+	-	+
TV:en	+	-	+	+	+
Bilplugg	+	+	-	+	+

The concepts that remained after the elimination matrix were the following four:

- **Vagnen** – This concept is like the existing test rig but integrates an HMI.
- **Bärbar** – A test rig that is portable and can be carried by hand.
- **Trådlös** – A test rig consisting of two parts: one signal register and one receiver.
- **Tunnkabel** – Similar to the existing test rig, but split into two parts: a trolley that receives the signal and a portable HMI connected to it.

All these concepts shared key traits: they were adaptable, transportable, and could be customized in various ways. After the elimination matrix, the number of concepts had been significantly reduced. Therefore, it was decided to investigate the remaining concepts further and take a deeper look into how they could potentially function. This would allow for a fair and informed selection in the next phase.

### 5.2.1. Vagnen

This concept (see Figure 24) is like the test rig that already exists within the Customer Adaptation department. It works by being directly connected to the truck's trailer connector. The signals are analyzed through a PLC housed in an electrical cabinet and the results are displayed both on an HMI and through external indicator lamps.

Furthermore, since the rig is built on a cart it can be easily moved around. Adapters, cables, and the battery can all be stored on the cart without adding significant weight meaning it does not negatively affect user interaction or handling.

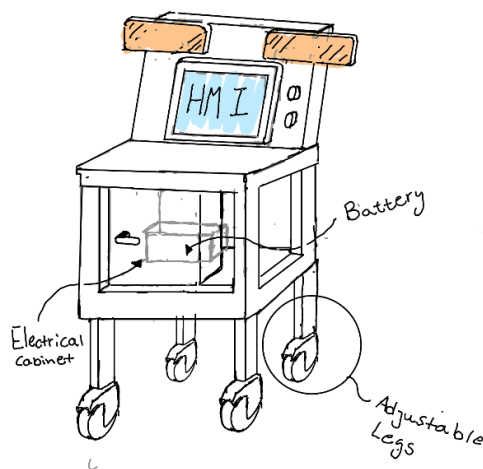
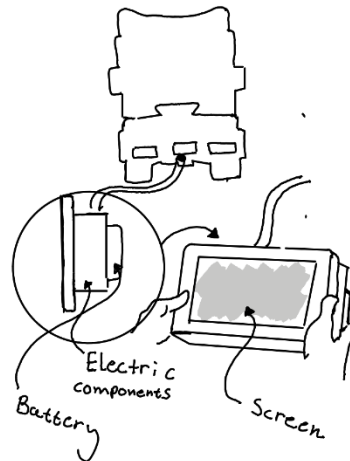


Figure 24 Vagnen

### 5.2.2. Bärbar

The concept Bärbar (see Figure 25) focuses on allowing the user to sit inside the truck and see the results as easily as possible while testing the different functions. It is designed as a complete module, with a screen, a potential battery, and electrical components reading the signals from the truck. The idea is to make the concept as transportable as possible by keeping it small and lightweight like a chunkier mobile device.



*Figure 25 Bärbar*

### 5.2.3. Trådlös

The concept Trådlös ( see Figure 26) has similar components to that of Vagnen, but it is powered directly by the truck. It would consist of an electrical cabinet with a smaller HMI, buttons, and compartments for different adapters. Everything would be housed inside the carriage of a suitcase. The concept is inspired by military radio suitcases. The suitcase would connect via Bluetooth to a phone or tablet using an app to mirror the image from the HMI.

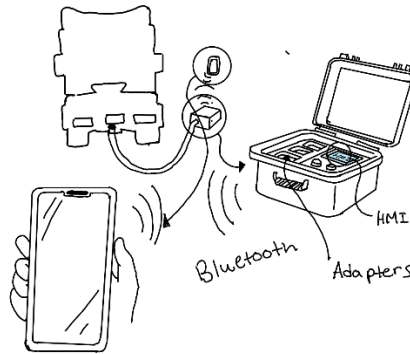


Figure 26 Trådlös

### 5.2.4. Tunnkabel

The concept Tunnkabel (see Figure 27) is similar to Vagnen, but with one important difference. The HMI screen would be detachable. This would make it possible to keep the larger parts of the system in one location while having the user interface in another, allowing the results to be seen inside the truck while using the functions.

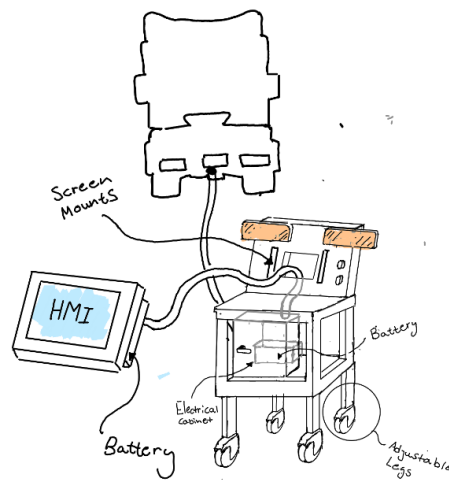


Figure 27 Tunnkabel

## 5.3. Pugh Matrix

In the concept review phase, a Pugh matrix was used to compare three test rig concepts that were ready for development. Concepts compared are Cart (Vagn), Wireless (Trådlös), and Thin Cable (Tunnkabel) with the baseline concept of Portable (Portabel) chosen because it was small and mobile and represented what technicians would want in a practical solution. The criteria for the comparisons were based on previously identified prioritized user and technical requirements and preferences, weighted by importance.

The Cart design, while heavier in design but receiving the highest overall score, was highlighted by its modularity, superior potential for future expansion and ease of integration into the Volvo system. The thin cable design was ranked next and was based on flexibility through a detachable interface screen, while being robust. The wireless design ranked the lowest due to technical uncertainties, signaling issues, and the difficulty of designing a stable wireless interface in a heavy industrial environment.

The matrix showed that although portability was an important aspect, ideas with superior structure, future expandability and improved ergonomic functionality were preferred. This provided the basis for prototyping and stakeholder confirmation of the Cart concepts.

Table 6 Pugh Matrix

Baseline Portable					
Criterion	Weight	Vagn	Bärbar	Trådlös	Tunnkabel
Support IO-Link connectivity for sensor integration.	4	1	0	0	1
Verify all standard and additional functional features of Volvo truck couplings.	1	1	0	0	0
Handle repetitive system restarts without failure.	3	0	0	-1	0
Maintain a compact form factor suitable for production environments.	1	-1	0	1	-1
Test hydraulic systems effectively.	2	1	0	0	1
Test pneumatic systems effectively.	2	0	0	0	1
Offer modularity for future hydraulic and pneumatic system expansion.	3	1	0	0	0
Be operable by a single technician.	1	1	0	0	0
Provide a user-friendly interface to minimize cognitive and physical strain.	3	0	0	0	0
Utilize sustainable, low-impact, and recyclable materials with minimal CO <sub>2</sub> footprint.	2	0	0	0	1
Prioritize components from existing Volvo inventory to reduce costs.	2	1	0	0	1
Remain operational for an entire shift without unscheduled downtime.	1	1	0	0	1
Ensure an operational lifespan of at least 10 years, with components replaceable through scheduled maintenance.	1	-1	0	0	0
Electrical and mechanical components must withstand at least 30 test cycles per year without additional maintenance.	3	0	0	-1	0
Fit within existing production spaces (space-efficient design).	1	1	0	1	0
Allow scalable manufacturing costs based on production volume.	2	0	0	0	0
Be compatible with additional test systems and sensors for scalability.	3	0	0	0	0
Enable integration of sensors/functions for measuring pressure, force, and other parameters.	2	1	0	1	0
Total Weighted Score.	—	15	0	-2	12

A black and white photograph of a test rig. In the center, a small, clear, cylindrical LED light is illuminated, casting a soft glow. The background is filled with a complex network of dark, curved cables and wires, creating a sense of depth and technical complexity. The overall tone is professional and technical.

## 6. Technical Solutions

*This part describes the final technical design of the test rig. It describes how the system is organized, what functions are performed by key components such as PLC and HMI, and what signal processing logic, protection measures and power supply are present.*

# 6.1. System Solution

The electrical system of the test rig is designed to simulate a trailer and analyze the signal connections from a heavy-duty truck to a trailer. The goal is to identify whether each individual pin on the trailer connector on the truck is functioning correctly. The system is divided into two main parts, the input side where signals are received from the truck see Figure 28. And the control side where the signals are interpreted and displayed through a user interface.

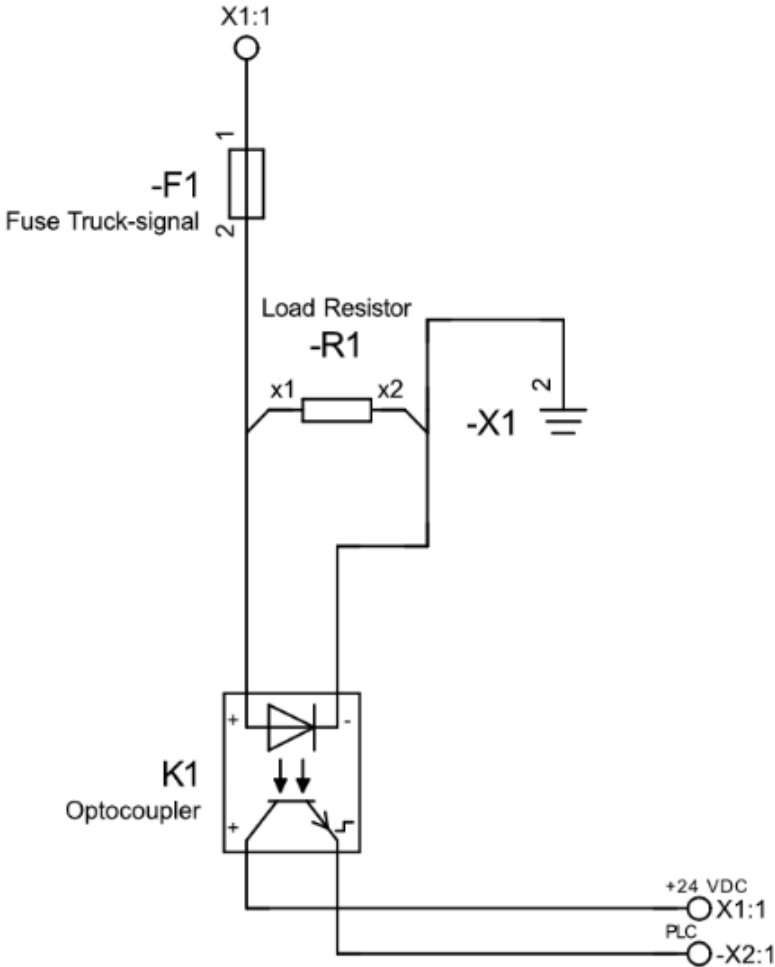


Figure 28 Wiring diagram input side (One Chanal).

This electrical system involves the following parts see Table 7

*Table 7 Electrical parts in the electrical system*

<b>Components</b>	<b>Purpose</b>
<b>3A/5A Fuses</b>	Protect each pin input from overload or fault conditions
<b>Load Resistors</b>	Simulate trailer load to stabilize signals and enable truck-side detection
<b>Optocouplers</b>	Electrically isolate and protect the PLC from voltage spikes and noise
<b>PLC + I/O Modules</b>	Analyze signals and convert them into usable digital outputs
<b>HMI</b>	Display pin status and system messages to the user
<b>12 V Battery Pack</b>	Independent power source for the system
<b>DC/DC Converter</b>	Convert and regulate voltage for use by control system
<b>Indicator Lamps</b>	Provide visual feedback on pin status
<b>Buttons</b>	Manual interaction with the system
<b>Electrical Cabinet</b>	Safe, enclosed housing for all components
<b>Emergency Button</b>	Shuts down the system instantly if a fault or dangerous situation occurs

The system needs to handle a maximum of 22 pins, and therefore a 25-pin DSUB connector is used. This choice allows the signals to be organized into three groups of eight pins each (8 bits per group), which simplifies wiring, improves signal handling, and provides a structured approach to signal management. Using a standard 25-pin connector also offers additional pins for system ground or future expansion if needed. Each pin from the connector is protected by a fuse to ensure that no high voltages or potential faults reach sensitive components such as the PLC or pose a risk to the user. After the fuses, load resistors are connected to each pin. This is necessary because the truck's signal validation system checks for a certain current draw on each pin to detect whether a trailer is connected. Without an appropriate load, the truck would not recognize the connection correctly. Each load resistor was selected to simulate the electrical characteristics expected by the truck's system. The load resistors are connected in parallel to each pin to minimize the overall resistance and to ensure sufficient current draw through the system. Using 24 V, 5 W resistors result in an individual resistance of approximately

115.2 ohms per channel. Each resistor is wired in parallel with an optocoupler, drawing a current of around 0.208 A per channel, accurately replicating the electrical behavior of an actual trailer connection. While each resistor remains safely within its rated 5W power limit. The next component the signals pass through are the optocouplers, which serve as an additional layer of protection for the PLC. These components isolate the control system from electrical noise, voltage spikes, and potential grounding issues. Further ensuring that only clean and safe signals reach the PLC.

The PLC is the central unit of the system. It receives and analyzes the incoming signals from the truck and converting them into digital outputs. These outputs are used to control various interface elements. Such elements are the HMI (Human Machine Interface), indicator lamps and buttons. The HMI provides an interface showing whether each pin is active and functioning correctly. The result is similar to the way a multimeter would display results.

The system is powered by a battery connected to a power module. This module regulates the voltage and ensures that the PLC, HMI and other components receive the correct power levels. The power system is for the control system. The truck only provides signal voltage. The reason for this setup with a battery is because if the truck would power the system there would be rapid power on and power off which could result in damaging the components.

For safety, emergency stop buttons are installed at key points in the system. These allow immediate disconnecting power, protecting both the equipment and the user in case of an emergency or fault. Additional components include industrial indicator lamp providing a clear visual indication of the truck and the pin's status. As well as push buttons that allow the user to interact with the test rig manually if needed. Finally, all electrical components, including wiring, fuses, and electronics, are housed within a sealed electrical cabinet to ensure safety, protection from environmental factors, and a clean, organized layout for easy maintenance.

The complete system can be seen in Figure 29. It should be noted that the wiring diagram below only shows one input signal from the truck, as all signals are connected in the same way. The same applies to the indicator lamps, where only one out of ten lamps are shown for clarity.'

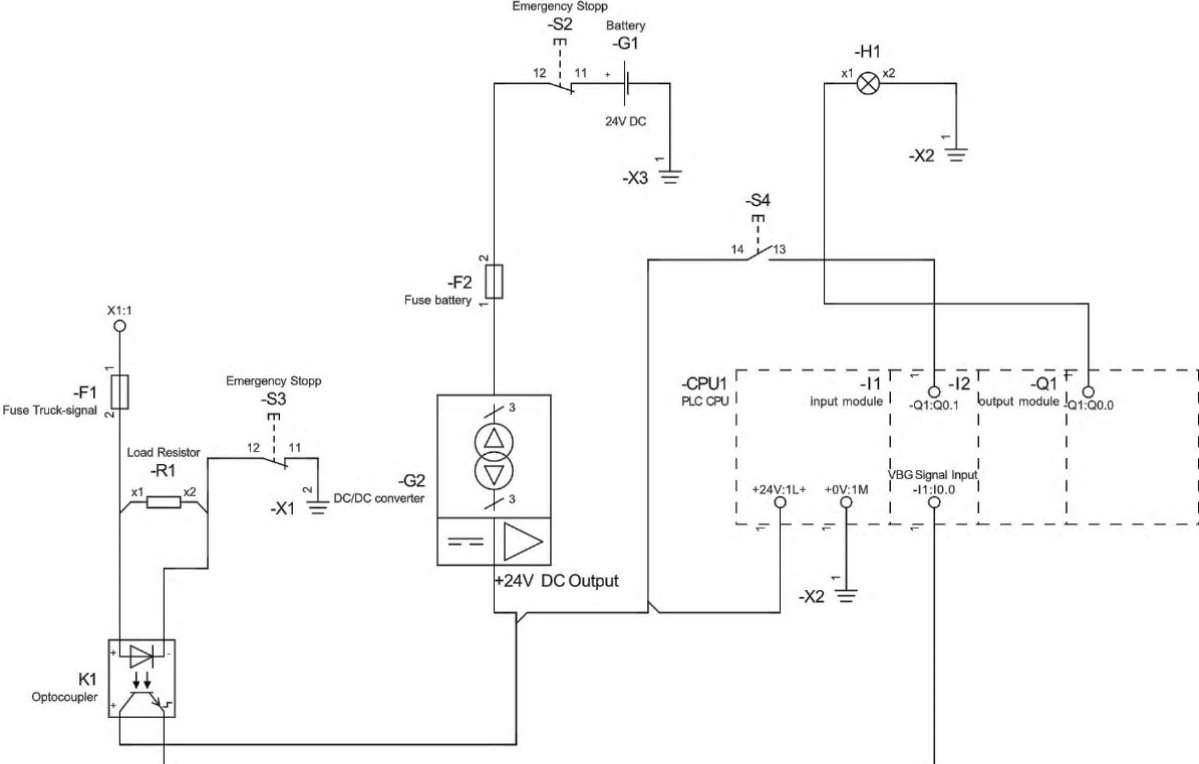


Figure 29 Wiring diagram of the complete electrical system.

# 6.2. Component Selection

The selection of appropriate components is crucial to ensure compatibility, durability and cost-effectiveness. A morphological matrix was used to compare key options and justify the final choices for the critical systems of the test rig.

## 6.2.1. PLC

Table 8 PLC Evaluation Matrix

Evaluation Criteria	Siemens S7-1500	Siemens S7-1200 G2	Raspberry Pi
Industrial reliability	Excellent	Very Good	Low
I/O support	High (scalable)	Medium (sufficient for CA)	Limited
PROFINET/Ethernet support	Full	Full, with isochronous real-time	Limited
Ease of integration with Volvo systems	High	High	Low
Size/footprint	Large	Compact	Very Compact
Cost	High	Moderate	Very Low
HMI integration	Full	Full	Requires external dev.
Modularity/future expandability	High	Medium High	Limited
Maintenance support & availability	Strong	Strong	DIY/Community
NFC-based diagnostics	No	Yes	No

Based on an evaluation shown in Table 8 of the various PLC/computer options available on the market for use on the test rig, the Siemens S7-1200 G2 is the most suitable choice. This PLC offers an optimal balance between functionality, reliability and cost efficiency. It has industrial-grade performance and high I/O capabilities that fit very well with the requirements of the CA environment. Its compact size is particularly ideal for use in space-limited environments, while still offering future expansion possibilities and modular expandability.

Compared to the bigger and more expensive S7-1500, the S7-1200 G2 provides appropriate levels of technical performance at much lower costs, making it better suited to the budget level of this project. Compared to the Raspberry Pi, which has limitations in industrial reliability, few built-in I/O features, and a sparse support base, the S7-1200 G2 provides robust and secure performance in a CA production environment.

A unique feature of the G2 is its integrated Near Field Communication (NFC) capability. This enables fast, wireless connection to diagnostic data and device options on handheld devices, making installation, troubleshooting and service much easier for maintenance. The integration with existing equipment used by Volvo increases its value as a functional and scalable solution. Overall, the S7-1200 G2 fulfills the needs of the project in terms of technical specifications while providing low cost and future development opportunities, making it the most optimal choice.

### 6.2.2. HMI

Table 9 HMI Evaluation Matrix

Evaluation Criteria	Unified Basic Panel MTP1200	Unified Comfort Panel MTP1200	Android-based screen
<b>Industrial reliability</b>	High	Very High	Low
<b>Compatibility with TIA Portal</b>	Full	Full	None
<b>Ease of integration with PLC (S7-1200 G2)</b>	Seamless	Seamless	Manual setup required
<b>Cost</b>	Moderate	High	Low
<b>Engineering effort (HMI config)</b>	Low	Low	High (custom dev)
<b>Standard features (logging, alarms, etc.)</b>	Yes	Yes + advanced features	Needs custom apps
<b>Scalability and expandability</b>	Medium	High	Low

The Unified Basic Panel MTP1200 is the optimal choice here as it provides basic industrial functions required for a stable HMI interface without extra costs and complexity in the form of a Comfort Panel. It is specially designed for direct interface with Siemens S7-1200 G2 using TIA Portal with high compatibility and usability. It supports basic graphical functionality and standard touch screen usage, which is sufficient to provide test data and basic control screens in this CA workshop scenario.

Compared to an Android-based display, the Basic Panel is more durable, has greater system stability and is easier to be maintained in an industrial environment. However, the higher price and extra graphical functionality offered by the Comfort Panel may be redundant for the current nature of this trailer test rig. Overall, the Unified Basic Panel MTP1200 is an affordable, robust and efficient option that meets both the technical and ergonomic requirements of operators and is best suited as the HMI in this application.

### 6.2.3. Optocoupler

Table 10 Optocoupler Evaluation Matrix

Criteria	Phoenix PLC- INTERFACE SSR	Optocoupler Terminal Block	Amazon Optocoupler Board
<b>Industrial-grade reliability</b>	Very High	High	Low
<b>DIN rail mount support</b>	Yes	Yes	No
<b>Ease of installation &amp; wiring</b>	Plug-and-play	Requires some wiring	Often DIY-level setup
<b>Support/documentation</b>	Excellent	Moderate	Poor
<b>Cost</b>	High	Moderate	Very Low

Phoenix PLC-INTERFACE solid-state relay is the most industrial and reliable optocoupler-based solution for use on the test rig. It is specifically designed for use with 24V industrial control systems and provides certified galvanic isolation, good switching performance and strong protection options. The plug-and-play integration and DIN-rail mountability make it easy to integrate directly into existing Siemens-based PLC architectures.

While cheaper Amazon-type boards may not have sufficient documentation, verified specifications or industrial certification, the Phoenix relay is designed to operate safely and reliably in industrial factory environments. Unlike a terminal block optocoupler, it also has better installation convenience and better isolation values, which are required for future long-term support as well as compliance in a production environment.

Although the price is higher, the Phoenix is unrivaled in terms of safety, ease of integration and reliability, making it optimal for a production-ready, maintenance-friendly and professional test rig.

#### **6.2.4. Power Supply**

The QUINT4-PS/12-24DC/24DC/2.5/PT power supply was chosen because the product fits control systems perfectly. It handles a wide input voltage range, making it stable even if the current is not perfect, and gives the possibility to power the system in several ways. The 2.5 A output matches what our control system needs without being oversized. It's also highly efficient, saves space by mounting on DIN rail and has smart features like boost mode and early fault detection. It is simply a reliable and future-proof choice for the test rig.

#### **6.2.5. Fuse Holder**

The PT 4-FSI/F was chosen because it is easy to use and fits well in the test rig. The push-in connection makes wiring quick and tool-free, saving time during installation. It also uses common car fuses already in the workshop, so replacements are quick and easy without the need for special parts. It is a practical and maintenance friendly choice.

#### **6.2.6. Load Resistor**

A 115 ohm load resistor was used to simulate 24V 5W LED lamps in the test rig. Load resistors are very similar to the actual electronic characteristics of the lamps, resulting in an accurate load behavior. The stability and quality of the signal is also maintained through this resistance during the tests, which helps the system to identify the load correctly. This also avoids a high resistance being wrongly identified as a fault or a missing lamp.

## 6.3. PLC Programming

The programming of the test rig was done using Siemens TIA Portal V20 with Ladder Diagram (LD), Function Block Diagram (FBD) and Structured Text (ST) as programming languages according to IEC 61131-3 standard. The Ladder Diagram was mainly used to perform simple logical operations, while FBD and ST were used to implement advanced and reusable function blocks. The program structure focuses on modularity, scalability and readability to ensure that future additions and modifications can be easily performed.

One of the main elements of the program is the channel activation manager. This function scans 24 input channels which represent different trailer signals. Each of these channels has a corresponding VBG label (e.g. “2A”, ‘2B’, “3A” etc.) The PLC scans these channels continuously to detect new activations, i.e. to detect when a channel changes from FALSE to TRUE. When an activation is detected, the system records the index and label of the active channel. This program block provides a detection of the last activated channel, and also updates a status output indicating the live status of the last active channel. The output of the channel activation manager is then directed to various graphical elements in the HMI so that operators can visually display active channels and directly interpret the results using a user-friendly interface.

A NATO function block has been designed to interpret numerical indices and translate them into the corresponding letters of the NATO connector alphabet. This translation mechanism outputs a set of letters and has a basic control structure to determine the correct letter to be output. If the input is outside the acceptable range of values (1 to 12), the block sends out a blank signal. The translated value of the resulting letter is then linked to a specific NATO section in the HMI where it is clearly visible to the operator.

To complete the validation process, an LED block was created that controls where LEDs corresponding to different functions of the trailer (e.g. warning lights, brake lights, fog lights) light up depending on the function.

In addition to signal monitoring, there is an SNTP server block in the program for time synchronization. The SNTP server is used to keep the HMI synchronized with accurate time information to provide stable connections.

## 6.4. HMI Design – Interaction

This section describes how users interact with the HMI to operate the test rig. It covers interface layout, navigation design, and visual indicators that improve usability during testing tasks.

### 6.4.1. Home Screen

The home screen serves as the initial interface for the user. It also serves as the central point from which all other screens originate (see Figure 30). The primary purpose of linking all other screens back to this home screen is for easy recovery in case of errors or unintended selections. If a user realizes they've clicked the wrong connector or made a faulty choice, they can swiftly return to this starting point and then make the correct choice. Facilitating easy recovery.

Signifiers have been strategically applied. This by having function that are intended to be used more frequently, such as the connectors (VBG, NATO, and 15-PIN), occupy larger spaces. Thereby being more visually prominent to clearly guide user attention. Mental models have been carefully considered in the design. Because the home screen is densely populated with information, clickable elements are clearly distinguished through visual cues like shading and subtle shadows. The intent being to effectively signal interactivity to the user and aligning with their expectations of how interactive buttons should appear.

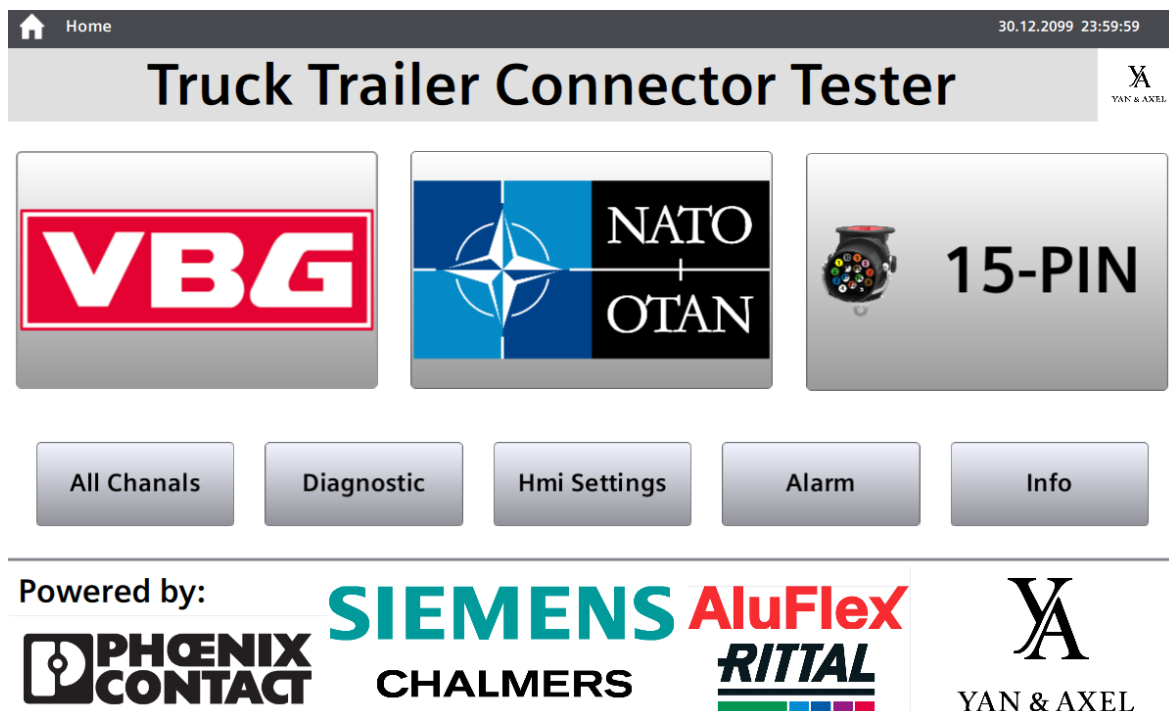
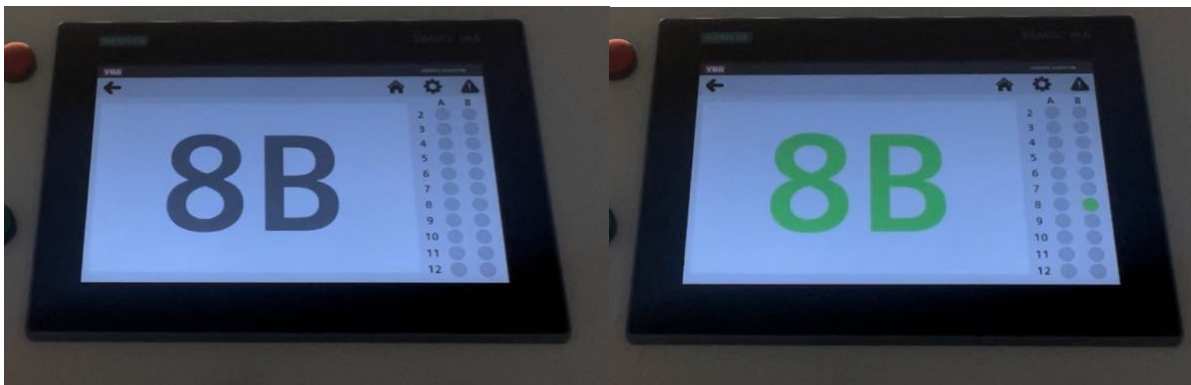


Figure 30 Home Screen

## 6.4.2. Signal Screen

The signal testing screens of the HMI, specific to each connector type (VBG, NATO, and 15-PIN), are presented in separate sections (see Figure 32 for VBG, Figure 33 for NATO, and Figure 34 for 15-PIN), but they follow the same logic and user interaction principles, despite slight variations in their individual layouts. Each screen is designed with clarity and rapid identification in mind.

The most recently activated pin is prominently displayed in large text at the center left of each screen. If a pin is active, the text appears in green (see Figure 31). This with intent of clearly indicating a successful connection leveraging the mental model associating green with “OK” or operational functionality. If a pin is inactive, it is displayed in gray, aligning with the conventional mental model where gray indicates inactivity or non-functionality.



*Figure 31 Activated Pin Screen*

All screens employ a left-to-right layout that aligns with natural reading patterns, positioning primary information (the active pin indicator) prominently on the left, while secondary information (an overview of all pins) is organized to the right. This approach follows the Law of Continuity, enhancing efficient scanning of information and supporting quick recognition, thus enabling operators to maintain focus on troubleshooting one pin at a time—a design choice validated through user interviews. Navigation elements, including the back button (arrow at the top left) and home and settings icons (top right), are consistently placed according to established usability heuristics, ensuring intuitive interaction across all screens.



Figure 32 VBG signal screen

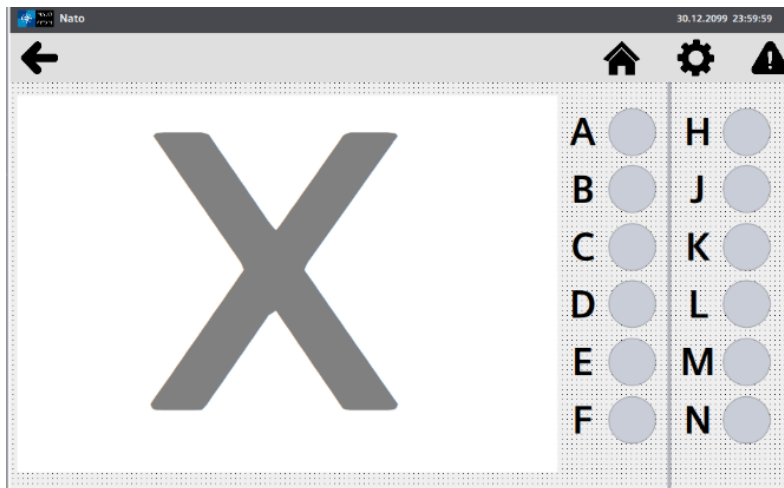


Figure 33 Nato signal screen



Figure 34 15-PIN signal screen

### 6.4.3. Chanel Screen

As noted by the technicians, there may be instances when other connector types could appear, potentially rendering the test rig ineffective. Therefore, an all-around screen, known as the channel screen, was added (see Figure 35). This screen is intentionally nonspecific, designed simply to test whether individual pins function correctly, regardless of their specific contact markings. While this screen may lack certain usability refinements, given its primary focus on broad functionality, essential usability elements such as inactive electrical functions being shown in gray and active functions being green are retained, aligning with established mental models. Additionally, the numerical layout follows a left-to-right pattern consistent with Western mental models, enhancing intuitive understanding of pin positioning and function.

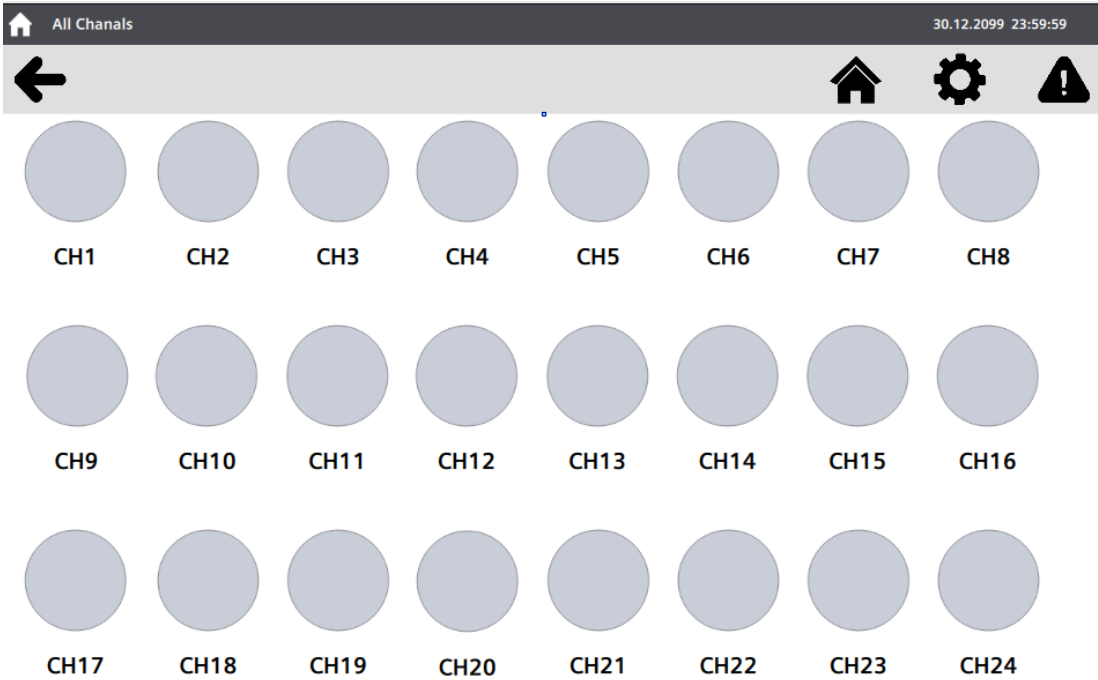


Figure 35 Channels Screen

### 6.4.4. Non-User-Focused Screens

Some screens are not intended for technician use, but interacting with them does not cause any issues. Their primary purpose is to support maintenance or repair tasks. This can be both software and hardware related.

#### Diagnostic screen

The Diagnostic screen's main purpose is to support maintenance when issues arise with the test equipment that require troubleshooting (see Figure 36). This screen is intended to test all possible technical-to-software interactions.

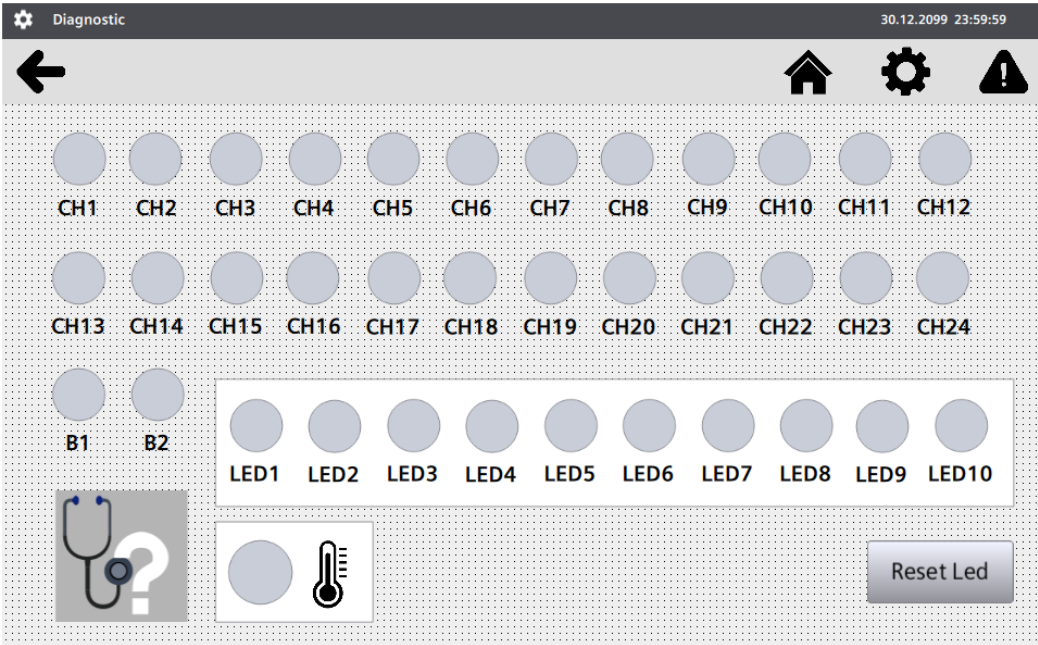


Figure 36 Diagnostic Screen

# System Diagnostics

From the Diagnostic screen, the System Diagnostic screen can be accessed by clicking the diagnostic symbol with a question mark. This screen allows for further investigation of diagnostics for maintenance purposes (see Figure 37).

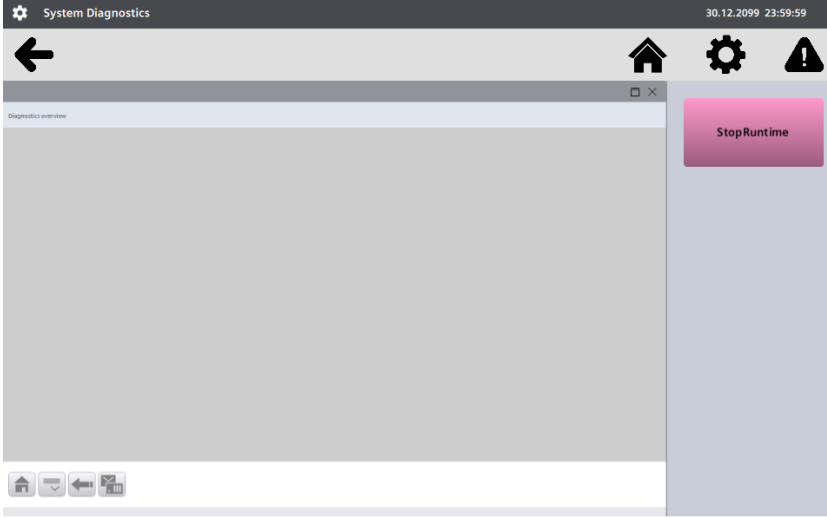


Figure 37 System Diagnostics

# Alarm Screen

The Alarm screen displays active and historical system alarms to assist in troubleshooting and monitoring. It includes important information such as alarm class, origin, area, and timestamps. This is for when each alarm was triggered and modified. Although users can interact with the screen, it primarily serves as a diagnostic tool (see Figure 38).

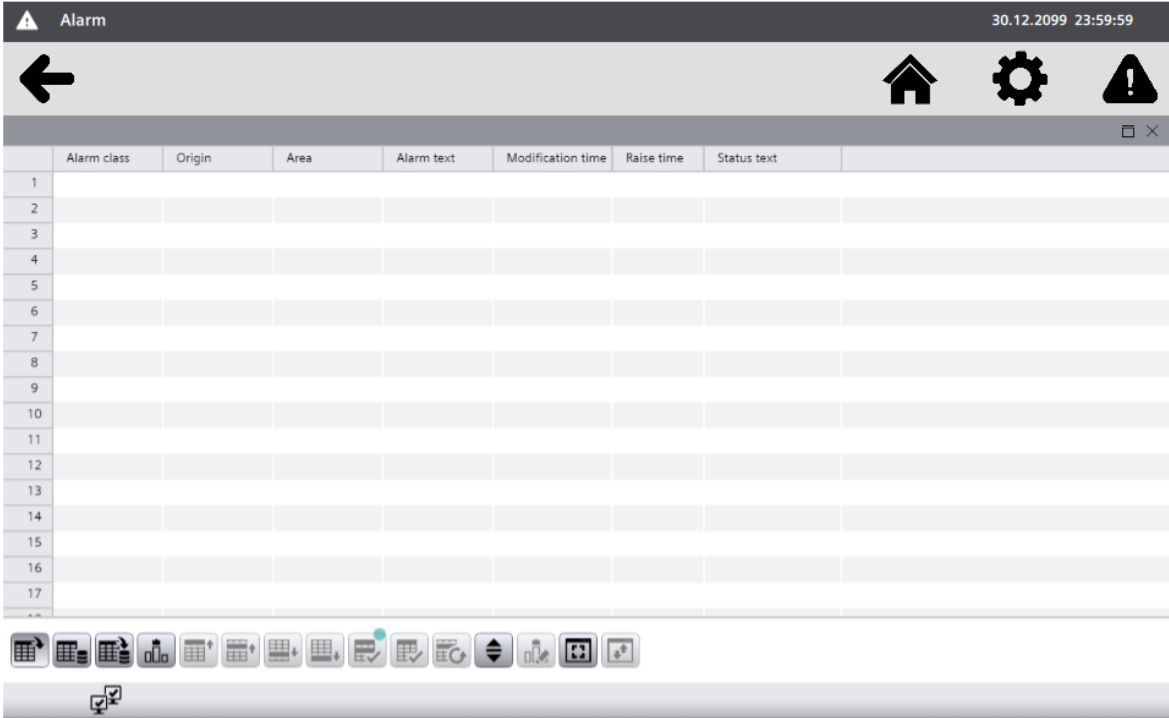


Figure 38 Alarm Screen

## 6.5. Low Fidelity Prototype

To better understand the electrical system of the truck and to avoid issues later in the development process, a low-fidelity prototype of the electrical system was created (see Figure 39) This prototype was used to test the connector and simulate the signal flow in Volvo's heavy-duty trucks, allowing early verification of functionality and identifying potential design challenges.

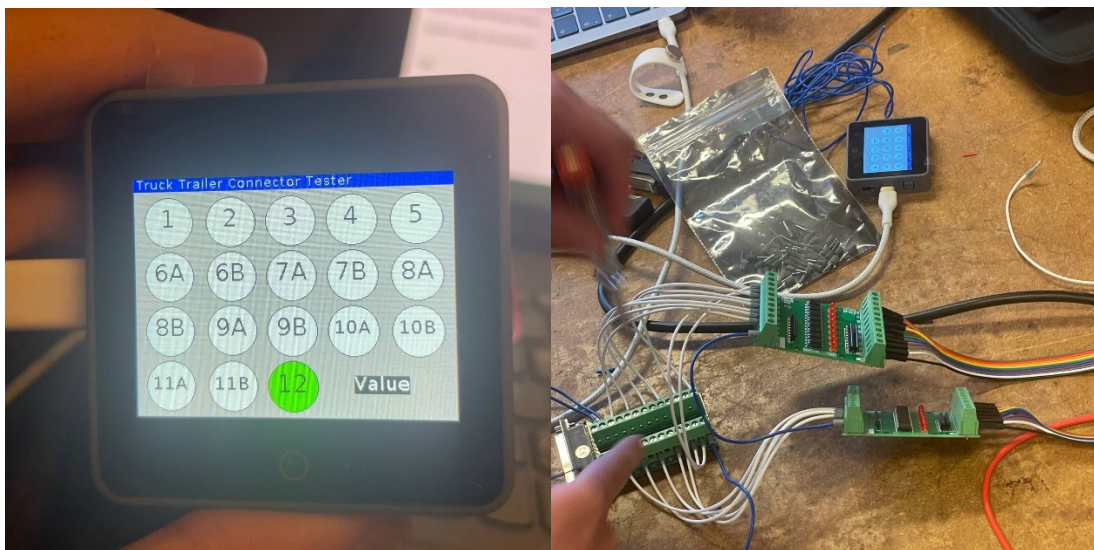


Figure 39 Prototype screen and modules without connection to the truck.

As a result of this testing, we discovered that the truck's electrical system includes a checking mechanism that detects whether a trailer is connected by measuring the load on the pins. To confirm this, we added load resistors to our prototype and verified that the system responded correctly, confirming our assumption.

The low-fidelity prototype followed the same structure as the intended electrical system. However, due to cost and time constraints, cheaper components were used to simulate those planned for the final version. An overview of the components used in the prototype and their representative counterpart can be seen below (see Table 11).

Table 11 Components used in the prototype and their representative.

<b>Component Function</b>	<b>Component on prototype</b>	<b>Component on final product</b>
<b>Connector Interface</b>	DSUB 25-pin cable + DSUB breakout board	DSUB 24-pin industrial connector
<b>Signal Isolation</b>	MEROURII Optocoupler Module (8-channel, 12–24V)	Industrial optocouplers
<b>Signal Handling &amp; Display</b>	Signal Handling & Display	PLC + HMI system
<b>Wiring &amp; Signal Routing</b>	AZDelivery Nano Terminal Adapter Board + jumper wires	24V industrial battery + DC/DC converter
<b>Power Supply</b>	M5Stack USB / internal battery	M5Stack USB / internal battery
<b>M5Stack USB / internal battery</b>	On-screen display via M5Stack	HMI screen + External indicator lamps

## **6.6. Maintenance**

A simple maintenance program has been created to keep the test rig operating in a consistent manner. Preventive maintenance must be performed every three years in the form of updating the PLC and HMI software, retightening all screws and bolts (as vibrations can cause them to loosen), replacing the D-sub 25 main cable with its connector and adapter, checking that the battery and power converter are working stably, cleaning, checking for dust, wear or damage, and testing the emergency stop functions and indicator lights to ensure they are working.

Corrective maintenance is only done when something breaks. As the rig is modular, most components can be easily replaced with little impact on the rest of the system. The diagnostic capabilities and well-labeled wiring with Wago connections make it easy for technicians to quickly solve problems. The majority of components are standard components, making repairs easier and downtime limited.



# 7. Final Product

*This section summarizes the completed prototype and presents its key features, including its technical capabilities, physical layout, and how it fulfills the stakeholder and user requirements identified earlier.*

# 7.1. Description

The final product is a test rig that is compact, mobile, and specifically designed to meet the daily needs of technicians working with signal testing between trucks and trailers. An image of the rig from the front can be seen in Figure 41, and a rear view with the electrical cabinet open is shown in Figure 42.

The rig is built on an anodized aluminium extrusion frame. The industrial cart is both lightweight and durable, making it well suited for demanding workshop environments. The cart's maximum dimensions are approximately 700 mm in length, 500 mm in width, and 1500 mm in height (see Figure 40). These compact dimensions ensure that it can be easily maneuvered and positioned in tight spaces, even when trucks are parked close to walls or other equipment an important requirement, as technicians often need access to trailer connectors limited angles from.

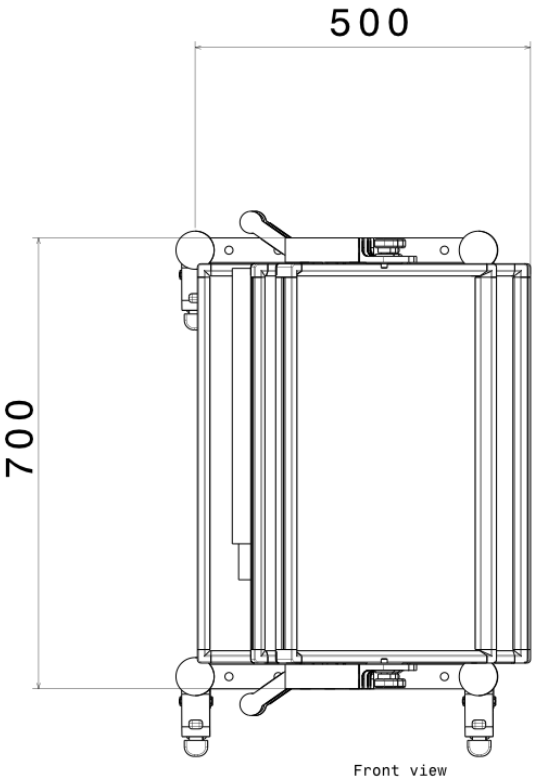


Figure 40 Dimensions of product.



Figure 41 Product from the front.

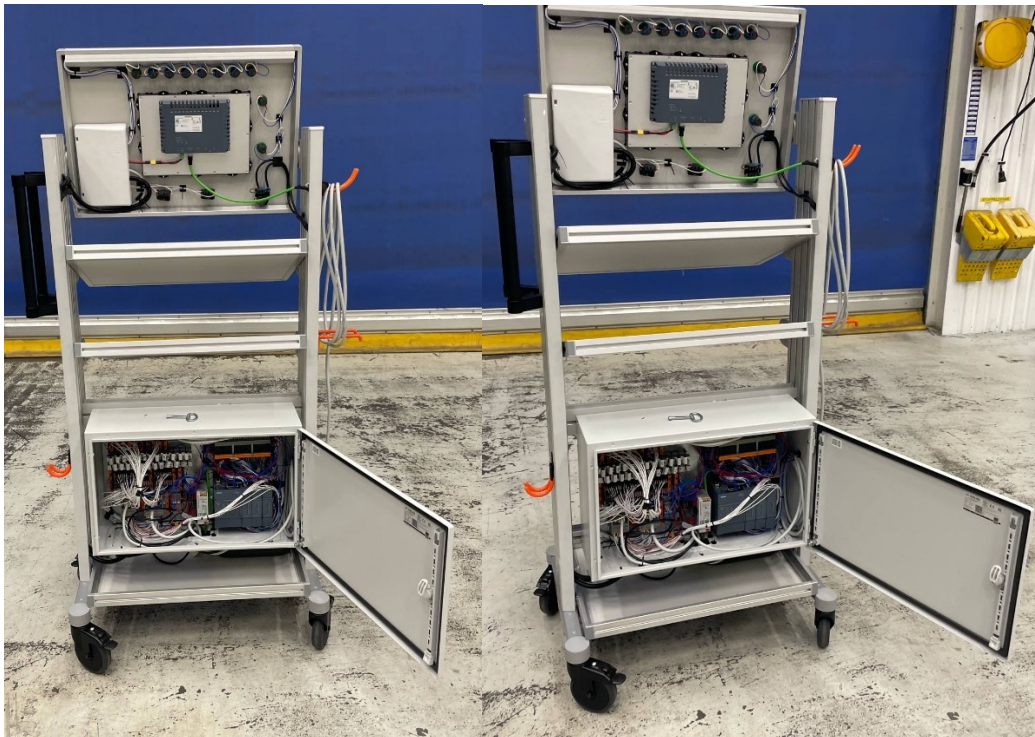


Figure 42 Product from the back.

Mounted at the top of the cart is an adjustable HMI display plate, designed to hold a 12” Siemens Unified Basic Panel. The tilt mechanism allows for optimal visibility from various operator positions. This is especially important given the feedback from users who wanted to be able to clearly see which pin was active even when sitting inside the cab of the truck. The HMI interface has been configured to show the currently active pin in large green. And in grey if previous activated. On the side of the display is a dot matrix visually represents all pins. This to enable detection of multiple active signals at once. This display setup ensures that technicians can reliably interpret test results even at a distance

In addition, other important features are two modular trays designed to hold adapter cables for various connector standards. These trays are framed in aluminium with raised edges to prevent slipping and can be repositioned to suit different working angels. The bottom shelf supports a fully enclosed electrical cabinet housing the PLC system, optocouplers, fuses, and DC/DC converter, along with a separate battery compartment. The system is fully self-powered and electrically isolated from the truck. This ensuring operational safety and reducing the risk of voltage disturbances. The power system is designed to be fully working during a whole operation shift from beginning to end

The entire construction is robust and estimated to require no regular maintenance for up to 10 years. Together, these design features make the test rig not only compact and portable but also highly functional, addressing real-world ergonomic and usability challenges identified during the observation and interview phases.

## **7.2. Preliminary Testing**

To ensure that the final prototype met expectations for both functionality and durability in real and demanding usage scenarios, a series of initial tests were conducted.

### **7.2.1. Functional Verification**

The first test phase aimed to confirm the preliminary functionality of the system with stable power supply conditions. The test rig was connected to a stable 24V regulated power supply and each HMI page was inspected in turn to confirm functionality and response. The test aimed to ensure that inputs in the way of signals through the truck contacts always triggered the resulting system responses in the HMI and indicator lights.

### **7.2.2. Load and Stress Test**

To confirm the reliability of the system in long-term use, a stress test was carried out where all 24 signal channels were triggered simultaneously in a continuous run for 2 hours. This represented an abnormally heavy usage scenario far beyond normal daily use. During the test, both manual observations and heat sensors tracked. The test confirmed that the enclosure maintained a constant internal temperature without overheating and that there were no thermal breaks or component breakdowns. This ensured that the power supply, load resistors, optocouplers and fuses were operating within safe margins even under heavy loads.

### **7.2.3. Field Test with VBG 14 In Real Environment**

After internal validation, the test rig was connected to a truck equipped with a VBG14 connector and placed in a real environment. During this test, the technician used the rig exactly as it would be used in CA scenarios. The HMI correctly identified and displayed active signal pins during various operations, and the cable interfaces were tested for ergonomic handling and durability. The interaction between the test rig and the truck signal output system worked as expected. No unexpected disconnections or signal losses were observed, confirming the reliability of the system in practical use.

#### **7.2.4. REBA**

A REBA analysis was used to assess the ergonomic impact of using the new test rig (see appendix D). REBA analyzes musculoskeletal risks based on posture, force/load, type of movement, repetition and connection when using the rig. A technician was observed using the test rig to perform standard couplings in a customized truck. The assessment focused on the primary body postures during key operation steps: moving the rig to the correct position, attaching and detaching adapters, and using the HMI.

The final score shows a low level of risk and means that current working postures and physical demands associated with the test rig pose little or no immediate risk of musculoskeletal disorders.



## 8. Discussion

*In the discussion, the project results are evaluated against its objectives and the strengths and weaknesses of the realized test rig are discussed. Technical trade-offs are also considered along with user feedback and areas for improvement. The section also describes possible future developments,*

## 8.1. Interpretation of Results

The scope of the project was to improve and develop a test rig solution based on an already existing product. This is a quite concrete results which made the research phase quite short making this project very technical development heavy. This could be a reason to the final solution fulfilling all requirements well. With that said some requirements were not fulfilled, but these were not as important as initially expected and could also not be fulfilled because of time constraints. Such requirements were, for example, the compatibility with pneumatic and hydraulic systems. Pneumatic systems were not considered as important in CA as at the end of the line. Hydraulic systems, on the other hand, where very important for the engineers to test, but according to the technicians it was better that they had a separate system for testing hydraulics rather than incorporating it into the electrical testing system. This was therefore an important point to consider, but was ultimately not included, since adding hydraulic compatibility would have taken too much time and having a separate system for it was considered a better solution.

## 8.2. Feedback From Users

Feedback and the technicians' thoughts have been an important factor throughout the entire project. One major focus was to prioritize showing the pin number on the HMI regardless of how the function itself looks. For example, instead of using physical blinker icons or graphics to represent functions the pin number was prioritized. This decision was based directly on technician feedback where they explained that when troubleshooting the truck they only focus on the pin number and not on what function it represents. Another important feedback point was that the test rig should be easy to move and transport. This is because one piece of equipment would need to be used across multiple trucks during a workday. This was carefully considered in the final design. One piece of feedback that was not fully followed was the technicians' strong interest in a smaller, handheld test rig. However, early in the project it was realized that this would be difficult to achieve within the technical and functional requirements. Instead, focus was placed on other feedback such as ensuring that adapters were easy to reach and organized during use.

## **8.3. Weaknesses and Uncertainties**

Safety and maintenance are two key aspects that have been considered throughout the project however there are still some uncertainties in this area. This regards the resistors, since they have not been tested during longer use. The resistors are there for a component that could be improved. The current resistors used are isolated to resist heat. However, they are sourced from Biltema, which means the quality is not production approved. This results in a resistor that works but is somewhat unreliable in the long term. If money and time had not been limiting factors, we would have used industry graded resistors from a more reliable producer to ensure higher durability and consistency. The equipment is mobile, and the electrical components are not rated for micro-vibrations. This is also an uncertain factor affecting the test rigs lifespan.

## **8.4. Further Work**

Although the developed test rig fulfills the main requirements of the project scope satisfactorily, there are some areas where there is room for further development and optimization.

### **8.4.1. Integration of Hydraulic and Pneumatic Testing**

One of the initial objectives was to be able to test both hydraulic and pneumatic systems. However, due to time constraints and the priority of electrical functions, these functions were excluded from the final product. In later versions, additional modular features may be added to allow the rig to check hydraulic operation and pneumatic pressure, possibly using pressure sensors or built-in pneumatic control valves. This would increase the functionality of the rig and be in line with the needs of the technicians.

### **8.4.2. Wireless or Remote Interface**

The current rig has a fixed HMI interface on board. While aiming for improved ergonomics and visibility, customer feedback showed that there was a strong desire for wireless functionality. In later developments, Bluetooth or Wi-Fi modules can be integrated to allow technicians to receive signal monitoring via tablets or smartphones in the cabin, increasing convenience and minimizing physical strain.

### **8.4.3. Logging of Results and Traceability of Data**

The results of the tests are currently only displayed in real time and are not stored. The future development would be to include a data logging system that records each test session, contact type and test result. This would allow traceability, fault tracking and quality control. Integration with Volvo's production database or cloud storage could be considered for easy documentation.

### **8.4.4. Extended Load Tests and Environmental Durability**

Although the rig is designed to be used in industry, extended testing under different environmental conditions (e.g. humidity, dust, temperature variations) remains to be performed. Life cycle tests to confirm the reliability of components such as fuses and resistors, especially in extreme operating situations, should be performed.



# 9. Conclusion

*The concluding chapter summarizes the findings in relation to the research questions presented in Chapter 1.*

The developed test rig is designed and optimised to verify a comprehensive set of electrical contacts, including VBG (14-, 17-, and 22-pin), NATO 12-pin and ISO 12098 (15-pin). However, the test rig can test more contacts to optimize both efficiency and accuracy, the rig supports simultaneous testing of up to 22 pins but is optimised for testing one function at a time. This configuration balances signal verification with operational speed, ensuring robust diagnostics while maintaining cycle time efficiency.

While the current prototype focuses on electrical systems it also incorporates modularity to support future testing of pneumatic, hydraulic systems or other kinds of testing. This modularity aligns with Volvo's broader goal of verifying all key systems to increase production quality and minimize manual rework. The rig enhances daily production efficiency by giving an user friendly reliable verification of electrical signals, improving ergonomics and enabling quicker fault isolation.

Integration with Volvo's production systems is achieved through Siemens' TIA Portal and PROFINET. This ensuring seamless connectivity with existing PLC and automation infrastructure. The test rig also embodies Industry 4.0 principles through future remote monitoring capabilities, data logging for traceability, and future potential for cloud integration and predictive diagnostics.

To maximize user-friendliness, ergonomic design principles were applied. The rig allows operation by a single technician, includes easy-to-read interfaces, and provides flexible adapter placements to reduce physical strain. Additionally, it accommodates diverse user groups through intuitive feedback mechanisms, modular hardware for varying workflows, and durable construction suitable for CA.

Key design parameters such as load simulation resistors, optocouplers for signal isolation, and fuse protection guarantee accurate and safe verification. The concept is fully documented, designed for long-term maintainability, and standardizable, enabling scalability across different Volvo production sites and workshops.

In summary, the test rig meets all critical requirements: it is technically robust, user-centric, scalable, and aligns with Volvo's long-term vision for smart, adaptable production tools.



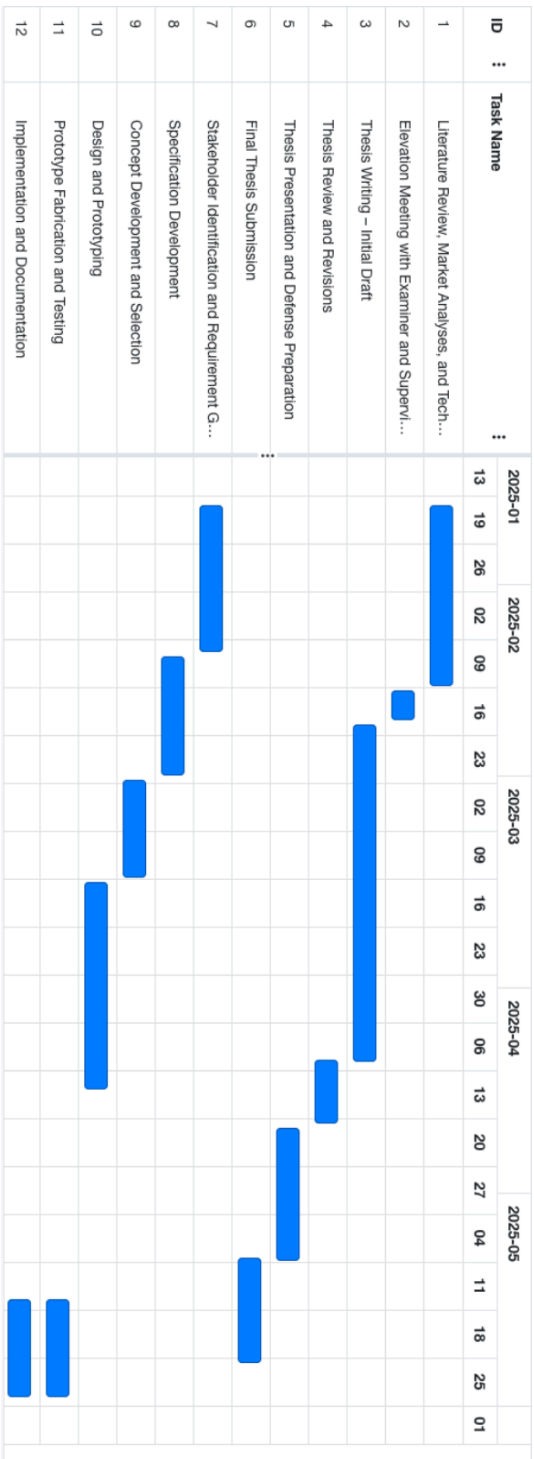
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# Appendix

## A Gantt Chart



# B Observation End of Line

## 1. Task Description

- **Task Name:** Test the different light functions on a standard truck
- **Purpose:** to ensure that the trailer connections are working properly both pneumatic and electric
- **Environment:** End of line. fast paste. Repetitive
- **Equipment/Tools Used:** Hands, connectors. Cables, Test rig

---

## 2. Observation

### Process Steps:

1. Identify the type of truck.
  2. Roll the test rig into position.
  3. One operator enters the truck; the second stays by the test rig.
  4. Begin with electric function testing, followed by pneumatic.
  5. Detach all connections and return the rig to its storage position.
- **Behaviour and Interaction:**  
Both operators observe the test rig during testing, which gives an impression of uncertainty and lack of confidence in the process.
  - **Problem Areas Identified:**
    - Poor visibility of pneumatic test results.
    - Difficulty inserting the contact connectors.
    - No clear sorting or organization of various connectors.
    - Lack of result registration or logging.
    - Pneumatic test procedure is ergonomically poor.
    - Many cables are damaged, frayed, or worn out.
    - Excessive resource usage for a standardized test process.

---

## 3. Thoughts and Notes

- Numerous add-on features were observed, such as paint protection layers and custom comfort grips on handles.
- Comfort enhancements on handles appear to be retrofitted rather than factory-standard.
- Various adapters are mounted in improvised, handmade locations rather than their intended, designed positions.

# C Observations and Analysis CA

## 1. Task Description

- **Task Name:** Test the different light functions on a modified truck
- **Purpose:** to ensure that the trailer connections are working properly
- **Environment:** Customer adaptation workshop. well-equipped with a variety of tools and machinery. It has a calm, non-stressful atmosphere where precision is key
- **Equipment/Tools Used:** Hands, connectors. Cables, Test Rigg

---

## 1. Observation

### Process Steps:

1. Roll the test rig into a good position to be able to see the result
2. Identify the correct socket to use.
3. Retrieve or select the appropriate adapter.
4. Connect the adapter along with the extension cord.
5. Test the indicators (blinkers).
6. Test any additional functions.
7. Record the test results. (done by memory)
8. Disconnect the connection.
9. Place the test rig in an appropriate location.

### Behaviour and Interaction:

- interacts with the tool in a calm manner.
- Had problems with getting the connections to fit well
- moves it with ease

### Problem Areas Identified:

- Problem.1 Difficult to see the values on the test rig especially for extra functions
- Problem 2. No registration of test result
- Problem 3. Difficult to fit the test rigg into some spaces. Takes space
- problem 4. The cables are clumsy and break no good cable management
- problem 5. ergonomic issue to look in the back mirror
- problem 6. adapters are placed non ergonomic
- problem 7. Difficult to connect adapters to the test rig

---

## 3. Analysis of Problems

- **Root Cause of Problems:**
- **Cause 1.** The lamps or numbers are not big or clear enough. its not possible to read out the information.
- **Cause 2.** The test rigg do not allow for this to be done easily therefore its no need
- **Cause 3.** The Test Rigg is too big
- **Cause 4.** The cables are big and no way to store them'

- **Cause 5.** mirrors image
- **Cause 6.** There is not enough space and holder for them
- **Cause 7.** Connectors not made for easy connections and repetitive use

#### **Impact of Problems:**

The working process takes longer. Values might get switched up which results in incorrect test results. The test rig is non ergonomic to work with because of placement of components. Testing needs frequent corrective maintenance to keep it working.

---

#### **Commentaries:**

Ingen loggning av resultat, Teknikerna kommer ihåg testresultaten manuellt. Detta är problematiskt eftersom hela testet måste göras om om det finns någon osäkerhet. En loggningsfunktion skulle bidra till att undvika onödiga omprovningar.

Lufttryckstestet är grundläggande, Endast förekomsten av luft testas, inte den faktiska trycknivån, vilket begränsar diagnosmöjligheterna.

Besvärliga anslutningar, Vissa kontakter är svåra att skruva i, särskilt när de är skadade. En specifik kontakt (17-polig) var lättare att använda än en annan som var kraftigt utsliten.

Problem med spegelns synlighet, För att kontrollera indikatorerna måste testriggen placeras så att den syns i backspeglarna, vilket kan vara obekvämt.

Sekvens för funktionstest, Testningen börjar ofta med att lastbilen slås på och blinkers aktiveras först.

Otydlig märkning: En funktion (11B) kunde inte verifieras eftersom en etikett var dåligt fäst och svår att se, vilket krävde att teknikern dubbelkollade manuellt.

Hjälp krävs ofta, Vissa anslutningar eller tester kräver hjälp av en annan person, särskilt när riggen är svår att placera eller i trånga utrymmen.

Osäkerhet om anslutningar, I flera fall var teknikerna osäkra på vilket kontaktdon som skulle användas och var tvungna att kontrollera manuellt.

Variationer i lastbilarna komplicerar testerna, Varje ny lastbilsmodell kan ha olika kopplingsbehov, t.ex. för att lyfta specifika axlar, vilket ökar komplexiteten.

Trångt arbetsutrymme, I trånga utrymmen är det svårt att manövrera testriggen och ibland måste man be någon annan om hjälp.

# D REBA



**ERGONOMICS** REBA Employee Assessment Worksheet Task Name: Test Rig 1 Date:

**A. Neck, Trunk and Leg Analysis**

**Step 1: Locate Neck Position**  
 1 Neck Score  
 Step 1a: Adjust...  
 If neck is twisted: +1  
 If neck is side bending: +1

**Step 2: Locate Trunk Position**  
 1 Trunk Score  
 Step 2a: Adjust...  
 If trunk is twisted: +1  
 If trunk is side bending: +1

**Step 3: Legs**  
 1 Leg Score  
 Adjust: +1, +2, +3, +4, +5, +6, +7, +8, +9, +10, +11, +12

**Step 4: Look-up Posture Score in Table A**  
 Using values from steps 1-3 above. Locate score in Table A.

**Step 5: Add Force/Load Score**  
 If load > 11 lbs: +0  
 If load 11 to 22 lbs: +1  
 If load > 22 lbs: +2  
 Adjust if shock or rapid build up of force: add +1 Force / Load Score

**Step 6: Score A, Find Row in Table C**  
 Add values from steps 4 & 5 to obtain Score A. Find Row in Table C.

**Scoring**  
 1 = Negligible Risk  
 2-3 = Low Risk. Change may be needed.  
 4-7 = Medium Risk. Further investigation. Change Soon.  
 8-10 = High Risk. Investigate and Implement Change.  
 11+ = Very High Risk. Implement Change.

**B. Arm and Wrist Analysis**

**Step 7: Locate Upper Arm Position:**  
 +1 +2 +3 +4  
 2 Upper Arm Score

**Step 8: Locate Lower Arm Position:**  
 +1 +2  
 2 Lower Arm Score

**Step 9: Locate Wrist Position:**  
 +1 +2  
 1 Wrist Score

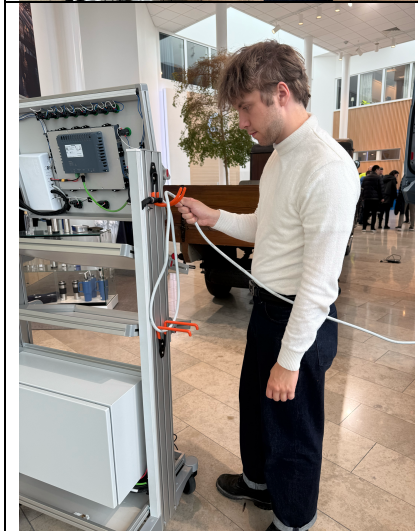
**Step 10: Look-up Posture Score in Table B**  
 Using values from steps 7-9 above. Locate score in Table B.

**Step 11: Add Coupling Score**  
 Well fitting handle and mid-range power grip: good: +0  
 Acceptable but not ideal hand hold or coupling acceptable with another body part: fair: +1  
 Hand hold not acceptable but possible: poor: +2  
 No handles, awkward, unsafe with any body part, unacceptable: +3

**Step 12: Score B, Find Column in Table C**  
 Add values from steps 10 & 11 to obtain Score B. Find column in Table C and match with Score A to row from step 6 to obtain Table C Score.

**Step 13: Activity Score**  
 +1 if more body parts are held for longer than 1 minute (static)  
 +1 Repeated small range actions more than 4x per minute  
 +1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA). Hegret, Macnamay, Applied Ergonomics 31 (2000) 201-205.



**ERGONOMICS** REBA Employee Assessment Worksheet Task Name: Test Rig 2 Date:

**A. Neck, Trunk and Leg Analysis**

**Step 1: Locate Neck Position**  
 2 Neck Score  
 Step 1a: Adjust...  
 If neck is twisted: +1  
 If neck is side bending: +1

**Step 2: Locate Trunk Position**  
 4 Trunk Score  
 Step 2a: Adjust...  
 If trunk is twisted: +1  
 If trunk is side bending: +1

**Step 3: Legs**  
 1 Leg Score  
 Adjust: +1, +2, +3, +4, +5, +6, +7, +8, +9, +10, +11, +12

**Step 4: Look-up Posture Score in Table A**  
 Using values from steps 1-3 above. Locate score in Table A.

**Step 5: Add Force/Load Score**  
 If load > 11 lbs: +0  
 If load 11 to 22 lbs: +1  
 If load > 22 lbs: +2  
 Adjust if shock or rapid build up of force: add +1 Force / Load Score

**Step 6: Score A, Find Row in Table C**  
 Add values from steps 4 & 5 to obtain Score A. Find Row in Table C.

**Scoring**  
 1 = Negligible Risk  
 2-3 = Low Risk. Change may be needed.  
 4-7 = Medium Risk. Further investigation. Change Soon.  
 8-10 = High Risk. Investigate and Implement Change.  
 11+ = Very High Risk. Implement Change.

**B. Arm and Wrist Analysis**

**Step 7: Locate Upper Arm Position:**  
 +1 +2 +3 +4  
 2 Upper Arm Score

**Step 8: Locate Lower Arm Position:**  
 +1 +2  
 2 Lower Arm Score

**Step 9: Locate Wrist Position:**  
 +1 +2  
 1 Wrist Score

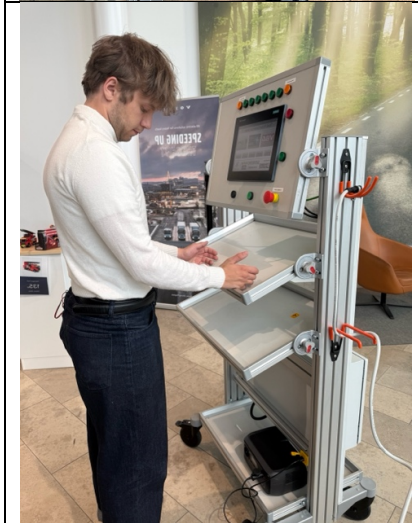
**Step 10: Look-up Posture Score in Table B**  
 Using values from steps 7-9 above. Locate score in Table B.

**Step 11: Add Coupling Score**  
 Well fitting handle and mid-range power grip: good: +0  
 Acceptable but not ideal hand hold or coupling acceptable with another body part: fair: +1  
 Hand hold not acceptable but possible: poor: +2  
 No handles, awkward, unsafe with any body part, unacceptable: +3

**Step 12: Score B, Find Column in Table C**  
 Add values from steps 10 & 11 to obtain Score B. Find column in Table C and match with Score A to row from step 6 to obtain Table C Score.

**Step 13: Activity Score**  
 +1 if more body parts are held for longer than 1 minute (static)  
 +1 Repeated small range actions more than 4x per minute  
 +1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA). Hegret, Macnamay, Applied Ergonomics 31 (2000) 201-205.



**ERGONOMICS** REBA Employee Assessment Worksheet Task Name: Test Rig 3 Date:

**A. Neck, Trunk and Leg Analysis**

**Step 1: Locate Neck Position**  
 2 Neck Score  
 Step 1a: Adjust...  
 If neck is twisted: +1  
 If neck is side bending: +1

**Step 2: Locate Trunk Position**  
 4 Trunk Score  
 Step 2a: Adjust...  
 If trunk is twisted: +1  
 If trunk is side bending: +1

**Step 3: Legs**  
 1 Leg Score  
 Adjust: +1, +2, +3, +4, +5, +6, +7, +8, +9, +10, +11, +12

**Step 4: Look-up Posture Score in Table A**  
 Using values from steps 1-3 above. Locate score in Table A.

**Step 5: Add Force/Load Score**  
 If load > 11 lbs: +0  
 If load 11 to 22 lbs: +1  
 If load > 22 lbs: +2  
 Adjust if shock or rapid build up of force: add +1 Force / Load Score

**Step 6: Score A, Find Row in Table C**  
 Add values from steps 4 & 5 to obtain Score A. Find Row in Table C.

**Scoring**  
 1 = Negligible Risk  
 2-3 = Low Risk. Change may be needed.  
 4-7 = Medium Risk. Further investigation. Change Soon.  
 8-10 = High Risk. Investigate and Implement Change.  
 11+ = Very High Risk. Implement Change.

**B. Arm and Wrist Analysis**

**Step 7: Locate Upper Arm Position:**  
 +1 +2 +3 +4  
 2 Upper Arm Score

**Step 8: Locate Lower Arm Position:**  
 +1 +2  
 2 Lower Arm Score

**Step 9: Locate Wrist Position:**  
 +1 +2  
 1 Wrist Score

**Step 10: Look-up Posture Score in Table B**  
 Using values from steps 7-9 above. Locate score in Table B.

**Step 11: Add Coupling Score**  
 Well fitting handle and mid-range power grip: good: +0  
 Acceptable but not ideal hand hold or coupling acceptable with another body part: fair: +1  
 Hand hold not acceptable but possible: poor: +2  
 No handles, awkward, unsafe with any body part, unacceptable: +3

**Step 12: Score B, Find Column in Table C**  
 Add values from steps 10 & 11 to obtain Score B. Find column in Table C and match with Score A to row from step 6 to obtain Table C Score.

**Step 13: Activity Score**  
 +1 if more body parts are held for longer than 1 minute (static)  
 +1 Repeated small range actions more than 4x per minute  
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