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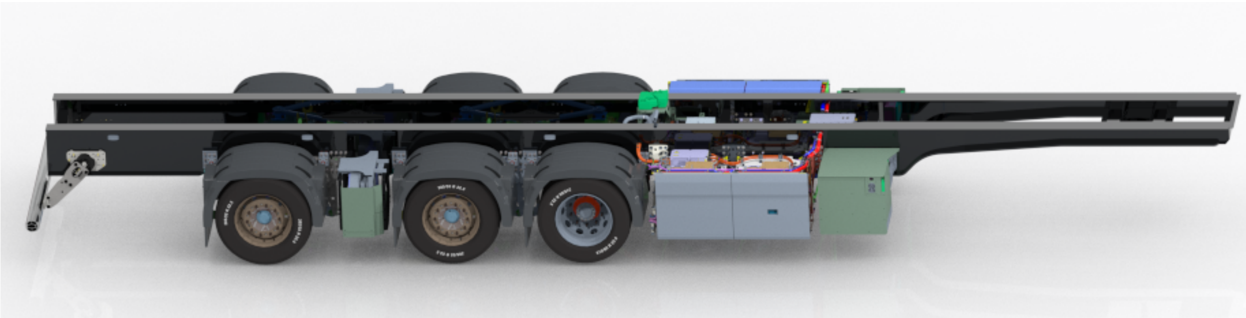

Design and Optimization of Trailer Chassis with Electric Driveline

Master's thesis in Product Development

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Gothenburg, Sweden 2024
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Cover: A render of the chassis for the next generation of the E-trailer.

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Abstract

Addressing the global urgency to reduce climate impact, Volvo Group is committed to reducing vehicle emissions by 40% by 2030. Trucks are essential to modern transportation, highlighting the importance of developing sustainable truck and trailer technologies. Sweden's new High Capacity Transport (HCT) regulation, aimed at lowering carbon emissions, supports this initiative. Furthermore, Volvo GTT is exploring new technologies including the E-trailer, an electric semi-trailer that possibly reduces fuel consumption by 5-20% compared to traditional models.

The purpose of this project is to develop and optimize the next generation of the E-trailer. This includes determining the necessary requirements for the design and development of the chassis utilizing existing Volvo components. Additionally, Hammar Maskin AB, assigned with constructing the prototype, must modify its chassis to integrate effectively with the existing components from Volvo GTT.

The methodology employed relies on a design thinking approach, structured into four interactive phases. The initial phase, "theoretical framework," involves collecting comprehensive information about the E-trailer and gaining insights into related fields. The second phase, "identification," focuses on assessing current market offerings and understanding customer requirements. The third phase, "development," encompasses the entire development process, detailing the tools and strategies used. The final phase, "finalization," thoroughly presents the developed concept, highlighting its specifications and features.

The final design of the E-trailer features a unique semi-trailer with a single chassis that integrates dimensions from Hammar Maskin AB at the front, near the gooseneck, and Volvo GTT's specifications towards the rear, creating a chassis that curves and widens at the back. The chassis has an I-shaped cross-section with specific cutouts to accommodate various components. Modifications have been made to the mounting of specific components, while others have been replaced to optimize the trailer's functionality and performance.

In conclusion, the project successfully developed an E-trailer that meets customer requirements. Hammar Maskin AB's chassis was able to adapt to Volvo GTT's components, making it feasible to develop a single chassis. Recommendations include analyzing the placement of certain components and calculating the weight. Additionally, for future generations, simplifying the chassis to make it suitable for mass production.
Keywords: E-trailer, CAD, Electric driveline, Trailer, Electric powertrain, Propulsion capabilities, Product development, Sustainability, HCT

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We would also like to acknowledge the valuable knowledge and feedback from other employees at Volvo GTT that significantly influenced our project. Additionally, our thanks go to our contacts at Hammar Maskin AB, Lucas Holmberg and Marcus Davidsson, for their excellent collaboration, support, and expertise.

We extend our heartfelt thanks to Docent Lars Lindkvist from the Department of Industrial and Materials Science at Chalmers University of Technology. As our supervisor and examiner throughout this Master's Thesis, Lars Lindkvist has provided invaluable feedback and support for both the project and this report.

Sofia Jost Auf Der Stroth & Elvira Sellgren, Gothenburg, June 2024

List of Acronyms

The acronyms used in this project are listed below. They encompass both general concepts in the field and specific terms used within Volvo Group Truck Technology.

Volvo GTT	Volvo Group Truck Technology
CAD	Computer-Aided Design
HCT	High Capacity Transport

List of Abbreviations

The abbreviation explain some of the words employed in the report. The abbreviations covers both general concepts in the field but also specific that are utilized within Volvo Group Truck Technology.

Trailer	The vehicle behind the truck that transport the goods
Semi-trailer	Trailer that does´t have any front axle
E-Trailer	Semi-trailer that is equipped with an electric driveline
Chassis	The frame of the trailer
HCT	Vehicles longer than 25.25 m and/or heavier than 64 tonnes
E-axle	An axle with the electrical components integrated in the axle
Gooseneck	The part where the chassis narrows down

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1 Introduction

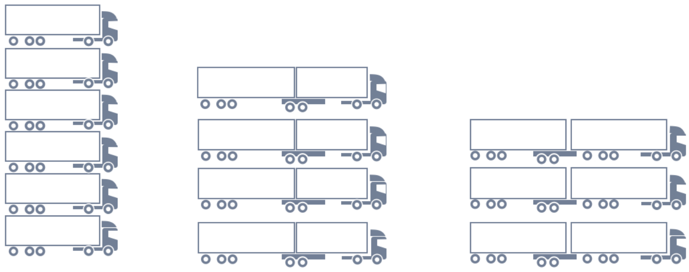
This chapter presents an overview of the foundational context and objectives of the project. Additionally, it outlines the scope and delimitation's of the master's thesis, along with the research questions that are addressed.

1.1 Background

An important turning point in the international effort to take action against climate change is the Paris Agreement. This agreement, which took place in 2015, brings countries together in an effort to reduce the negative effects of climate change. Being a legally binding agreement, it provides a specific goal: to limit global warming and prevent the continuing increase in temperature. Its primary objective is to keep the rise in global average temperature well below 2°C over pre-industrial levels while attempting to maintain the increase to 1.5°C or less (United Nations, 2024).

One of the greatest challenges of today is climate change, and Volvo Group Truck Technology (Volvo GTT) is leading the way among businesses that support the goals of the Paris Agreement in reducing global warming. Volvo's strategy acknowledges the transportation industry's critical role in global climate change, especially regarding reducing dependency on fossil fuels. Therefore, the primary goal of Volvo GTT is to develop and innovate products that significantly decrease carbon emissions while benefiting the environment. Volvo's strategy covers a wide range of areas, from reducing emissions in its operations to addressing the emissions of greenhouse gases originating from the usage of its offered products. Thus, Volvo GTT has set ambitious targets for the truck industry in particular, aiming to reduce emissions per vehicle by 40% by 2030 compared to 2019. Further, the ultimate goal is to have 100% fossil free vehicles within Volvo Group (Volvo Group, 2024b).

Numerous efforts may be considered to improve the transportation industry's situation regarding climate change. Trucks account for a significant portion of the modern transportation system, therefore investigating strategies to minimize the harm is of importance. Thus, the development of trucks and trailers is becoming increasingly important. Investigating the transport efficiency of large trucks via appropriate load packaging is a significant contributing factor. A fully utilized solution is the usage of longer trailers, such as DUO-trailers, which reduces the number of trucks on the road from six to three (*Figure 1.1*) (Volvo Group, 2024a). This not only improves transportation efficiency but also cuts down on fuel usage and the negative impact on the environment (Volvo Group, 2024b).



Vehicles & Drivers:	6 units	4 units	3 units
Vehicle length:	16.5 m	25.25 m	32 m
Load/ Vehicle:	100 m^3	150 m^3	200 m^3
Fuel consumption:	3.5 ml/m^3km	3 ml/m^3km	2.5 ml/m^3km
CO_2 emissions:	100 %	85 %	73 %

Figure 1.1: Single trailer compared to DUO-trailer

New regulations are set to transform the dynamics of road transport in Sweden, in a move that aligns with efforts to minimize environmental impact through the transportation sector. To manage larger capacity loads, the maximum allowed vehicle length was raised from 25.25 meters to 34.5 meters on December 1, 2023. Longer trucks are predicted to dramatically reduce the number of trucks on the road, resulting in reduced carbon emissions and improved transportation efficiency. In Sweden alone, it is predicted that this adjustment may reduce emissions from heavy truck traffic by 4-6% (Trafikverket, 2024b). In addition to these adjustments, Volvo GTT is investigating new technologies such as the electrically powered semi-trailer, more commonly referred to as E-trailer. The trailer, equipped with battery connections, offers dual charging capabilities through traditional loading stations and by utilizing energy from regenerative braking. When compared to conventional semi-trailers, the E-trailer has the potential to increase fuel economy by 5-20%, depending on topography, speed profile and battery capacity. Moreover, the E-trailer is anticipated to enhance dynamic stability, as well as improve traction and braking performance.

Volvo GTT has developed prototypes of previous generations of the E-trailer, all featuring a dual-chassis design. This approach was initially investigated to study the integration of chassis from different producers, including Volvo GTT and other companies. The dual-chassis setup involves a lower chassis integrated by Volvo GTT, which includes components such as axles, suspensions, and the electric driveline, while an upper chassis from another company supports the goods storage.

This design strategy was chosen to facilitate manufacturing by utilizing standard components from Volvo GTT. However, it introduced several challenges. The primary issue is the inconsistency in standard dimensions across different manufacturers, impacting compatibility and complicating the integration process. Additionally, the dual-chassis configuration can lead to an increased overall weight of the E-trailer. The foundational work for this project, including the concepts and designs for the previous generation, was developed as part of a master's thesis at Volvo GTT in 2023, setting the groundwork for this development (Fernvik, L. & Sateei, S., 2021).

1.2 Objectives

The primary purpose is to explore and determine the necessary requirements for the design and development of a semi-trailer chassis, utilizing existing Volvo components such as axles, suspension systems, and batteries. The thesis focuses on two primary objectives including the adaption of Volvo components, where the feasibility of adapting existing Volvo components for integration into a semi-trailer chassis at Hammar Maskin AB is investigated. For this generation, the E-trailer's utilization was limited to being positioned at the end of an HCT combination. Following this research, Computer-Aided Design (CAD) models for the chosen chassis concept are developed. These models serve as an illustration for the potential manufacturing and assembly of the chassis, providing a visual and technical representation of the design. As an additional objective, the thesis explores the integration and packaging of the powertrain, batteries, electrical components, cooling package, and cabling within the chassis framework.

1.3 Limitations

The project focused strictly on the development of a concept and the creation of CAD models. This included the initial design phase where various ideas were conceptualized and translated into digital models using CAD software. The project did not extend to the creation of physical prototypes or the testing of the developed concepts. As the project was an early step in the process, it did not include an assessment or analysis of the costs associated with the developed concept. The project was specifically limited to adapting components from Volvo GTT to a semi-trailer chassis at Hammar Maskin AB with a specific emphasis on heavy-duty trucks. This master's thesis project accounts for 30 ECTS credits per person, indicating the estimated workload and academic value of the project. It has been carried out during the spring semester of 2024, which provided a clear time frame for the project's duration and deadlines.

1.4 Research Questions

How can Hammar Maskin AB's chassis as well as including parts be adapted to fit Volvo GTT's components?
The chassis of Hammar Maskin AB differs in design and dimensions. Notably, Hammar Maskin AB's chassis is slightly narrower and the thickness of the beams are different compared to the chassis used by Volvo GTT, which prevents a direct fit with Volvo's components. Understanding the accepted modifications of the chassis and adapting to Volvo's components is therefore crucial.

Is it feasible to develop a single chassis concept that allows for the direct integration of Volvo GTT's components into Hammar Maskin AB's chassis?
Assessing whether the structural design and dimensions of Hammar Maskin AB's

chassis can accommodate the components from Volvo GTT. Refine Hammar Maskin AB's chassis to enable the direct incorporation of Volvo GTT's components into it.

What modifications are necessary to transition from the previous generation to an advanced design of the E-trailer?
Identifying and understanding the changes required to evolve from the previous generation of the E-trailer to a more advanced, next-generation design.

What strategies can be employed to reduce the weight of the E-trailer while accommodating the additional components required for its electric driveline?
A traditional semi-trailer without an electric driveline typically weighs around 6000 kg, whereas the existing E-trailer, equipped with an electric driveline, has an approximate weight of 9800 kg. While it may not be feasible to reduce the E-trailer's weight to the level of a non-electric semi-trailer due to the additional components required for the electric driveline, efforts can still be made to decrease its overall weight.

1.5 Outline of the Report

The report is formatted in a chronological order to generate a clear picture of both the entire work process, but also the development of the product. The second chapter is methodology which addresses the diverse techniques and instruments employed throughout the project. The third chapter is a theoretical framework and includes the knowledge that was gathered during the project of the project and provides a understanding of the subject. The fourth chapter is the identification phase and incorporates a market analysis and the identification of requirements. The fifth chapter is the development phase and covers the entire development of the E-trailer, including both the concept generation and the concept elimination. The sixth chapter is finalization and presents, explains and analyzes in detail the final concept. The seventh chapter is the discussion of both the process of the project and the result. The eighth chapter is the conclusion and entails the answers to the research questions. The final chapter is further recommendations and covers proposals for further development of the E-trailer.

2

Methodology

An overview of the methodology utilized in this project is illustrated in *Figure 2.1*, including all the methods employed. The process was based on the design thinking process, however it was customized altered specifically for this project.

2.1 The Design Thinking Process

The initial step involved gathering information to establish a theoretical framework, viewed as empathizing with the customer. This was followed by the identification phase, where market analysis was conducted to assess current market offerings and prioritize identified requirements. The third stage, the development phase, focused on generating and evaluating concepts. These first three stages were interactive, both within and across the phases. The final stage entailed product finalization, during which the definitive concept was refined and analyzed.

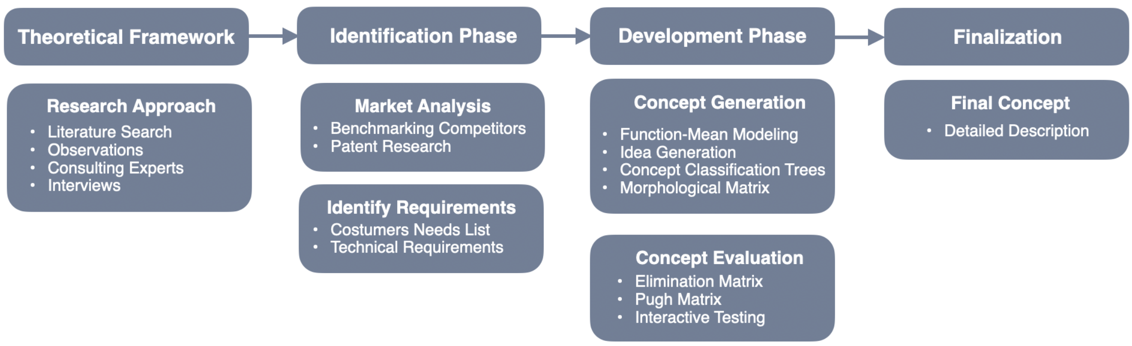


Figure 2.1: Flowchart providing an overview of the project's methodology, illustrating the sequential phases.

The methodology implemented in this project is rooted in the design thinking process. This approach emphasizes a systematic way of working that provides six essential attitudes: flexibility in thought, integral collaboration, empathy, cooperation, imagination, and experimentation, as outlined in the literature on design thinking (den Dekker, T., 2020). The design thinking process encourages a set of correlated attitudes essential for effective problem solving. Flexibility in thought implies a balance between optimism and a critical view, integrating analysis with synthesis, and managing divergent and convergent thinking. Working integrally involves collaboration to foster cohesion and address complex problems, emphasizing the value of being a person with deep expertise in one area complemented by broader knowledge of colleagues, enhancing team synergy and effective collaboration. Empathy is crucial for deeply understanding customers needs by adopting similar perspectives. The attitude of cooperation highlights the importance of team effort and building upon others' ideas to create optimal solutions. Imagination advocates for expressing concepts visually through sketches, prototypes, and videos rather than just verbally. Lastly, experimentation promotes a hands-on approach where learning is achieved through practical engagement and mistakes are viewed as opportunities for gaining insight. Additionally, the design team should aim to find the "innovation sweet spot" by considering the factors of feasibility, viability, and desirability in projects.

The design thinking process is an interactive methodology that includes the following phases: discovery, definition, development, and implementation. In the discovery phase, the focus is on gathering inspiration and insights about the subject while empathizing with customer needs. The definition phase involves structuring and prioritizing these insights to clarify the problem. The development phase encompasses the formulation, development, concretization, testing, and refinement of various solutions. Once a viable solution is developed, it progresses to the implementation phase, where it is executed and applied (den Dekker, T., 2020). In alignment with the design thinking process, the methods of conceptual development draw on the process model proposed by Ulrich, Eppinger, and Yang (2020), incorporating tools and techniques outlined in this methodology (Ulrich, K., Eppinger, S., & Yang, M., 2020).

2.2 Research Approach

This section outlines the methodology utilized for data collection and analysis to gain a comprehensive understanding of the E-trailer and the factors influencing its development. A multifaceted approach was employed, which involved conducting literature reviews, making observations, and consulting with experts in the field. Furthermore, interviews were conducted with key stakeholders, including customers such as Hammar Maskin AB and Volvo GTT, to gather insights into specific demands and preferences.

In academic research, two primary research strategies frequently surface: qualitative and quantitative research. Qualitative research focuses on words, exploring the inductive relationship between theory and research. This approach aims to understand how participants interpret experiences and surroundings. Common methods in qualitative research include qualitative interviewing, focus groups, and snowball sampling. This strategy is typically iterative, with information collection and analysis occurring simultaneously. In contrast quantitative research emphasizes numbers over words, focusing heavily on collecting numerical data. This method aligns more with the principles of natural sciences and maintains an objective perspective. The data gathered in quantitative research is intended to be quantifiable, allowing it to be transformed into variables for statistical analysis. Unlike qualitative research, the quantitative approach is less interactive and more structured in its execution

(Bell, E., Bryman, A. & Harley, B., 2019).

This project was conducted using a mixed methods research approach, which integrates both qualitative and quantitative research strategies. When employing mixed methods, two critical issues must be addressed. The first, known as the priority decision, involves determining whether one of the two strategies is given more emphasis than the other, or if the two are considered equally important. The second issue, the sequence decision, involves deciding the order in which the research tools are applied (Bell, E., Bryman, A. & Harley, B., 2019). For this project, qualitative research was the primary strategy for addressing both issues, although elements of quantitative research were also incorporated.

2.2.1 Literature Search

A literature search is a fundamental approach for acquiring a thorough understanding of a subject. Initially, to gather information efficiently, this process is best undertaken through online searches. Achieving effective results from online searches requires a strategic balance between the selection of keywords according to the limitations and defining the scope of the search to ensure all relevant materials are included while filtering out irrelevant ones (Ulrich, K., Eppinger, S., & Yang, M., 2020). Additionally, snowball sampling is a valuable technique in qualitative research. It involves broadening the research scope by exploring additional sources cited in the initially retrieved literature. By integrating these two approaches, the search can yield deep insights and illuminate areas of the subject that are previously unexplored (Parker, C., 2023).

The literature search employed a mixed-methods research approach, integrating both qualitative and quantitative strategies to conduct a comprehensive analysis of existing information. The qualitative aspect focused on gathering insights from prior research within the subject area, identifying knowledge gaps and employing snowball sampling to further expand the scope of knowledge. Additionally, the quantitative approach was utilized due to the presence of various dimensions, measurements, and analyses (Fischler, A. S., 2024). This process involved gathering information through targeted keyword searches, with keywords carefully selected to cover relevant aspects of the investigated topic. The selected keywords, utilized in both Swedish and English, encompassed variants of terms such as *"E-trailer," "Electrified trailer," "Electric driveline", "High Capacity Transport", "HCT", "Semi-trailer", "Propulsion", and "Self-propelled".* Primary sources for these searches included Google Scholar, Volvo Group's internal documents, and the Chalmers Library to ensure the accuracy of the information gathered. Additionally, Computer-Aided Design (CAD) models of previous generations of E-trailers, electric trucks, and existing trailers by Hammar Maskin AB were meticulously measured and analyzed.

2.2.2 Observations

When utilizing qualitative research in the development of hardware, observations serve as a valuable tool for gaining a deeper understanding of the product and collecting relevant data. Observing customers when using the product can reveal critical details that enhance understanding of the product's functionality and potential customer needs (Ulrich, K., Eppinger, S., & Yang, M., 2020). Typically, observations rely on employing a single sense, such as sight for visual observation or hearing for auditory perception, to gather detailed and specific insights (Smit, B., Onwuegbuzie, A. J., 2024).

Multiple visual observations were conducted throughout the project to gather in-depth information. Study visits to Hammar Maskin AB provided insights into the construction of Hammar Maskin AB's chassis, enhancing understanding of existing capabilities and limitations. Observations at Volvo GTT focused on existing trailers and trucks to acquire knowledge about typical operations. Additionally, observing the previous generations of the E-trailer helped to gain a deep understanding of the components, identifying which aspects were beneficial to develop further and which should remain unchanged. Observations of Volvo GTT operating a road train further clarified the trailer's characteristics, revealing potential development opportunities and refining the understanding of customer needs.

2.2.3 Consulting Experts

Consulting experts is a valuable method for enriching and deepening understanding of a specific subject. These specialists might include company professionals, university professors, or consultants within the field (Ulrich, K., Eppinger, S., & Yang, M., 2020). These experts often have networks that connect to other professionals, which can yield second-generation leads and potentially result in important information. Additionally, experts in specific areas of a project can provide insights that are particularly valuable during the concept generation phase, offering targeted knowledge and experienced perspectives that enhance the development process in the concept generation phase.

Given the complexity and early stage of the project, a substantial amount of information was gathered from experts within the field, primarily from Volvo GTT, as well as from Hammar Maskin AB and Chalmers University of Technology. The main professionals consulted are outlined in *Table 2.1*, although additional experts also contributed to the project.

Table 2.1: List of consulted experts

NAME	TITLE	COMPANY
Clive Misquith	Product Architect	Volvo GTT
Emil Pettersson	Senior Product Architect	Volvo GTT
Lena Larsson	Fellow Product Architect	Volvo GTT
Lars Lindkvist	Docent at Industrial and Materials Science	Chalmers University of Technology
Marcus Davidsson	Design engineer /Constructor	Hammar Maskin AB
Lucas Holmberg	Team Leader - Technical Sales support	Hammar Maskin AB

2.2.4 Interviews

Interviews are a fundamental qualitative research method that involves providing open-ended questions to interviewees, typically in an unstructured format. The primary goal of interviews is to obtain in-depth knowledge regarding the "why" and "how" aspects of a project, and are often conducted one-on-one, preferably in a face-to-face setting (Tenny, S., Brannan, J. M., Brannan, G D., 2024). Interviewing customers is particularly effective for gaining a deeper understanding of the customer's needs and is an excellent method for acquiring insights. Additionally, it provides valuable information about customer expectations regarding the developed product (Münch, J. & Özal, N., 2024).

Throughout the project, multiple interviews were conducted with customers, forming the basis for the Customer Needs List (*Section 2.3.1*). The customers involved were Volvo GTT and Hammar Maskin AB. Continuous communication with the following companies was maintained to ensure optimal results.

2.3 Market Analysis

This section details the methodologies used to perform an in-depth market analysis, an essential tool that offers numerous benefits. These include gaining insights into existing concepts, increasing productivity, and enhancing product distinctiveness. The market analysis encompasses a thorough examination of competitors and a patent search.

2.3.1 Benchmarking Competitors

Benchmarking is a highly effective method of acquiring knowledge from external sources. By benchmarking competitors, valuable insights are gained about the existing market, facilitating a deeper understanding of the current offerings and the differing features of each competitor. Additionally, this method enables an understanding of the characteristics of the leading products within the industry, providing a basic measure of desirable performance, and assisting in idea generation (Albersa, A., Revfia, S.,Kraus, F. & Spadinger, M., 2019).

The competitors benchmarking for the E-trailer was conducted using the following keywords in different combinations: *Electric, Semi-trailer, Semitrailer, Self-propelling, eTrailer, E-trailer, Electrified trailer, Driven, Drivetrain, Propulsion, and E-axle.* Although the selection of keywords was thoughtfully considered, not every combination yielded the anticipated results. These keywords were searched using web browsers such as Google and Microsoft Bing, as well as an internal web page of Volvo Group. Furthermore, additional information about the competitors was obtained from a previous master's thesis concerning the previous generation of the E-trailer at Volvo GTT (Gustafsson, A. & Olsson, E., 2023).

2.3.2 Patent Research

Patents are often described as a temporary monopolies, typically expiring after 20 years in most countries. A patent document involves valuable technical information including drawings and a detailed description of the product (Ulrich, K., Eppinger, S., & Yang, M., 2020). Performing a patent search is a essential step in the development of a new product. It is crucial to thoroughly investigate existing patents within the project's field to gain knowledge of other companies' advancements and to identify existing patented concepts within the field.

The patent search was conducted utilizing the Espacenet database, employing various combinations of keywords. These keywords included: *Electric, Semi-trailer, Semitrailer, Self-propelling, eTrailer, E-trailer, Electrified trailer, Driven, Drivetrain, Propulsion, E-axle, Trailer Dynamics, VAK, Einride, Range Energy, Randon, Scania, and ZF.* However, some of the search combinations either yielded no results or irrelevant ones. Moreover, patents older than 20 years were excluded from the search. The classification "Motor vehicles; Trailers" was frequently used in the search to ensure the retrieval of only the most relevant patents.

2.4 Requirements Identification

This section describes the methodologies implemented to identify requirements for the project. It involved creating a Customer Needs List and a List of Metrics, which were closely linked to ensure that all customer needs were adequately met. These tools helped systematically capture and quantify the project's requirements, facilitating a focused and efficient development process.

2.4.1 Customer Needs List

The Customer needs list is a method to organize the various customer demands and rank the needs by importance. To understand the needs, it is necessary to gather raw data from the customers, which can be performed through interviews, focus groups, and observing the product in use. It is beneficial to address latent needs, needs that most of the end customers may not yet recognize but will appreciate once fulfilled (Ulrich, K., Eppinger, S., & Yang, M., 2020).

The Customer needs list was derived mostly from the answers gathered during the interviews, but also from observations (*Section 2.1.2 & 2.1.4)*. Each of the needs was ranked 1-5 depending on importance, 1 indicating the lowest importance meanwhile 5 represented the highest. The primary customers in this project were Volvo GTT and Hammar Maskin AB. The customer needs were categorized into two topics, Hammar Maskin AB and Volvo GTT, to define which needs were requested from the respective company.

2.4.2 List of Metrics

A List of Metrics is a structured method for defining the technical requirements necessary for a new product. The primary objective is to ensure customer satisfaction with the final product. The technical requirements are specifically designed to satisfy the customer's needs and ideally, with the aim that all customer needs are fulfilled by the metrics. The List of Metrics serves as a bridge between technical specifications and customer expectations concluded from the customer needs list, potentially enhancing customer satisfaction. Additionally, the matrix specifies the unit of measurments, marginal value, ideal values, and the methods used for verification (Ulrich, K., Eppinger, S., & Yang, M., 2020). As a quantitative research method, the List of Metrics transforms customer needs into measurable variables, facilitating the fulfillment of customer requirements effectively.

The Customer Needs List was prioritized by ranking needs on a scale from 1 to 5, with the needs ranking 4 or 5 designated as "requirement" in the List of Metrics, and the remainder categorized as "desires". The List of Metrics was organized into four categories including Trailer, Chassis, Axles, and Regulations. This organization facilitated the translation of customer needs into specific dimensions or design requirements wherever feasible. Furthermore, each metric was linked to the specific customer need it addressed by assigning it the corresponding need number, ensuring a clear alignment between customer expectations and technical specifications.

2.5 Concept Generation

This section outlines the methodologies employed in the concept generation phase. The process includes function-means modeling, which provides a structured approach to connect functions with potential solutions. Additionally, a brainstorming session was held to facilitate creative idea generation, and concept classification trees were used to organize and refine component ideas systematically. Furthermore, a morphological matrix was utilized to assemble the ideas into coherent product concepts.

2.5.1 Function-means Modeling

Function-means modeling is a crucial technique in functional analysis that provides a graphical representation of a system's functional description, offering a visual overview of its operations. It employs a hierarchical structure, where the primary function of a system is divided into sub-functions, each identified with a specific means to fulfill the function (Isaksson, O., Landahl, J., Levandowski, C., Müller, J., Raja, V., Raudberget, D. & Panarotto, M., 2019). This method not only clarifies the operations of a product, whether they are active or passive, but also organizes information effectively. As a result, function-means modeling proves to be a beneficial tool for discovering and developing design solutions, facilitating a clearer understanding and communication of how a product functions at multiple levels.

2.5.2 Idea Generation

A brainstorming session is an effective method for encouraging a group of individuals to produce creative ideas in a structured framework. The technique is performed with a group of individuals that spontaneously express thoughts to generate solutions. All members of the team are active participants during the session and contribute with thoughts and ideas (Al-Samarraie, H. & Hurmuzan, S., 2018). This step is creative where all opportunities that are generated are based on the knowledge possessed by the involved individuals Ulrich, K., Eppinger, S., & Yang, M., 2020.

Ulrich et al. (2020) describe five guidelines that can be useful to keep in mind during a brainstorming session. The authors emphasize the significance of suspending judgment during concept generation and that it is beneficial to develop a large number of ideas, prioritizing quantity over quality. Moreover, guidelines highlight the value of welcoming all ideas, even those that can be considered infeasible. Additionally, the authors clarify the importance of creating a lot of sketches and building models during the idea generation.

2.5.3 Concept Classification Trees

A concept classification tree employs a systematic approach to thoroughly examine all generated solutions. Within a project, all problems are divided into subproblems where respective solutions are distributed (Ulrich, K., Eppinger, S., & Yang, M., 2020). The different solutions for a sub-problem can further be categorized into subcategories, simplifying the process of excluding less viable solutions. The methodology yields an advantage in organizing by providing a visual overview of all potential solutions, thereby facilitating the identification of a comprehensive solution to the entire problem. Additionally, the technique enables the prioritization of more promising ideas by allowing for the elimination of sub-solutions with lesser potential, ultimately resulting in more efficient use of time and resources on viable options. Moreover, the technique allows for the reduction of sub-solutions with less potential, resulting in more time spent on promising ideas.

2.5.4 Morphological Matrix

A Morphological Matrix serves as a creative tool for idea generation, simplifying complex products into more manageable components (Ulrich, K., Eppinger, S., & Yang, M., 2020). It takes the form of a table or grid, organizing different categories that demonstrate individual components along with various possible functions. This setup allows for the elements within each category to be combined in various ways, consequently generating more ideas. The grid arranges each component along an axis, defining and categorizing several alternatives or values for each. This matrix provides a comprehensive way to explore possible combinations by graphically illustrating how these options interact with the other components.

2.6 Concept Evaluation

Concept evaluation describes the the phase in the product development process where various concepts and ideas are systematically analyzed and assessed to determine the feasibility, viability and potential success of the concepts before committing significant resources to development. According to (Ulrich, K., Eppinger, S., & Yang, M., 2020), this phase is crucial for assessing different ideas and concepts generated during the ideation phase to identify which hold the most promise for further development. It is a step further in the development process from the idea generation phase.

2.6.1 Elimination Matrix

An Elimination Matrix, also known as concept screening matrix, is designed to compare and evaluate multiple concepts against a set of criteria to determine which concepts are most viable and should be kept and carried forward in the development process (Ulrich, K., Eppinger, S., & Yang, M., 2020) . The first step in the elimination process involves identifying the criteria which will be used to evaluate each concept. These criteria might differ considering what factors that are important and might include factors such as cost, technical feasibility, customer needs, and alignment with the company strategy. Thus, the criteria should be relevant to the projects goal and objectives.

The matrix format is built out of the product concepts listed in rows and the evaluation criteria listed in the columns, providing a structured framework for the comparison process. Each concept is then rated against each criterion, being both qualitative and quantitative. In the instance of a certain criteria being more important than others the matrix might be adjusted to reflect upon this by assigning weights to each criterion which conclude in weighted scores for each concept. Further, the concepts are ranked based on the overall assigned scores in order to identify which concepts are most promising and should be considered for further development.

The Elimination Matrix is a systematic tool used to identify weaker concepts during the design and development process. It specifically targets concepts that do not meet essential criteria or are significantly lower in performance compared to other options. This method helps simplify the selection process by focusing on the elimination of concepts that are less likely to achieve the desired outcomes, ensuring that only the most viable options are considered moving forward. The use of an elimination matrix enhances decision-making efficiency by clearly distinguishing between promising and inefficient concepts based on predefined criteria.

2.6.2 Pugh Matrix

A Pugh Matrix is a tool used in the concept screening phase in order to compare the relative potentials of multiple design concept against a set of criteria (Ulrich, K., Eppinger, S., & Yang, M., 2020). This method is particularly useful in narrowing down a large number of concepts to a manageable few and improving the concepts in the concept screening stage. The method employs a matrix as a visual tool in order to compare, evaluate, improve and narrow the different alternatives based on specific criteria relevant to the customer needs and critical factors. For instance, the criteria may include durability, ease of manufacturing and ease of handling.

The Pugh Matrix initially starts with the selection of criteria that are important based on customer needs and requirements. The alternative concepts are inserted in the matrix and a reference concept is selected. The concepts are then entered at the top of the matrix, and the selection criteria are listed along the left-hand side. The additional concepts are then rated against the reference concept using a simple scoring system with plus (+), zero (0) or minus (-) to indicate whether each concept is better than, the same as, or worse than the reference concept in consideration to each criterion. Finally each concept receives a Net Score and rank which than concludes to if each concept should be continued with or not, combine, or revised.

2.6.3 Interactive Testing

Interactive testing, or prototyping, refers to the process of evaluating the functionality of the developed concept. In the testing cycle one or more concepts are tested to verify that the customer needs and requirements have been met, and any issues are identified in order to be corrected during further development. Prototyping serves several critical functions in the product process. It facilitates learning by allowing developers to see and test solutions to problems directly. Additionally, it enhances communication through active engagement with customers and stakeholders, ensuring that feedback is incorporated into the development process. Prototyping also verifies the integration of different components, confirming that all parts function together as expected. This process supports iterative cycles of testing and refinement, which are essential for decision-making and continual improvement.

Moreover, prototyping is emphasized as a crucial method for integrating various aspects of product development. It enables the refinement of concepts, exploration of design options, validation of functionality and performance, and informed decision-making based on direct feedback and observations. This approach helps ensure that the final product meets or exceeds the expectations set during its conception and development stages.

Analysis of the Turning Radius Requirements
To calculate the required wheelbase for the trailer to meet the turning radius requirements, a internal program called WIS (Weight Information System) was utilized. This software can create simulations of turns with different inner and outer radius. In the simulations different models of vehicles may be employed and customized. By utilizing WIS, fast results could be obtained without the need to test a physical model.

CAD-models
To carry out a thorough interaction testing, CAD-models were used during the interactions. To achieve a distinct concept description of each interaction was 3D CAD models developed. The the CAD software that was utilized for this was Creo which is an PTC product. Utilizing a CAD-model is a simple and cheap method to create prototypes. It facilitates an interactive process, enabling to assess the feasibility of ideas efficiently. Additionally, it fosters clear communication and understanding among both customers and employees.

Moreover, the creation of CAD models streamlines the process for producing visual prototypes at a later stage. By implementing CAD-models, potential errors and possibilities for improvement can be identified early, before the physical model is constructed. Employing CAD modeling offers a straightforward and cost-effective approach to prototype development.

Within Creo there are also possibilities for carrying out simple calculations on the model. By carrying out simple calculations for stiffness and displacement of the different ideas can the various solutions be easily compared. To obtain an equivalent comparison, the same materials and dimensions should be used.

2.7 Finalization

This section describes the methodologies used to present in detailed the final concept. It covers a detailed description of the final concept and analysis on the final concept.

2.7.1 Detailed description of the Final Concept

A digital prototype was developed and implemented using the software Creo, with the aim of providing a visualization of the detailed design of the E-trailer along with the dimensions of it. By employing a digital prototype, the process becomes more cost-effective and facilitating easier modifications. Furthermore, it simplifies the process of changing, adding, or fixing components and facilitates the procedure of producing the physical prototype. Utilizing a CAD-model, also makes it possible to add materials and through that create an estimate of how much the developed parts of the E-trailer weigh.

3
Theoretical Framework

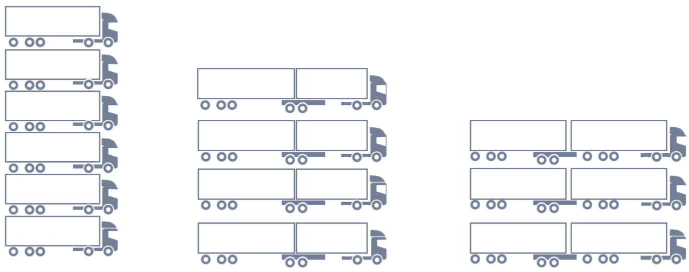
The following chapter defines essential theoretical frameworks relevant to the project, initiating with a detailed overview of High Capacity Transport (HCT), given the project's goal to position the E-trailer at the end of an HCT vehicle train. This is followed by an analysis of electrically driven trailers and its components. Additionally, the chapter examines the regulatory framework and standards controlling high capacity transport in Sweden. It concludes by explaining fundamental concepts and conventions and introducing the companies collaborating on the project.

3.1 High Capacity Transport

High Capacity Transport (HCT) encompasses the use of longer and heavier vehicles, potentially reducing fuel consumption by 40% (Trafikverket, 2024a). Vehicles classified within the HCT category either extend beyond 25.25 meters in length or exceed a weight of 64 tonnes. In 2011, Trafikverket introduced the HCT program, which lead to the establishment of a roadmap in 2013, administered by CLOSER. The primary objective of this initiative was to reduce the climate impact of heavy-duty vehicles by (Asp, 2024b). Following the implementation of the HCT program, the permitted maximum length for heavy-duty vehicles on specific roads in Sweden has been extended to 34.5 meters (Closer, 2024). The HCT program enables collaboration across multiple sectors, involving various organizations. For instance, the Swedish Transport Agency focuses on infrastructure development, while companies like Volvo and Scania concentrate on designing specific types of vehicles (Asp, 2024a).

The HCT Duo Demo project represents an initiative aimed at assessing the viability and effects of integrating HCT vehicles into Sweden's logistics system, with a particular focus on deploying various configurations of vehicles that are 30 meters in length. The project takes place on the route between Hallsberg and Örebro, with an anticipated completion date of December 2024. The goal of the HCT Duo Demo is to gather insights into the impacts that longer vehicles may have on efficiency, costs, and safety.

The DUO2 project, another initiative within the same framework, is being tested by Volvo between Malmö and Gothenburg. This project is focused on the development of longer vehicles, with the objective of reducing fuel consumption by 20% (Closer, 2024). This initiative is aimed towards achieving results that include a reduced environmental footprint, enhanced safety features, and a decrease in the required number of drivers. It is illustrated in the project's documentation *(see Figure 3.1)* that employing DUO-trailers can reduce carbon dioxide emissions by 27% compared to the use of semi-trailers for transporting an equivalent volume of goods (Volvo Group, 2024a).



Vehicles & Drivers:	6 units	4 units	3 units
Vehicle length:	16.5 m	25.25 m	32 m
Load/ Vehicle:	100 m^3	150 m^3	200 m^3
Fuel consumption:	3.5 ml/m^3km	3 ml/m^3km	2.5 ml/m^3km
CO_2 emissions:	100 %	85 %	73 %

Figure 3.1: Comparison between a semi-trailer and the DUO-trailer

3.2 Electrically Driven Trailer

An electrically propelled semi-trailer, also known as an E-trailer, is equipped with an integrated electric drive system, featuring an electric motor and energy storage systems, such as batteries. This configuration not only allows it to assist the towing vehicle, whether a conventional diesel truck or an electric truck, in propulsion but also transforms a conventional semi-trailer into a hybrid vehicle. The primary goal of this technology is to significantly reduce fuel consumption, emissions, and the overall costs associated with transporting goods. By coupling with either conventional or electric trucks, E-trailers contribute to fuel savings, emission reductions, and enhanced operational efficiency, marking a step towards transforming freight transportation into a more sustainable and economical industry.

The primary benefit of electrically driven trailers lies in enhancing the energy efficiency of freight transportation without the immediate need for replacing the existing truck vehicles. This enables significant reductions in the logistics industry's carbon footprint, allowing for a gradual adoption alongside current vehicles. Electric semi-trailers offer an ideal solution for businesses seeking to reduce environmental impact and fuel expenses, particularly those reluctant to shift to fully electric trucks due to range, cost, or infrastructure challenges.

Additionally, E-trailers feature functions that support the main tractor's engine during periods of high power demand and regenerate energy during braking or downhill driving. This capability not only boosts fuel efficiency by an estimated 15 to 20% but also enhances the vehicle's tractive and rough terrain performance, gradeability, braking capacity, and overall driving conditions.

3.2.1 Beneficial attributes

The E-trailer offers several advantageous features that set it apart from conventional trailers. It includes key components and functionalities that enhance its performance beyond that of traditional models. The following sections detail specific elements that contribute to the e-trailer's enhanced performance, providing insight into what distinguishes it from traditional models.

Integrated Electric Motor
This function offers additional power, particularly advantageous for transporting heavy loads and uphill driving. By alleviating the workload on the truck's engine, it contributes to notable enhancements in fuel economy and substantial reductions in carbon dioxide emissions.

Energy Recuperation
E-trailers can regenerate energy during braking or downhill driving, storing it in onboard batteries. This energy can then be used for propulsion or to power onboard systems, further enhancing fuel efficiency.

Hybridization
When connected to a conventional diesel truck, an E-trailer can effectively turn the combination into a hybrid vehicle. This setup can lead to reduced fuel consumption and lower emissions, as the electric motor assists the diesel engine, especially during acceleration and uphill driving.

Traction and Acceleration Improvement
The additional power provided by the e-trailer's electric motor can improve the vehicle's overall traction and acceleration capabilities, making it safer and more efficient to operate, especially under challenging road conditions.

Noise and Brake Wear Reduction
Electric propulsion operates more quiet than conventional diesel engines, contributing to noise pollution reduction. Additionally, using the electric motor for regenerative braking reduces wear on mechanical brake components, lowering maintenance costs and downtime.

3.3 Regulations and Standards

The following section outlines the regulations currently governing E-trailers in Sweden. It also presents the national standards concerning weights, lengths, and widths for trailers within the country. Additionally, this section discusses the impact of international standardization on trailer regulations. Moreover, it covers the specific laws and regulations applicable to trailers equipped with electric drivelines in Finland, where the operation of such E-trailers is legally permitted.

3.3.1 E-trailers in Sweden

Currently, Sweden has not implemented any regulations for trailers with an electric driveline. Consequently, operating trailers with propulsion capabilities on Swedish roads remain illegal. According to definitions set by the United Nations Economic Commission for Europe (UNECE) regulations, self-propelled trailers are explicitly excluded from permitted vehicle types. (United Nations, 2023).

Various UNECE regulations, including principles concerning braking (Regulation 13) and electric powertrain vehicles (Regulation 100), do not cover trailers with an electric driveline. Currently, it is permitted to operate E-trailers that employ regenerative braking without propulsion capabilities. However, the regulation concerning other propulsion abilities acts as a regulatory constraint, limiting the entry of trailers with electric drivelines into the Swedish market.

Regarding electric powertrain vehicles, efforts are currently underway to extend the scope of regulations for electric powertrain vehicles to encompass E-trailers as well, with a focus on safety. To legalize E-trailers with propulsion capabilities in Sweden, several other regulations require reconsideration, including, but not limited to, Regulation 89 concerning speed limiters, Regulation 155 for Cyber Security, and Regulation 48 for lighting requirements. Additionally, there are regulations from the European Union that impose restrictions on E-trailers in areas such as carbon dioxide emissions, battery durability, and end-of-life considerations for batteries.

3.3.2 Standard Weights

In Sweden, four distinct load capacity classes "Bärighetsklasser" (BK) exist, which, in combination with the axle distance, indicate the maximum permissible load on the roads. Nonetheless, specific roads are subject to unique maximum weight restrictions, which are indicated by specific signage in such instances. In Sweden, the load capacity classes are categorized as BK1 to BK4. In combination with Gross Weight Tables, these classifications define the maximum permissible gross weight for a vehicle, taking into account the distance between its first and last axle (Trafikverket, 2022a).

For BK1, the maximum allowed gross weight is 64 tonnes, given that the distance between the first and last axle of the vehicle is equal to or greater than 20.2 meters. For BK2, the limit is 51.4 tonnes for a distance of 18.5 meters or more. BK3 allows for a gross weight of 37 tonnes within a range of 21.6 to 22 meters. For BK4, the allowable maximum gross weight is 74 tonnes, provided the distance between the first and last axle is 20.2 meters or greater. Additionally, the allowed gross weight across the wheels of each trailer or truck cannot exceed the overall vehicle's permitted gross weight between the first and last axle (Trafikverket, 2022a).

BK4 was introduced in Sweden in 2018, and by 2022, about 26% of Sweden's state road network was authorized for BK4 vehicles. According to the implementation plan, the goal is to extend this to 48% of the state road network by 2025. A considerable part of Sweden's road network presently complies to the loadbearing capacity class BK1. However, the strategic aim for the coming years is to transition BK1 roads to BK4 roads. The primary differences between BK1 and BK4 is that BK4 roads are capable of supporting loads that are 10 tonnes heavier (Trafikverket, 2023).

Furthermore, regulations specify the minimum allowable distances between the first axle of the trailer and the last axle of the truck, which vary according to the type of heavy-duty vehicle combination. For instance, in the case of a semi-trailer connected to a truck, as illustrated in *Figure 3.2*, the minimum distance required to travel on a BK1 road is 5 meters, whereas for BK4 roads, this requirement is reduced to 4 meters.

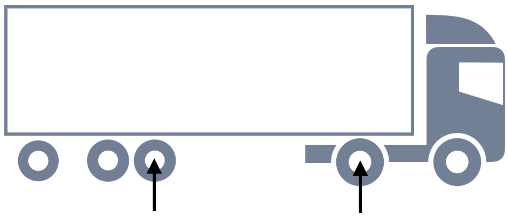


Figure 3.2: Minimum distance between marked axles

3.3.3 Standard Lengths and Widths

On December 1, 2023, Sweden implemented new regulations extending the maximum vehicle length to 34.5 meters on specific segments of its road network. The roads subject to this updated regulation are highlighted in green in *Figure 3.3*, encompassing around 590 kilometers of national roads designated for this purpose. Additionally, smaller, approved detours around the Gothenburg area are marked in blue in *Figure 3.3*, indicating these are also permissible for transport. Vehicles exceeding 25.25 meters in length are required to display a "long road train" sign at both the front and rear, according to the regulations (Trafikverket, 2022b).

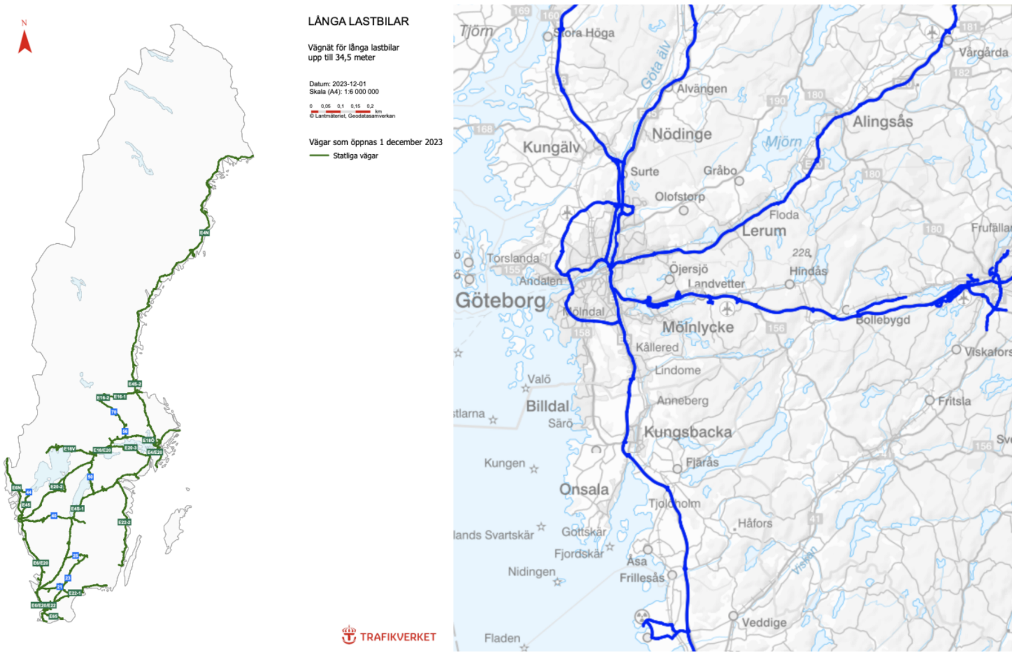


Figure 3.3: Road network for vehicles exceeding 25.25 meters (Trafikverket, 2022b)

The maximum allowed width for vehicles is 2.55 meters. However, vehicles equipped with a temperature-controlled superstructure including side walls at least 45 mm thick are permitted a maximum width of 2.60 meters. Additionally, there are two trailer variants, measuring either 7.82 meters or 13.6 meters in length. These trailers can be combined in different configurations (Transportstyrelsen, 2024a). Various trailer combinations are possible utilizing the two trailer variants, accommodating vehicle lengths from 25.25 meters up to 34.5 meters. *Figure 3.4* showcases some of these combinations, with steerable wheels characterized by being highlighted in red (Larsson, L. Pettersson, E., 2022).

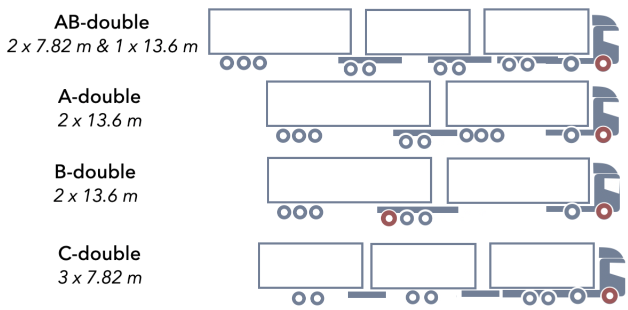


Figure 3.4: Combinations of trailers from 25.25 meters to 34.5 meters

According to regulations in Sweden and the European Union, it is required that a truck must be capable of completing a 180-degree turn while remaining within an outer radius of 12.5 meters and an inner radius of 5.3 meters (Larsson, L. Pettersson, E., 2022). Furthermore, for road trains in Sweden, the regulations require the same outer radius requirement for the 360-degree turn, but the inner radius is reduced to 2.0 meters (Transportstyrelsen, 2024a). In Sweden, there is no official maximum height restriction for vehicles, however, most truck manufacturers typically design vehicles to be under 4.5 meters tall to ensure they can safely pass under bridges and tunnels. This regulation is created to ensure vehicles fit within infrastructure constraints and maintain safety standards throughout the country (Transportstyrelsen, 2024b).

3.3.4 International standardization

This project adhere to international standards established by International Organization for Standardization (ISO), an independent, non-governmental organization. There are 19 standards that cover the semi-trailer. Some of these standards address the coupling between the tractor and the semi-trailer, as for example ISO 4086:2001, ISO 337:1981, and ISO 1726-2:2023. However, since this project is utilizing Hammar Maskin AB's already existing kingpin design, these standards will not be applicable. Other standards cover primary safety, verification, and performance requirements. Since this project is an evolution of an existing product, most of these standards do not apply. The only ISO standard relevant to the development of the E-trailer at this stage is ISO 1726-1:2000.

ISO 1726-1:2000, titled "Road vehicles - Mechanical coupling between tractors and semi-trailers - Interchangeability", includes regulations on various components, among which is the gooseneck for semi-trailers (as shown in *Figure 3.5*). The standard specifies that the dimensions of the gooseneck must meet the following minimum values: $l_2 \geq 750$ mm, $\gamma \geq 4$ degrees, $r_2 \geq 450$ mm, and $r_3 \geq 2300$ mm (International Organization for Standardization, 2000).

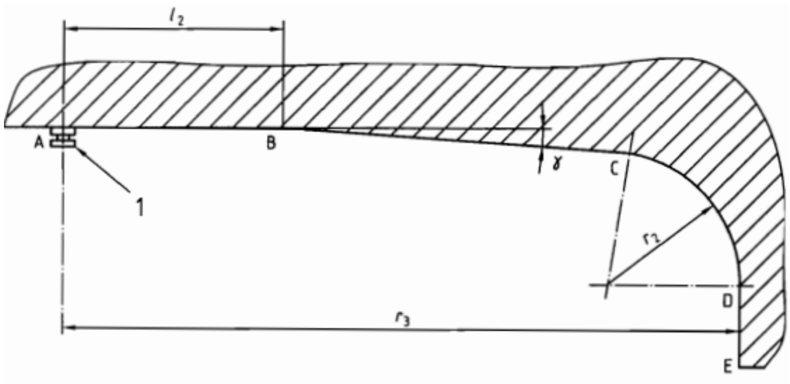


Figure 3.5: Specifications for the Contour and Dimensions of the Gooseneck Structure

3.3.5 Regulations in Finland

In Finland, regulations for trailers with an electric driveline align with the standards set for traditional trailers. In 2019, the country adopted a maximum length limit of 34.5 meters for heavy-duty vehicles across the majority of its road network, with certain exceptions in specific cities, bridges, and similar structures due to special load capacity constraints. Additionally, since 2013, a weight limit of 76 tonnes and a height limit of 4.4 meters have been in place on most of the road network. Finland currently permits 11 different combinations for HCT vehicles, as shown in *Figure 3.6* (Larsson, L. Pettersson, E., 2022).

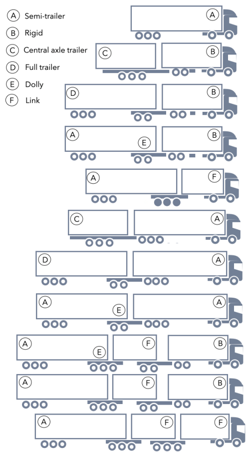


Figure 3.6: Regulations for Permissible Combinations in Finland

3.4 Fundamental Concepts and Conventions

The following section addresses the fundamental concepts and conventions that are featured in the trailer and provides a thorough overview of the product. It considers the essential components that are fundamental to this project including the axle combinations and variants that are commonly used by Volvo GTT.

3.4.1 Core Components

In this section, the foundational elements that contribute significantly to the overall performance and reliability of the trailer are explained. Understanding these core components are crucial for comprehending how trucks and trailers are designed to meet the demanding requirements of transportation and logistics.

Wheelbase

The wheelbase, illustrated by number *(3)* in *Figure 3.7*, of a semi-trailer is the distance from the kingpin *(1)* to the first axle *(2)* on the trailer. It influences the vehicle's stability, maneuverability, and ride comfort. In contrast, the wheelbase of the truck refers to the distance between the center of the leading front wheel and the center of the leading driven axle (Volvo Group, 2023).

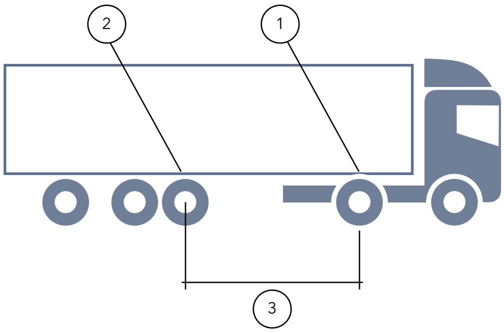


Figure 3.7: Detailed Illustration of the Wheelbase of a semi-trailer

Chassis

The chassis frame, labeled as number 1 in *Figure 3.8*, serves as the backbone of a vehicle, crucially balancing strength and flexibility. This may be considered the main component of what is referred to as the trailer, as it holds the majority of components, including axles, batteries, and suspension systems. It must endure torsional stresses to navigate road irregularities while bearing heavy loads without bending (Volvo Group, 2023). Constructed from high-tensile steel, chassis frames offer a robust yet lightweight structure. This choice of material ensures that the frame can support considerable weight while minimizing the vehicle's overall mass. In the trucking industry, reducing the weight of the truck's components translates into higher payload capacity and lower fuel consumption, making every kilogram saved essential for efficiency and profitability.

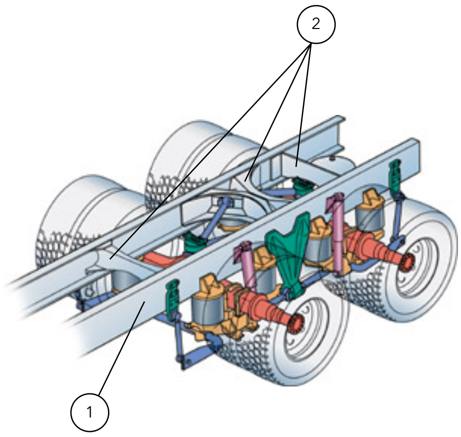


Figure 3.8: Detailed Illustration of the Semi-Trailer Chassis

The design of the chassis involves two longitudinal side-members *(1)* in a U-shaped profile, connected by cross-members *(2)* using bolts or screws. This structure supports the vehicle's cab, body, engine, and transmission. Certain truck models feature a widened frame at the front to accommodate the engine and radiator, demonstrating the frame's adaptability to different configurations. The suspension systems are also attached to the frame, integral to the vehicle's stability and ride comfort. The chassis design is essential to a truck's operational performance, maintaining the balance between durability and a lightweight construction. This balance enhances the vehicle's economic and environmental efficiency, while also maintaining its strength and reliability.

Kingpin and fifth wheel

The kingpin on a trailer is an essential component used in the connection between a semitrailer and the towing truck, specifically in fifth wheel coupling systems. It's a steel pin that extends from the bottom of the front of the semitrailer. The kingpin is designed to fit into the groove of the fifth wheel, a horseshoe-shaped mechanism which is mounted on the tractor truck. The fifth wheel has two key functions: it evenly distributes the semi-trailer front weight across the tractor for stability, and it securely locks the kingpin to ensure the trailer stays attached during transport. This coupling mechanism also enables the trailer to turn around the kingpin's axis, enabling improved maneuverability (Volvo Group, 2023).

Suspension system

The suspension system's task is to absorb bumps caused by road surface irregularities. Various components make up the suspension system on a trailer, each contributing unique characteristics. The design of the wheel suspension on the trailer is crucial for the vehicle's maneuverability. Heavy vehicles face high demands on the wheel suspension due to significant load variations, causing stress on both the vehicle's suspension and the trailer's wheel suspension. One major component of the suspension system that is crucial for the trailer's suspension is the air-filled rubber bellows, illustrated in *Figure 3.9*.

Air-filled rubber bellows, integral to truck suspension systems, absorb road surface irregularities to improve ride quality (Volvo Group, 2023). The rubber bellows adjust spring resistance through air compression based on load changes, utilizing a design that includes durable rubber reinforced with nylon threads for precise suspension control. Trucks also utilize specific air bellows for tag and pusher axles, allowing axle lifting for enhanced flexibility. Furthermore, vehicles equipped with an air suspension system can accurately measure the load on each axle.

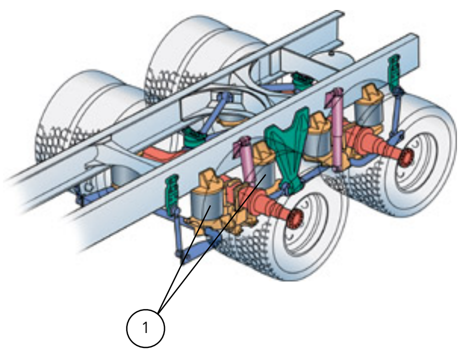


Figure 3.9: Detailed Illustration of the Air-Filled Rubber Bellows placement

Roll Stabilisers

Roll stabilisers *(see Figure 3.10)*, also known as anti-roll bars, enhance the torsional rigidity of the suspension system and can be fitted to both the front and rear suspension of the trailer (Volvo Group, 2023). Made of a torsionally rigid material and shaped like an arc, roll stabilizers *(1)* are attached to the frame with link rods *(2)* and to the axle with clamps *(3)* . Anti-roll bars connect the two sides of the suspension, providing essential stability to the vehicle. Typically, one or two anti-roll bars are placed on each axle to ensure good stability not only over the axles but also throughout the entire chassis.

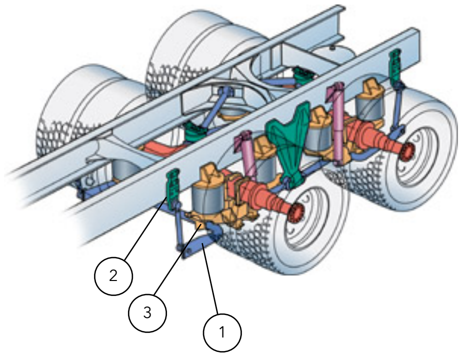


Figure 3.10: Detailed Illustration of the Roll Stabiliser Components

Rear Suspension Bump Stop

Bump stops is a crucial component to ensure safety of the suspension system by preventing the system from coming in contact with other parts. It is positioned so that the axle does not hit the chassis when the terrain becomes rougher and instead it hits the bump stop which is equipped with a rubber surface.

3.4.2 Axle Configurations

Trucks are engineered to accommodate a variety of cargo types and driving conditions, leading to the necessity for different axle configurations as shown in *Figure 3.11*. These configurations include both driven and non-driven axles, depending on the specific needs of the vehicle. In the trucking industry, a numerical designation system is widely used to generally describe axle combinations, encompassing both the truck and the trailer. This system indicates the total number of wheels on a vehicle, including both the truck and the trailer, and specifies how many of those wheels are driven. In cases where the axle has twin wheels on each side, each pair is counted as a single wheel for the purposes of this designation. Each axle configuration is designed to meet specific requirements, balancing load capacity, traction, fuel efficiency, and the ability to navigate various terrains. Understanding these configurations is crucial for selecting the appropriate truck for specific tasks, ensuring that it can handle the demands of the cargo and the driving conditions encountered.

A common example of this numerical designation is a 4x2 truck, which signifies a vehicle with four wheels, two of which are driven. This simple yet effective coding provides immediate insight into the vehicle's driving capabilities and potential applications. Here's a breakdown of the most common axle combinations, illustrating the diversity in design and function (Volvo Group, 2023):

- **4x2**: This configuration has four wheels, with two being driven. It's a standard setup for lighter trucks, offering good fuel efficiency and simplicity.
- **4x4**: All four wheels in this setup are driven. This configuration is ideal for off-road or challenging driving conditions, providing enhanced traction and control.
- **6x2**: With six wheels, only two are driven. This combination allows for increased load capacity while maintaining fuel efficiency, often seen in longer haul trucks.
- **6x4**: Here, four out of the six wheels are driven, offering better traction than a 6x2, making it suitable for heavy loads and uneven terrain.
- **6x6**: All six wheels are driven in this configuration, maximizing traction and stability, ideal for extreme conditions and off-road applications.
- **8x2**: This setup features eight wheels, with only two driven. It's used for trucks that need to support very heavy loads but primarily travel on well-maintained roads.
- **8x4**: With eight wheels and four driven, this configuration supports heavy loads while providing better traction and control, suitable for a variety of challenging driving environments.

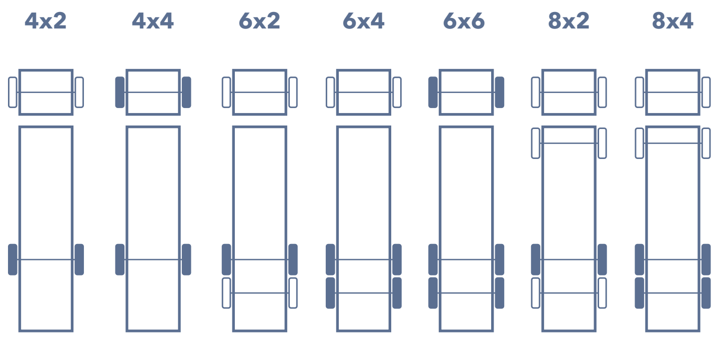


Figure 3.11: Detailed Illustration of Various Axle Combinations

3.4.3 Axle Variants

Trailers can be designed with a variety of axle configurations, featuring different variants and placements. The specific role of a trailer and the positioning of its axles assign distinct names and functions to each axle. The subsequent section discusses various configurations and corresponding functions, highlighting the adaptability of trailer axles to meet diverse transportation needs.

Tandem axle
Tandem axles refer to a configuration where two sets of axles are placed close together, on a vehicle, most commonly observed in semi-trailers (Volvo Group, 2023). This arrangement allows for the even distribution of a vehicle's load over a larger

area of the frame, enhancing the trailer's ability to carry heavier weights. The close spacing between the axles offers several benefits, including improved stability, especially at high speeds or under highway conditions, and greater maneuverability. In the event of tire damage, the tandem setup can prevent serious damage by redistributing the weight to the remaining tires. Additionally, tandem axles often feature mechanisms, such as air-slide suspension in newer models, that enable the adjustment of the axle position to optimize load distribution. While providing the advantage of carrying additional weight and improving stability, tandem axles may require a higher initial investment and can lead to reduced tire life if the load is not evenly distributed.

Tag axle
A tag axle is defined as an additional non-driven axle situated behind the main driven axle. Its primary purpose is to support additional load, improve stability, and distribute the vehicle's weight more evenly across its chassis. Depending on the vehicle's design and requirements, a tag axle can be liftable to reduce tire wear and fuel consumption when not needed or steerable to improve maneuverability.

Pusher axle
A pusher axle is an additional axle positioned in front of the vehicle's driven axle, enhancing load capacity and distribution without being directly powered. Unlike tag axles situated at the rear, pusher axles assist in supporting the vehicle's front section. The positioning of the pusher axles allows for improved vehicle dynamics and stability.

Lift axle
A lift axle, as its name suggests, is a mechanism designed to raise or lower an axle, along with the wheels attached to it, either manually by the driver or through an automated system. This feature is primarily found in heavy-duty trailers and trucks, offering enhanced flexibility in managing the vehicle's weight distribution. The ability to adjust the axle's position can lead to improved fuel efficiency under various load conditions by optimizing traction for the wheels in contact with the road, while simultaneously reducing overall friction by minimizing rolling resistance. Moreover, the inclusion of a lift axle contributes to the vehicle's maneuverability, facilitating a tighter turning radius and smoother handling. Additionally, the capacity to lift the axle when it's not required helps in decreasing tire wear, thereby prolonging tire life and yielding environmental benefits by reducing tire waste.

Steerable axle
A steerable axle is an axle configuration found in certain vehicles, such as heavy trucks and trailers, designed to turn and steer independently from the vehicle's primary steering mechanism. This feature stands in contrast to fixed axles, which are immovable and aligned permanently with the vehicle's frame. The primary advantage of steerable axles is their contribution to enhanced maneuverability and handling, enabling vehicles to navigate through tight corners, execute sharp turns, and generally perform better in a variety of driving conditions. Additionally, steerable

axles may be advantageous by reducing tire wear through improved tire alignment as well as increasing load capacity by optimizing weight distribution, which, in turn, decreases the stress placed on individual axles.

E-axle

An electric axle, or e-axle, integrates the electric motor, power electronics, and transmission into one compact unit that powers the vehicle's or trailer axle directly. This axle variant reduces the size and weight compared to traditional engine and transmission systems, lowering power consumption and costs. It is particularly advantageous for heavy-duty vehicles such as trucks, as it improves efficiency and provides additional chassis space for extra components (Volvo Group, 2023). The compactness of the e-axle also allows for the installation of more batteries, which can increase the vehicle's range. Despite its reduced size, the e-axle is capable of producing power levels comparable to conventional systems, providing adequate traction for the vehicle.

Rear suspension

There are two types of rear suspension variants, single-axle system and bogie. A single-axle system consists of one axle meanwhile a bogie consists of two or three axles on the same mount. The axle configuration in a bogie can be either two driven rear axles or one driven rear axle together with one or two non-driven axles that are either a pusher axle or a tag axle. The non-driven axle in a bogie can also be a lift axle and the distance between the axles can be distinguished between different models.

3.5 Steel Structure

A structure composed of beams with various cross-sectional shapes made from structural steel is known as a steel structure. Opting for steel instead of materials like wood, concrete, or stone provides several advantages. Steel constructions are lighter in weight, have shorter construction times, and are more resistant to water and gas. Additionally, forming beams with specific cross-sectional shapes enhances these benefits. This technology ensures high durability and bearing capacity while allowing for a smaller volume compared to structures with undefined shapes. Numerous cross-section variants exist, each with distinct advantages and disadvantages (*Figure 3.12*) (Pebsteel, 2024). In these beams, the horizontal parts are known as the flanges *(1)*, and the vertical part of the cross-section is called the web *(2)*.

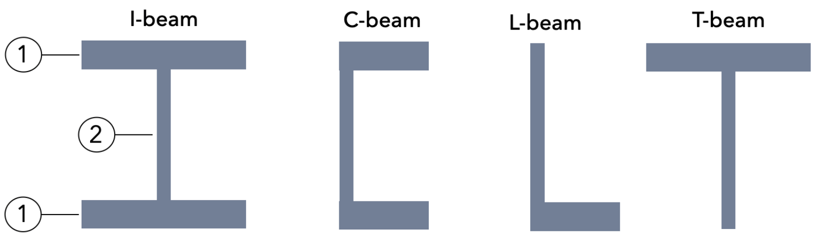


Figure 3.12: Cross-section shapes

One of the most common shapes is the I-shape, which is utilized by Hammar Maskin AB. Another common structure, the C-shape, is used by the Volvo Group. Both the C-shape and I-shape beams exhibit relatively high stiffness compared to other shapes. However, the I-beam has slightly higher stiffness, can carry greater shear, and is capable of bearing heavier loads within the web's plane. In contrast, the C-shape tends to be more cost-effective. Additionally, there are various other cross-sectional structures, such as L-shaped and T-shaped beams. However, these shapes, along with other common structures, have lower stiffness compared to both the I-shape and C-shape. (Engineering discoveries, 2024).

3.6 Collaborating company

The project is being conducted in response to requirements from Volvo Group and will also involve collaboration with an additional company. Hammar Maskin AB will assist in constructing the chassis, a stage that will occur after the completion of the current project. Founded in 1974, Hammar Maskin AB stands at the front of the sideloader manufacturing industry, known for its unique approach to container handling. The company has built a reputation on its commitment to developing smart, efficient, and versatile logistics solutions.

The core of Hammar Maskin AB's products is sideloader technology, which is defined by self-loading trailers with cranes on both ends of the trailer. This specialization has allowed the company to achieve an influential presence in the global market, with customers in 122 countries. As Hammar Maskin AB's influence has expanded internationally, it has strengthened itself as an essential provider in mobile container logistics. The company has significant influence and is leading the way in enabling the transportation and operations of containers across nations, as indicated by the reach of its solutions and its widespread adoption by clients worldwide (Hammar Maskin AB, 2024).

4

Identification Phase

This chapter presents the findings from the market analysis, including a benchmarking of competitors to the E-trailer and an exploration of related patents. Additionally, it showcases the results of the requirements analysis, featuring a customer needs list and a list of metrics.

4.1 Market Analysis

This section provides an overview of potential competitors and applicable patents relevant to the E-trailer, emphasizing certain examples that are considered to be most relevant to the project. In order to comprehend the context of the project and recognize unique value propositions or potential challenges in the development and commercialization of the E-trailer, it aims to provide an understanding of the competitive landscape and intellectual property issues.

4.1.1 Benchmarking competitors

This section serves as an introductory guide to the competitive landscape within the E-trailer industry, offering a detailed overview of the market's key players and the variety of vehicle options that exist. The evaluation aims to outline the specific trailers offered by these organizations, emphasizing the unique advantages that each company claims regarding its products. This approach will help in understanding the competitive landscape, identifying key features that set each competitor apart, and assessing how these differences might impact the positioning and development of the E-trailer in the market.

VAK
On May 25, 2023, VAK issued a press release for an eco-friendly and energy-efficient E-trailer. The trailer was introduced to Finnish roads in May 2023, with Ahola Transport becoming the first company to utilize it in June of the same year. The trailer can utilize the energy generated during travel and braking to assist with starting, acceleration, and uphill driving. This assistance led to a 20% improvement in acceleration from 0 to 70 km/h and a 10% increase in speed when driving uphill. During testing, VAK's eTrailer reduced fuel consumption by 5-10%. The objective of the company is to introduce 5-10 more pilot units during 2024 and commence serial production of the electric trailer by 2025 (*Figure 4.1*) (VAK, 2024).

Figure 4.1: VAK's eTrailer (Heavy lift news, 2024)

Einride

On May 23, 2022, Einride introduced an electric semi-trailer and marketed it as "the most intelligent trailer to hit the road". The trailer is equipped with cameras and sensors for real-time monitoring to enhance security against theft. Additionally, the trailer is connected to Einride Saga, an intelligent operating system. Saga facilitates real-time data to optimize cargo space, end-to-end monitoring, and enables predictive maintenance. Furthermore, the trailer has a fossil-free range of 650km and can be fully loaded in 30 minutes Einride, 2024.

Figure 4.2: Einride's electric trailer and Saga (Einride, 2024)

Trailer Dynamics

On November 21, 2022, Trailer Dynamics unveiled a semi-trailer with an electric driveline. The company expresses that the E-trailer will significantly reduce carbon dioxide emission by between 20% to 40%, while also offering a range extension of up to 650 km with the assistance of batteries. This trailer is compatible with all other trucks. Moreover, it reduces the operational costs compared to a traditional trailer, recovers energy during braking, and supports the drive (Trailer Dynamics, 2024b). Trailer Dynamics replaced one of the axles that is free-wheeling with an electrified axle (*Figure 4.3*). The modular batteries within the trailer utilize lithium iron phosphate technology, making the batteries highly suitable for heavy goods transportation. Additionally, the trailer features real-time control at the kingpin to ensure that the forces are transferred and a safe control at the electric driven axle. The trailer is also equipped with a Predictive Drivetrain Control for intelligent and optimal transport (Trailer Dynamics, 2024a). Moreover, the E-trailer features a fully electric cooling system, reducing noise and enhancing sustainability, as well as an integrated control unit with active ride control and ultra-fast data processing capabilities (GIGANT GmbH, 2022). DB Schenker ordered 2000 E-trailers from Trailer Dynamics in 2022, with plans to gradually introduce the trailers to the European road network throughout 2024 (DB Schenker, 2024).

Figure 4.3: Trailer dynamics electric trailer's chassis (GIGANT GmbH, 2022)

Randon

On October 14, 2019, Randon introduced a semi-trailer featuring an electric auxiliary traction system. The company aims for the trailer to achieve up to 25% reduction in fuel consumption, although this outcome depends on the circumstances. When the vehicle is connected to a trailer or descending slopes, the vehicle employs energy recovery, enhancing uphill performance and overall effectiveness. The motor operates similarly to a generator, repurposing kinetic energy and storing it within the battery. The electric driveline that the semi-trailer is equipped with, known as e-Sys, incorporates an electronic control unit (ECU), a switch, a battery, and a WEG electric motor integrated into an axle (*Figure 4.4*). Additionally, an algorithm oversees this process by analyzing usage patterns and operational parameters (Randon Companies, 2024).

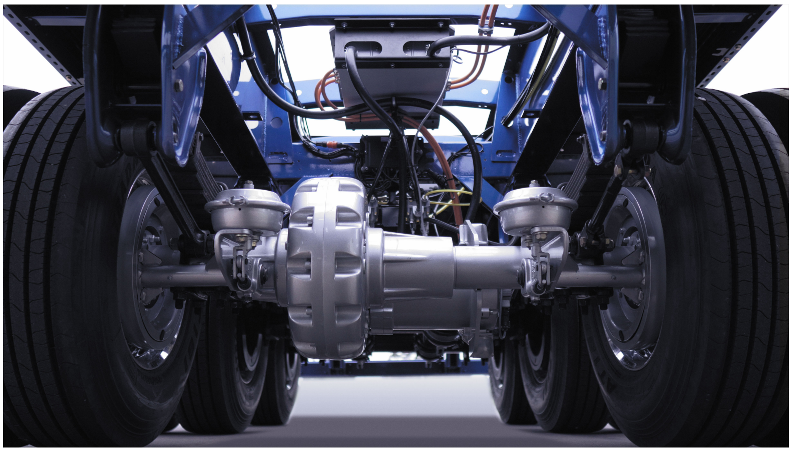


Figure 4.4: Randon's electric axle (Randon Companies, 2024)

ZF

On September 20, 2023, ZF presented the latest version of electrification for trailers. The company's objective is to achieve a 16% reduction in carbon dioxide emission and fuel consumption for the trailer. Moreover, the plug-in hybrid version aims to reduce carbon dioxide emissions by up to 40%. ZF's system has two electric axles and a modular battery system, enhancing energy recovery and providing traction support (*Figure 4.5*). Additionally, the trailer captures energy during braking, thereby extending the range of electrified heavy-duty trucks (ZF, 2024).

Figure 4.5: ZF electric trailer (ZF, 2024)

Range Energy

On May 8, 2023, Range tested an electric semi-trailer that is designed to reduce diesel consumption by 30% to 40%. A DCFC charger takes 45 minutes to charge the trailer whereas an AC charging takes it 10.5 hours and the trailer has an energy capacity of 200kWh (Range Energy, 2024). The trailer features a standard interface, ensuring compatibility with various tow vehicles. The trailer operates using a drive system coupled with an embedded sensor. Equipped with a smart kingpin, it measures the weight exerted by the trailer load on the truck and can transmit signals to the e-axle to aid propulsion. Additionally, the powertrain lessens the engine load during acceleration and harnesses kinetic energy through regenerative braking. Furthermore, the batteries are possible to customize and scale according to customer requirements, with a maximum of 800 volts. (Range Energy, 2023).

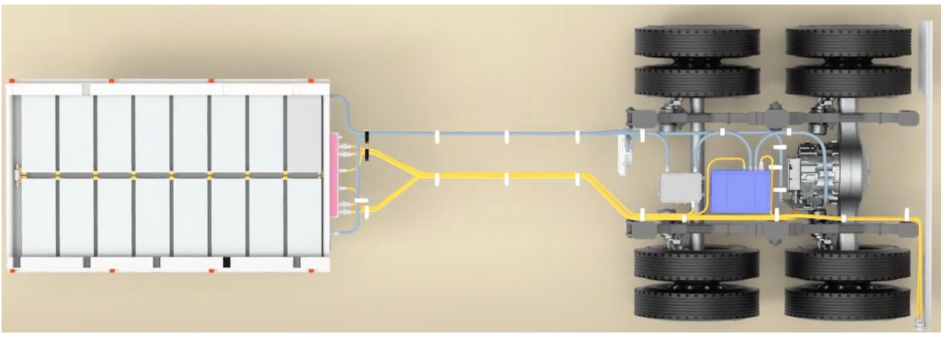


Figure 4.6: Range electric trailer's driveline (Range Energy, 2023)

Solar panels
In addition to developing trailers with electric drivelines, some companies have started experimenting with solar panels. Notably, Scania and Randon are among these companies (*Figure 4.7*). On August 31, 2023, Scania introduced a solar-powered project featuring a trailer equipped with solar cells on its sides, designed to attach to a hybrid-electric truck. This trailer is expected to have 200kWh energy storage connected to the solar panels (Scania, 2023). Similarly, on November 8, 2022, Randon released a video showcasing their trailer with solar panels installed on the roof, capable of generating up to 15 kW (Randon, 2022).

Figure 4.7: Trailer with solar panels: Scania (Scania, 2023) & Randon (Mobilidade Estadâo, 2022)

4.1.2 Patent Research

This section provides an overview of the patent research, summarizing the most relevant and intriguing patents related to the E-trailer. The evaluation focuses on assessing the technological advancements, potential applications, and innovative aspects of each patent.

Patent: CN109435699A
Published: 2019-03-08
Used Keywords: Electric and Semitrailer
This patent describes an intelligent semi-trailer that consists of a frame, a power unit, an air suspension rack with a driven tandem axle, multiple battery packages, and a steering device. The steering device is electrically connected separately to both the power unit and the batteries, allowing for precise control of these components. According to the inventors, the control device offers significant benefits, including the ability to adjust the motor's operating state. Additionally, the trailer enhances safety during downhill travel, improves fuel efficiency, optimizes operational performance, and reduces environmental impact.

Patent: CN116265270A
Published: 2023-06-20
Used Keywords: Trailer, ZF, and Driven
ZF has applied for this patent to control a liftable drive axle on a trailer using a lifting bellows. The method involves filling the lifting bellows with air while simultaneously reducing the air pressure in the load-bearing bellows. The drive axle is positioned either in front of or behind the non-driven main axle and is supported on the frame by at least one load-bearing bellows. Lifting the axle offers several benefits, such as reduced tire wear, improved maneuverability with a smaller turning radius, and enhanced axle traction.

Patent: DE102022123162B3
Published: 2023-08-31
Used Keywords: Trailer and Trailer Dynamics
The patent, applied by Trailer Dynamics, utilizes mainly a trailer equipped with an electric drive system. The aim is to reduce the amount of negative effects from the existing methods for battery mounting and improve the battery box. In this patent, the battery box is mounted to the chassis and its side beams, designed to be mechanically isolated from other trailer components. This innovation aims to reduce the dynamic loads on the battery box, consequently enhancing stability within the area. As a result, driving dynamics for the trailer is expected to improve.

Patent: FR2980438A1
Published: 2013-03-29
Used Keywords: Semi-trailer and Propulsion, Electric, or Self-propelling
This patent includes a semi-trailer with an electric driveline that can maneuver independently when, for example, loading the trailer, without requiring connection to a truck.This process involves installing a propulsion device on one of the rear axles

of the trailer and a steering axle at the front. The system is designed to be easy to operate, allowing the driver to focus on operating the vehicle while the trailer's propulsion and steering mechanisms enhance overall performance.

Patent: WO2023072496A1
Published: 2023-05-04
Used Keywords: ZF, Electric and Semi-trailer or Semitrailer
ZF applied for this patent with the goal of enhancing energy storage capabilities in semi-trailers equipped with an electric driveline. Through greater energy storage and devices, the trailer can supply the entire load and completely relieve the truck of the whole load. Additionally, the need for high-power charging during the day is eliminated, as the batteries can be recharged at a lower power level during rest breaks. The payload capacity is expected to be at least 15 tons to at least 18 tons.

Patent: US11453292B2
Published: 2022-09-27
Used Keywords: Electric and Semi-trailer or Semitrailer
This patent aims to improve semi-trailers with an electric driveline by reducing the space occupied by electric components. The innovation features an electric motor in the vehicle that functions as an electromotive brake during braking. This eliminates the need for a mechanical braking system in the trailer, thereby freeing up additional space. Furthermore, this removal eliminates some potential maintenance requirements, reduces the weight of the trailer, and lowers the cost of it.

Patent: US2015060160A1
Published: 2015-03-05
Used Keywords: Electric and Semitrailer
The patent applies for a semi-trailer equipped with an electric driveline and includes at least one electric drive system. Additionally, the trailer has an interface so it is possible to couple the electric drive system at the trailer to an electric drive system at the truck.

Patent: US11884124B2
Published: 2024-01-30
Used Keywords: E-axle and Drivetrain
This patent introduces a chassis integrated with an e-axle system designed to access and analyze route data. The data, compressed into lines, provide insights regarding the terrain, indicating whether the route will be downhill, uphill, or flat. With this information, the e-axle system can be adjusted depending on the terrain resulting in positive effects. The e-axle can be raised to minimize rolling resistance on downhill slopes, lowered to enhance power for uphill acceleration, and improve regenerative capabilities or braking efficiency.

Patent: US2020238990A1
Published: 2020-07-30
Used Keywords: Electric and Semi-trailer

The patent concerns a smart kingpin utilized in an electric semi-trailer, where the primary purpose is for a sensor positioned at the kingpin to detect forces applied to at least a part of the connection device. Moreover, the system involves the operation of at least one electric motor responsible for driving multiple wheels. The electric motor is controlled by a control system and is linked to the sensor located at the kingpin.

Patent: WO2023110358A1
Published: 2023-06-22
Used Keywords: Trailer, ZF, and driven
This patent concerns an electric semi-trailer equipped with friction brakes. The electric system is used for multiple functions, including braking during normal conditions. The trailer is also equipped with friction brakes that come into use in more demanding braking situations. The axle with an electric driveline also has friction brakes, so it is switched off when required to use the friction brakes. It intends to use the deceleration moment to calculate the required compensation on the driven shaft, ensuring the driven axles and non-driven axles will perform almost identically when the friction brakes are engaged.

4.2 Identified Requirements

In this section the outcomes of identifying both customer demands and technical requirements is presented. It encompasses both a customer need list and a list of metrics.

4.2.1 Customer Needs List

The primary customers in this project were Volvo GTT and Hammar Maskin AB. Throughout the project, there has been continuous communication, requiring trade-offs between the different desires of the companies to ensure optimal outcomes. The customer's requirements were summarized in a Customer needs list, see *Table 4.1*. The needs with the highest importance were prioritized for finding solutions, with a ranking system in the table where 5 indicates very important needs and 1 indicates not so important needs.

Table 4.1: Table Illustrating the Generated Customer Needs List

NUMBER	PART	CUSTOMER NEED	IMP.
1	**Hammar Maskin AB**		
1.1	Chassis	The dimensions of the entire front section align with Hammar's previous chassis	3
1.2	Chassis	Smooth curves	3
1.3	Chassis	Maximize the use of I-shape sections	5
1.4	Regulations	The trailer complies with finish regulations	5
2	**Volvo GTT**		
2.1	Axles	Semi-trailer containg three axles	5
2.2	Axles	One driven axle and one tag or push axle	4
2.3	Axles	Stearable third wheel	4
2.4	Axles	Lift axle or axles	4
2.5	Chassis	Utilize Volvos components	4
2.6	Chassis	The chassis width by the batteries and axles aligns with Volvo GTT's previous chassis	5
2.7	Chassis	Reduce the weight of the chassis	3
2.8	Chassis	Good ground clearnance	4
2.9	Regulations	The trailer complies with Swedish regulations	5

4.2.2 List of Metrics

In response to the seventeen different needs, twenty-three technical requirements were defined and categorized into three groups, as detailed in *Figure 4.2*. The initial category, "Chassis", examined twelve different metrics, including the shape of the beams, design of cross-members, and chassis dimensions. The subsequent category, "Axles", considered the demands and wishes regarding the characteristics of the axles. The third category, "Regulations", outlined ten demands that the E-trailer had to fulfill according to both Finnish and Swedish regulations. To ensure that the various values of the metrics were met, a range of verification methods were employed. This was primarily performed through measurements and simulations in the CAD-software Creo, however, observations and tests of the E-trailer were also conducted to validate the remaining metrics.

Table 4.2: List of Metrics

METRIC NUMBER	NEED NUMBER	METRIC	IMP.	UNIT	MARGINAL VALUE	IDEAL VALUE	REQUIRMENT/ DESIRE	VERIFICATION
1	**Chassis**							
1.1	1.1	Widht between the outer edges of the flanges		mm	945	945	Requirement	Measurements in CAD
1.2	1.1	Width between the inner sides of the webs in front of the neck		mm	779	779	Requirement	Measurements in CAD
1.3	1.1	The dimensions before the neck align with Hammar's previous chassis		Binary	Fail	Pass	Desire	Measurements in CAD
1.4	1.2	Length of the narrowing section	3	mm	250	300	Desire	Measurements in CAD
1.5	1.2	Corner radius	3	mm	> 10	> 20	Desire	Measurements in CAD
1.6	1.3	Proportion of I-shaped beam		%	40	50	Requirement	Product Testing
1.7	2.5	Use of Volvos components		Binary	Pass	Pass	Requirement	Product Testing
1.8	2.5, 2.6	Modify the chassis to accommodate Volvo's components		Binary	Pass	Pass	Requirement	Measurements in CAD
1.9	2.6	Widht bewteen inner part of the web's behind of the neck		mm	836	836	Requirement	Product Testing
1.11	2.7	Weight	3	Kg	<9800	<7900	Desire	Simulations in CAD
1.12	2.8	Ground Clearance		mm	180	240	Requirement	Measurements in CAD
2	**Axles**							
2.1	2.1	Three axles		Binary	Pass	Pass	Requirement	Product Observation
2.2	2.2	One driven and one tag or push axle		Binary	Pass	Pass	Requirement	Product Observation
2.3	2.3	Sterable third axle		Binary	Fail	Pass	Requirement	Product Observation
2.4	2.9	Lift axle		Quantity	1	2	Requirement	Product Observation
3	**Regluations**							
3.1	1.4, 2.9	Total trailer length		mm	<13087	<13087	Requirement	Measurements in CAD
3.2	1.4, 2.9	Turning radius, outer edge		m	<12.5	<12.5	Requirement	Simulations
3.3	1.4, 2.9	Turning radius, inner edge		m	<5.3	<2	Requirement	Simulations
3.4	2.9	Weight including load		kg	<41000	<41000	Requirement	Simulations
3.5	1.4	Trailer height		mm	<4400	<4400	Requirement	Measurements in CAD
3.6	2.9	Distance kingping to first axle		mm	>6200	>7000	Requirement	Measurements in CAD
3.8	1.4	Trailer width		mm	2550	2550	Requirement	Measurements in CAD
3.9	2.9	Distance from the kingpin to the trailer's end		mm	<12000	<12000	Requirement	Measurements in CAD
3.10	2.9	Distance from kingpin to the front		mm	<2040	1005	Requirement	Measurements in CAD
3.11	1.4, 2.9	Comply with ISO standards		Binary	Pass	Pass	Requirement	Measurements in CAD

5

Development Phase

This chapter presents the results from the development phase, utilizing various methods for concept generation including Function-Means Modeling, Concept Classification Trees, Idea Generation, and a Morphological Matrix. The developed concepts were then evaluated and refined using an Elimination Matrix, Pugh Matrix, and Interactive Testing.

5.1 Concept Generation

This section exhibited the results of the concept generation, including Function-Means Modeling, Idea Generation, and Concept Classification Trees. The different sub-solutions were illustrated in a Morphological Matrix.

5.1.1 Function-Means Model

Function-means modeling was conducted to enhance the understanding of the E-trailer's functions. This method provided insights into how different sub-functions were accomplished using various means, with the primary function of the E-trailer being "Transport goods" *see Figure 5.1*. The project focused on four key areas: ensuring safety, providing storage, offering comfort, and facilitating mobility.

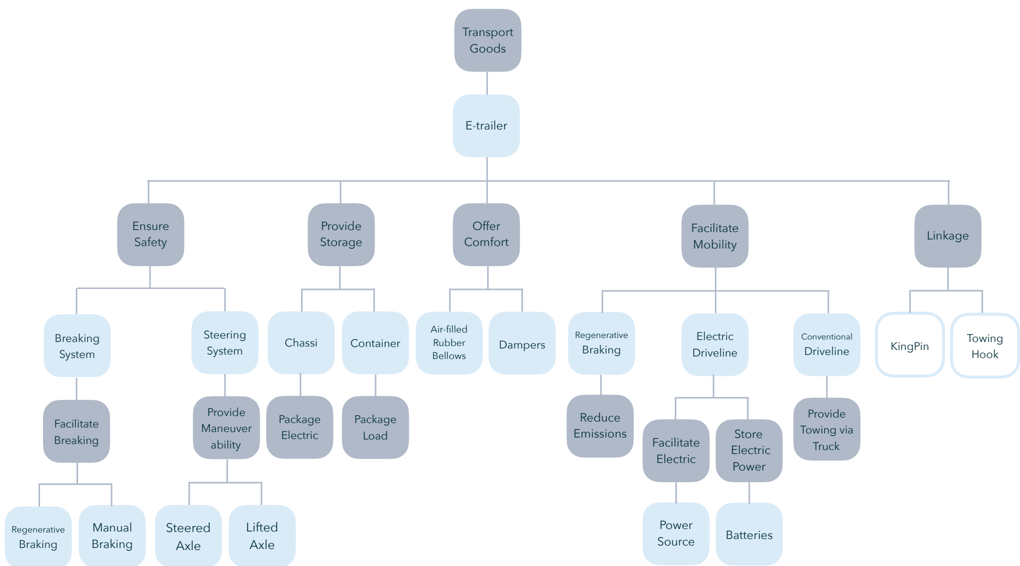


Figure 5.1: Function-means Modeling

5.1.2 Idea Generation

Throughout the project, multiple brainstorming sessions were carried out and experts in the field participated on several occasions, the experts were presented further in *Section 2.1.3*. This approach yielded high-quality solutions to each problem. During the sessions the focus on one sub-function, defined in the function-means modeling, at a time to maintain clarity and ensure effective cooperation among all participants. The sub-functions were evaluated to identify the parts with the highest priority for further development.

While the sessions were ongoing, the guidelines outlined by Ulrich et al. (2020) were kept in mind to reach the optimal outcome, *see Section 2.4.2*. All judgment was eliminated, all ideas were welcome, and quantity was prioritized over quality to ensure that every idea was brought up. This approach meant that even initially deemed unreasonable ideas could be reinterpreted by another participant, resulting in viable solutions. Moreover, numerous sketches were generated, facilitating a deeper understanding for all participants, enabling the identification of potential issues, and thus enhancing the productivity of the session.

5.1.3 Concept Classification Trees

Concept classification trees were created based on the sub-functions that were identified as the highest priority for further development during the idea generation phase. The solutions for the sub-functions that were initially deemed unfeasible or did not meet customer requirements at all, were not added to the concept classification trees. Instead, only the solutions that were considered possible to implement with a relatively successful result are illustrated. This section presents five concept classification trees and describes the different solutions for each sub-function a bit further. The solutions that initially were considered feasible, but could be ruled out relatively quickly were marked with white squares in the trees.

Ensure Safety
The first area identified was ensure safety and addressed maneuverability, stability, mobility, and component positioning as illustrated in *Figure 5.2*.

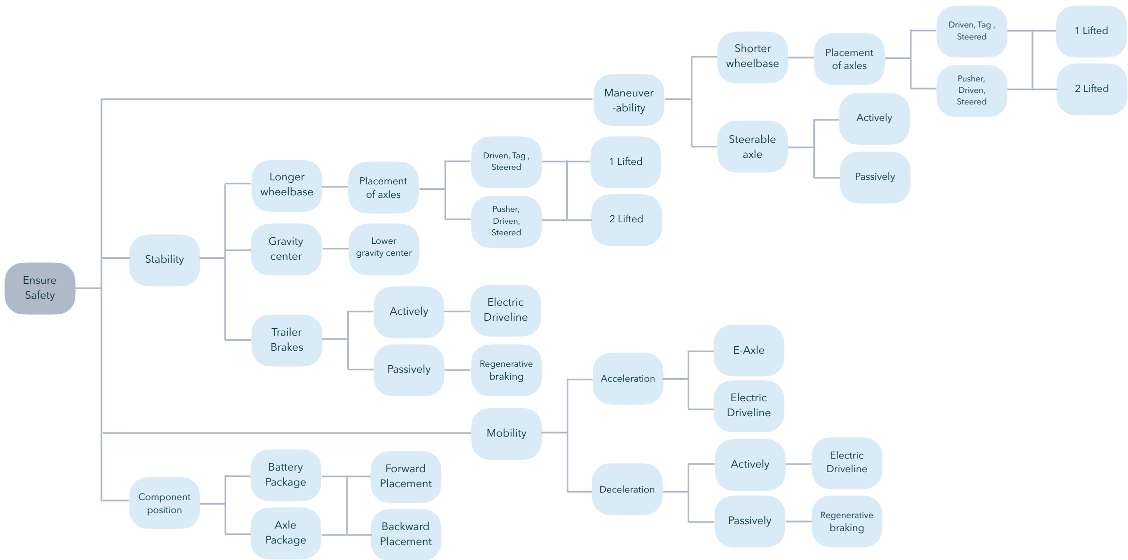


Figure 5.2: Concept Classification Tree, Ensure Safety

An approach to achieve increased maneuverability was to employ a shorter wheelbase, which relied on the placement and order of the three axles. The first option was to place the driving axle first, resulting in a shorter wheelbase compared to the second option, which positioned the driving axle in the middle. The E-trailer's maneuverability could also be improved through raising an axle, which was achievable when the vehicle carried a lighter load. This could be achieved by applying a lift axle. The first option was to place a lift axle in the middle, meanwhile, the driving axle was positioned at the front having one lift axle.

Another alternative was to utilize two lift axles, one in the middle and one in the back. Alternatively, when the driving axle was placed in the middle, either the first axle alone or both the first and last axle could be lifted. The last axle was steerable, offering two various options: forced steering, in which the driver actively controls the wheelbase, or co-steering, in which the wheel reacts passively to the vehicle's movements. The forced steerable axle resulted in better maneuverability, however, it was also more expensive and could be considered unnecessary compared to a co-steerable axle. Additionally, to achieve a shorter wheelbase, the wheels could also be placed forward on the chassis.

Ensuring safety through enhanced stability could be achieved by employing a longer wheelbase. This can be accomplished by positioning the driven axle in the center and making the first axle lifted. Alternatively, placing the driven axle at the front creates a shorter wheelbase, which increases maneuverability but decreases stability. As mentioned earlier, there are several options for the placement of lifted axles. The placement of the lift axles affect the length of the wheelbase. Another factor that affected the stability of the trailer was the center of gravity, the lower it was placed, the higher stability was obtained. Moreover, the choice of brakes influences the stability of the trailer. It can involve either active brakes facilitated by the electric driveline, passive brakes through regenerative braking, or a combination of both. The electric driveline applies brakes when necessary, controlled by the driver. In contrast, the regenerative brake recovers kinetic energy during activities such as downhill driving, which can then be reused to power the vehicle.

The third aspect that can impact safety assurance was mobility, which encompassed both acceleration and deceleration. To accelerate the E-trailer, one option was to utilize an E-axle and another option was an electric driveline. The E-axle offered a more compact design but contributed with higher weight to the driven axle compared to an electric powertrain which provided a more even weight distribution. Moreover, Volvo GTT had not yet advanced sufficiently in the development of E-axles, making it unsuitable for the project at this stage. However, it was marked with white, indicating its potential as a viable option in the future. The deceleration could utilize either active brakes facilitated by the electric driveline, passive brakes through regenerative braking, or a combination of both.

The final aspect impacting the safety of the trailer was the positioning of the battery package and the axle package. Both packages could be shifted either forward or backward, but the placement of each influences the other and can only be adjusted within a certain range. The placement of the battery pack significantly impacts load distribution, particularly if moved forward. Similarly, the location of the axle influences the wheelbase. One approach was to retain the distance utilized in the previous generation of the E-trailer. Alternatively, shifting the axle approximately 300 mm forward compared to the earlier generation of the E-trailer, contributing to improved maneuverability and reduced radius of curvature.

Provide Storage

The subsequent area was provide storage and considered the storage of load, battery package, and axle package (*Figure 5.3*).

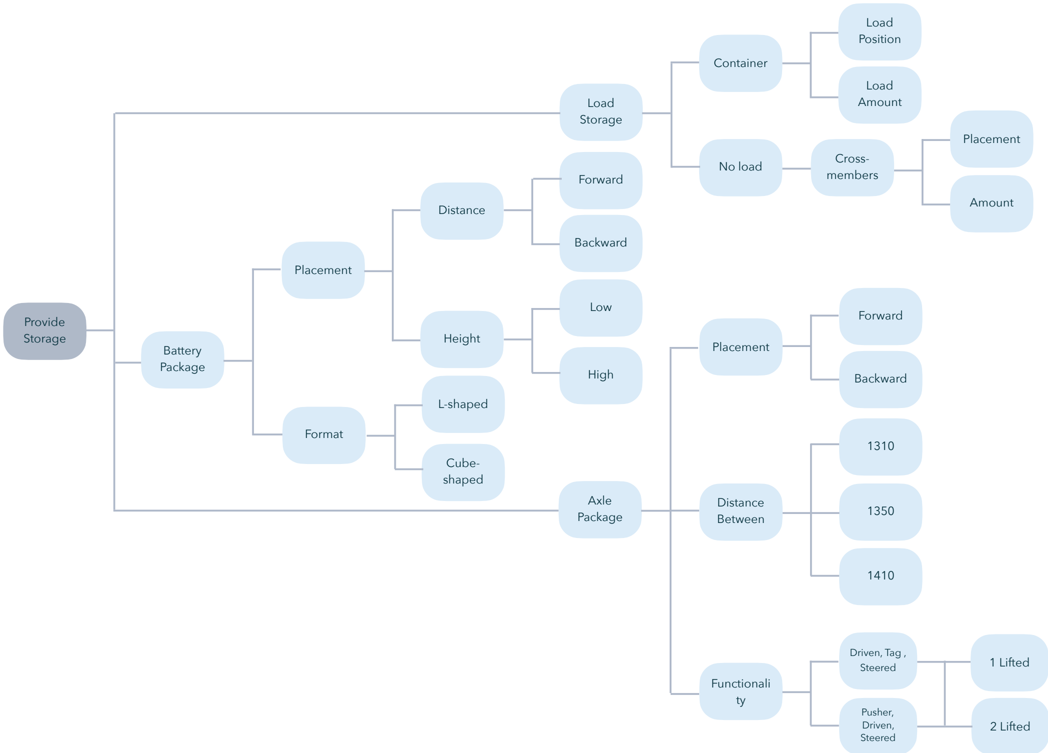


Figure 5.3: Concept Classification Tree, Provide Storage

The E-trailer featured two different load storage configurations, one with a container and one without any load. Factors affecting the chassis when the E-trailer carried a container included the weight and its distribution. When the trailer was unloaded, it became more unstable, as the load contributed to its stability. Therefore, designing a stable chassis through the strategic placement of cross-members was crucial. The number of cross-members represented a trade-off between stability, weight, cost, and interference. Placement was particularly important around the axles, which served as load-bearing points. Additionally, the cross-members needed to be positioned to achieve optimal stiffness.

Considering the battery package, two factors affected the outcome, placement and format. The height placement provided various benefits. A higher position results in better ground clearance, while a lower position provides a better center of gravity. Additionally, the batteries can be positioned either forward or backward, resulting in beneficial changes to the wheelbase. Furthermore, there are two different possibilities for the formatting of the battery package. The first option is a cubic shape, mounted on the outer edges of the chassis and extending outward from the edge. The other alternative is an L-shaped package, also mounted on the outer edge, but extending below the chassis as well.

The final package concerns the axles and incorporated considerations of placement, distance, and functionality. One option was to position the axles 300 mm forward to enhance maneuverability, while another was to maintain the same position as in the previous generation of the E-trailer. Alternatively, placing the axles further back improved stability. The distance between axles also varied. One configuration featured 1350 mm between both wheels, as in the earlier generation of the E-trailer. Another setup involved 1410 mm between the first axle and 1310 mm between the second, following Hammar Maskin AB's design. Additionally, there were options to use either 1310 mm or 1410 mm between both axles. The arrangement and specific properties of the axles significantly influenced both maneuverability and stability.

Offer Comfort

The third identified sub-function was to offer comfort and included mobility, stability, components, and noise as illustrated in *Figure 5.4*.

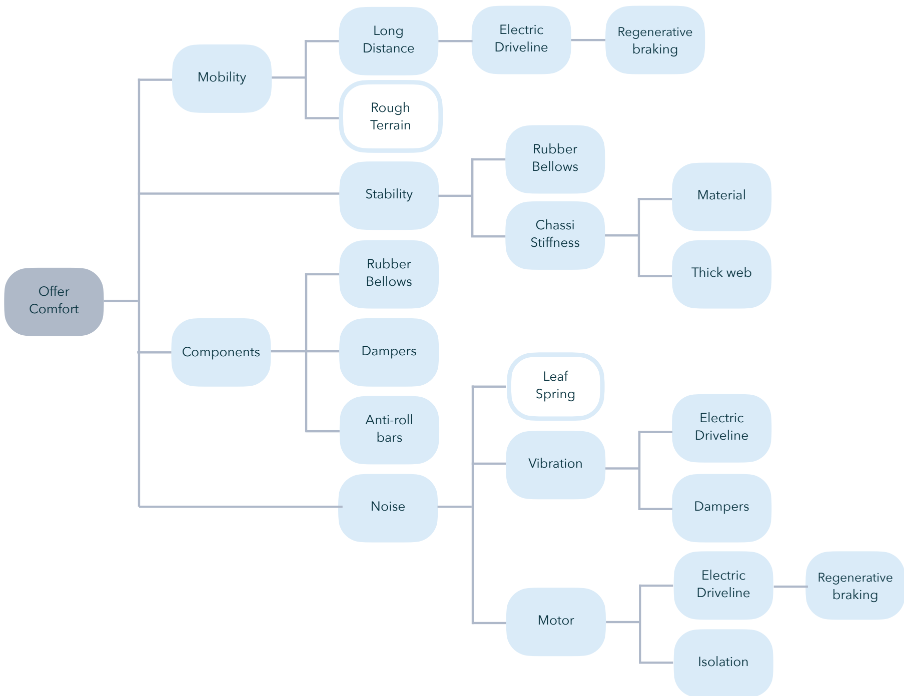


Figure 5.4: Concept Classification Tree, Offer Comfort

A factor that influenced the comfort during mobility was the roughness of the terrain. The comfort during mobility was influenced by terrain roughness. However, the intended application of the trailer being within High Capacity Transports (HCT) implies usage on roads comparable to the BK4 standard in Sweden, which are of relatively high quality. Therefore, road quality was not considered a significant factor in this study. Another critical factor identified was the relevance of driving comfort over long distances. To improve comfort, the implementation of an electric driveline and regenerative braking was considered, as these features contribute to a smoother driving experience.

Comfort was also influenced by the stability of the trailer, which was enhanced through the use of rubber bellows. Additionally, the stiffness of the chassis was optimized through a detailed analysis of the advantages and disadvantages of various materials, the thicknesses of webs and flanges, beam shapes, cross-members, and the overall chassis design. This thorough examination aimed to achieve an optimal balance between durability and performance, contributing significantly to the trailer's stability and handling characteristics.

Furthermore, several components have been identified that could refine comfort, including anti-roll bars, air-filled rubber bellows, dampers, and leaf springs. These elements play crucial roles in enhancing the vehicle's suspension system, contributing significantly to a smoother ride by mitigating vibrations and improving stability under various driving conditions.

Dampers are essential for stabilizing the trailer in a vertical direction and are mounted between the suspension system and the beams. Anti-roll bars are essential for enhancing vehicle stability. The options considered were to utilize a single anti-roll bar, as seen in the previous generation of the E-trailer, or to employ dual anti-roll bars for improved chassis stability. Air-filled rubber bellows, another key component of the suspension system, not only enhance driver comfort but also reduce the risk of damaging the cargo within the container. Although leaf springs could potentially substitute air-filled rubber bellows, they were promptly ruled out in favor of the bellows. This decision was influenced by the fact that leaf springs are quite simple in design and typically associated with vehicles designed for rough terrain, such as military vehicles, and therefore less suitable for the intended context of this project.

Lastly, reducing noise was a crucial consideration for the comfort of both the driver and the surrounding environment. Noise in this context originates from two main sources: vibrations from the trailer and the motor of the truck. The installation of dampers on the trailer can significantly reduce these vibrations, resulting in smoother movement. Furthermore, an electric driveline helps mitigate vibrations by maintaining more consistent mobility. Additionally, engine noise can be reduced through enhanced insulation. Moreover, the adoption of an electric driveline equipped with regenerative braking contributes to noise reduction, as it requires the engine to operate less frequently, thereby decreasing overall noise emissions.

Facilitate Mobility

The final subject addressed was facilitating mobility, which involved examining components related to both the electric and conventional drivelines (*Figure 5.5*). This sub-function also concentrated on evaluating how these factors impact the environment, a critical consideration for the E-trailer. The analysis included assessing the environmental benefits of adopting an electric driveline, such as reduced emissions and lower noise pollution, aligning with broader sustainability goals for vehicle design and operation.

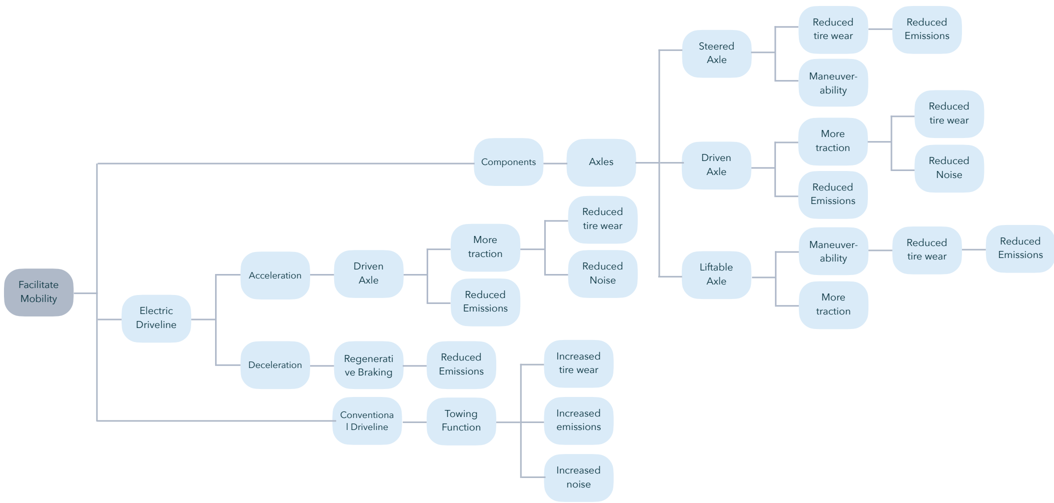


Figure 5.5: Concept Classification Tree, Facilitate Mobility

The axle components significantly influence mobility, depending on the types of axles utilized. Placing a steerable axle at the rear of the vehicle enhances maneuverability, allowing for tighter turns and improved handling. Utilizing a driven axle increases traction and can contribute to noise reduction by optimizing power delivery and reducing strain on the drivetrain. Incorporating a lift axle not only boosts maneuverability when raised but also increases traction when lowered, particularly under heavy loads or adverse conditions. Employing any of these three different axle configurations contributes to reduced tire wear, which in turn decreases emissions by improving fuel efficiency and extending tire life.

Adding an electric driveline also significantly enhanced mobility. This driveline supports both acceleration, through the use of a driven axle, and deceleration, via regenerative braking. As noted earlier, employing a driven axle increases traction, which in turn reduces emissions by optimizing power delivery and efficiency. This also leads to reduced tire wear and lower noise levels. Moreover, the use of regenerative braking contributes to the overall reduction in emissions by capturing and reusing energy typically lost during braking processes, further enhancing the environmental benefits of the electric driveline.

Lastly, the trailer was coupled to a truck equipped with a conventional driveline, which included a towing function. While this setup is essential for propelling the vehicle forward, it unfortunately increases tire wear, emissions, and noise, leading to an overall negative impact on environmental and operational efficiency. However, the towing function remains critical as it provides the necessary force to move the combined weight of the truck and trailer, underscoring a key trade-off in the design and functionality of transportation systems that rely on conventional drivelines.

5.1.4 Morphological Matrix

A Morphological Matrix was developed to systematically organize and visually represent the sub-solutions for various sub-functions, aiding in the conceptualization process. This matrix was specifically designed to include only feasible sub-solutions, thereby simplifying the generation of viable concepts. The Morphological Matrix comprised eleven parameters, each accompanied by a set of alternative solutions. This section will further examine a few of these parameters to provide a clearer understanding of the potential configurations and implications for design and functionality (*Table 5.1*).

Table 5.1: Morphological Matrix

NUMBER	PARAMETERS	ALTERNATIVE SOLUTIONS			
		A	B	C	D
1	**PLACE CHANGE** in web distance	In front of the neck	At the neck	Behind the parking leg	
2	**DETERMINE** axle distance	First: 1410mm, Second: 1310mm	Both: 1350mm	Both: 1370 mm	
3	**DETERMINE** web thickness	4 mm	5 mm	6 mm	
4	**APPLY** innerliners	No	Yes, 1 mm thick	Yes, 2 mm thick	
5	**DESIGN** cross-beams	Volvo's existing	Hammar's existing	Combination of existing	Design new
6	**SHAPE** Cross-section	C-shaped	L-shaped	J-shaped	I-shaped
7	**DESIGN** batteries	Rectangle	L-shaped		
8	**PLACE** batteries	Inside chassis	Outside chassis	Around chassis	
9	**ANALYZE** axle configuration	First: Pusher, Second: Driven	First: Driven, Second: Tag		
10	**POSTITION** lift axle	First	Second	First and Third	
11	**OPTIMIZE** wheelbase	<6700 mm	6700 mm < X < 7000 mm		

An essential parameter in the Morphological Matrix was the placement and adjustment of the web distance, which varied due to the specific demands over different sections of the chassis. For Hammar Maskin AB, maintaining the front chassis dimensions consistent with other models was critical, resulting in a required web distance of 779 mm. On the other hand, Volvo GTT needed a web distance of 836 mm to accommodate certain components, which made it necessary to adjust the chassis width at a specific point. The proposed adjustments included narrowing the chassis from the front and then expanding it before the end of the neck, making changes at the neck, or altering the width behind the parking leg. Each adjustment was strategically planned to ensure compatibility with the necessary components while preserving the structural integrity of the chassis.

5.2 Concept Elimination

This chapter addresses the outcomes of the concept evaluation and elimination process, including detailed analyses on the methodologies and tools used. Included in this analysis are the Elimination Matrix and Pugh Matrices, which were essential in systematically comparing and contrasting different design options based on specified criteria. Additionally, interactive testing was conducted to effectively assess the performance and feasibility of each concept. This combination of quantitative and qualitative evaluation methods provided a solid framework for making informed decisions about which concepts to advance and which to eliminate from further consideration.

5.2.1 Elimination Matrix

Based on the Morphological Matrix, different ideas were discussed with a team of experts. The team contributed knowledge and facilitated an initial evaluation to eliminate sub-solutions that did not meet customer demands. The outcome of this evaluation was illustrated in an Elimination Matrix (*Table 5.2*), which visually represented the feasible and infeasible options, thereby enhancing the decision-making process and focusing on solutions that aligned with customer requirements.

Table 5.2: Elimination Matrix

(+) Fufills criteria
(-) Does not fufill criteria
(?) Need more informaiton

:Yes :Maybe No

	ALTERNATIVE SOLUTIONS	FUFILL HAMMAR'S DEMANDS	FUFILL VOLVO'S DEMANDS	FEASIBILITY	REASONABLE COST	SAFE	ENOUGH INFROMATION	COMMENT	DECISION
A	PLACE CHANGE in web distance								
A.1	In front of the neck	(-)	(+)	(+)	(-)	(+)	(+)	To complex to produce	No
A.2	At the neck	(?)	(+)	(+)	(?)	(+)	(+)	Shorter wheelbase, however, uncertain about the complexity of	Yes
A.3	Behide the parking leg	(?)	(?)	(?)	(+)	(+)	(+)	Uncertainty if it results in in an excessively long wheelbase	Maybe
B	DETERMINE axle distance								
B.1	First: 1410mm, Second: 1310mm	(+)	(-)	(?)	(+)	(+)	(+)	Does not match Volvo's standardized hole distance	No
B.2	Both: 1350 mm	(+)	(+)	(+)	(+)	(+)	(+)	Most sutiable in this stage	Yes
B.3	Both: 1370 mm	(+)	(-)	(?)	(+)	(+)	(+)	Does not match Volvo's standardized hole distance	No
C	DETERMINE web thickness & APPLY innerliners								
C.1	4 mm + No innerliner	(-)	(-)	(?)	(+)	(+)	(+)	Too narrow	No
C.2	4 mm + 2 mm thick innerliner	(-)	(?)	(?)	(+)	(+)	(+)	Could work, but does not have the same dimensions as Hammar's	No
C.3	5 mm + No innerlinners	(+)	(?)	(?)	(+)	(+)	(+)	Could work, however, not where the components are positioned	Maybe
C.4	5 mm + 1 mm thick innerliner	(-)	(+)	(?)	(+)	(+)	(+)	Does not match Hammar's dimensions	No
C.5	6 mm + No innerliners	(?)	(+)	(?)	(+)	(+)	(+)	Could work, however, not at the front	Maybe
D	DESIGN cross-beams								
D.1	Volvos existing	(?)	(-)	(+)	(+)	(+)	(?)	May become unstable and does not match Hammar's width	No
D.2	Hammars exsisting	(-)	(?)	(+)	(+)	(+)	(?)	Dont fit the width at Volvos components	No
D.3	Combination of existing	(?)	(?)	(+)	(+)	(+)	(?)	Most stable, however, the two existing widths vary	Maybe
D.4	Design new	(?)	(+)	(?)	(-)	(+)	(?)	Would be more expensive	No
E	SHAPE Cross-section								
E.1	C-shaped	(-)	(+)	(?)	(+)	(+)	(+)	Difficult for Hammar to produce	No
E.2	L-shaped	(-)	(+)	(?)	(+)	(+)	(?)	Difficult for Hammar to produce	No
E.3	J-shaped	(?)	(+)	(?)	(+)	(?)	(?)	Uncertanties about the stiffness	Maybe
E.4	I-shaped	(+)	(-)	(-)	(+)	(+)	(+)	Will clash with Volvos components	No
F	DESIGN & PLACE batteries								
F.1	Rectangle, inside chassi	(+)	(+)	(-)	(?)	(+)	(?)	Uncertainty if there is enought place	No
F.2	Rectangle, outside chassi	(+)	(+)	(+)	(+)	(+)	(+)	[illegible]	Yes
F.3	L-shaped, Around chassi	(+)	(+)	(-)	(?)	(?)	(-)	Not a established Volvo component get	No
G	ANALYZE axle configuration & POSTITION lift axle								
G.1	First: Pusher & Liftable, Second: Driven	(?)	(?)	(+)	(+)	(+)	(+)	Longer wheelbase, better stability	Maybe
G.2	First: Driven, Second: Tag & Liftable	(+)	(+)	(+)	(+)	(+)	(+)	Shorter wheelbase, better manuverbility	Yes
G.3	First: Pusher & Liftable, Second: Driven, Third: Liftable	(?)	(?)	(+)	(+)	(+)	(?)	Longer wheelbase, less tire wear	Maybe
H	OPTIMIZE wheelbase								
H.1	<6700 mm	(?)	(+)	(?)	(+)	(?)	(+)	There are uncertainties about its feasibility, will likely affect the	Maybe
H.2	6700 mm < X < 7000 mm	(+)	(+)	(+)	(+)	(+)	(+)	Most likely to fulfill all demands	Yes

The majority of the sub-functions were thoroughly evaluated to ensure optimal outcomes and explore all possibilities. This comprehensive evaluation was feasible due to that most sub-functions did not impact each other. However, sub-functions with mutual impacts were evaluated collectively and included in the combined evaluation of C, F, and G. The Elimination Matrix included eight different functions, each with two to four various solutions. Five solutions met all parameters, while seven others had potential and required further analysis. Sixteen ideas did not fulfill all the criteria and were consequently eliminated. Additionally, two of the solutions that met the parameters were considered optimal sub-solutions, specifically B and F, and were selected as the final solutions.

5.2.2 Pugh Matrix

A second round of discussions involving experts and customers was conducted to better understand customer preferences for sub-solutions and to explore the potential for developing and combining new ideas. The outcomes of this second evaluation, along with the newly formulated ideas, were presented in five different Pugh matrices. Without a reference product for comparison, the various ideas were compared to one another and scored accordingly. The criteria were weighted, given that there were only a few criteria for each sub-function and that these criteria significantly impacted customer satisfaction. This approach ensured that the evaluation process accurately reflected the importance of each criterion in meeting customer needs and expectations.

The first Pugh matrix addressed the placement of the change in distance between the two webs, as shown in *Table 5.3*. The most crucial criteria for this area was achieving a shorter wheelbase than the earlier generation to meet the turning radius requirements. Consequently, sub-solution A.2, which involves placing the change at the neck, was considered the optimal choice.

Table 5.3: First Pugh Matrix: Change in web distance

PLACE CHANGE in web distance			
CRITERIA	**IMP.**	**A.2**	**A.3**
Wheelbase <6700 mm	5	1	0
Hammar's dimension at the front	3	0	1
	Total:	**5**	**3**

The second Pugh Matrix addressed the web thickness, with two options taken further from the Elimination Matrix, as shown in *Table 5.4*. Additionally, a new alternative, C6, was developed as a combination of C3 and C5. This new solution featured a thickness of 5 mm at the front until the web distance widened, after which it changed to 6 mm until the end. This configuration met all the demands of both companies and was evaluated to be the best solution.

Table 5.4: Second Pugh Matrix: Web Thickness

DETERMINE web thickness				
CRITERIA	IMP.	C.3	C.5	C.6
Hammar's dimensions at the front	5	1	-1	1
Fit Volvo's components	5	-1	1	1
High stiffness	4	-1	1	0
	Total:	**-4**	**4**	**10**

The third Pugh Matrix managed the design of cross-members and only had one idea left that may be feasible, as illustrated in *Table 5.5*. Conversely, a new alternative was developed which was a combination of D3 and D4. The idea was to utilize Volvo's existing cross-members and modify Hammar Maskin AB's wider. This resulted in the two had the same width and fit the chassis web distance after the neck. The newly developed alternative, D5, reserved the highest points and therefore was the superior variant.

Table 5.5: Third Pugh Matrix: Cross-members

DESIGN cross-beams			
CRITERIA	IMP.	D.3	D.5
Fit the width of the chassis	5	-1	1
Over-dimension	2	0	1
Time comsuming production	2	0	-1
	Total:	**-5**	**5**

The fourth Pugh Matrix addressed the shape of the cross-section, initially identifying only one potentially feasible solution, as shown in *Table 5.6*. However, after further discussion, two new solutions were developed. Both of these new solutions combined elements of E3 and E4, aiming to retain the I-shape in as many sections as possible and using a J-shape where components needed to be mounted. The execution of these ideas differed in the following ways: the first concept, E5, proposed creating cutouts wherever necessary for the components, while the second concept, E6, involved creating holes in the flange and widening the flange at these holes. Both E5 and E6 received high scores, necessitating further analysis to determine which one was most suitable.

Table 5.6: Fourth Pugh Matrix: Cross-section

SHAPE Cross-section				
CRITERIA	IMP.	E.3	E.5	E.6
Fits Volvo standardized components	5	1	1	1
Easy to produce	2	0	0	-1
High Stiffness	5	-1	1	1
	Total:	**0**	**10**	**8**

The fifth Pugh Matrix addressed the axle configuration and the placement of the lift axles, as shown in *Table 5.7*. All solutions were evaluated, with the most crucial criteria being a short wheelbase. Consequently, option G2, which involves placing the driven axle first, was considered the optimal alternative.

Table 5.7: Fifth Pugh Matrix: Axle Configuration & Lift Axle

ANALYZE axle configuration & POSTITION lift axle				
CRITERIA	IMP.	G.1	G.2	G.3
Short wheelbase	5	-1	1	-1
Easy to produce	3	0	0	-1
Low tire wear	2	-1	-1	0
	Total:	**-7**	**3**	**-8**

5.2.3 Calculations on the turning radius requirement

To determine the required wheelbase for the trailer to meet turning radius requirements, the internal software Weight Information System (WIS) was utilized. The goal was for the trailer to navigate a 180-degree curve with an inner radius of 2 meters and an outer radius of 12.5 meters. At this stage of development, the E-trailer was positioned last in a High Capacity Transport (HCT) road train. Additionally, the street width was 8893 mm, and the rear out swing was 603 mm. These parameters were critical in ensuring the trailer could achieve the necessary turning radius while maintaining stability and maneuverability.

The results indicated that using a wheelbase of 5600 mm resulted in an outer radius of 12500 mm and an inner radius of 2069 mm (*Figure 5.6*). This was deemed sufficient for the early stage of E-trailer development and thus set the wheelbase requirement at 5600 mm, ensuring the trailer meets the necessary turning radius requirements.

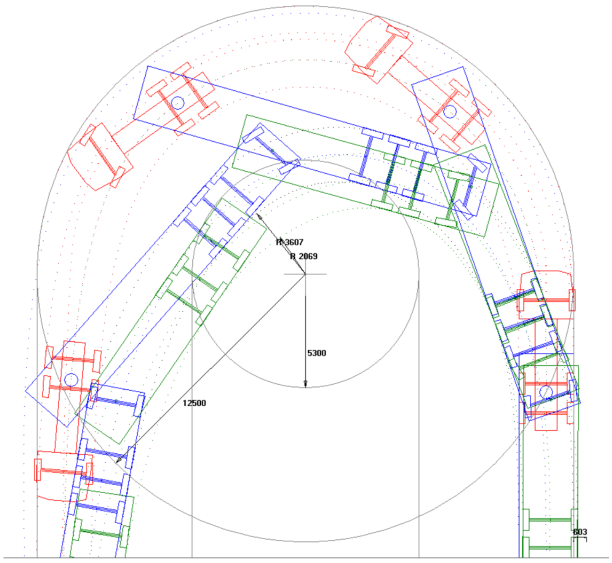


Figure 5.6: The turning radius requirement

5.2.4 Interactive Testing

The interactive testing was conducted in multiple cycles to achieve a superior outcome. These tests were performed using Creo Parametric, providing a clear and deep understanding of the various solutions. Prototypes from each iteration were presented to stakeholders throughout the project to gather feedback and input for further improvements. This iterative process ensured that the final design met customer needs and expectations while optimizing functionality and performance.

First interaction

The first iteration was developed based on the Morphological Matrix, focusing on the optimal alternative solutions at that stage. As illustrated in *Figure 5.7*, the web design is straight with an inner distance of 836 mm. The web thickness was determined to be 6 mm to accommodate Volvo GTT's components, and the cross-beams were a combination of both companies' existing designs. The cross-section was J-shaped, and the batteries were designed in a rectangular shape and mounted outside the chassis. This configuration aimed to balance compatibility with existing components and optimize the overall design for performance and functionality.

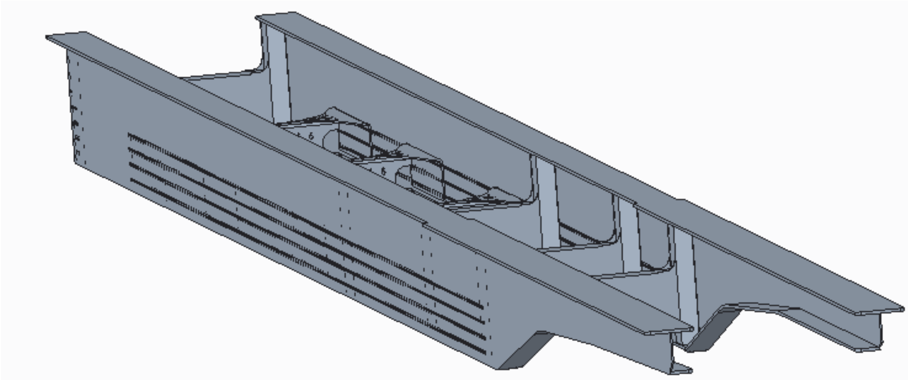


Figure 5.7: Interaction one: J-shaped cross-section

Second interaction
The second iteration, developed after the Pugh Matrices, involved changing the shape of the cross-section from J-shaped to I-shaped to enhance customer satisfaction. The two options, E5 (creating cutouts) and E6 (creating holes), were analyzed to understand their effects on the flanges, chassis stiffness, and complexity.

For E6, it was determined that relatively large holes would be necessary to thread fasteners for the components, with an additional margin to prevent friction while driving the E-trailer. Expanding the flange posed a risk of interference with other components. Considering these factors, E6 was excluded, and E5, which involved creating cutouts, was deemed the preferable sub-solution (*Figure 5.8*).

Additionally, the web distance was adjusted at the end of the gooseneck to meet both customers' requirements. In front of the gooseneck, the web distance was 779 mm with a thickness of 5 mm. Behind the gooseneck, the web distance was 836 mm with a thickness of 6 mm. The flange distance was 12 mm but increased to 20 mm at the front to achieve higher stiffness. The remaining areas remained unchanged, with the front section to the gooseneck retaining the same design as Hammar Maskin AB's previous chassis.

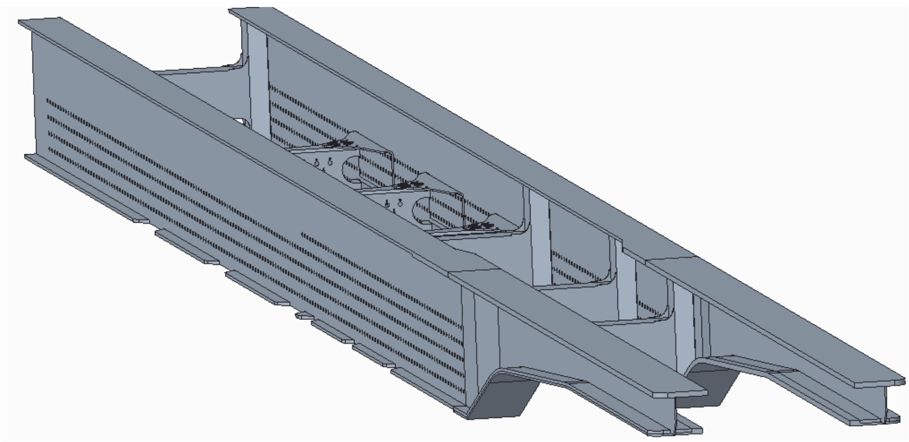


Figure 5.8: Interaction two: I-shaped cross-section with cut-outs

In this iteration, the axles and batteries were mounted to the chassis (*Figure 5.9*). However, after creating a CAD model and mounting the components, it was discovered that the wheelbase was approximately 6800 mm, which exceeded the calculated required wheelbase by 1200 mm. This difference suggested that more changes were necessary to make sure the design complied with the requirements for best performance and mobility.

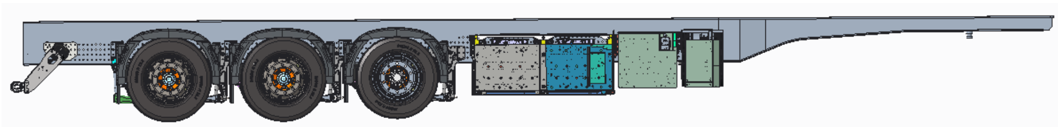


Figure 5.9: Interaction two: Mounted components

Third interaction
The third iteration of the concept focused on reducing the wheelbase to balance the turning radius requirements and Hammar Maskin AB's demands. After discussions with both customers, it was concluded that the gooseneck should be shortened to achieve this goal (*Figure 5.10*). The gooseneck was reduced to be as close as possible to the minimal approved dimensions according to ISO 1726 standards. This adjustment aimed to ensure compliance with regulatory requirements while optimizing the wheelbase for improved maneuverability and meeting customer specifications.

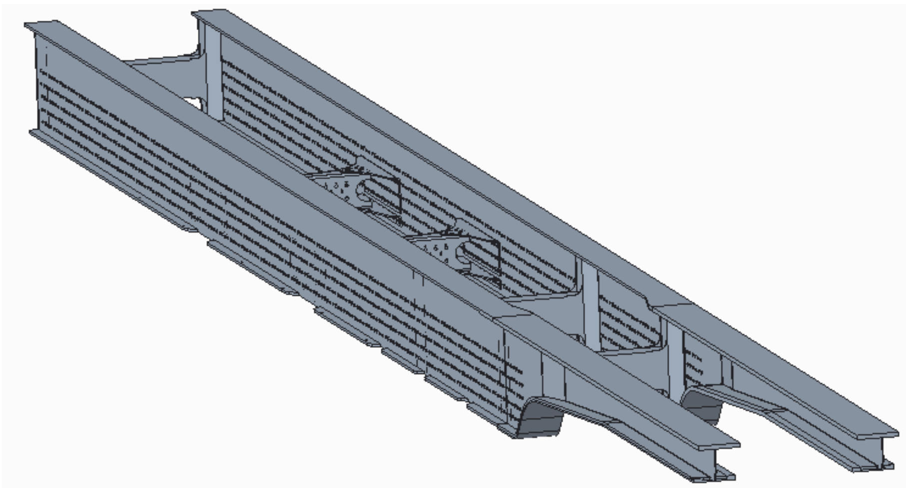


Figure 5.10: Interaction three: Shorter wheelbase

Additionally, all components were moved forward as much as possible(*Figure 5.11*). Unnecessary holes were removed to simplify the design. Furthermore, the first and second single axles were replaced with a bogie, helping to reduce the wheelbase by utilizing only one wheel suspension. Given the shorter wheelbase, stability was affected. To maintain stability, the distance between the second and third axle was increased to 1800 mm, and the distance between the first and second axle was set to 1350 mm. These adjustments ensured that the E-trailer remained stable while achieving the required turning radius and meeting customer demands.

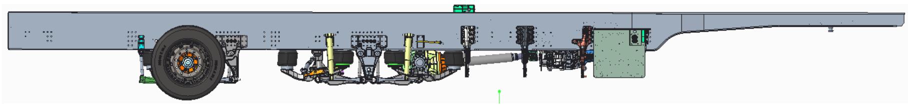


Figure 5.11: Interaction three: Shorter wheelbase

Fourth interaction
The fourth and final iteration involved moving the third axle backward to make room for the radiator between the second axle and the third axle (*Figure 5.12*). To increase the chassis stiffness, two anti-roll bars were added: one on the second axle and one on the third axle. The driven axle retained a single anti-roll bar to maintain a desired level of flexibility, balancing rigidity and maneuverability.

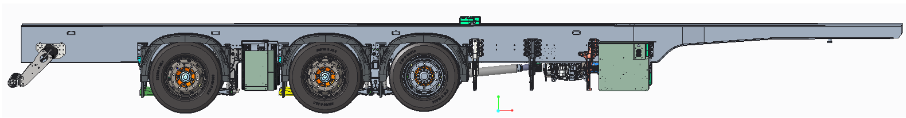


Figure 5.12: Interaction four: Changed axle distance

6

Finalization

This chapter outlines the final concept of the E-trailer and provides a detailed description of the final solution. It presents the CAD model and CAD drawings and covers further calculations on the stiffness of the developed chassis. The CAD model and drawings offer a comprehensive visual representation of the E-trailer's final design, illustrating the placement of all components and the overall structure. An additional calculation was conducted in Creo to get an approximately weight of the developed chassis.

6.1 Detailed description

Based on the fourth iteration, a detailed construction of the E-trailer was established. Components not specifically addressed in this section remained the same or were positioned similarly to those in the previous generation of the E-trailer.

Several key aspects were considered when defining the detailed construction of the chassis. To achieve the calculated wheelbase, all components were mounted as far forward as possible. Additionally, the hole alignment was adjusted upwards by 12 mm. The new measurement from the bottom edge of the flange to the center of the first hole was now 60 mm, compared to the previous 48 mm. This modification provided better stability for the chassis.

Moreover, the ground clearance of the previous generation of the E-trailer was approximately 180 mm. For this generation, it was desirable to increase the ground clearance by roughly 240 mm to reduce the risk of damaging components underneath while driving. The component closest to the ground was the battery package, making it crucial to raise this component. To achieve this, new holes were added 60 mm above the four existing ones, effectively elevating the batteries and other low-hanging components.

The cut-outs for the fasteners to the axles required an estimated margin of 20 mm, as illustrated in *Figure 6.1.* The cut-outs for the battery package and anti-roll bars required an estimated margin of 10 mm due to variations in geometries. Additionally, the flange behind the battery package was reduced from 48 mm to 38 mm to ensure the battery packages did not make contact with the flange when driving. To meet the customer's preference for soft shapes, a radius was applied to most corners, enhancing both the aesthetic and functional aspects of the design by reducing stress concentrations and improving durability.

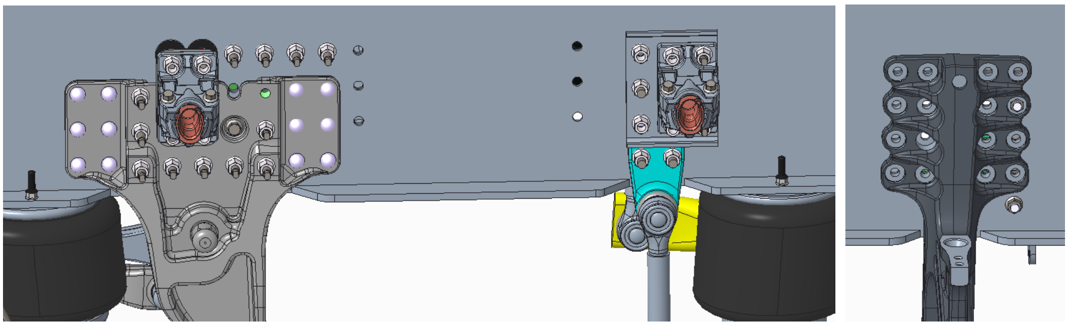


Figure 6.1: Cut-outs for axle attachment, anti-roll bar, and batteries

To reduce the number of parts requiring cut-outs in the flange, several adjustments were made. The attachment of the air-filled rubber bellows was modified, as shown in *Figure 6.2*. Instead of attaching the air-filled rubber bellows to the web, the attachment points were moved to the flange. This modification improved the thickness of the frame, allowing for the removal of a support that was previously placed on the inside of the chassis.

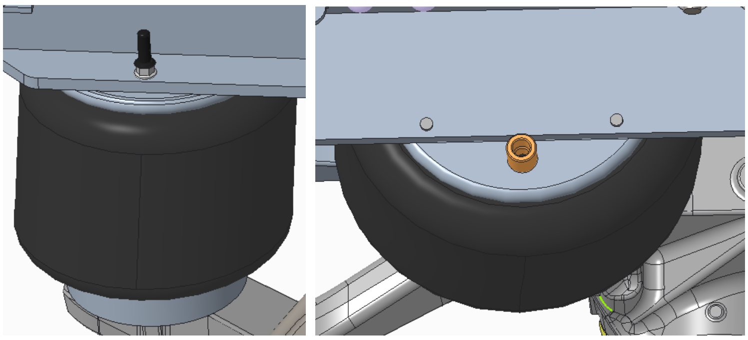


Figure 6.2: Modified attachment to the air-filled rubber bellows

The attachments to the chassis for the first and second axles were changed from two singles to one boogie, as mentioned in *Section 5.2.4*, which also reduced the number of cut-outs. Furthermore, the bump stops were modified to take advantage of the flange instead of making cut-outs (*Figure 6.3*). An additional metal plate was added between the bump stop and the flange, along with the bracket, ensuring the correct distance to the axles. Additionally, two anti-roll bars were added to the second and the third axle to achieve a higher stiffness. However, the first axle, which is the driven axle, was left without an additional anti-roll bar to maintain desired flexibility.

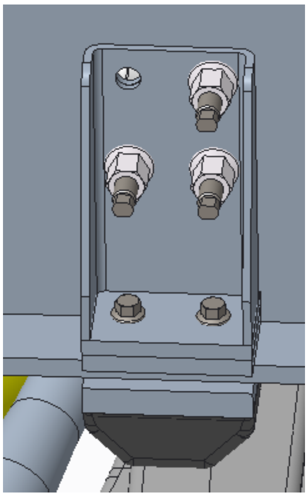


Figure 6.3: Modified attachment to the bump stops

6.2 Final CAD-model

In the CAD program Creo, an assembly for the entire trailer was designed to both facilitate understanding and communication, but also to simplify production and potential developments or improvements. *Figure 6.4* presenters the E-trailer from the side, illustrating the positioning of the axles in relation to each other and to the gooseneck. The first axle is driven, the second axle is lifted, and the third axle is passive steerable.

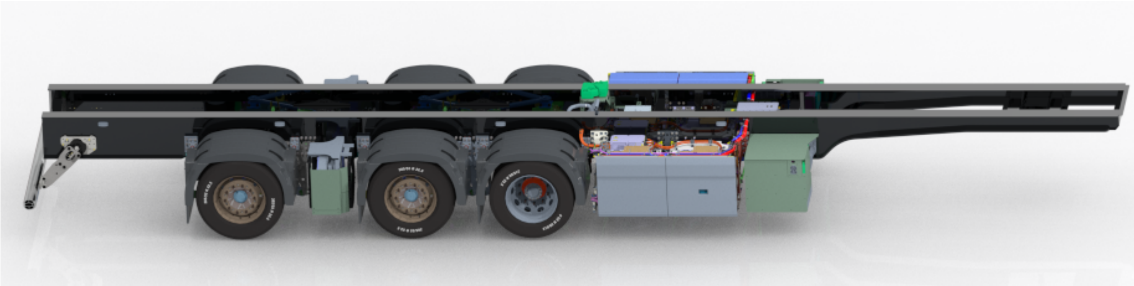


Figure 6.4: Render of the E-trailer: Side view

Figure 6.5 presents a view from the top, illustrating the packaging on the chassis and the placement of all components relative to each other. As shown, all parts were pushed forward, with the radiator positioned between the second and third axle. Space was left along the back to allow for the placement of additional items, such as a storage box. The batteries, which have a rectangular shape, are mounted on the outside of the chassis as far forward as possible. The cross-members used in the design are a combination of Volvo GTT's existing ones and a modified version of Hammar Maskin AB's existing cross-members.

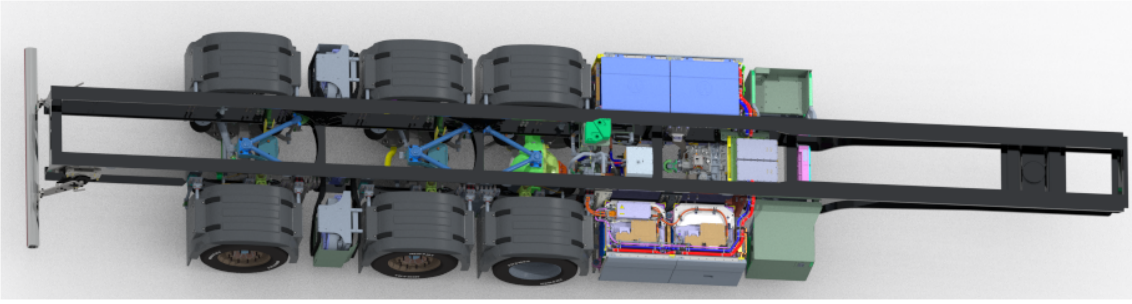


Figure 6.5: Render of the E-trailer: Top view

The assembly drawing of the E-trailer's most crucial dimensions is presented in *Figure 6.6*. The wheelbase measures 5600 mm, and the ground clearance is defined as 227 mm. However, this value is somewhat flexible due to the air-filled rubber bellows, which allow for slight movement of the chassis. Other key dimensions include a chassis width of 2498 mm and a height of 1181 mm. The front section of the chassis has a web distance of 779 mm between the inner sides and a web height of 150 mm. In the rear, the web distance increases to 836 mm, with a web height of 490 mm. The distance between the first and second axle is approximately 1372 mm, while the distance between the second and third axle is 1935 mm to accommodate the radiator.

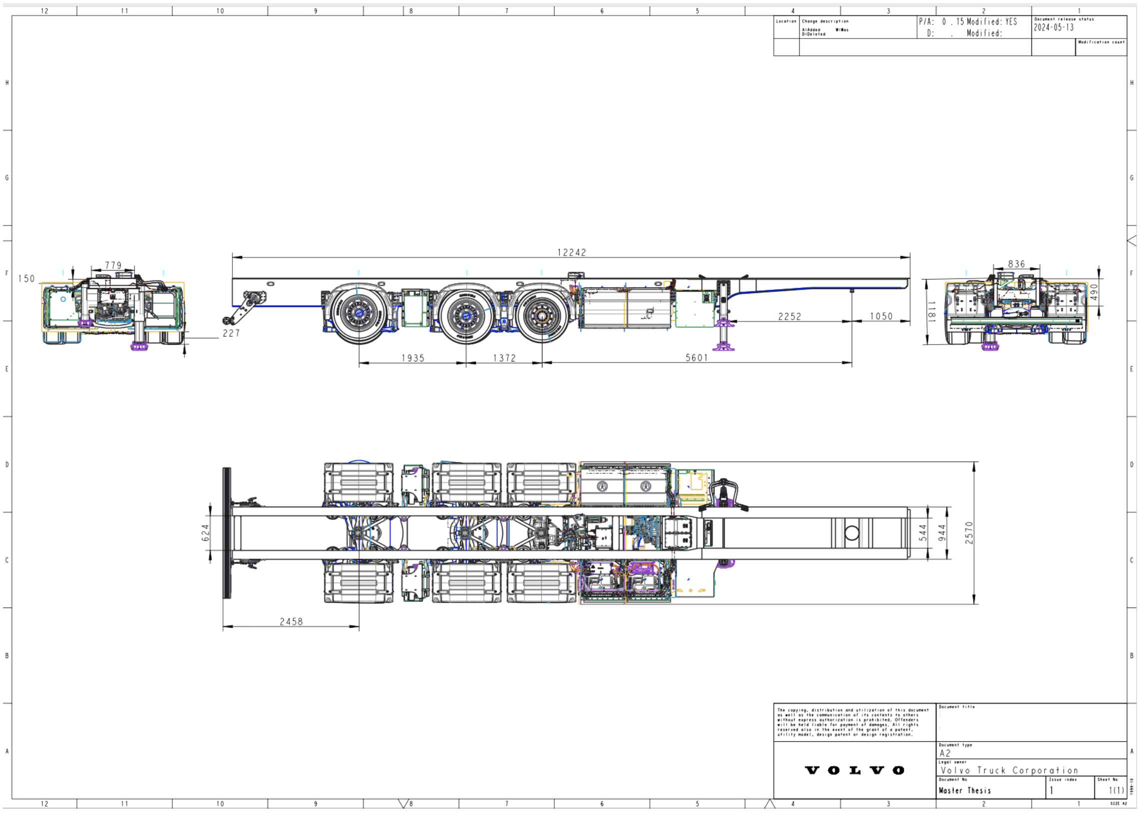


Figure 6.6: Assembly drawing of this generation of the E-trailer

Additionally, drawings were created for the parts developed during the project. The developed beam, illustrated in *Figure 6.7*, presents the form and design of the gooseneck, which meets the ISO 1726-1:2000 standard for all beam dimensions. Each beam was made 29.5 mm wider to meet both customers' demands for web distance, with the change in web distance placed at the gooseneck to achieve a shorter wheelbase.

The web thickness is 5 mm in the front and 6 mm behind the widening. The cross-section utilized is I-shaped with cut-outs for mounting the axles, anti-roll bars, and battery arrangement. Some parts from Hammar Maskin AB were created in CAD to ensure they fit. The dimensions of the cross-member was modified to fit the developed chassis, meanwhile the cross-member for the front and the cross-member with the kingpin maintained the same design.

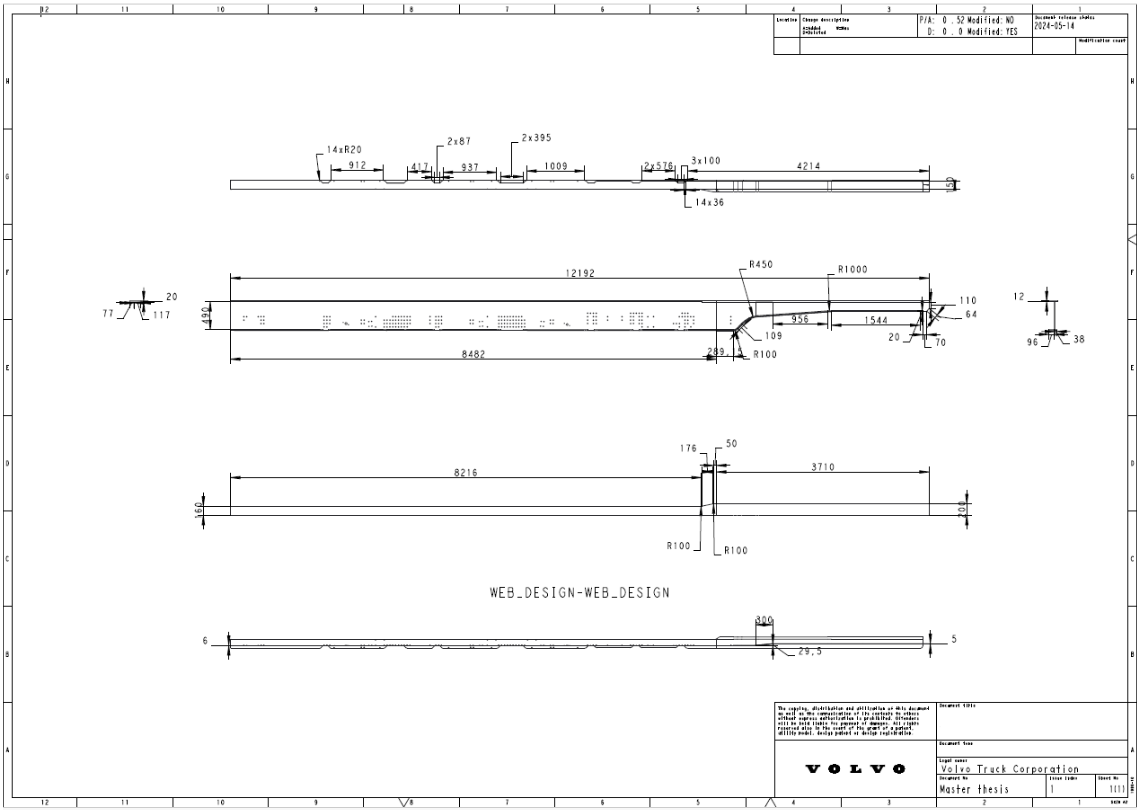


Figure 6.7: CAD drawing of the developed beam

6.3 Final Calculations

To approximate the weight of the developed chassis, a calculation was carried out in Creo Parametric. This calculation was performed on an assembly of the developed or modified components of the E-trailer. All these components were assigned steel as the material, with a Young's Modulus of 2.1 10^7 kPa and a Tensile Yield Stress of 650 MPa. The mass of the components illustrated in *Figure 6.8* was determined to be 1974 kg.

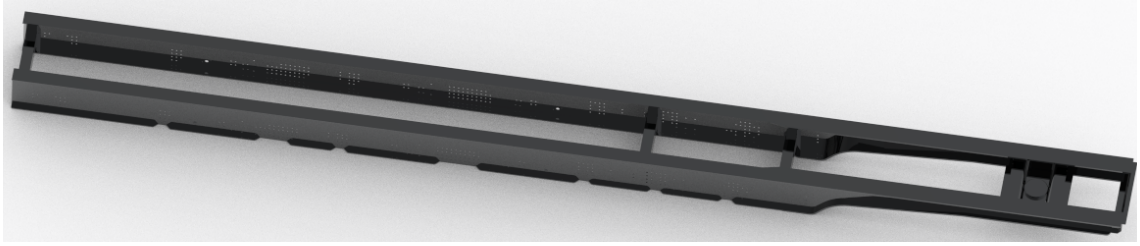


Figure 6.8: Assembly drawing of the current generation of the E-trailer

7
Discussion

This chapter discusses the methodology utilized in the project, examining the final concept and conducting an analysis to validate both the methodology and the results. Additionally, it addresses the consequences and ethical aspects related to the project, ensuring a comprehensive understanding of the impacts and responsibilities associated with the development of the E-trailer.

7.1 Methodology and Theoretical Framework

The methodology used in this project was adapted from the design thinking process, incorporating minor modifications to enhance its suitability for complex projects. This approach supports an interactive, non-linear process that allows for iterative refinement by enabling movement back and forth between different phases. Moreover, many of the tools employed in this project align with the Ulrich, K., Eppinger, S., & Yang, M., 2020 model, which is recognized for its adaptability and practicality in guiding product development.

7.1.1 Theoretical Framework

The theoretical framework served as the core of the research and development process, offering a structured approach to achieving the project's objectives. The framework integrates design thinking principles with qualitative and quantitative research research methods, ensuring a comprehensive analysis of the subject.

A thorough literature search was conducted to gather essential information, primarily using resources from the Chalmers library and Volvo Group's internal web page. Additionally, data from various companies' websites were incorporated. The literature study is considered highly credible due to the varying selection of sources and cross-verification of data. Although the objectivity of using companies' own websites can be debated, the information obtained was primarily used to develop the theoretical framework and did not introduce bias. This was particularly evident in cross-verifying data on the environmental benefits of High Capacity Transport (HCT) and electric trailers with multiple sources, ensuring accuracy and reliability. The literature research not only provided foundational knowledge but also highlighted existing gaps and opportunities in the market, supported by diverse and credible sources.

Observations played a critical role in understanding the operational dynamics of trucks, conventional trailers, and previous generations of the E-trailer. Direct interaction with these products through observation and interaction significantly enhanced the knowledge and awareness of the subject. This hands-on approach provided practical insights that were invaluable for the subsequent design and development phases. Observations were conducted at key locations, including Hammar Maskin AB and Volvo GTT, where existing trailers and trucks were examined. Additionally, observing the earlier generations of the E-trailer allowed for a deeper understanding of the components, identifying beneficial aspects to be retained and areas for improvement.

Given the project's early stage of development, consulting experts in the field was essential for gathering high-quality information, supporting development, and providing support. Experts from Volvo GTT, Hammar Maskin AB, and Chalmers University of Technology were essential in forming the project's direction. Collecting information from experts is an efficient approach to acquiring in-depth knowledge, though it is acknowledged that different interpretations and personal opinions may slightly influence the information. Continuous consultations with these experts provided clarity and guidance, particularly in areas requiring specialized knowledge. However, it is important to recognize the potential for subjective biases and to account for these when integrating expert advice into the theoretical framework.

Interviews were conducted with the primary customers, Volvo GTT and Hammar Maskin AB, to understand the specific demands and requirements for the project. These interviews were designed as ongoing discussions in smaller groups, facilitating a more dynamic and interactive exchange of ideas. However, in retrospect, the interviews could have been structured more formally and conducted earlier in the process to gain a clearer understanding of the demands sooner in the process. The challenge was to identify specific needs before acquiring a deeper understanding of the subject, which justified the initial unstructured approach. While the primary focus was on immediate customers, future stages of the project should include interviews with end customers to ensure that the final product meets broader market needs and expectations.

7.1.2 Data Collection Methods

In both benchmarking of competitors and patent research, keywords were utilized to narrow down the search, making the choice of keywords essential. Using incorrect or missing keywords could have led to significantly different and inconclusive outcomes. The keywords were therefore carefully selected, erring on the side of including too many rather than too few to ensure no important information was missed. While limitations were necessary for feasibility, the employed keywords were considered well-chosen.

Interviews with the primary customers, Volvo GTT and Hammar Maskin AB, were conducted to understand the specific demands for the project. However, since the process was interactive and the interviews were unstructured, it became challenging to accurately determine and prioritize the various customer requirements. A more structured approach to interviews, where customer requirements are clearly defined and prioritized, would likely have been beneficial. This structured method would have allowed for a better understanding of the importance of different customer needs and facilitated clearer communication. When translating customer requirements and desires into technical specifications, trade-offs had to be made based relative importance. Despite the initial challenges, the iterative nature of these interviews ultimately led to a more precise understanding of customer needs, guiding the development process effectively.

7.1.3 Development Process

The traditional development process was utilized during the formulation of the E-trailer. This method is generally effective and adaptable for various products as it generates a large number of ideas. However, for this particular project, there were many existing frameworks to adhere to, making such a number of ideas impractical. Instead, the project required extensive testing and iterative improvements with the support of experts and the customer. A more suitable method for this project could have been working in sprints, following a framework like Scrum. This approach would have allowed the first CAD model to be generated and presented to the customer earlier, enabling quicker feedback and more efficient adjustments.

7.2 Research Questions and Objectives

This section discusses the areas addressed by the research questions in the project, including the challenges in adapting the chassis, the feasibility of a single chassis concept and the transaction to a advanced E-trailer design.

7.2.1 Adaption of Chassis

The standard chassis designs and dimensions of Volvo GTT and Hammar Maskin AB presented significant challenges during the project. Hammar Maskin AB typically uses an I-shaped cross-section, whereas Volvo GTT employs a C-shaped cross-section, affecting how components interact with the flange. The variations extended to the thicknesses of both the web and flange, as well as differences in the width between the inner parts of the webs.

Hammar Maskin AB aimed to retain as many of existing dimensions as possible to simplify production. In contrast, Volvo GTT prioritized maintaining the original dimensions to ensure compatibility with the components. Despite the complexities and potential for further development, the project successfully adapted Hammar Maskin AB's chassis to accommodate Volvo GTT's components.

7.2.2 Feasibility of a Single Chassis Concept

In previous generations, a double chassis was utilized, where the collaborating company placed its chassis for the container on top of Volvo GTT's chassis adapted for the components. The aim for this generation was to develop a single chassis, if feasible. It turned out to be possible, although resulting in a complicated solution. However, this single chassis was specifically adapted for collaboration between Volvo GTT and Hammar Maskin AB. As a result, this generation of the E-trailer is not yet ready for mass production or applicable to other companies.

To make the model feasible for collaboration with more companies, it needs to be significantly less complex and more generalized. Nevertheless, given the early stage of development, achieving this level of generalization was not the goal for this iteration but remains a target for future development.

7.2.3 Transition to a Advanced E-trailer Design

Numerous modifications were necessary for the previous generation of the E-trailer to ensure feasibility. The ambition to create a single chassis made this generation more advanced than the previous one. While some modifications might be seen as unnecessary due to increased complexity, these changes were essential to adapt to a specific type of production and meet various customer requirements.

A significant proportion of these modifications will require further analysis and simplification to develop a solution more suitable for production. This project did not take into account the cost of the prototype, but it is an important factor to consider in future iterations.

7.3 Development and Finalization

This section discusses the final concept of the project, focusing on how it aligns with customer demands. It also explores potential improvements and provides some recommendations for the E-trailer, aiming to enhance its design and functionality based on feedback and analytical findings.

7.3.1 Customer requirements

The project involved two highly knowledgeable customers, were both deeply engaged in the product's development and had strong opinions that necessitated careful evaluation. This involvement required significant trade-offs, constraining the scope for creative and creative ideas. Consequently, the solution became relatively complex, which might have been simplified with less specific requirements. Despite these challenges, the solution developed successfully meets the most critical criteria outlined in the List of Metrics (*Section 4.2.2*).

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The specification required the width between the outer flanges to be 945 mm, which aliens with the models dimension. The widths between the inner parts of the web measured 779 mm at the front and 836 mm at the rear, aligning with the requirements. Most dimensions in front of the gooseneck align with Hammar Maskin AB, although the gooseneck was designed slightly shorter to meet turning radius requirements, prioritizing regulatory compliance over production ease. The chassis's beam was I-shaped, designed with minimal cut-outs to adapt to the components while preserving structural integrity. The ideal ground clearance was targeted at 240 mm, with a minimum acceptable clearance of 180 mm. The measured clearance of 227 mm posed measurement challenges in the model due to varying air volume in the air-filled rubber bellows, which affects clearance.

Axle specifications matched the definition in the List of Metrics. The wheelbase was practically perfect, with a measured length of 5600 mm which was the same as the calculated demand. The trailer's width was measured at 2498 mm, which was within the maximum allowed width. All other regulatory requirements listed in the List of Metrics were met. The gooseneck, designed with soft edges, narrowed by 300 mm and the estimated weight was below 9800 kg but not less than 7900 kg. The final concept successfully fulfills most specified requirements and desires, with only a few compromises. However, the solution's complexity currently limits its readiness for mass production, necessitating further development and analysis to refine and simplify the design.

7.3.2 Potential Improvements

Given that the E-trailer is in its emerging stages of development, there exists considerable potential for improvement in this generation. The project time frame was limited, and many decisions were informed by expert consultations, which were deemed adequate for this phase but will require more detailed analysis in further developments.

One significant area for further examination is the placement of the radiator. Currently, its placement is based on an estimate, necessitating additional analysis to determine how effectively it operates in its current location and whether adjustments, such as adding protective measures or altering its position, are necessary. Presently, the radiator is positioned between the second and third axles, as implemented in this project. An alternative could be placing it behind the third axle, potentially requiring a cone-shaped guard to manage airflow effectively. A comparative evaluation of these alternatives should be undertaken prior to prototyping the E-trailer.

Additionally, the mounting arrangement for the tank for the cooling system, which expands above the chassis edge, needs redesigning. This component was tailored to the specifications of the previous generation and must be adapted for this generation due to design variances. Furthermore, a detailed weight analysis is crucial, along with exploring opportunities for further weight reduction, which remains a critical aspect of the E-trailer's development.

Special beams designed to secure containers must also be developed before the prototype construction begins. Moreover, the placement of the parking legs requires reassessment, currently situated near the gooseneck to maintain the correct wheelbase. However, as this is the most vulnerable part of the beam, alternative mounting positions for the parking legs should be considered to enhance structural integrity.

7.4 Validation and Ethical Aspects

This section critically evaluates whether the project has met its established expectations and assesses the validity of the methodologies employed. Additionally, it explores the robustness and applicability of the final concept, ensuring that it adheres to both performance expectations and ethical aspects in its design and potential implementation.

7.4.1 Methodology

The methodologies employed throughout the project are well-established and widely recognized, generating a high degree of credibility to the research findings. The information collection process was continuously designed to ensure high validity, with particular attention paid to minimizing bias. Continuous and direct communication with the customer significantly reduced the risk of misunderstandings, facilitating the generation of well-defined requirements. Although the development approach used in the project is considered highly credible and effective, it may not have been the optimal choice for every aspect of this specific project. Nonetheless, the methods and tools utilized throughout were reliable and validated.

7.4.2 Final Concept

The design and dimensions of the final concept were largely established based on estimates from experts with extensive field experience, providing a strong foundation of validity to these aspects. However, given the unique characteristics of the product, which differ from typical industry models, it is crucial to conduct detailed calculations and analyses on as many components as possible to ensure accuracy.

While calculations were meticulously performed for the wheelbase, other elements such as the margins of the cut-outs and the flange behind the battery were only estimated. With additional time, these components should also be quantitatively analyzed to enhance the overall validity of the design. Furthermore, the prototype was developed using CAD software, which, while effective in preliminary stages, may not fully capture potential errors that could manifest during the physical construction of the prototype. Therefore, transitioning from a virtual model to a physical prototype should be approached with careful validation to identify and adjust any inconsistencies.

7.4.3 Ethical Considerations

The increasing number of instances of vehicles in today's environment greatly intensifies ecological damage. This reality creates an ethical dilemma whether the focus needs to be on enhancing existing vehicle technologies or should efforts move towards alternative transportation methods that minimize environmental impacts. While developing entirely new solutions is demanding of resources, requiring significant time, investment, and consumer acceptance, small improvements to existing vehicles remain a practical approach. High Capacity Transport (HCT) road trains and E-trailers exemplify such advancements, offering a reduction in carbon emissions. Reports suggest that HCT could diminish Sweden's climate footprint by 4-6%, and E-trailers might enhance fuel efficiency by 5-20%. However, these figures also need to be analyzed in regard to the environmental consequences of battery manufacturing, including recycling and disposal.

The full life-cycle analysis of these vehicles should encompass not only the operational efficiency but also the origin of the electricity used, whether from renewable sources or more damaging ones. Furthermore, the ethical implications extend beyond environmental concerns to the social impact of raw material extraction. For instance, the mining of lithium, cobalt, and mica—key components in electric vehicle batteries, raises significant ethical issues. There are documented instances of child labor, particularly in mica extraction in Madagascar. Regardless of how common these activities are, they are categorically unethical and need to be prevented. In addition, the extraction and manufacturing operations often take place in environments with poor worker safety and inadequate wages.

It is imperative that companies involved in the production of E-trailers ensure supply chains uphold ethical standards that respect human rights and environmental integrity. This requires a close evaluation of the sources of materials, labor standards, and the wider societal effects considering advancements in technology, to minimize the risk of such ethical violations.

8 Conclusion

This thesis has successfully accomplished the development and optimization of a next-generation semi-trailer with an electric driveline, effectively addressing all the posed research questions. The collaborative efforts between Hammar Maskin AB and Volvo GTT have led to the creation of a design that integrates seamlessly with components from both manufacturers, meeting the distinct requirements of each.

The chassis design incorporates a widened section at the gooseneck, effectively adapting the front part to meet the specifications of Hammar Maskin AB and adjusting the rear part to accommodate Volvo GTT's components. This design strategy not only enhances adaptability but also ensures compatibility with both manufacturers' requirements. Key modifications at the gooseneck include adjustments to the web thickness and the spacing between the webs. Additionally, the chassis's cross-section was strategically modified to include cut-outs where components are mounted, optimizing space and functionality. Furthermore, Hammar Maskin AB's cross-members were elongated to align seamlessly with the new chassis design. These comprehensive modifications collectively address and fulfill the first research question: *How can Hammar Maskin AB's chassis as well as including parts be adapted to fit Volvo GTT's components?*.

The integration of Volvo GTT's mounting hole patterns and dimensions into Hammar Maskin AB's design proved successful, demonstrating the viability of a single chassis concept. This integration allowed for seamless incorporation of components into Hammar Maskin AB's chassis framework. Consequently, this confirms the feasibility of developing a unified chassis design that supports direct integration of Volvo GTT's components, affirmatively answering the second research question: *Is it feasible to develop a single chassis concept that allows for the direct integration of Volvo GTT's components into Hammar Maskin AB's chassis?* Yes, it is indeed possible.

Several crucial modifications were implemented from the previous generation to advance the design of the E-trailer. Firstly, adjustments were made to the web and flange thicknesses, as well as the web design, including the distance between webs. The chassis's cross-section was evolved into an I-shape with strategic cutouts for component integration. Furthermore, the hole pattern was shifted upwards by 12 mm, and an additional row of holes was added to elevate the batteries by 60 mm. The air-filled rubber bellows and bump stops were relocated to the flanges, enhancing structural stability. Additionally, two anti-roll bars were incorporated at the middle axle and one at the last axle, and the first and second single axles were converted into a bogie configuration. These comprehensive changes affirmatively address the third research question: *What modifications are necessary to transition from the previous generation to an advanced design of the E-trailer?*

To reduce the trailer's weight, a strategic shift to a single chassis design was implemented instead of the previous double chassis configuration. Additionally, employing an E-axle may contribute to further weight reduction. These strategies effectively address the fourth research question: *What strategies can be employed to reduce the weight of the E-trailer while accommodating the additional components required for its electric driveline?*, confirming that both questions have been satisfactorily resolved.

9
Further recommendations

Due to the fact that the E-trailer was at an early stage in development and that the project was limited to an definite period of six months, there are some identified areas that need to be analyzed and developed further.

Before constructing a real prototype of this generation, further development is necessary. Initially, the placement of the radiator requires additional analysis. Secondly, the packaging of the cooling system's tank needs reevaluation, as it currently extends beyond the chassis edge. Moreover, calculating the total weight and exploring opportunities for reduction are crucial steps in the ongoing development of the E-trailer. Additionally, special beams designed to secure the containers must be developed. Lastly, the positioning of the parking legs also warrants reassessment.

For the next generation, several recommendations have been identified to address existing challenges. The complexity of the chassis, due to varying customer dimension requirements, has resulted in production difficulties and high costs, making it unsuitable for mass production. Additionally, it is recommended to explore the potential use of an E-axle as an alternative. For the current generation, the margins for cut-outs and the narrowing of the flange behind the battery package were estimated; moving forward, implementing precise calculations is advised. Furthermore, conducting interviews with end customers is recommended to better understand their specific requirements.

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