Claus

Enabling last-mile delivery in urban environments with limited mobility access

TU Delft

DNAMX power innovations

Master thesis C.E. Ameln

Claus *or* Enabling last-mile delivery in urban environments with limited mobility access

Master thesis
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19 August 2022

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Abstract

In this report the development and design of Claus is presented. Claus is an auxiliary drive train module for last-mile delivery hand trucks. The objective of the concept is to enable delivery workers to deliver parcels to the growing amount of addresses in urban environments with limited mobility access.

Due to the combination of urbanization, the rising popularity of e-commerce and rising congestion levels in cities, delivery companies are increasingly struggling to transport their goods to the customer. Conventional delivery fleets, consisting of big delivery vans to handle the rising delivery volumes, are not suited to the urban environment anymore as cities are undergoing rising congestion rates and as automobiles are becoming a less prioritized mode of transport. Consequently, delivery workers have to cover larger distances from the van to the front door of the customer by foot. Usually, delivery workers use hand trucks to cover these last meters, but as these distances increase, walking the hand truck becomes a time consuming job.

Claus is proposed as a solution for this last leg of parcel delivery. Claus is an auxiliary module with a built in electric drive train that connects to any regular hand truck. By connecting Claus to a hand truck, a four-wheel vehicle is created that can transport a the delivery worker along with his or her cargo. The hand truck acts as both the cargo carrier as well as the steering device, while Claus acts as a standing deck and a drive train. Thanks to Claus' geometry and volume, Claus can be transported in a conventional delivery van similarly to the hand truck. By bringing both a hand truck and Claus during delivery shifts, delivery workers are enabled to quickly and easily cover areas that are becoming less accessible to delivery vans.

Two prototypes were created that were used to validate the concept. A technical prototype acted as a means to validate the driving characteristics and the ergonomics. Furthermore, it was used to validate technical aspects such as the battery capacity and the drive train system. An aesthetic prototype was used to communicate the design to the stakeholders.

Keywords: last-mile mobility, last-mile delivery, hand truck, light electric vehicle, logistics

Table of Contents


OPEL
VIVARO
STANLEY.

Glossary

Last-mile

The last mile refers to final leg of transportation of people and goods. The 'last-mile' covers the distance from the last transportation hub to the final destination.

Last-meter

In the context of this report the 'last-meter' refers to the part of the last-mile in which goods are transported from the delivery vehicle to the front door of the customer.

Drop-off

Drop-off refers to the activity of the customer dropping off a package at a parcel point or postal office

Pick-up

Pick-up refers to the activity of the customer picking up a package at a parcel point or postal office

Platform

A platform is a collection of production assets that is shared among a range of different products. The concept of a platform will be further elaborated on in chapter '**Analysis - Modularity Approach'**

OEM - Original Equipment Manufacturer

An OEM is a supplier or producer of components or sub-assemblies which the producer of the final product uses to compose a final product.

LEV - Light Electric Vehicle

A LEV is any electric vehicle that is significantly smaller than a conventional passenger car. Typically, LEV's do not reach speeds higher than 30km/h.

BEV - Battery Electric Vehicle

Any vehicle equipped with an electric motor that is powered by batteries.

ICE - Internal Combustion Engine

Refers to vehicles equipped with an internal combustion engine.

Deferred delivery

Delivery within 1-3 days

Same-day delivery

Delivery within 24 hours

Instant delivery

Delivery within a very short amount of time. Typically within 2 hours, often even within 10 minutes.

Backshoring

Relocation of production back to the home country of the firm.

Nearshoring

Relocation of production closer to, but not within the home country of the firm.

USP - Unique Selling Point

Unique property of a product that distinguishes it from the competition.

Mobility scooter or Scootmobiel

A mobility scooter is an electric vehicle which purpose is to assist less mobile people, such as elderly and handicapped, in their day-to-day needs.

Body-in-white

Production stage of an automobile in which the main frame is joined together, but no additional components or sub-assemblies are assembled yet.

Architectural plan for Rotterdam Pompenburg. Urbanization and less space for automobile transportation poses challenges for the last-mile delivery sector.

INTRODUCTION

In this section, the research topic is introduced. The chapters are based on the original project brief that was established for the kick-off of the project. The original project brief can be found in Appendix A.

The last chapter presents a project roadmap of the activities that were executed over the course of the project.

Introduction

Introduction

European urban infrastructures are undergoing a transformation due demographic and political trends. Ongoing urbanization puts a high strain on current urban infrastructures which are most often not designed for the growing amount of automobile traffic. In addition, the European Green Deal states that the European Union must reduce emissions from cars by 55% before 2030 (Delivering the European Green Deal, 2021). As a result, European cities are urged to invest in more sustainable alternatives to guarantee citizens reliable, fast and clean transportation. However, this transformation poses challenges for the logistics sector since urban areas are becoming less accessible for the conventional fleet of delivery vehicles. Next to accessibility challenges, the parcel volume that has to be handled by the logistic companies has risen enormously. In 2019 e-commerce still showed a worldwide growth rate of 20,5% (Statista, 2022). as a result, delivery workers have to deal with high time pressures (Boysen et al., 2020).

Amsterdam cluttered with cars

These problems mostly occur in the very last leg of the supply which is often referred to as the 'last-mile'. The last-mile can be defined as the final part of the supply chain where the parcels, foods, or groceries land in the hands of the final recipient. In research from Capgemini (2019) it is estimated that the last mile accounts for 41% of the overall supply chain costs. In spite of this high market share, delivery companies do not operate very efficiently within the last mile delivery domain, due to the before mentioned challenges.

Next to the efficiency challenges for delivery businesses and the high shipping costs for the final recipient, online retailers are stakeholders in this problem as well since they typically take on a portion of the delivery costs in order to offer their customers lower shipping prices. (Capgemini, 2019)

Given these challenges, many efforts have been done to improve the supply chain accordingly. Envisioned solutions range from alternatives on a vehicle level such as electric cargo bikes, to pilots with delivery drones and autonomous vehicles, to strategic reorganization of the overall supply chain (World Economic Forum, 2019). Although a lot of development is focused on single vehicles for specific delivery scenarios, there is little development on modular vehicles that can be configured to multiple specific delivery scenario. Since the circumstances in which delivery vehicles operate differ enormously among delivery businesses and urban environments, a modular approach for delivery vehicles enables delivery businesses to configure their fleets according to their individual interests.

A second factor that has become of interest in the last decade is the relocation of manufacturing closer to the market. This term is often referred to as backshoring or nearshoring (Fratocchi et al., 2014). There are various motivations for back- and nearshoring production among which are shorter lead times, mitigation of supply chain risks and higher perceived quality by the customer in the case of European and American producers (di Mauro et al., 2018) (Colamatteo et al., 2021).

The production of a modular light electric vehicle might offer a strategic opportunity for some automotive OEM's. Traditional automotive power train OEM's have a reason to tap into new markets since the internal combustion engine (ICE) is slowly getting replaced by battery electric vehicles (BEV) (Ciftci et al., 2022),(Govindan et al., 2022). The facilities and knowledge that is present at these OEM's might offer a good foundation for production of LEV's close to market. At the same time these companies can also establish a strategic shift in their product portfolio.

The objective of this study is to develop a concept for a modular electric vehicle that can be configured to multiple delivery use-cases. Local production of this vehicle will be explored as a means to ensure flexible production.

The first section of this study will examine the context of last mile delivery by exploring the stakeholders' activities and interests. Also, other context factors such as an in-depth analysis of modular product architecture and future scenarios are performed. In the subsequent section, the developed concept is presented. Finally, this concept will be evaluated in the validation section which encompasses several user tests and recommendations for future development of the concept.

Depot employee sorting parcels

Problem definition

The last-mile delivery problem is a very complex and large problem. Therefore, it is beyond the scope of this master thesis to provide a feasible holistic solution for the overall last-mile supply chain problem. Instead, the scope of this project is to conceptualize a solution for a sub-problem in the last-mile delivery problem. The main sub-problem that is of interest in this project is the instance when the delivery worker has to transport goods from the main delivery vehicle to a recipient or the other way around. These 'last-meters' or 'in-between' moments are of significance since they influence the delivery speed to a great extend. This project aims to deliver a vehicle concept for the last-meter that takes the challenges of the last-mile into account. At the same time the architecture of the vehicle should enable the user to configure the vehicle according to the particular cargo type, travel distance and traffic situation. On a final note, the design of the vehicle should account for local production. The aim is to explore what automotive production methods are suited for producing this vehicle close to the market.

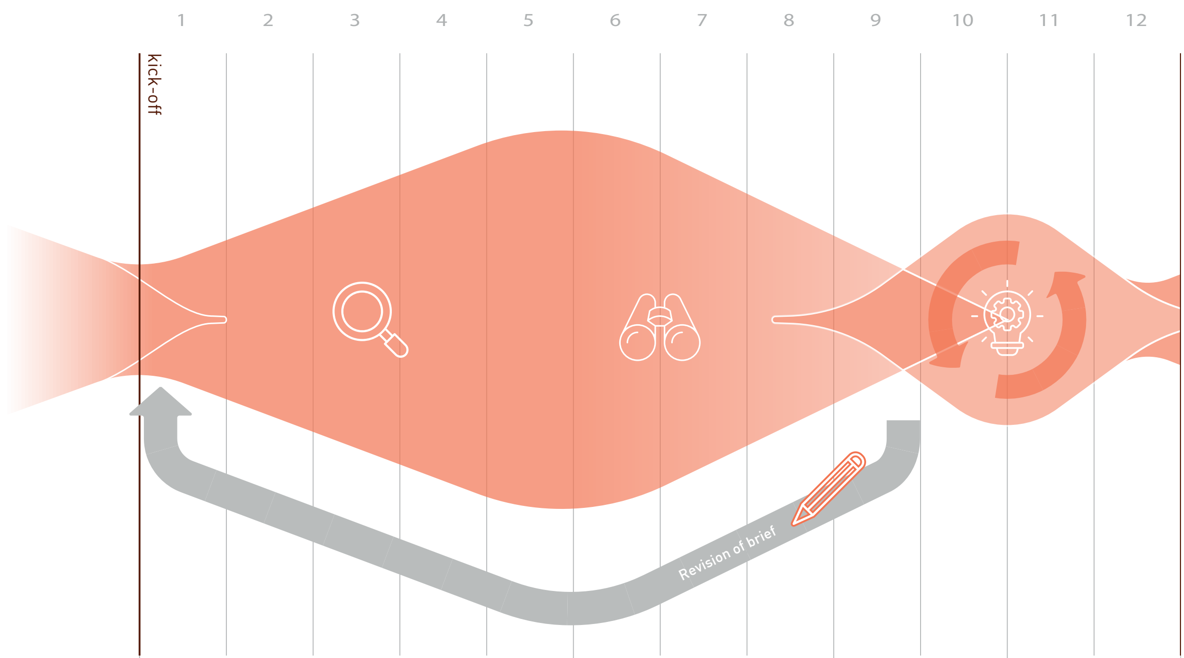
PostNL delivery worker delivering the 'last-meter'

Assignment

A concept for a modular delivery vehicle will be generated by studying the problems of the last-mile delivery ecosystem and by exploring those through the lens of multiple delivery scenarios that have future potential. Automotive production methods will be explored through which a production proposal for the vehicle will be generated. The modular architecture will be defined by pinpointing the needs and use-cases of all the different stakeholders.

Project Roadmap

This roadmap is a visual representation of the progression of the project from the kick-off meeting till the graduation ceremony.



Orientation & defining brief

The phase prior to the kick-off meeting consisted of orientation on the subject and writing the initial project brief.

Contextual research & stakeholder identification

Finding relevant data and stakeholders on context factors

Research into:
Last-mile delivery
Manufacturing - Local Production
Urban environment

Scenario exploration

Through multiple potential scenarios the future of last-mile delivery was explored. This has set the scene for product conceptualization of a product with a viable future.

In this phase a beginning was made on the unique selling points by filtering and composing the relevant data from the prior phase

Ideation & Experimental rototyping & Contextual inquiry

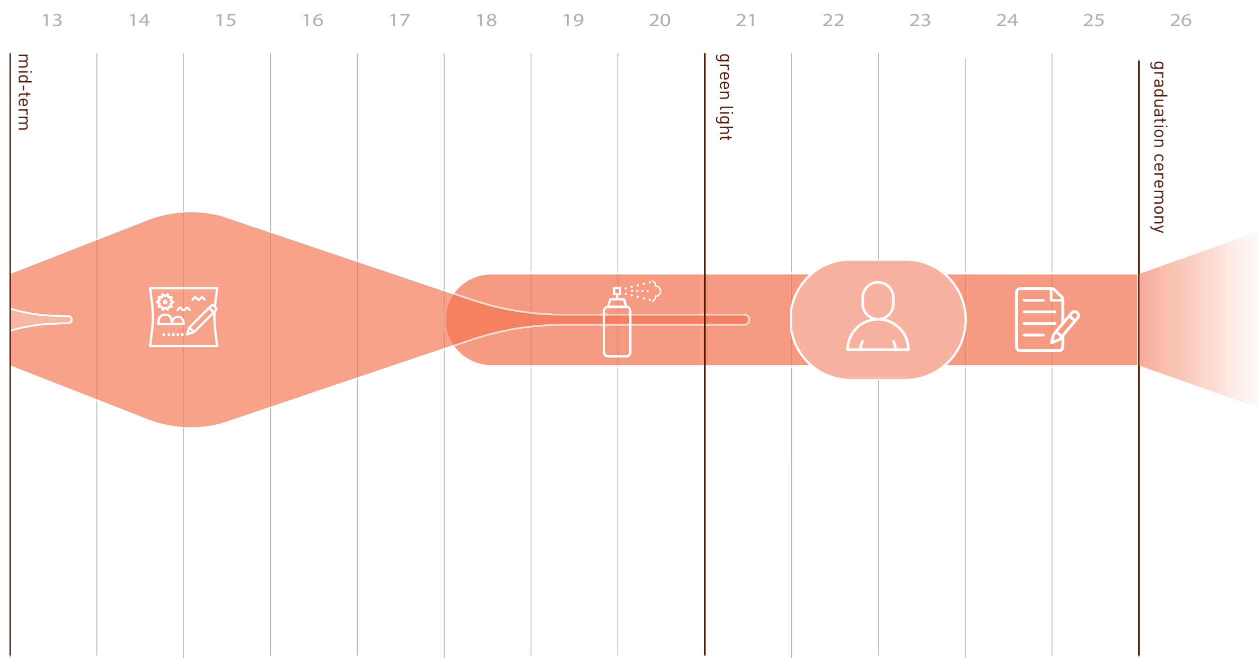
USP's & Functional freeze

By reviewing the future scenarios and the USP's the initial ideation phase was started.

Various concepts based on hand trucks were established because the hand truck turned out to be a strategic domain for further exploration.

Selection of the concepts took place resulting in three concepts. Subsequently, the strengths of the three concepts were combined to form a single concept. Prototyping of this concept followed.

On basis of this prototype a new concept was made that was feasible to realize within the time given for this project. The functionalities of this concept were pinpointed. From this point on the concept was fixed.



Look and Feel & Ergonomics & Technical challenges

The look and feel of the concept was explored through multiple collages. The ergonomics were evaluated by both desk research and prototype testing.

Some technical challenges such as the steering mechanism were also tackled in this phase.

Package & materialization

This phase consisted of defining the production techniques, materials and looks of the product.

In addition, the cost price was estimated.

Prototyping

Prototyping both a technical and an aesthetical prototype of the final design.

User testing Validation

This phase consisted of testing the prototypes on several aspects such as ergonomics, drive characteristics and power provision.

Reporting

Bicycle graveyard - Hangzhou, China

What initially began as an initiative to offer Hangzhou citizens better and cleaner shared mobility, ended up in thousands of deserted bicycles cluttering the streets of Hangzhou. Once the Chinese government decided to round up all the deserted bicycles, the bicycles had no other destination than a dedicated graveyard.

ANALYSIS

This section of the report elaborates on the context of the stakeholders as well as last-mile mobility. The conclusions of each individual research topic were translated into implications for the final design. On their turn these implications translated into five unique selling points.

To conclude this chapter the five unique selling points were composed and elaborated on.

Stakeholders

Multiple stakeholders were identified and discussed. The diagram below displays the stakeholders that are involved within the scope of this project.

Within the domain of last-mile delivery four sub-domains were identified, namely meal delivery, parcel delivery, on-demand grocery delivery and normal grocery delivery. Therefore, some stakeholders are represented by sub-categories. These are indicated in the diagram by the darker table.

The following couple of chapters elaborate on the main categories of stakeholders.

Manufacturers	**Retailers**	**Delivery Businesses**
OEM's	Restaurants	Meal delivery services
	E-commerce stores	Parcel delivery services
	On-demand grocery business	
	(Online) Supermarkets	

Delivery Workers	**Recipients**	**Municipalities**
Meal delivery workers	•	Citizens
Parcel delivery workers	•	European Union
On-demand delivery workers	•	
Grocery delivery workers	•	

Delivery Workers

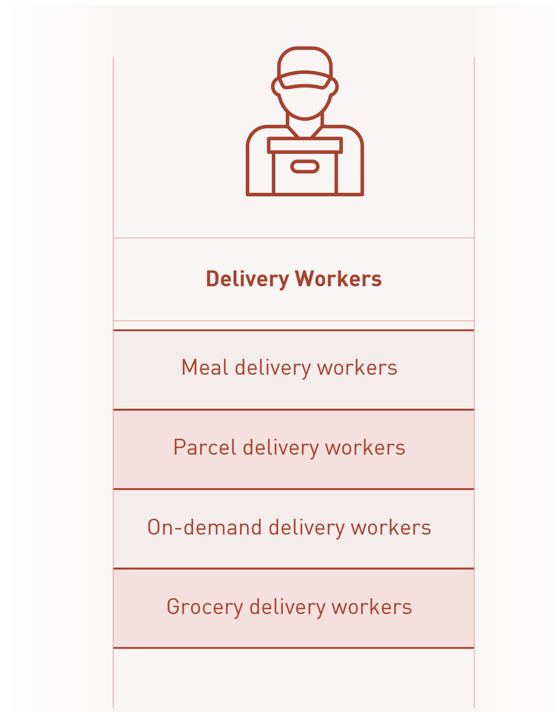
Delivery workers ship goods and foods on behalf of the delivery business from the retailer to the recipients. Delivery workers are the actual users of delivery vehicles. The specific activities that are carried out by the delivery workers differ among the various types of delivery businesses.

To get familiar with the activities and pain points of the delivery workers, field research was done. A contextual inquiry with a parcel delivery worker was done and in addition a brief observational study was done on on-demand delivery workers and meal delivery workers. Since the final design is mostly focussed on parcel delivery workers this chapter highlights the parcel delivery workers. Contextual studies into other segments can be found in Appendix G. The full contextual inquiry on the parcel delivery worker including a photo report can be found in Appendix F

Parcel delivery workers

The interviewed delivery worker mentioned that an average parcel delivery worker has to deliver around 200 parcels per day. That gives the delivery worker 120 seconds per parcel for delivery. This puts a high strain on delivery workers. The delivery worker that was studied also mentioned that delivery in urban areas could be a daunting task due to a combination of the time pressure and traffic situations.
According to the delivery worker driving the van to each individual delivery destination results in irritated road users due the van obstructing the road at every stop. An alternative is to gather a selection of parcels and walk them to their destinations with a hand truck, while the van is parked on the corner of the street. However, the distance that could be covered in a time-efficient way by foot is very limited.

The delivery worker himself did not often use a hand truck for these last legs of delivery. He said that his particular route through rural areas did not necessarily needs a hand truck since he could stop his van in front of every address without any problems. However, he mentioned that delivery workers in big cities such as Amsterdam very often use hand trucks to carry 20-30 parcels through streets and through apartment buildings. According to the delivery worker these delivery workers sometimes travel for 1,5 km with the hand trucks.



The inquired delivery worker searching for the correct parcel.

Implications for design - Delivery worker

- The design should ensure that the delivery worker can work efficiently yet enjoy his or her work. Therefore the product should not be physically demanding to use.
- Manoeuvrability is of importance since its use environment is a crowded urban setting.
- Every city, every route, and every delivery is unique. The design should be customizable to each situation.
- Delivery workers are on a very tight time schedule and therefore they do not have the time to delicately handle their tools.

The delivery worker mentioned that the work can be physically demanding in some situations. He mentioned that especially routes that include shops or businesses often contain heavy packages. Repeatedly loading, unloading and carrying these parcels can be exhausting. In general, every route is physically demanding to some extend since every stop requires the delivery worker to get out of the van and carrying packages to front doors.

Delivery Businesses

Delivery businesses are responsible for bringing goods from retailers or depots to recipients. These businesses are either in-house logistic departments or stand-alone logistic companies. The delivery businesses are responsible for managing the delivery fleet. An appropriate logistics approach with an appropriate fleet can result in lower shipping costs and better customer and delivery worker satisfaction. For example, electrification of the fleet ensures lower fuel expenses.

Retailers

The retailers of goods and foods either have in-house delivery services or they have contracts with external delivery businesses. Very often the retailers take on a portion of the delivery costs to offer the customer lower prices (Capgemini, 2019). Therefore, lower shipping costs are of interest for retailers as well.

Implications for design - Retail and Business

- The vehicle is able to offer efficient parcel delivery .
- An electric drive train is desired for affordable power consumption.

Retailers	**Delivery Businesses**
Restaurants	Meal delivery services
E-commerce stores	Parcel delivery services
On-demand grocery business	
(Online) Supermarkets	

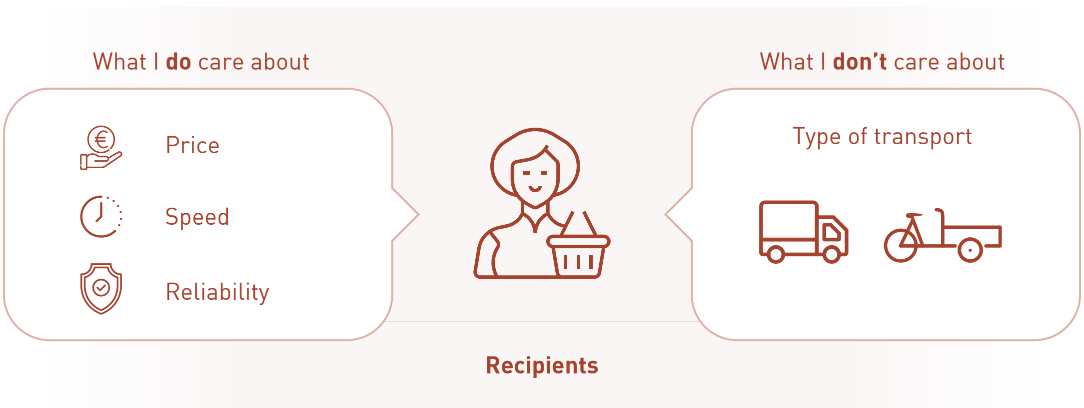
Recipients

The final recipient of the goods is both the person who ordered goods and the person who finally receives the ordered goods, meals or groceries. The exact characteristics of the recipient are dependent on the type of goods that are ordered. For example, a person who orders a meal or on-demand groceries is most likely at home and has good awareness of the delivery process. A consumer who orders parcels online does often have limited control or overview over the supply chain.

However, since the final design is initially focussed on parcel delivery, this chapter discusses the characteristics of the recipient of parcels.

As e-commerce is growing, the last mile delivery sector is starting to get more user oriented (McKinsey & Company, 2016). Also, since competition is fierce, shipping companies are focussing on customer experience to gain strategic advantages over their competitors.

Recipients have distinct desires that shipping companies have to take into account. A survey by McKinsey & Company (2016) with respondents from both Western and Asian countries mapped these customer desires to better understand customer preferences. The report by McKinsey suggests that the means of transportation is of lesser importance than the price, the speed and the reliability.



Implications for design - Recipient

- The price, the speed and the reliability of parcel delivery are key factors which the recipients concern. The design should take these factors into account.

Municipalities

Municipalities are important stakeholders since they prescribe the layout of cities' urban infrastructure. Appendix L is a more elaborate study into the urban context. In this chapter the most relevant findings are presented.

Originally, most infrastructures of European cities were not build for the rising number of automobile traffic that is currently dominating cities. The introduction of the car brought huge advantages for citizens thanks to the possibilities it offered for quick and flexible transit. When the popularity of the car grew, the infrastructure of cities had to be revised drastically. Nowadays, the automobile infrastructure is reaching its limits. Commuters are struggling each day with congestion during peak hours and transporters of goods are struggling with higher volumes, more traffic, and cities' emission regulations.

European cities have to rethink their mobility strategies in order to offer their citizens reliable, safe and clean mobility and to reach the emission reduction goals that were stated in the European Green Deal.

In many European cities this has resulted in investments in alternatives to the car such as better and smarter public transport and bicycle lanes in order to motivate citizens to choose a sustainable mode of transport. Other initiatives aim to demotivate citizens to use cars. This includes congestion zones, emission zones, and high parking fees.

For last-mile delivery providers these initiatives result in a worsening work environment. LMD businesses have to find solutions by either abandoning the conventional delivery vans or by deploying their fleet of vans in a smarter way.

Municipalities

Citizens

European Union

Safety

In the last decade the popularity of LEV's has grown significantly resulting in a number of new vehicle types that can not directly be categorised into any existing laws and regulations. In chapter **Validation - Discussion | Recommendations - Rules and regulations** this topic is explored in greater detail. A main focus point of the existing laws and regulations is that the safety of the driver and other road users is guaranteed.

Implications for design - Municipality

- The vehicle should not emit any greenhouse gasses or particular matter directly when in use.
- The vehicle should not pose a safety hazard for other road users.
- The vehicle should offer an alternative to the conventional delivery van or it should operate in collaboration with conventional delivery vans.

Delivery van blocking traffic in the city centre of Amsterdam

Manufacturers

Local production of the product is one of the criteria that was desired by DNAMX. The main motivation behind local production is that it allows for more flexibility down the whole supply chain.
In addition, global geopolitical tensions and unstable transportation logistics result in a fragile supply of products from other parts of the world (di Mauro et al., 2018).

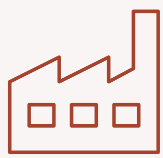
Since the before mentioned challenges are occurring world wide, local production is relevant across the globe. However, to limit the scope of this project, local production in Europe is the focus area.

This chapter elaborates on the role of local suppliers in producing products near market.

OEM's

Since the aim is to manufacture the vehicle in local manufacturing plants, manufacturers play an important role. It is of interests to the assembly lines and OEM's that the design of the vehicle is in line with their capabilities and facilities.

The production of light electric vehicles might offer a strategic opportunity for some automotive OEM's. Traditional automotive power train OEM's have a reason to tap into new markets since the internal combustion engine (ICE) is slowly getting replaced by battery electric vehicles (BEV)(Ciftci et al., 2022),(Govindan et al., 2022). The facilities and knowledge that is present at these OEM's might offer a good foundation for production of LEV's close to market. At the same time these companies can also establish a strategic shift in their product portfolio.



Manufacturers

OEM's

Materialization

To ensure feasible production in Europe, the amount of manual labour should be minimized. The big advantage of production in Asia is that manual labour is abundant and cheap. In Europe however, manual labour is expensive.

Local production is already practiced by the automotive industry. Therefore, the automotive industry is a source of inspiration regarding production and assembly techniques that can be deployed for local production. A summary of production techniques that are used in the automotive industry is provided in Appendix C. It is important to keep in mind that the automotive industry deals with enormous production volumes and enormous investment capitals. When choosing a particular production technique the investment costs should be weighed against the production volume.

In the conceptualization phase, the summary of automotive production techniques and assembly is used to select an appropriate production technique for the product.

BMW factory in Germany

Implications for design - Manufacturers

- Automated production techniques prevent the need for expensive manual labour
- Enabling automated production techniques implicates large investment costs and therefore large production volumes to ensure feasible consumer prices.
- The automotive industry acts as an example for local production.

Modularity Approach

Platform

In the broadest sense, a platform is a collection of production assets that are shared by a set of products (Robertson & Ulrich, 1998). These assets can range from components, to production equipment, to supply chains, to testing methods and even to relationships with a network of suppliers. The development of a platform is always a trade-off since too much common assets result in a uniform product family while too less common assets result in higher overall engineering and production costs. The right balance between these two factors is dependent on factors such as production volume, diversification among target groups, product dimensions and the available production facilities.

An important aspect of the platform strategy is the modularity of products. In the automotive industry modules are defined as follows: "A group of components physically close to each other, that are both assembled and tested outside the facilities and can be assembled very simply onto the car "(Sako & Warburton, 1999). This definition implies that the product architecture should be designed in such a way that these modules can be assembled directly onto the product, in this case a car. The main challenges of designing a modular product architecture are added engineering time and costs, complex tolerance management and structure redundancies due to splitting the product into modular chunks.

A modular product architecture aims to build products with standard building blocks called modules. These modules can be connected to each other via standardized interfaces. The customer or assembly worker can configure a range of products by composing a specific selection of modules.

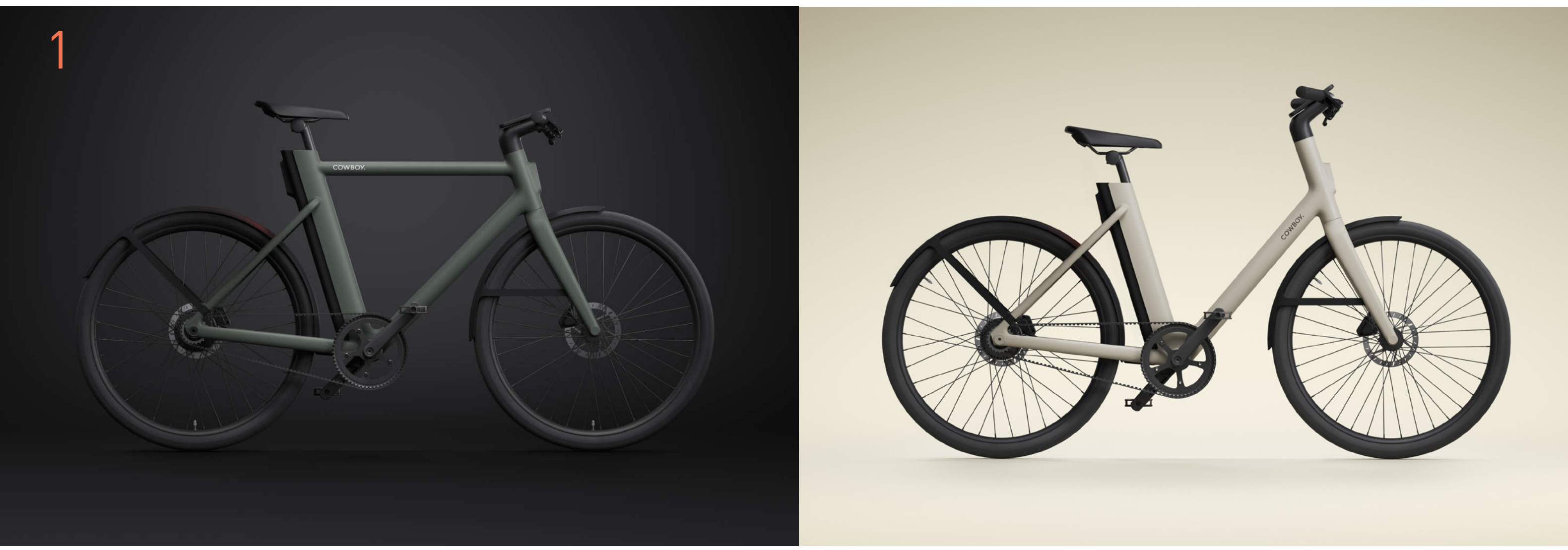
In order to design a successful modular product architecture, one approach suggests to subdivide the product into multiple functional chunks that will later form the modules (Zomeren et al., 2012). A logical subdivision is initially made on the basis of sub-functionalities of the product. For example, the power provision for an electric vehicle translates into a chunk containing the battery module including batteries and the battery housing. However, conversion of some product functionalities into modules is not so straightforward. In the case of mechanical steering, the steering functionality of a vehicle is achieved through a steering wheel that is connected to the wheels. The connection is made with multiple chains and links that travel through various other segments of the vehicle. In this case conversion into a module is a tedious job since the individual components interface with a multitude of other components which do not play part in the steering functionality. A well considered design decision has to made in order to define what components are included in the module and what components are not included. Too less components might result in no added benefit of modularity, too many components might result in engineering redundancies that increase total production costs. Other factors such as supplier capabilities, assembly line capabilities and production volume play a role in this decision making as well. In order to ensure strategic benefit of a platform, the end products should offer added customer value and offer lower purchase prices. When executed well, a platform drops the production costs for each product in the product family, thanks to shared engineering costs, shared facilities, larger batch production and quantity discounts in supply chains. However, the effect of a platform product architecture can have detrimental effects on the structural integrity of the product, which can create the need for complex engineering solutions which in turn can result in higher part counts, and a more complex assembly line. These solutions therefore only add costs to the product. This is directly opposed to the initial intentions of the platform concept. To illustrate the benefits and the threats of the platform strategy two case studies are done. The first case study examines the well executed Volkswagen MEB-platform, the second case study showcases the threats of a platform by studying a concept for an electric scooter platform. These case studies can be found in Appendix D.

Four types of modularity

Four modular sub-architectures were identified by studying modular products. The main differences between the set-ups are whether the assembly of the modules occurs at the production side or at the customer side. The objective of this classification is to find an appropriate module architecture for the final design.

1. Shared components

This set up is used by companies to reduce costs by sharing components across multiple products. The benefit of this approach is that these components do not have to be produced and engineered for every single product in the companies' product portfolio. For example, a bicycle producer can use the same breaks, fenders



1

The Cowboy C4 and the Cowboy C4 ST are different bike although they have many components in common

The Volkswagen MEB-platform acts as basis for a wide variety of vehicles.

Lundia closets can be infinitely expanded and configured.

2

3

and head tubes across the whole product portfolio while still developing a diverse product family. In this set-up the customer usually has some control over the configuration of the product, but the manufacturer assembles the product.

2. Interchangeable modules
A product that allows for interchangeable modules can receive a varying selection of modules at the same interface. This is done so that the manufacturer is able to produce a wide range of products by composing specific selections of modules. For example, the MEB-platform by Volkswagen AG can act as the basis for utility vans as well as for small family cars by composing the corresponding battery pack, battery housing, electric motor, etcetera.

3. Customer configuration
In this set-up the customers themselves are in control over the module configuration during the use-phase. For some products it does not make sense to have them assembled in the factory. Photographers for example, want to be able to make close-up photos and landscape photos with the same camera so they do not have to buy and carry multiple camera bodies. In this case the user can assemble a variety of different lenses to the camera to tailor the camera to the specific use-case of the moment.

4. Customer expansion kits
In this setup the customer is able to infinitely expand a product by adding modules. An example is the Lundia closet. This closet can be tailored to a specific space by adding as much modules as needed. Typically every module has an interface that receives the following module.

Upon analysing the four types of modularity that are discussed in this chapter it is a logical choice to pursue the Customer Configuration (3)

DSLR cameras offer the possibility for the user to fit a variety of lenses

modularity. Since customer configuration enables the user to compose the product on the spot to tailor it to the specific use-case, it fits the last mile delivery domain. In parcel delivery, every city, every neighbourhood and every delivery puts the delivery worker in a different situation as was concluded from the contextual inquiry. If the delivery worker was provided with a vehicle that can be tailored on the spot the specific delivery situation, it offers the delivery worker a strategic benefit.

It should be noted that the four types of modularity can be combined in one single product. For example, a specific Nikon camera body likely shares components with other Nikon body models, thus making a Nikon camera both of the *customer configuration* type as well as the *shared components* type.

Implications for design - Modularity

- The delivery worker should be able to control the modules him or herself in order to tailor the vehicle to a specific delivery situation.
- The modules should be divided in logical subdivisions that can be assembled and tested prior to final assembly.

Product Benchmark

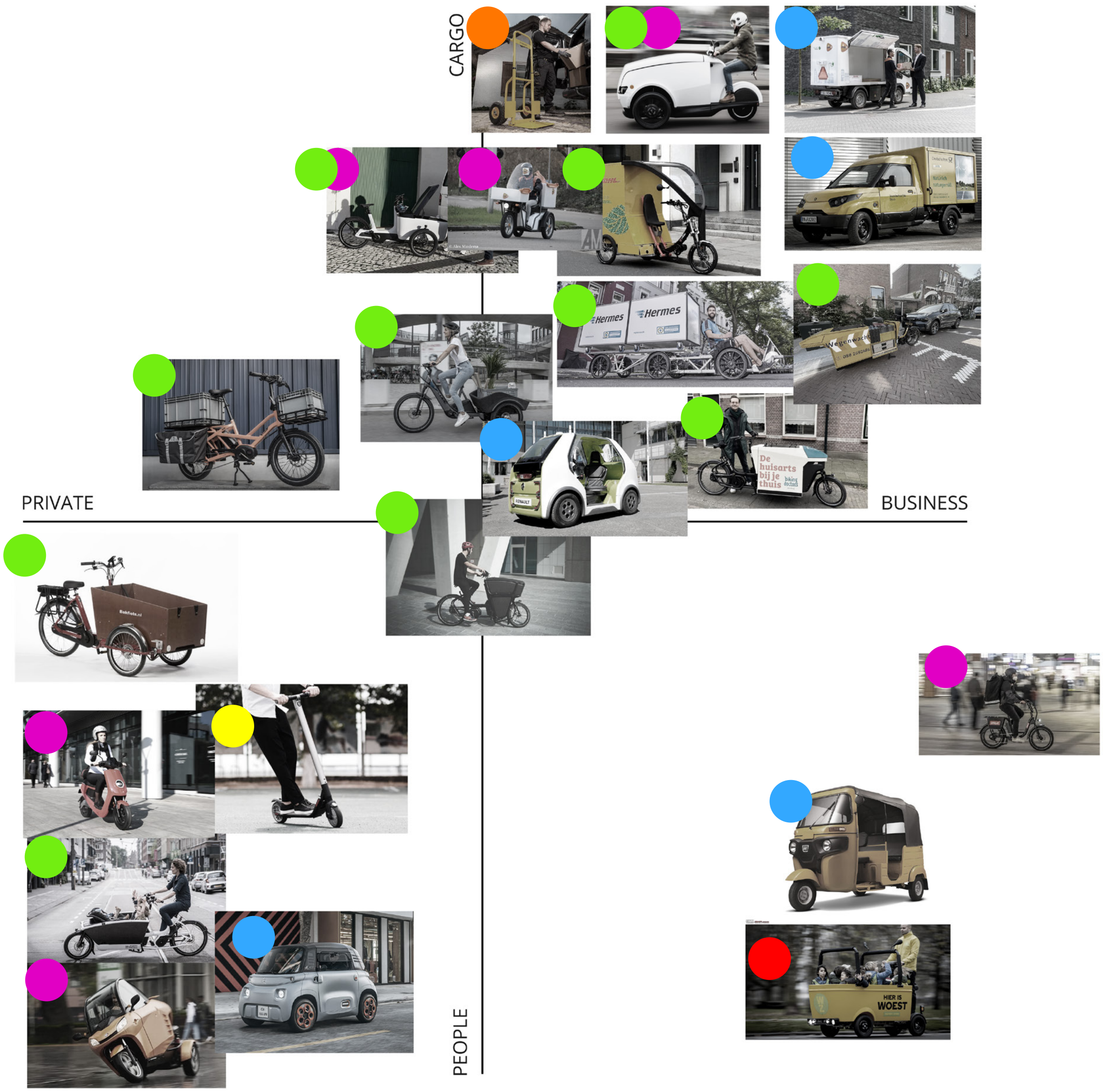
A product benchmark was done to analyse what kind of vehicles are currently deployed for transportation in the last-mile domain.

From this benchmark several vehicle categories were derived that are listed below. The vehicles that were identified reach from the private domain to the corporate domain and from cargo vehicles to passenger vehicles. The matrix on the right page displays all the vehicles on two axes with the before mentioned variables.

An interesting outcome is that all vehicles either resemble a conventional delivery van albeit electric or that these vehicles do not have the parcel capacity of a delivery van.

Furthermore, it is striking that human powered vehicles are very abundant, especially vehicles that are electrically assisted and resemble bicycles.

- Hand truck
- Cargo bicycle
- e-Scooter
- e-Step
- Delivery Van
- Stint



Various types of vehicles were identified in the last-mile delivery domain.

Scenarios

The future of LMD is widely speculated. Since the LMD problem is occurring worldwide it is a main point of interest for many research institutes, consultancy firms and universities. These institutes propose a wide range of scenarios that might occur either in the near or far future. However, in literature no definitive solution or suggestion is proposed as the future of last-mile delivery is dependent on too many factors that can not be known in advance.

In addition to the range of solutions that literature proposes, a couple of other scenarios were drafted that were based on the various sources of literature. These scenarios along with a description can be found in Appendix E.

As no definitive solution is proposed, it was studied whether different types of vehicles occur in these future scenarios.

The first column of the table below displays the various vehicle types that were found in the previous chapter. The first row displays the scenarios that were composed and found in literature. The body of the table indicates whether a specific vehicle type plays a part in which scenarios. This method indicates which vehicle type occurs in the most scenarios. This vehicle type has a higher chance of long-term benefit as the chances are higher that it will remain significant in the near future.

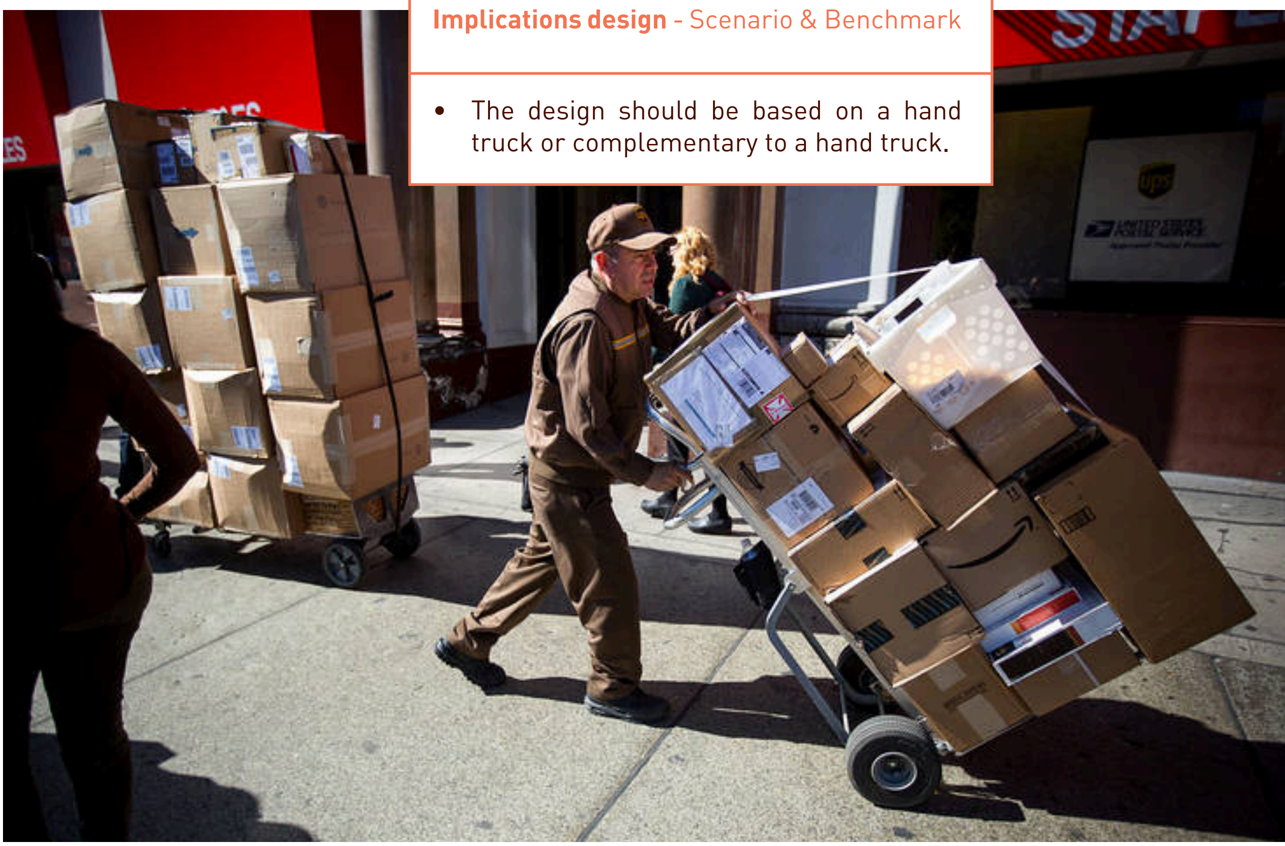
	Business as usual	Trunk delivery	PUDO Cafe (social hub)	Mobile Packstation	Automated Vehicle for parcel drop-off	Automated Vehicle for pick-up and drop-off	Public transport Delivery	Hybrid Delivery with Van and LEV's	LEV's	
Description	Delivery with conventional delivery vans	Trunks of people their personal automobiles are being used as a postal box by delivery workers	In every neighborhood a social hub acts as a parcel point for drop off and pickup.	A packstation is frequently placed in neighborhoods. Location is based on data.	An automated vehicle does the pick-up from local businesses. (first-mile)	Automated vehicles are doing both pick up and drop off. Vehicle acts as mobile packstation.	Public transport is equipped with cargo boxes that can be emptied at bus/tram stops.	A van equiped with multiple LEV's and cargo boxes drives the first leg. LEV's do the last, dense urban leg.	Business as usual, but with dedicated LEV's as replacement for conventional vans	
Hand cart	1	1	1	1	1	0	1	1	1	8
Cargo bicycle	1	1	1	0	1	0	0	0	1	5
e-scooter	1	1	1	0	1	0	0	0	1	5
e-step	1	0	0	0	0	0	0	1	1	3
Delivery van	1	1	1	1	0	0	0	1	0	5
Stint	1	1	1	1	0	0	0	0	1	5

Conclusion

In almost every scenario the hand truck occurs as an auxiliary tool for the delivery worker. The relevance of the hand truck likely lies in the versatile characteristics that come in handy when a delivery worker needs to deliver the last-meter, as was also seen during the contextual inquiry Moreover, the hand truck is an affordable tool that is easy to use and applicable to all kinds of deliveries. Therefore, the hand truck is used as a starting point for further ideation on the design of a LMD mobility solution.

Implications design - Scenario & Benchmark

- The design should be based on a hand truck or complementary to a hand truck.



In New York delivery drivers use hand trucks to transport packages through city blocks and apartment buildings.

Unique Selling Points

Five unique selling points were deducted from the context research. The diagram below indicates how the conclusions from the context research were translated into the five USP's. On the next page the USP's are discussed in detail.

The function of the USP's is to establish a starting point for ideation and to gain strategic benefit over the competitors. The implications on design that were established in the prior chapters both act as a basis for the USP's but also complement the USP's. Also, the USP's are used to establish a list of criteria.

1. The customer is able to adapt the vehicle to his or her specific demands by using modules

2. The delivery worker is able to manoeuvre the vehicle through areas that are hard to reach with conventional delivery vans.

3. The vehicle is not a nuisance or safety hazard to other road users during use.

4. The vehicles make the job of the delivery worker physically less demanding.

5. Local production

Implications for design - Recipient

- The price, the speed and the reliability of parcel delivery are key factors which the recipients concern. The design should take these factors into account.

Implications for design - Retail and Business

- The vehicle is able to offer efficient parcel delivery .
- An electric drive train is desired for affordable power consumption.

Implications design - Scenario & Benchmark

- The design should be based on a hand truck or complementary to a hand truck.

Implications for design - Modularity

- The delivery worker should be able to control the modules him or herself in order to tailor the vehicle to a specific delivery situation.
- The modules should be divided in logical subdivisions that can be assembled and tested prior to final assembly.

Implications for design - Delivery worker

- The design should ensure that the delivery worker can work efficiently yet enjoy his or her work. Therefore the product should not be physically demanding to use.
- Manoeuvrability is of importance since its use environment is a crowded urban setting.
- Every city, every route, and every delivery is unique. The design should be customizable to each situation.
- Delivery workers are on a very tight time schedule and therefore they do not have the time to delicately handle their tools.

Implications for design - Manufacturers

- Automated production techniques prevent the need for expensive manual labour
- Enabling automated production techniques implicates large investment costs and therefore large production volumes to ensure feasible consumer prices.
- The automotive industry acts as an example for local production.

Implications for design - Municipality

- The vehicle should not emit any greenhouse gasses or particular matter directly when in use.
- The vehicle should not pose a safety hazard for other road users.
- The vehicle should offer an alternative to the conventional delivery van or it should operate in collaboration with conventional delivery vans.

1. The customer is able to adapt the vehicle to his or her specific demands by using modules

With the concept vehicle the delivery worker is able to configure the vehicle on the spot to his or her specific use case. The hand truck acts as the base module to which one or more other modules can be added. The hand truck can be used on its own as well for short distance delivery jobs.

2. The delivery worker is able to manoeuvre the vehicle through areas that are hard to reach with delivery vans.

The vehicle is designed for a dense and crowded urban context. Therefore it is of importance that the vehicle can be manoeuvred through dense and populated environments effortlessly by the delivery driver. This goes for both driving on the sidewalk an driving on the road.

3. The vehicle is not a nuisance or safety hazard to other road users during use.

Citizens and other road users are important stakeholders since they directly interact with the vehicles during operation. They form the public opinion on the delivery business or retailer. A good and safe interaction with the vehicles on the road can help to form a good brand image for the operating company.

4. The vehicles make the job of the delivery worker physically less demanding.

The job of the delivery worker can be physically demanding due to long shifts and due to lifting heavy loads repeatedly. Healthier and less stressed work force can help to boost productivity. Therefore the vehicle should help the delivery workers to make their jobs physically less demanding.

5. Local production

Local production of the product is one of the criteria that was desired by DNAMX. The main motivation behind local production is that it allows for more flexibility down the whole supply chain.
In addition, global geopolitical tensions and unstable transportation logistics result in a fragile supply of products from other parts of the world.
Next to a strategic advantage on logistics, local production can also offer an opportunity for traditional power train OEM's. Due to the electrification of automobiles, ICE OEM's might have to find other strategic markets to tap into.


40
40

Render of the final design in the context of a delivery van.

ACTUALIZATION

In this section the design outcome is presented based on the USP's and the research of the prior section. An extended ideation phase preceded the eventual design. However, in this chapter only the final design and the motivations for the design features are presented. The ideation activities can be found in Appendix H & I

At first, some general topics regarding the design are discussed to support the general direction and dimensions of the design. Subsequently, the sub-components are discussed to clarify the motivations for the materialization of the design. Finally, a cost estimation is done to shed light on the consumer price of the product. The cost estimation also acts as a means to see how the product performs in the market. A second product benchmark was done to compare the price and functionalities to other last-mile mobility products.

Design Outcome

Materialization

Manufacturing

Look & Feel

Package

Cost Estimation

Design Outcome

Claus is an auxiliary module with a built in electric drive train that connects to any regular hand truck. By connecting Claus to a hand truck, a four-wheel vehicle is created that can transport both the users along with their cargo. The hand truck acts as both the cargo carrier as well as a steer, while Claus acts as a standing deck and a drive train. Thanks to Claus' geometry and volume, Claus can be transported in a conventional delivery van similarly to the hand truck. By bringing both a hand truck and Claus during delivery shifts, delivery workers are enabled to quickly and easily cover areas that are becoming less accessible to delivery vans.

Given the quick attach and release coupling point, the delivery worker is offered the choice between using an individual hand truck or using the hand truck together with Claus. This enables the delivery worker to cover smaller distances with a standalone hand truck and larger distances with Claus attached.

Claus TM

General Specifications

Weight w/o battery: ±18,9 Kg

Battery weight: ±1-3 Kg

Top speed: 6 km/h

Dimensions (lwh): 120cm, 35cm, 40cm

Motor: 300W transaxle motor

Without Claus

- Short distances 0-50 m
- Human powered

The conventional hand truck is being used in delivery work for short distances. Usually, a delivery worker unloads the hand truck along with the cargo from the van to subsequently walk the hand truck with the cargo to the final destination. Once the parcels are delivered, the delivery worker loads the hand truck back into the van to proceed to the next addresses.

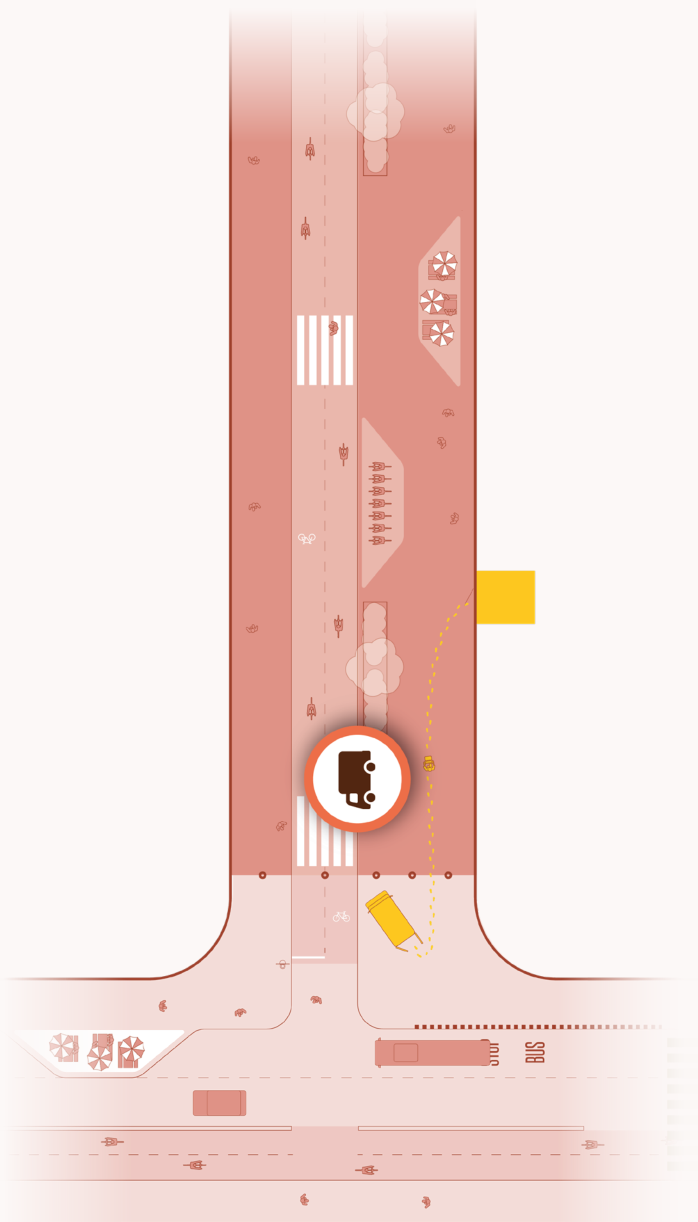
In contrast to carrying parcels by hand, the hand truck enables the delivery worker to transport a multitude of packages. In addition, it ensures that the delivery workers do not have to carry the weight of the cargo their selves.

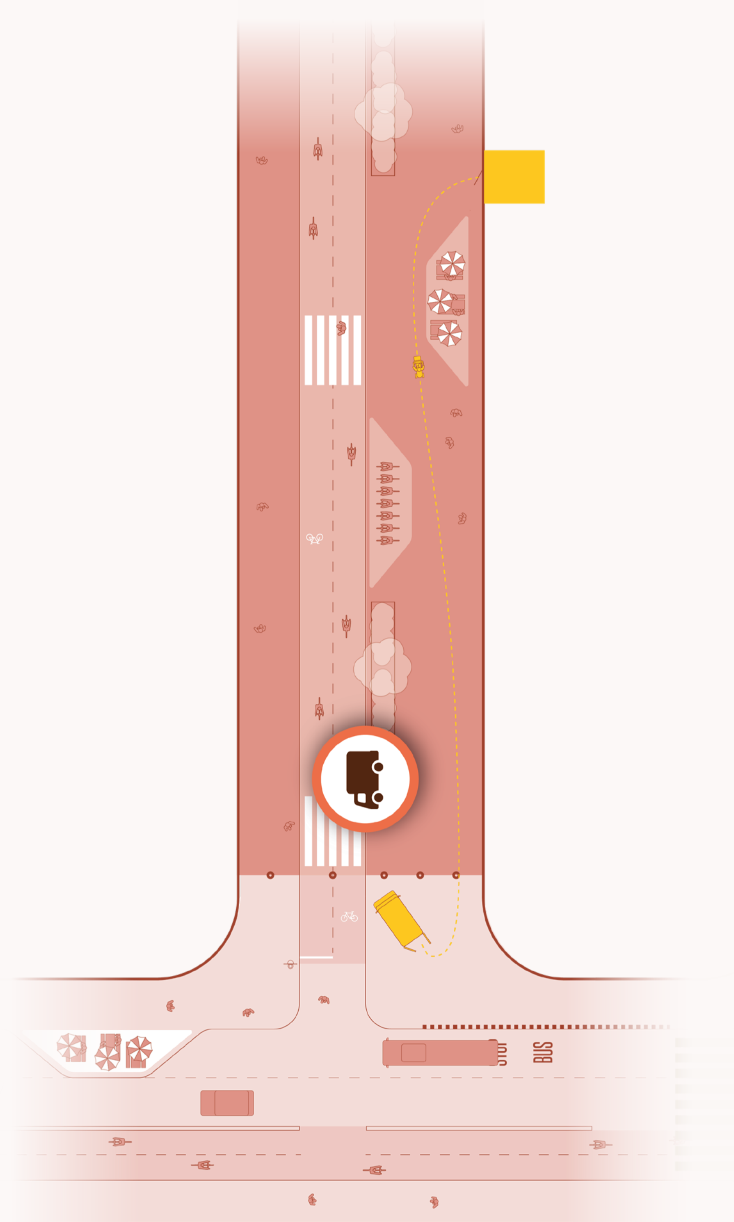
With Claus

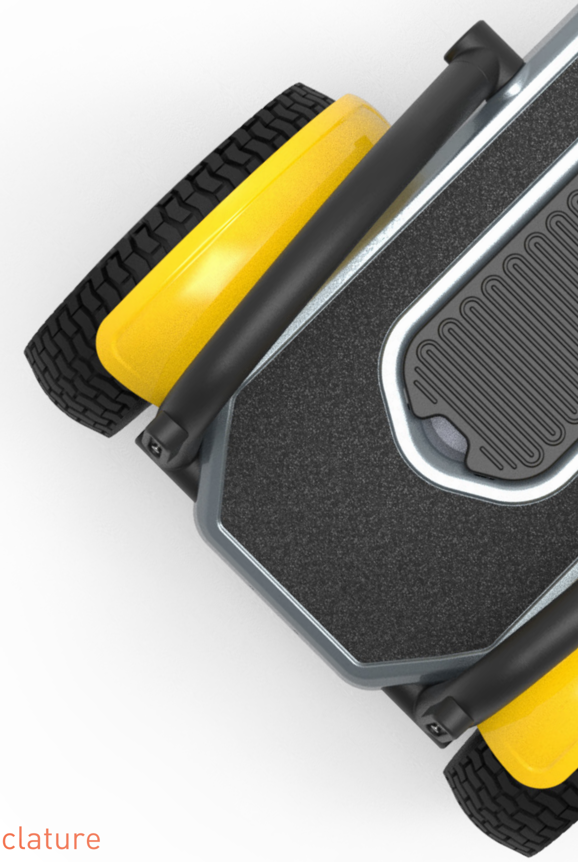
- Medium distances 20m - 5km
- Electric motor

Claus broadens the potential of the hand truck by extending the range and by minimizing the physical effort for the user.

This allows the delivery workers reach addresses that are hard to reach due to congestion or traffic regulations. Once delivery workers place their van at the perimeter of a congested zone, they can attach Claus to their hand trucks and reach further in a shorter timespan compared to delivery with a standalone hand truck.


BUS


BUS



USP's

1. The customer is able to adapt the vehicle to his or her specific demands by using modules
The delivery workers are able to choose whether they use the hand truck separately or whether they will use the hand truck in combination with Claus.

2. The delivery worker is able to manoeuvre the vehicle through areas that are hard to reach with delivery vans.
Since Claus is of equal dimensions to the hand truck, it does not require a lot of space. Moreover, Claus can take tight corners without any problems.

3. The vehicle is not a nuisance or safety hazard to other road users during use.
Claus has a maximum speed of 6km/h. Moreover, it can be clearly spotted since the driver is in an upright position. The driver is standing a little bit higher than the average pedestrian thanks to the elevated deck. This ensures that the driver has overview over the traffic situation.

4. The vehicles make the job of the delivery worker physically less demanding.
Claus enables the delivery worker to carry packages over longer distances without the need to walk. This means that the delivery worker is not required to get in and out of the van at every stop.

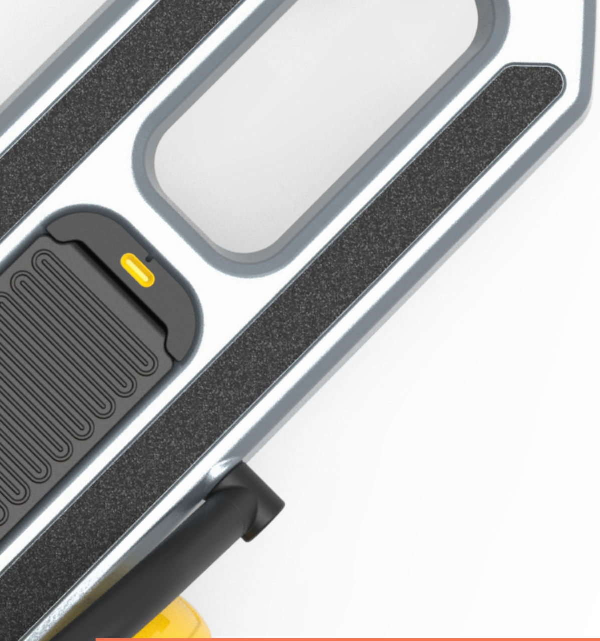
5. Local production
In order to prevent manual labour, production techniques are selected which ensure that local manufacturers can produce the vehicle.

Nomenclature

The name of the final product is **Claus**, which is an acronym for '***Conrad's Letzter-meter Anhang für Utilität Stockkarre'***

Thanks to the German origin of the name, Claus is supposed to evoke a feeling of German robustness. In addition, Claus is supposed to give a certain character to the vehicle that the users can relate to as a buddy which they always can rely on.

Claus evokes the association with Santa Claus. A parallel can be seen in the sense that both Santa Claus and Claus bring packages to people their homes.



Distance vs. time gain

Input variables

Walking speed hand truck	**4 kmph**
Driving speed with Claus	**6 kmph**
Amount of legs per shift	**20**

Distance / leg	Time / day
100 m	**10 min**
200 m	**20 min**
400 m	**40 min**
800 m	**80 min**
1200 m	**120 min**

Time gain

Thanks to Claus a delivery worker can gain time compared to delivery with a standalone hand truck. In order to indicate how much time is gained during one shift, a calculation is made on basis of a couple variables. An important variable is the length of a single leg (**d**leg). A leg is defined as the distance from the delivery van to the delivery address and back to the delivery van again. Secondly, the total amount of legs (**n**leg) a delivery worker drives during one shift dictates the total time gain during one day. The last two parameters are the walking speed without Claus (**v**walk) and the driving speed with Claus (**v**claus).

In the table to the left a time gain calculation is done on basis of a range of leg distances. The lower right column indicates how much time can be gained per leg distance. The formula on the bottom of this page was used to calculate these values.

Conclusion

To evaluate whether the time gain is significant and whether the assumptions on input variables are correct, a pilot study should be conducted. A rough proposal for a pilot study is done in the chapter **Validation - Discussion | Recommendations - Pilot study**

If the example calculation resembles reality, the gained time is significant. As delivery workers are under high time pressures and as they are required to deliver one package every two minutes, a 40 minutes time gain per day results in 12 more seconds per package or 20 more packages per shift.

$$t_{gain} = (d_{leg} * v_{claus} - d_{leg} * v_{walk}) / (v_{claus} * v_{walk}) * n_{leg} * 60$$

Materialization

Base frame

The main structural element of Claus is the base frame. The base frame is a steel deep drawn blend that provides structural integrity thanks to its geometry. Among other reasons, sheet metal forming was chosen as the most appropriate production technique thanks to the high level of automation that can be achieved (See **Actualization - Manufacturing**).

The remainder of the components can theoretically be made and fastened with various methods. Since the aim of this concept is to prove and test the functionalities and added value of the overall concept, no extensive production analysis will be done for the components. However, some manufacturing recommendations are done in this visual as a starting point for production analysis. Local production and reducing manual labour is taken into consideration in these recommendations.

E-kit embodiment

The housing for the electronics will consist of injection moulded plastic components. Injection moulding is chosen due to the geometric complexity of the parts. Furthermore, plastic is lightweight while providing sufficient protection for the electronics. The E-kit cover must provide sufficient structural integrity to hold the weight of the delivery worker. This is why the cover will be produced of steel similarly to the base frame.


Coupling cover
Injection moulded plastic
Coupling tube
Steel tube
E-kit cover
Deep drawn steel
Handle tube
Aluminium bend tube
Handle holders and feet
Glass filled injection moulded plastic
E-kit embodiment
Injection moulded plastic
Brackets
Folded sheet steel
Tail light
Sourced part (bicycle industry)
Transaxle motor
Sourced part

Handlebars

The handlebars consist of several components, namely the brackets that attach to the base frame, the handlebars themselves and the feet for storing the drive train module in its upright position. The brackets can be made from glass filled injection moulded plastics. The addition of glass fibres ensures more strength that is desired in plastic parts that bear loads. This is relevant for the handlebar brackets since they transfer loads from the handlebar to the base frame.

The handlebars themselves do not have a complex shape since they consists of a single curved tube. This offers the opportunity to simply bend a aluminium tube to the specified geometry.

Fenders

The only function of the fenders is to protect the driver from dirt and water while driving. This means that the fenders do not bear a significant load. Thanks to this, the geometry of the fenders does not have to be very complex apart from the fact that they need ribs and curved surfaces to provide some stiffness. The relatively simple geometry allows for vacuum forming as a production technique.

Fasteners

The current design relies a lot on mechanical fasteners such as bolts and metal screws. Bolts and nuts however are difficult and expensive to automatically assemble. It is recommended that the fasteners will be revised in the future for optimizing the assembly line. An alternative that is worth exploring is to integrate form closures such as snap fingers into the injection moulded parts for faster and more affordable assembly to the base frame.

Assembly

The design relies on several sub-assemblies that can be assembled independently from the base frame. This architecture allows for flexibility in product development and it allows for parallel assembly within the assembly line.

E-kit assembly

The first sub-assembly is the e-kit sub-assembly. This assembly consists of the e-kit embodiment, the transaxle motor, the main electronics, the tail light and the battery connections. Optionally, the wheels can be assembled to this sub-assembly as well.

Coupling assembly

The second sub-assembly is the coupling sub-assembly. This assembly consist of the couple tube, the couple cover and the residual components such as the safety release and lock.

Handlebar assembly

The third sub-assembly are the handlebars. The front and rear handle brackets and the feet can be assembled to the main handlebars prior to assembly to the base frame.

Manufacturing

In the table below several appropriate production techniques were identified for manufacturing the frame. These production techniques were selected from the prior research into production techniques. (See Appendix C) The frame is by far the most important component since it is the basis for every other component and since it is the main structural element of Claus. The selection of the production technique should take several factors into account. Namely, the amount of assembly that is required, the form freedom and the investment and material costs. By plotting the identified production techniques against these factors an overview was made to select the most appropriate technique.

Stamping was chosen as an appropriate production technique thanks to its application in the automotive industry and thanks to the high levels of automation that can be achieved.

As described in **Appendix C**, the automotive industry deploys stamping for producing body panels. Almost every body-in-white for production automobiles is made from stamped sheet metal. Also, as almost every automobile production plant houses their own body shop, sheet metal stamping is a wide-spread and highly automated production technique. A potential drawback of sheet metal stamping is that it involves high investment costs due to complex dies and expensive tooling. Therefore, it should be noted that the production volume should be high in order to deploy stamping in a cost efficient manner.

Production technique / *Criteria*	**Stamping**		**Extrusion**		**Tubular frame**		**Hydroforming**	
Weight/rigidity ratio	5	Depends on design	5	Depends on design	5	Very good, like bicycle	5	Depends on design
Form freedom	4	cupped design	3	Only straight or bend profiles, however not limited to sheet material	3	Limited unless expensive hydroformed tubes are used	4	Limited dimensions
Manual assembly labour	5	No assembly of frame itself	2	Cast metal nodes	1	Brazing of nodes	4	Depends on design
Material costs	5	Single piece of sheet metal	4	Aluminum is expensive	5	Only metal tubing required	5	Tubing or sheet metal
Investment costs	1	Expensive tooling	4	Extrusion die	5	Very limited investment cost	1	Expensive tooling

Look & Feel

Several collages were made in order to choose a direction for the product. Based on these collages several initial sketches were made together with the team of DNAMX and with Stefan Akkerman. These exploration are presented in Appendix M.

The chosen direction for the look & feel was the 'Powertool' direction. Powertools have a very distinct form language that communicates robustness and strength.

These characteristics of powertools matches the core values of Claus. Due to their strict time schedules, delivery workers do not have the time to delicately handle their tools. This is why the robustness of the design is an important aspect; the users should have the feeling that they do not damage Claus when quickly loading and unloading it from the van.

The muscular look of powertools matches Claus since it can convince the user that the product is a reliable helping tool for moving cargo and therefore alleviating the user from physically daunting tasks.

POWERTOOL

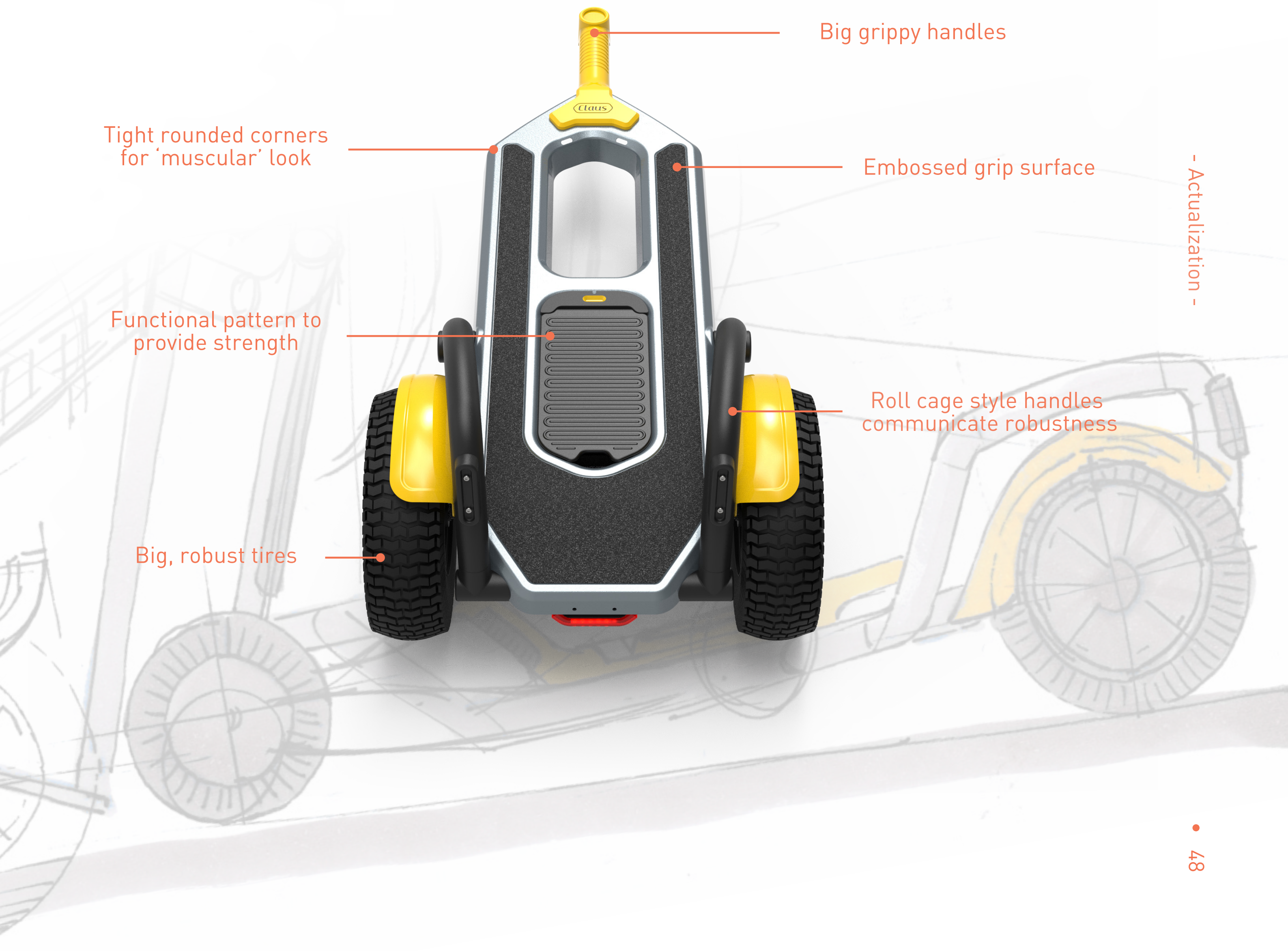
Muscular - Strength

Robust

Stimulating

The image below displays how the elements of the powertool form language are translated into the design of Claus. The 'muscular' rounded corners are integrated into the design of the frame.

The ruggedness is integrated by implementing roll cage style handle bars similar to the handlebars of the construction radio in the collage. Furthermore, the fat tires give Claus a rugged, fool-proof look.



Colour ways

The colours of the product have been evaluated by making a series of renders that showcase the aesthetic characteristics of the design in combination with the colours. Also, the original look & feel collage was consulted in order to make an informed decision to match the original idea of look & feel.

Lemon Howl was considered the most appropriate colour in relation to the powertool look & feel. Yellow in combination with black is a frequently used colour palette for powertools thanks to the high contrast and high visibility which can create a stimulating appearance.

The colours can also be customized to specific customers to match their brand image and the other vehicles of the customers delivery fleet. The image below displays an example of this.

Midnite Mayhem

Nifty Neptune

Lemon Howl

Package

The purpose of this chapter is to elaborate on each individual sub-system of Claus that is not discussed in the prior chapters. Each sub-system that is discussed in this chapter is pointed out on the image below. Every sub-chapter discusses one sub-system. Both the design criteria and the current specifications are pointed out in each sub-chapter to shed light on the motivation for specific choices.

Dimensions

The figures below displays the overall dimensions of the vehicle and the rough positioning of other components.

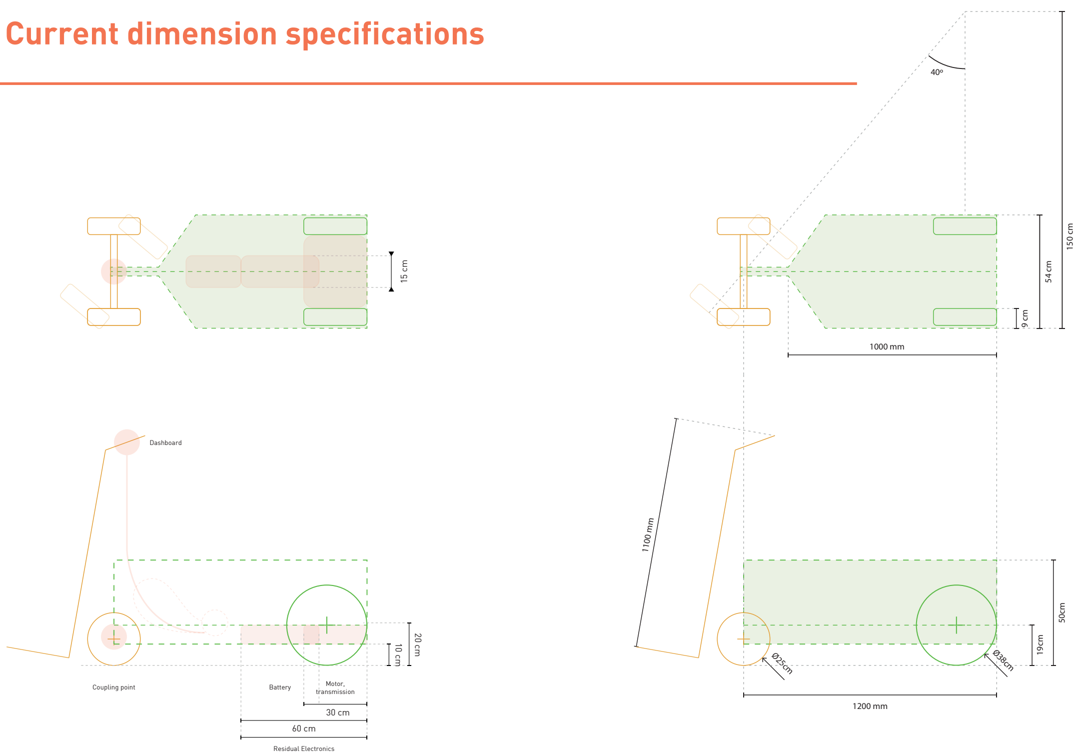
The green area is the area in which the frame is located. The dimensions of the green area are defined by both the ergonomic research (**Validation - User tests - Ergonomics**) in combination with experimental prototyping (**Appendix I**). At the front of the frame the area becomes more narrow. This is because the hand truck requires some space to steer. The exact dimensions of the narrow front area are defined to acquire a turning circle of three meters (R=150cm, see upper right schematic.)

The positioning of the motor is defined by the axis of the rear wheels. In addition, it is required that the centre of mass is positioned as far backwards as possible for a stable storage position. This is also the reason that the batteries and electronics are positioned as far back as possible as well. Storage characteristics and the motivation for the positioning of the centre of mass are elaborated on in a separate sub-chapter. (**Actualization - Package - Storage**)

Dimension criteria

- Turning circle of three meters.
- Similar volume to a conventional hand truck.
- Centre of mass moved as far backwards as possible for storage characteristics.
- Dimensions conform to ergonomic test.

Current dimension specifications



Electronics

The electronics are divided into two main sections; the electronics that are integrated in the drive train module (in-board) and the electronics that are integrated in the dashboard. The in-board electronics house the main processor since the frame of the drive train module can offer good physical protection and because the e-kit sub-assembly is located on the frame as well.

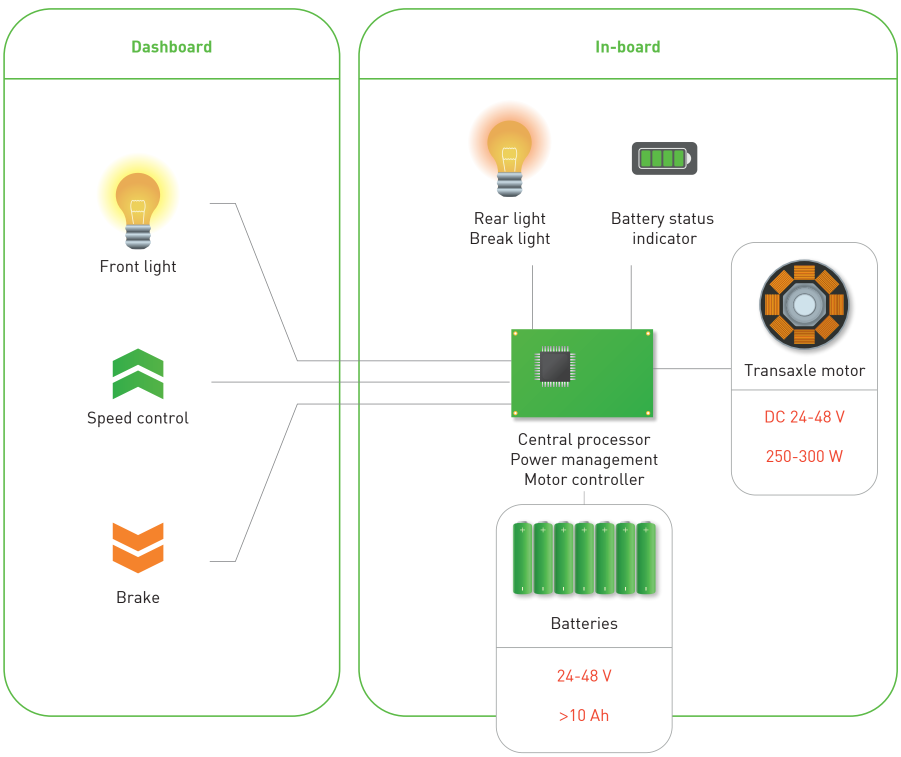
The dashboard houses the drive controls and a front light. The front light is integrated in the dashboard to obtain a higher position that is situated above the cargo instead of being obstructed by the cargo.

The specifications of the motor and battery are elaborated on in later chapters.

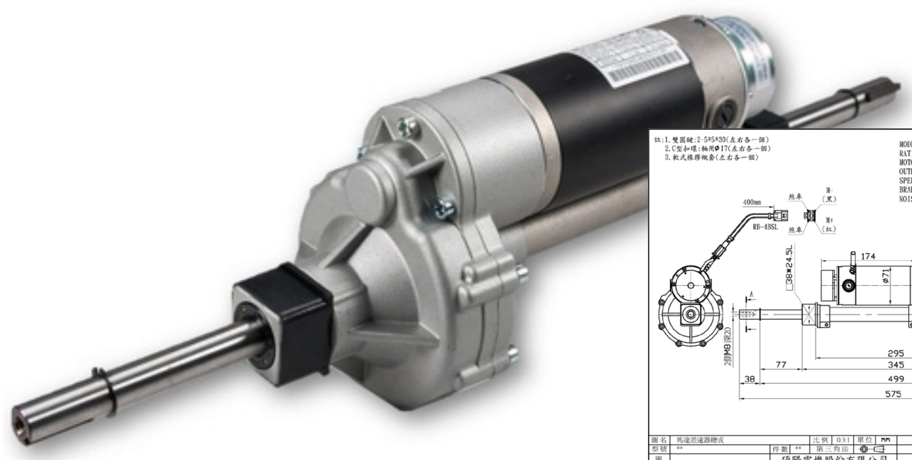
Electronics criteria

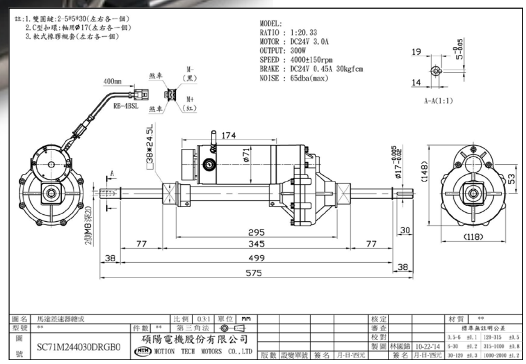
- Good physical protection from weather, dirt and impact.
- One central processor processes everything from the user input to the motor power and the battery status.

Current electronics specifications



Motor and transmission





The transaxle motor was chosen since it can power both rear wheels with a single motor. In addition, a transaxle is both an electric motor and a differential mechanism combined. This means that it can be bought as a single sub-assembly.

The transaxle motor is also used for other mobility purposes such as mobility scooters and therefore proves itself as an efficient motor for transporting persons.

The top speeds of mobility scooters typically range from 6kmph to 30kmph. As Claus is required to have a top speed of 6kmph, a transaxle motor that is used in low-speed mobility scooters has been taken as a starting point. Therefore, the motor should have a continuous power rating of around 300 Watts. The voltage of these motors typically range from 24 Volts to 48 Volts. As a 24 Volt motor was used in the technical prototype this is currently the voltage rating of choice. Higher voltages might work more efficient, but this is a topic for future research.

The specific motor that is displayed in the images below is not necessarily the chosen transaxle motor. However, it does represent the general direction for the motor.

Motor criteria

- The motor has enough power to propel Claus up to 6km/h including driver and cargo.
- It should be possible to power the motor with a li-ion battery

Current motor specifications

- DC Motor - Transaxle sub-assembly
- DC 24 V
- 300 Watt

Battery

The battery specifications are relatively complex as multiple aspects should be considered and balanced against each other. For example, the battery should not be to heavy since the user has to constantly tilt Claus in and out of the van, but on the other hand the battery should have sufficient capacity to assist the delivery workers for the duration of their shifts. Since the battery specifics rely on yet unknown variables such as the travel distance of Claus during a shift and on the motor voltage, a final decision on the battery specifics have not yet been made. However, this chapter also provides a guide to compose the appropriate battery specifications that correspond to a specific use-case. Also an example battery is presented based on a 24V motor and a total travel distance of 8km.

As mentioned in the previous chapter, the battery should be balanced with the motor in terms of voltage and discharge current.
The voltage magnitude of the motor has effect on its efficiency. This also goes for the voltage magnitude of the battery. For a maximum efficiency over both the battery and the motor, the optimum voltage has to be found. However, since efficiency optimization is beyond the scope of this project, this is a topic for future research.

Finally, as many e-bikes operate on a 300W motor, e-bike batteries can be a good candidate for powering the transaxle motor. This offers the opportunity to buy the batteries as sub-assemblies from bicycle OEM's instead of designing and producing the battery from scratch.

Battery criteria

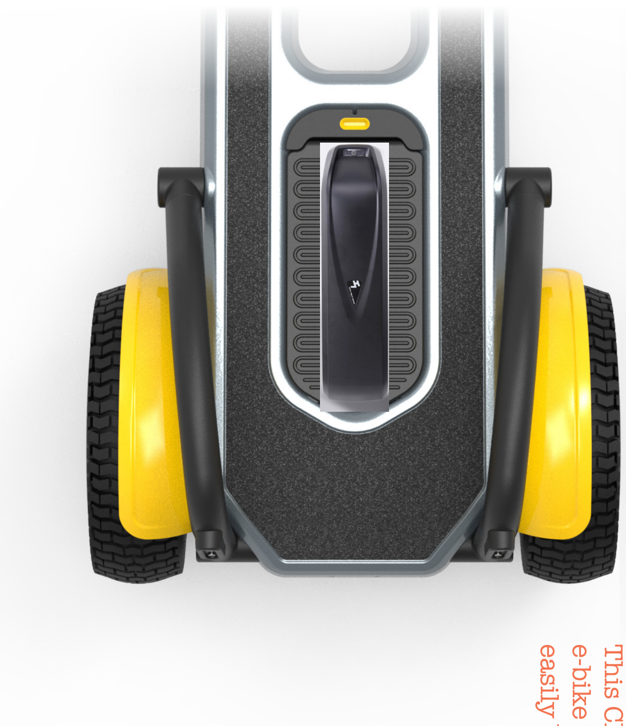
- The battery can easily be reached and swapped by the user.
- The battery is able to provide enough power for a full work shift.
- The battery is located close to the rear of the drive train module for better weight distribution (See: **Actualization - Package - Storage**)

Current battery specifications

- Li-ion battery for optimal capacity, weight ratio.
- NOTE: The exact battery specifications depend on a number of variables. At the end of this chapter a guide for selecting batteries is provided.

Claus' frame has two openings which can be used to store electronics and batteries in a protected casing that is flush with the deck. The rear opening is used for the batteries to ensure that a low centre of gravity can be established when Claus is stored in a vertical position. The front opening has the exact same geometry as the rear opening and therefore it can be used for a battery extension pack (See '**Validation - Discussion | Recommendations**').

Either one big battery pack can be used opposed to multiple smaller ones. The benefit of multiple smaller battery packs is that consumers are able to configure the batteries to their specific use-case, by increasing or decreasing the capacity and therefore also the total weight and the range.



This Claus has a single e-bike battery that can easily be swapped.

This Claus houses two example batteries from the following page connected in parallel for more capacity.

BATTERY SELECTION GUIDE

This battery selection guide helps to select a suitable battery based on a variety of input variables. As some of the variables are not yet known, such as the desired range of Claus, this guide is currently used to explore the ballpark of possible batteries on basis of assumed variables. An example battery was calculated for this purpose. This example is displayed on the right page. In the future, when more variables are known, this guide can be used for a final selection.

Continuous discharge current

The continuous discharge current is the current at which the motor can safely operate for longer periods without overheating. This number is incorporated in the power rating of the motor. To acquire the continuous discharge current (I_{dis}) the power rating (P_{motor}) of the motor should be divided by the motor voltage (U_{motor}).

$$I_{dis} = P_{motor} / U_{motor}$$

Battery capacity

To give an indication of the required capacity of the motor (C_{bat}), the duration of the motor usage is multiplied by the continuous discharge current. The duration depends on the distance travelled (d_{leg}; distance of one leg - n_{leg}; amount of legs per work shift) and the speed at which Claus drives.
It is assumed that the user drives at full speed (v_{con}, 6kmph) during which the motor operates at the continuous discharge current.

$$C_{bat} = (d_{leg} * n_{leg} / v_{con}) * I_{dis}$$

Battery layout

The layout of the battery pack depends on the voltage which the battery pack should provide and on the required battery capacity. The battery pack voltage (U_{pack}) should be equal to the rated voltage of the motor (U_{motor}).
Most Li-ion batteries are built from standard cells. To acquire the battery pack voltage, a certain amount of these cells need to be connected in series (n_{serial}). To acquire the required capacity, a certain amount of cells need to be connected in parallel ($n_{parallel}$). By dividing the required capacity of the battery by the individual cell capacity (C_{cell}), the amount of cells that need to be connected in parallel is found. With every additional parallel group of cells, the battery pack's maximum discharge current (I_{pack}) raises with the maximum discharge current of an individual cell (I_{cell}).

The weight of the pack (m_{pack}) is calculated by multiplying the total amount of cells by the individual cell mass (m_{cell}).

$$n_{serial} \text{ (number of cells in serial configuration)} = U_{pack} / U_{cell}$$

$$n_{parallel} \text{ (number of cells in parallel configuration)} = C_{bat} / C_{cell}$$

$$I_{pack} = n_{parallel} * I_{cell}$$

$$m_{pack} = n_{serial} * n_{parallel} * m_{cell}$$

Battery pack example

Input variables + (Samsung ICR 18650-26FM cells)

- Motor voltage : **24 V**
- Motor power : **250 W**
- Top speed : **6kmph**
- Leg distance : **400 m**
- Leg amount : **20**

Output

• Battery pack capacity	**14 Ah**
• Cell configuration	**6 serial 6 parallel**
• Cell amount	**36**
• Battery pack max discharge current	**60 A**
• Battery pack weight	**1,6 Kg**

The grey dots in the background represent individual battery cells. Together they display the dimensions of the example battery to scale.

Samsung ICR 18650-26FM - Typical cell

- Voltage : 3,7 V
- Capacity : 2600 mAh
- Max. discharge current : 10 A
- Weight : 43,8 g
- Width, Height : 18 mm, 65 mm

Dashboard

The dashboard is a separate device that is connected to the drive train module through an electric wire. It allows the user to control the speed of the vehicle. Other options such as wireless controls via Bluetooth can be explored in future research, but are out of scope for the moment.

A connection mechanism should be integrated in the dashboard to quickly and easily connect the dashboard to the cargo module. This topic is covered in the future recommendations.

Braking is done through dynamic braking on the electric motor. The motivation for dynamic braking is that the infrastructure for dynamic braking is already present and it reduces the amount of components compared to mechanical braking.

Dashboard criteria

- The dashboard is connected to the drive train module by an electric cord.
- The dashboard can be connected to the cargo module quickly and easily.
- The speed can be controlled in a logical manner on the dashboard.
- The braking can be controlled in logical manner on the dashboard
- The dashboard has an integrated front light that is projected forwards.
- Claus' frame should have a receptor for the dashboard if its not in use.

This image displays a simple dashboard that has a push button for speed control. At the moment this is the current state of the dashboard. In the recommendation chapter the further development of the dashboard is discussed.

Current dashboard specifications

- Connection through an electric wire.
- Speed control and braking is done through push buttons on the dashboard.
- A quick connection allows quick assembly on the hand truck as well as on the frame.

Coupling point

The coupling point between Claus and the hand truck should allow for three degrees of freedom for the user to be able to steer and tilt the hand truck. (See image on the next page)

When the hand truck is both tilted backwards and simultaneously steering to either the left or right, it rotates both over the X-axis as well as over the Z-axis.
If the horizontal Y-axis were to be fixed, Claus would roll in the same direction as the hand truck. The direction of this tilting effect in the drive train module is opposite to the desirable tilt while driving. This is why an additional degree of freedom is desirable in the Y-axis.

Coupling point criteria

- The coupling point allows for three degrees of freedom. (Roll, Pitch, Yaw)
- The coupling point should allow for quick attachment of the drive train module to the cargo module.
- To release the module the user has to use a safety release prior to de-attaching the module.

Current coupling point specifications

- Ball joint - 3 DOF.
- Ball on hand truck, cup on Claus.
- Quick release and quick attach

Ball joint

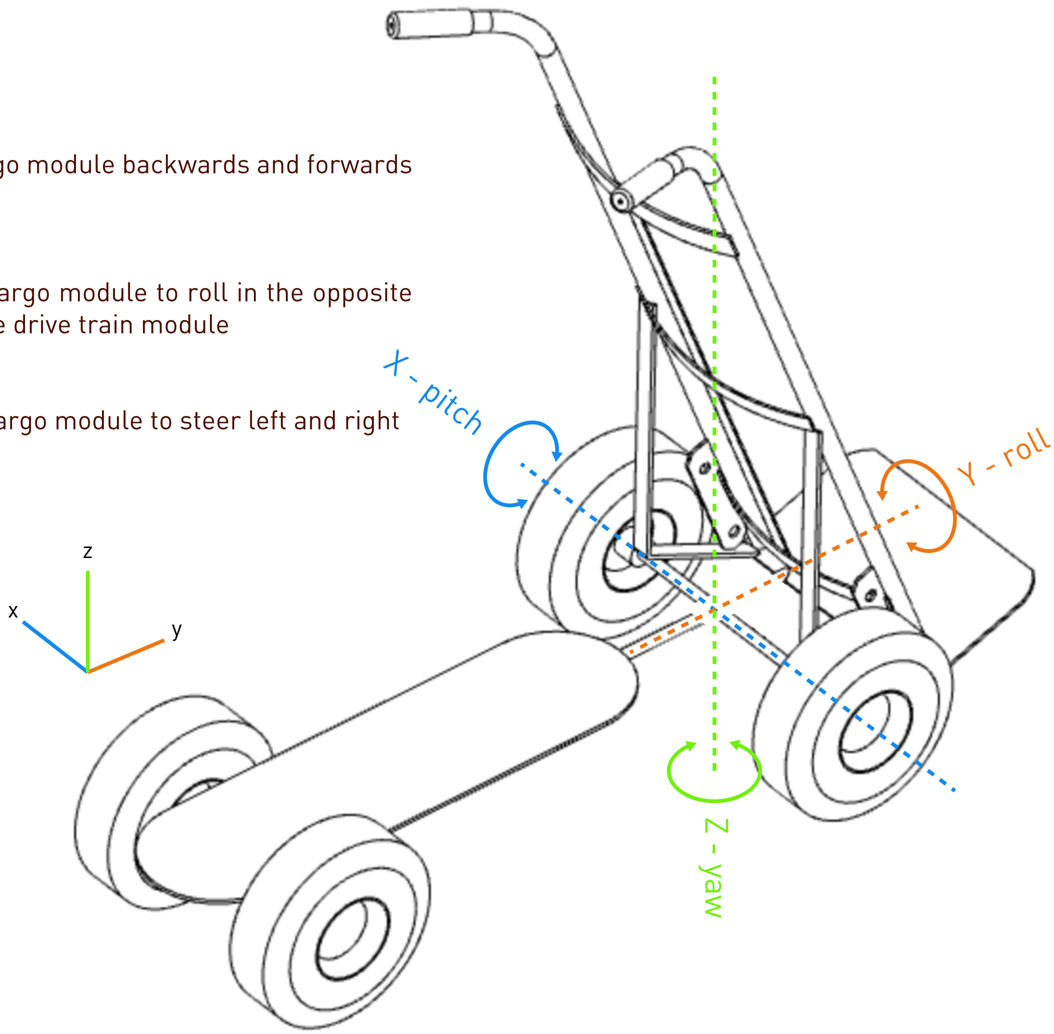
To allow the three degrees of freedom between Claus and the hand truck, a ball joint is the most appropriate and simple solution. A ball joint allows rotation in three different axes. A ball joint also ensures connection to a single point which makes quick release and quick attach functionalities easier to implement.

The connection of the ball to the hand truck and the quick release mechanism are not yet detailed. This is a topic for further research. (See '**Validation - Discussion | Recommendations**')

X —
Tilting the cargo module backwards and forwards

Y —
Allowing the cargo module to roll in the opposite direction to the drive train module

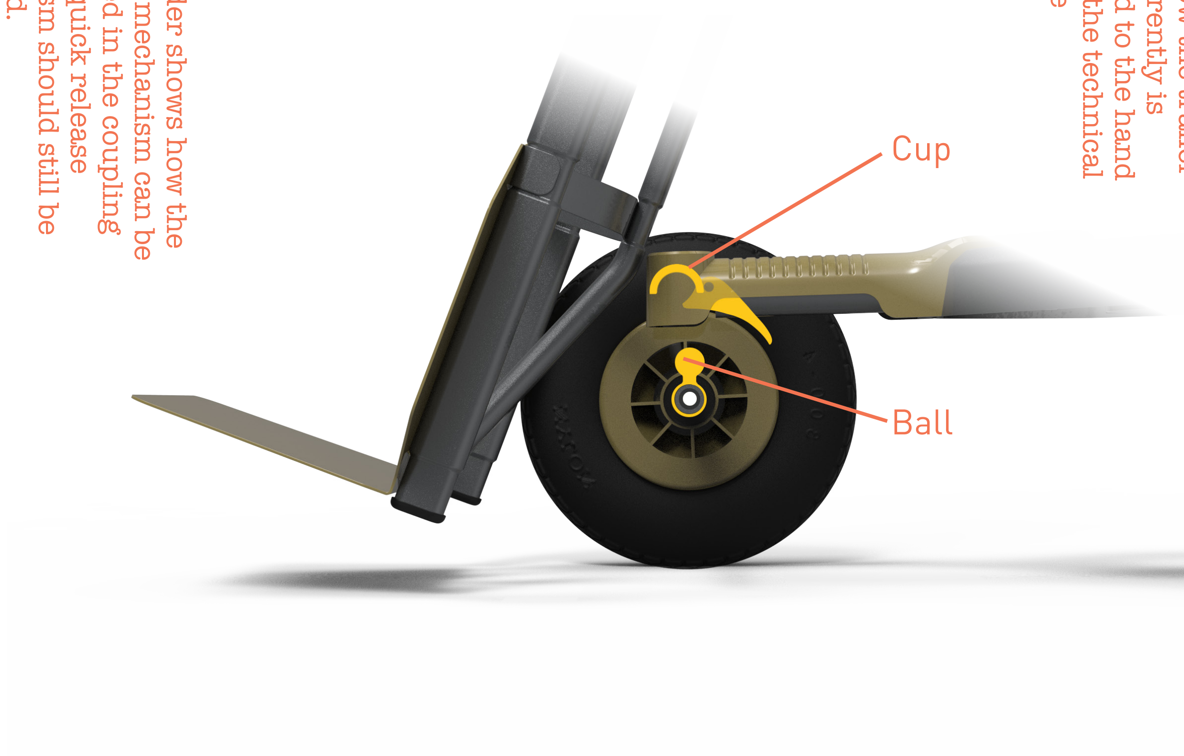
Z —
Allowing the cargo module to steer left and right



Cup and Ball

The ball joint connector consists of a ball and a cup. The cup fits on the ball and can slide over the surface of the ball in three degrees of freedom. Claus embodies the cup and the hand truck embodies the ball. The choice for this configuration is based on the configuration of ball joints in other vehicles such as caravans and trailers. In these vehicles the ball joint is always attached to the car (front) while the cup is always connected to the trailer (rear).
On the other hand, in Claus' case the rear unit (Claus) is pushing the front unit (hand truck), where in the trailer case, the front unit (car) is pulling the rear unit (trailer). Nevertheless, the prototype testing pointed out that this configuration works without any problems. However, if the coupling point will be designed to a higher level, this principle can be reconsidered if necessary.

This is how the trailer hitch currently is connected to the hand truck on the technical prototype



This render shows how the ball joint mechanism can be integrated in the coupling point. A quick release mechanism should still be developed.

Lighting

The choice was made to integrate the front light into the dashboard in order to prevent the front light from being obstructed by cargo on the cargo module. Sub-chapters 'Dashboard' and 'Electronics' also discuss this matter.

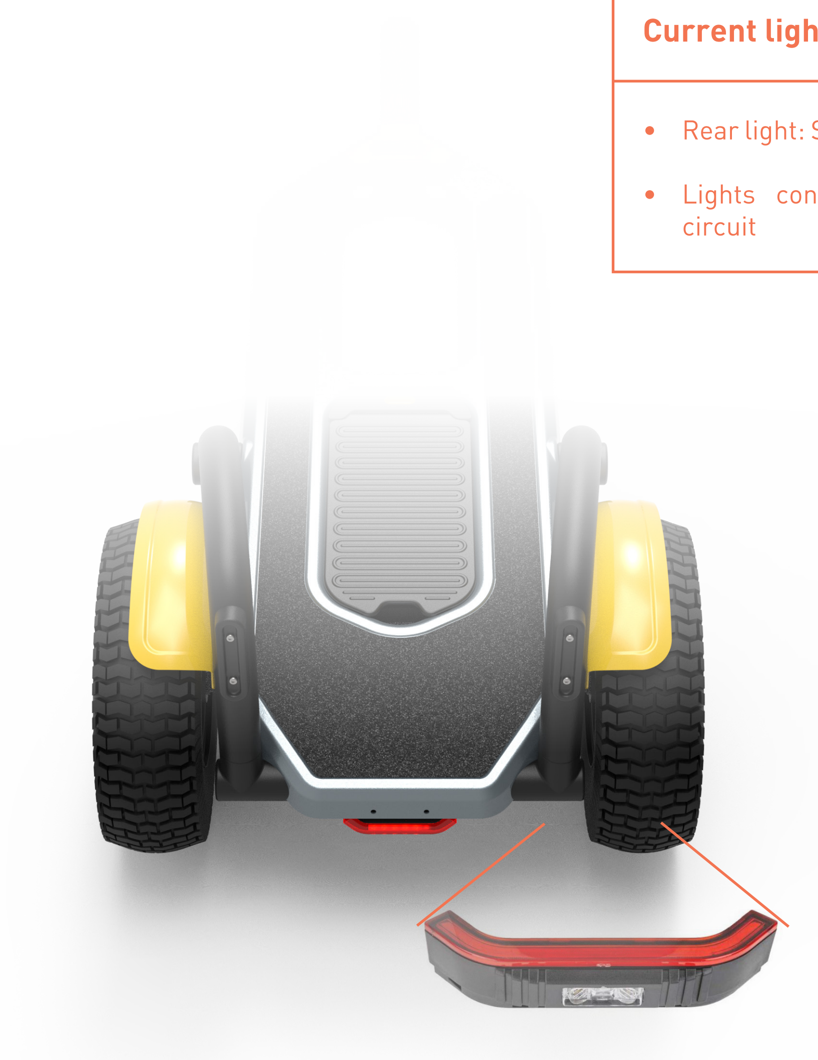
The rear light is an off the shelve component. The current light originates from the bicycle industry. The Spanninga Aerflow 2.0 V-light is displayed in the image below and it is also integrated in the aesthetic prototype.

Lighting criteria

- The front light (white) should be projected forwards and it should not be obstructed by cargo on the cargo module.
- The rear light (red) should be projected backwards.
- The lights should be powered by the batteries.

Current lighting specifications

- Rear light: Spanninga Aerflow 2.0 V light
- Lights connected to the electronics circuit



Spanninga Aerflow 2.0 V-light

Wheels

The diameter of the wheels is defined by a trade-off between the comfort for the driver, look & feel and the effect it has on the height of the frame. A diameter that is too big results in a frame that is positioned higher from the ground which in turn results in a higher standing position which can cause ergonomic problems in relation to the hand truck. Too small wheels however can result in worse drive characteristics and a look & feel that does not match the intended appearance.

The current wheel diameter of 30 - 40 cm is defined through experimental prototyping and look & feel explorations. (See **Appendix I**)

Wheels criteria

- The drive train module should have inflatable rubber tires for a comfortable ride.
- The wheels including tires should have a diameter of approximately 33 cm for a comfortable ride and rugged look.

Current wheels specifications

- 30 - 40 cm diameter
- Inflatable tires

Hand truck

The objective of Claus is that it can connect to multiple types of hand trucks. However, due to time limitations it is not feasible to test any hand truck that is on the market. Prototyping and testing was done with a basic hand truck with air tires and double handles. The overview on this page elaborates on the parameters that are involved in hand trucks that are currently on the market. This overview acts as an exploration into different types of hand trucks that can put the testing of prototypes with the hand truck that was used in the user tests into perspective.

This sub-chapter does not present criteria and specifications since the hand truck itself is not considered a part of the design scope.

Handles

Double handles

Single horizontal bar

Protruding mid tube

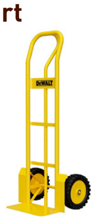
Wheels

Air tires

Solid plastic tires

Triple stair wheels

Back support



Full rack

Horizontal bars

Additional functions

Foldable

Slide rails

Storage

The storage volume and characteristics of Claus are essential since delivery drivers should be able to store it a fully packed delivery van and they should be able to quickly load and unload it.

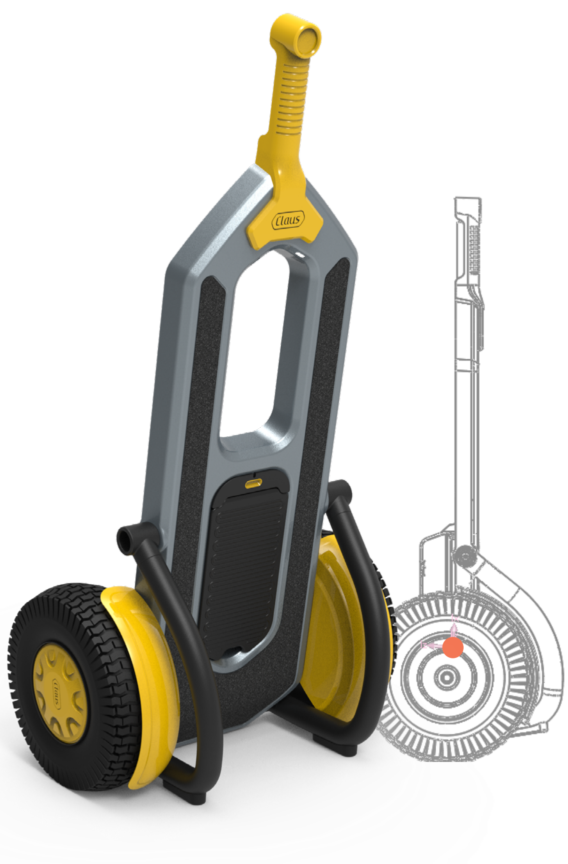
The handles on the rear of Claus serve multiple functions. First of the handles can be used to lift Claus easily and comfortably. Secondly, two 'feet' at the rear of the handles act as support points that can be used to store Claus in an upright position. In its upright position Claus requires a minimum amount of floor space which comes in handy when storing it in a delivery van. Moreover, in its upright position Claus takes up roughly the same volume as a delivery van.

Storage criteria

- Claus should have a low centre of mass in its upright position to guarantee a stable standing position.
- Claus should be stored in a similar way to the hand truck because this is what delivery workers are familiar with and because it is a proven concept.

Current storage specifications

- Centre of mass is ±30cm above the ground in Claus' upright position.



Cost Price Estimation

The composition of the cost price depends largely on the production volume of the product. This cost price estimation relies on several scenarios which encompass various production volumes.

Production volumes

In the Netherlands alone 991.000 delivery vehicles are registered (Centraal Bureau voor de Statistiek, 2022). This includes vehicles for construction, industry and rental. Extrapolating this number for the European continent on basis of population numbers gives us 42 million delivery vehicles in Europe alone.
If 1% of this market is reached, grossly 400.000 units can be sold. This production volume is considered the best case scenario. A quarter of this number is considered worst case scenario.

Tooling costs

By far the most expensive tooling is the tooling for the deep drawn frame. This is due to multiple progressive dies that should be made from high strength steel. The estimated costs for the tooling is set at 2 million Euros. This number is informed by DNAMX.

Tooling for injection moulded tooling is estimated at 20.000 Euros per mould. The glass fibre tooling is estimated slightly higher because of increased wear in the die due to the glass fibres.

Tooling for less complex production techniques such as tube bending and vacuum forming are estimated at 15.000 Euros.

Sourcing and material costs

Some of the components can be sourced and therefore do not require additional tooling and development. The transaxle motor for instance can be bought as a complete assembly. The price for the transaxle motor is set at 30 Euros.

As was concluded in the 'Batteries' sub-chapter, batteries come in low-end and high-end varieties. The pricing difference between those two is significant and therefore the additional price of the batteries is calculated separately. The production price of the high-end and low-end batteries is calculated by determining the consumer price of two 8Ah batteries and consequently reverse calculating the production price by subtracting the margins that were used in the price calculation for Claus itself.

The estimated costs for the sheet metal material of the base frame is 15 Euros, labour and maintenance costs of the deep drawing equipment is estimated on 15 Euros. In total, that makes 30 Euros for the frame.

For the remainder of the product specific components 2 Euros per component was set as a price for material and labour.

Table

The table on the next page displays the price range of Claus on basis of a couple parameters. The first parameter is the production volume and the second parameter is the costs of the batteries.

Base			
	Transaxle motor	€	30
	Wheels	€	10
	Tail light	€	2
	Frame	€	30
	Handlebar holders feet (6x)	€	12
	E-kit embodiment (2x)	€	4
	Handlebar tubes (2x)	€	4
	Fenders (2x)	€	4
	Anti-slip layer	€	1
	Couple mechanism	€	5
	Couple cover	€	2
	Fasteners	€	2
	Assembly	€	10
	Packaging	€	5
	Base Total	€	121

Material and labour costs per component.
The sum of all component costs is given in the last row.

Amortization							
	Tooling Base frame *Deep drawing*	€	2.000.000				
	Tooling Handlebar holders *Injection moulding (4x)*	€	100.000				
	Tooling E-kit embodiment *Injection moulding (2x)*	€	40.000				
	Tooling Coupler cover *Injection moulding (1x)*	€	20.000				
	Tooling Handlebar *Tube bending*	€	15.000				
	Tooling Fenders *Vacuum forming*	€	15.000				
	Tooling Assembly *Custom jigs, etc.*	€	15.000				
	TOTAL	€	2.205.000				
	Production volume		***400.000***		***200.000***		***100.000***
	Amortization	€	6	€	11	€	22

The total cost for all tooling is translated into tooling costs per unit on basis of the production volume.

Margins							
	Production price	€	127	€	132	€	143
	Production margin (30%)	€	164	€	172	€	186
	Retail margin (30%)	€	214	€	223	€	242
	Transport (10%)	€	235	€	245	€	266
	Other (15%)	€	270	€	282	€	306
	BTW (21%)	€	327	€	342	€	370
	Consumer price without bat	**€**	**327**	**€**	**342**	**€**	**370**

The amortization costs are added to the base total. The margins for production, retail, transport, etc. are added to this number. The three columns take the different production volumes into account.

The last row displays the total consumer price without batteries per production volume.

		High-end batteries						***Low-end batteries***	
	Production price batteries	€	100	€	80	€	50	€	30
Margins									
	Production price	€	100	€	80	€	50	€	30
	Production margin (30%)	€	130	€	104	€	65	€	39
	Retail margin (30%)	€	169	€	135	€	85	€	51
	Transport (10%)	€	186	€	149	€	93	€	56
	Other (15%)	€	214	€	171	€	107	€	64
	BTW (21%)	€	259	€	207	€	129	€	78
	Battery Consumer price	**€**	**259**	**€**	**207**	**€**	**129**	**€**	**78**

The margins for the batteries are set at the same as the margins for Claus itself. The consumer price of the batteries per battery type is displayed in the last row.

Production volume	**Price incl. high-end batteries**						**Price incl. low-end batteries**	
400.000 (€327)	€	586	€	534	€	457	**€**	**405**
200.000 (€342)	€	600	€	548	€	471	€	419
100.000 (€370)	**€**	**629**	€	577	€	499	€	448

This table shows the consumer price per production volume in combination with the price per battery type. In the lower left corner the most expensive scenario is represented (€ 629,-). In the upper right corner the most affordable scenario is represented (€ 405,-).

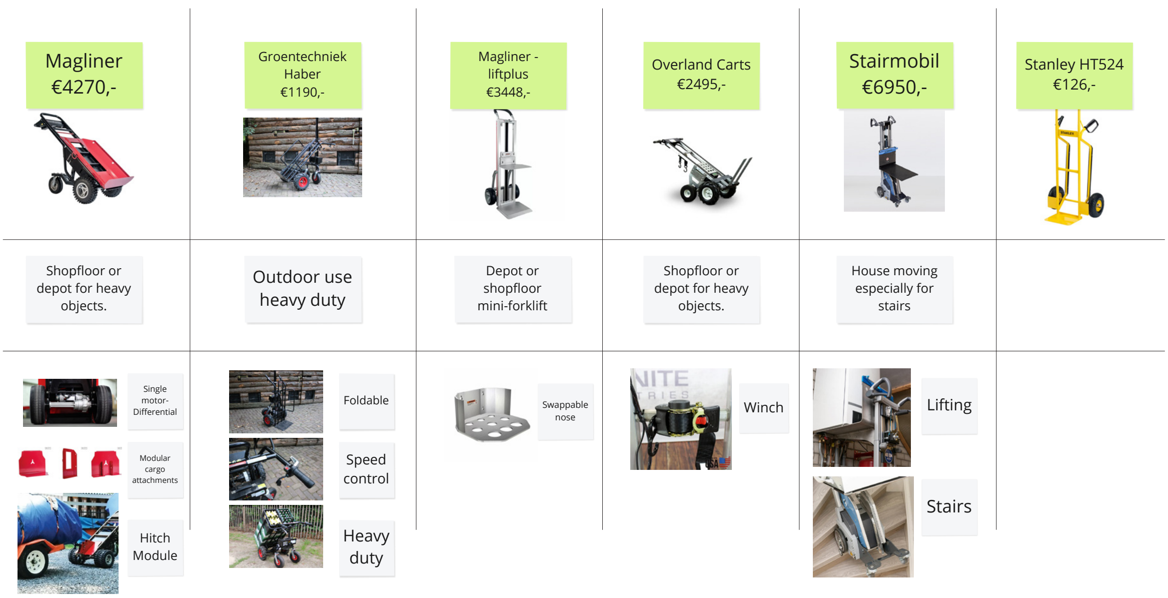
Price Benchmark

A benchmark was done with electric hand trucks and other small LEV's to assess how Claus performs in the market.

Since Claus is a new product category, it is not possible to compare Claus with direct competitors. Therefore two benchmarks are done. One benchmark explores electrified hand trucks, the second benchmark explores LEV's that are currently popular on the market.

Hand trucks

In the image below a selection of electrified hand trucks is made. At the very right a conventional non-electric hand truck is added for comparison purposes. The selection clearly shows that electrified hand trucks that are currently on the market either are focussed on heavy duty use-cases or that they operate in a niche such as house moving. In addition, the electric hand trucks have a high price range, ranging from around 1200,- to 7000,- Euros.

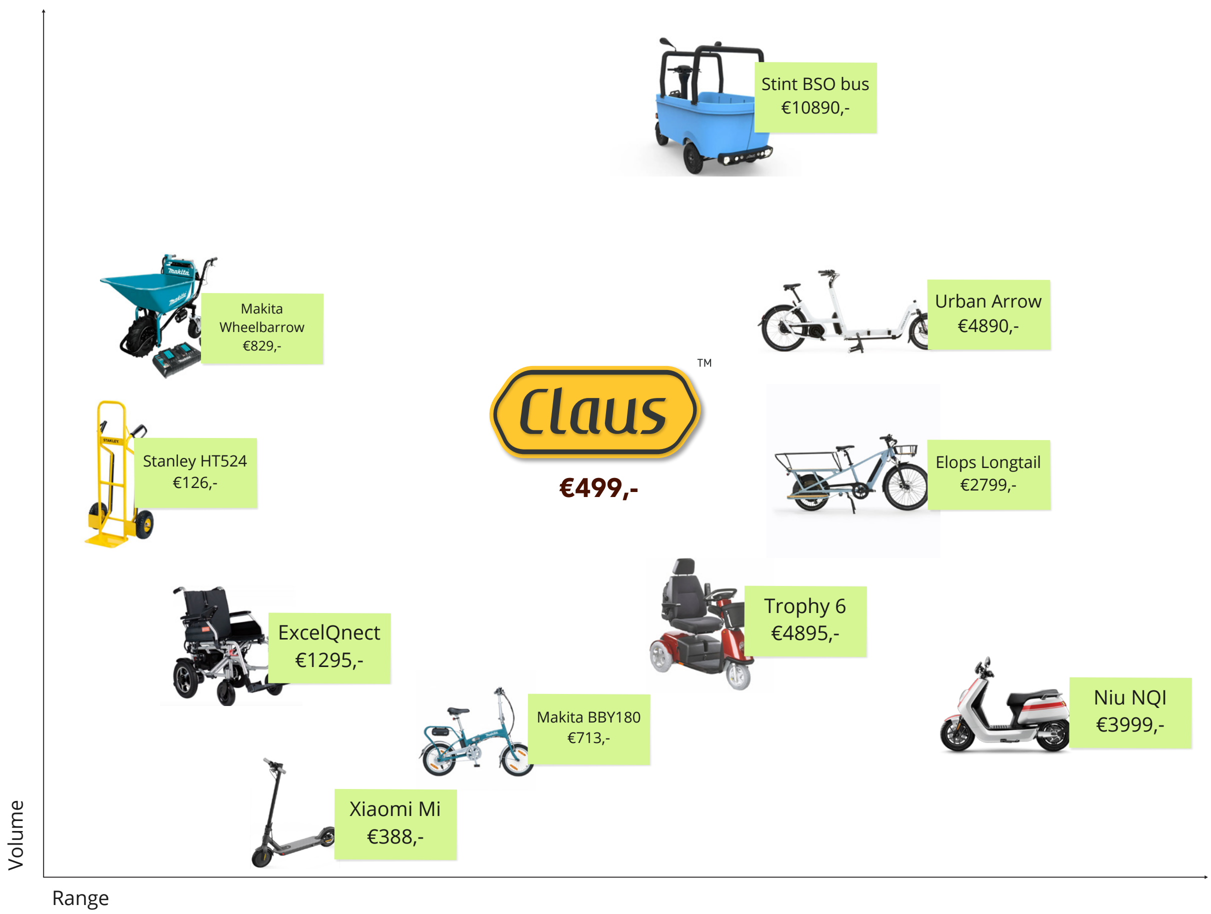


LEV's

The second benchmark explores other LEV's that are currently on the market. Both LEV's for utility purposes as well as LEV's for personal use-cases are included to give a complete overview of the market.

In the graph below a selection of LEV's are plotted in a graph. Some of the LEV's originate from the prior product benchmark (**Analysis - Product Benchmark**), others were found along the way during the design process. The vertical axis represents the cargo or people volume that the vehicle can transport from low to high. The horizontal axis represents the range for which the vehicles are intended from low to high.

Claus is plotted in the graph as well to indicate where Claus stands in the market. In comparison to the other LEV's, Claus has a medium range and a medium cargo volume. It also can be seen that the price is very reasonable compared to its surrounding competitors.



Stanley Quitz is manoeuvring the technical prototype through a narrow corner in Bergen op Zoom.

VALIDATION

This section discusses how the current design was simulated and tested. Furthermore, this section also elaborates on aspects of Claus that are not yet validated. The 'Discussion | Recommendations' chapter discusses topics that need additional attention in order to bring Claus to the next level.

Prototypes

Two prototypes were created that were used to validate the concept. A technical prototype acted as a means to validate the driving characteristics and the ergonomics. Furthermore, it was used to validate technical aspects such as the battery capacity and the drive train system. An aesthetic prototype was used to communicate the design to the stakeholders.

Functional prototype

Goal

The main goal of the functional prototype is to test and evaluate the most vital functions of the concept such as the manoeuvrability and steering, but also technical aspects such as motor power and battery capacity

Deviations from design

Less vital functions, such as the handlebars are not be included in the functional prototype. The look and feel is of less importance for the functionality of the concept and is therefore not incorporated in the technical prototype. However, ergonomics are of vital importance, thus the overall dimensions are adopted. However, the elevation of the deck is slightly higher than intended.

For the technical testing of the battery and motor, the prototype underwent several iterations. This is clearly indicated in its own sub-chapter.

Other factors that differ from the design are:

The coupling point, Hebie F1 Anhangerkupplung

No fenders

Dashboard consists of a magnet with a pot-meter.

The weight of the prototype is close to the intended weight of the design. The prototype without battery is 18 Kg. The weight of the design is 18,9 Kg

Aesthetic prototype

Goal

The most important goal of the aesthetic prototype is to communicate the design to the spectator. The prototype approaches the final design as close as possible to convey a realistic and convincing idea of the design.

The second goal of the aesthetic prototype is to assess aesthetic qualities and to study dimensional relations. Also, by placing the prototype in its intended use-environment it will represent how the final product will fit in the environment.

Deviations from design

The embodiment of the electronics will consist of a solid piece of foam. Therefore the cover will not be able to open and the battery will not be included in this prototype.

The deep drawn frame will consist of a solid piece of foam. In contrast to the steel deep drawn frame, the foam model will not be hollow.

Since the aesthetic model mostly consists of other materials than the materials in the design, most fastening methods will deviate.

Other factors that differ from the design are:

- No dashboard

- No functioning coupling point

- As the prototype does not have a motor or batteries it is much lighter than the design.

User tests

The user tests encompasses various test to evaluate the performance of the current concept.

The tests range from user-tests that evaluate the overall handling and decoupling to technical tests that aim to optimize the drive train characteristics.

Manoeuvrability

Research questions

Q1 How does Claus handle urban infrastructure (sidewalks, tight corners, etc.) and surrounding traffic (pedestrians, cyclists, automobiles, etc.)?

Q2 How tight is the turning radius in the current design?

Methods

The technical prototype was taken out to the streets of inner city Bergen op Zoom during late afternoon 16:00 - 17:00. To test the general interaction with the surrounding traffic and the urban infrastructure, the technical prototype was driven several times up and down the street both over the main road and over the sidewalk through regular traffic. The test site consisted of a mixed environment with all kinds of traffic (pedestrians, automobiles, cyclists).

Cornering test with cargo over a 1.5 meter turning radius.

The radius of the turning circle of the prototype was under 1.5 meters.

To test whether Claus' turning circle met the 1.5m requirement, a turning circle of 1.5m was drawn with tape on the ground. Claus was manoeuvred over the tape to see whether it stayed within the lines. Tests were done both with and without cargo. In this test the cargo consisted of an empty guitar casing that was transported in an upright position.

Claus managed to stay within the 1.5 m turning circle both with and without cargo. As cargo with a high centre of mass forces the user to tilt the hand truck further backwards, sharp corners force the users to sway the handles farther away from them. This can result in ergonomic problems. However, with the cargo that was used in the test this was not a problem.

Results

Thanks to Claus' relatively low top speed (6kmph) and thanks to the slightly elevated standing position of the user, the user has a good overview on traffic situations. Furthermore, the turning circle of Claus was small enough to turn the vehicle around at the main road without any additional manoeuvres.

Discussion

Both tests were done with only a single test subject. Testing with multiple test subjects with various body compositions would shed light on the ergonomics of the turning radius. Also, most of the long runs on the streets were performed without cargo. Driving with cargo for a longer time might point out precarious situation during manoeuvring the vehicle.

Ergonomics

Research Questions
Q1 What is an appropriate length for the drive train module?

Methods | Desk Research
The length of Claus is defined by the maximum distance of the users body to the wheel axis of the hand truck.

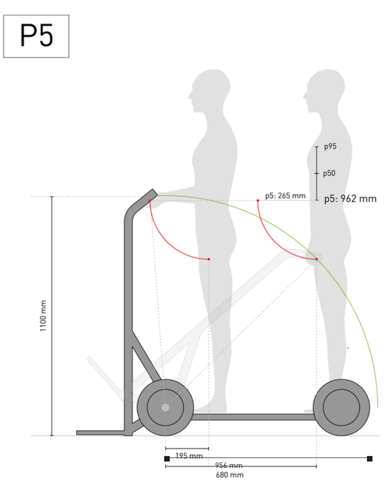
If the hand truck is tilted backwards, the user is removed further away from the wheel axis. However, there is a limit to which the user can comfortably hold the handles of the hand truck. It is assumed that the users only have a comfortable position when their bodies are in a straight standing position. As the hand truck tilts backwards, the handles also move downwards. From a certain distance from the hand trucks wheel axis, the users should bent to keep hold of the handles. This is regarded as the maximum distance. An additional factor that comes into play for finding the maximum distance is that the users are able to rotate their lower arms. If the lower arms are swung down, the users can grab the handles as low as possible without bending their bodies. Therefore, the maximum distance is measured with the users lower arms in a swung down position. The figures display the trajectory of the lower arm with a red line.

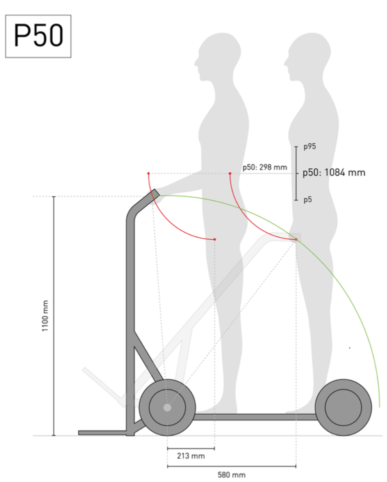
As this distance differs per body length, P5, P50, and P95 are evaluated. The shortest people are able to move the furthest backwards as can be seen in the figures. Therefore, the maximum distance from the wheel axis of a P5 human being is regarded as an appropriate length for Claus.

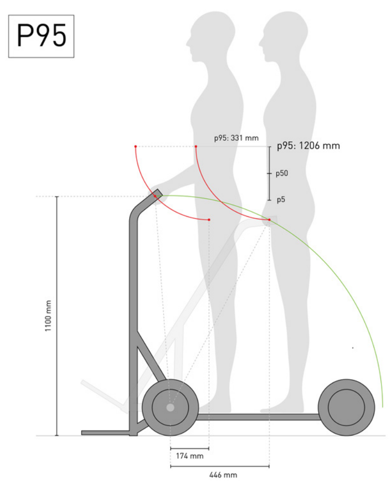
Results | Desk research
According to the desk research, the total required length of the drive train module is 95,6 centimetres. (See figure P5)

Methods | Physical testing
The technical prototype was built according to the dimension that was found during the desk research. This prototype was subsequently tested by multiple people.

Results | Physical testing
The physical ergonomic test showed that a little bit more length of the drive train module was required than the results of the desk research indicated. This is probably due to the assumption of a comfortable stance. In reality the user does not hang his or her upper arms completely vertical next to the body. As can be seen in the photo below, the test subject has his upper arms slightly pointed forwards.







Discussion
In general, hand trucks are ergonomically optimized already. In the modular setup with Claus, the user is elevated 10-15cm above the ground which results in a higher stance in relative to the hand truck. Especially for longer users this results in a sub-optimal standing position. In chapter Validation - Discussion | Recommendations, a proposal is done for an additional, higher steer that can be attached to hand trucks.

Stefan Akkerman testing the ergonomics of the technical prototype

Loading parcels

Loading Claus

Loading hand truck

Loading and unloading

Research questions

Q1 How long does it take to load and unload Claus and the hand truck in a delivery van?

Methods

For this test the test subject was asked to store the cargo, Claus and the hand truck in a small delivery van. In the beginning, Claus was assembled to the hand truck and five cardboard boxes were stored on the hand truck. This test was repeated the other way around to study the unloading speed.

Results

The full disassembly including loading cargo, hand truck and Claus into the van took less than two minutes.

Assembling and unloading everything from the van also took less than two minutes.

Discussion

Loading and unloading time under two minutes is significant since it shows that loading and unloading Claus does not require a lot of additional time compared to loading and unloading only a hand truck. However, a timed run without Claus was not performed so the actual time difference is not known.

Storage in van

Decoupling the dashboard

Uncoupling

Coupling point

Research questions
Q1 Is a mid-sized ball joint/trailer hitch strong enough for the current use case?

Q2 Does the current coupling point allow for the three required rotational DOF's (pitch, yaw, roll)?

Q3 How long does it take to couple and uncouple Claus to a hand truck?

Methods
A Hebie F1 Anhangerkupplung was used to study how a mid-sized ball joint mechanism performs in the current prototype during use. During all the tests, this coupling point was used for connecting and steering the hand truck. The dashboard should also be coupled and uncoupled by the user when assembling Claus. In the technical prototype it can be connected with a magnet to the steel hand truck.

The duration of coupling and uncoupling was measured during the loading and unloading test.

Results
During all the tests that were performed with the technical prototype the Hebie F1 Anhangerkupplung did not cause any problems whatsoever. Also, steering and tilting the hand truck went smooth and as intended.

Discussion
The current ball joint connector does not necessarily have the same safety pin/release as the eventual design. However, this test does act as a proof of principle for the mechanism in general.

In the technical prototype the dashboard was connected with a magnet only. The final connection mechanism is yet to be designed, but will likely be working with a alternative mechanism.

Motor | Battery

Research questions

Q1 Can the a low-power transaxle motor provide enough power to propel Claus during normal use?

Q2 How does the range corresponds to the battery capacities of the used batteries?

Q3 How high is the discharge current at full throttle continuous speed (transaxle motor)?

Q4 How does the motor responds to different types of batteries (See table)?

Methods

The motor that is used in the technical prototype is the Pihsiang M4-7uM. While its exact specifications could not be found, the mobility scooters in which it is integrated could be traced (f.e. Shoprider Wispa) These mobility scooters typically operated at 300 W continuous discharge, so it is assumed that this is the continuous discharge rating of the motor.

To test the motor power several iterations were done with various batteries to find a fitting power supply for the motor. Also, in the first iterations of the prototype another motor was used, namely a 24V 260 W hub wheel motor that was fitted in between the two rear wheels.

To find the top speed of Claus the throttle was fully opened while the distance travelled and the time travelled were measured.

To find the range of Claus, the prototype was driven on the streets of Bergen op Zoom until the batteries did not provide enough power anymore for propelling Claus faster than walking speed.

To find the continuous discharge current, a multimeter was wired in series to the battery output. When Claus was driving at constant speed, the current was read from the multimeter.

Results

The test results for each iteration are provided in the table below on the facing page. The first iteration (V1) was fully functional and therefore a clear range is found. Further iterations were done with the transaxle motor. The setup with powertool batteries and the transaxle motor did not result in a useful test result.

The last iteration (V4) gave a clear indication of the discharge current. At continuous speed (±6kmph) the multimeter gave a reading around 10 Amps. When more power was needed it read spikes up to 15 Amps.
The range of the last iteration (V4) is not yet tested.

Pihsiang M4-7uM transaxle motor mounted in an early version of the technical prototype

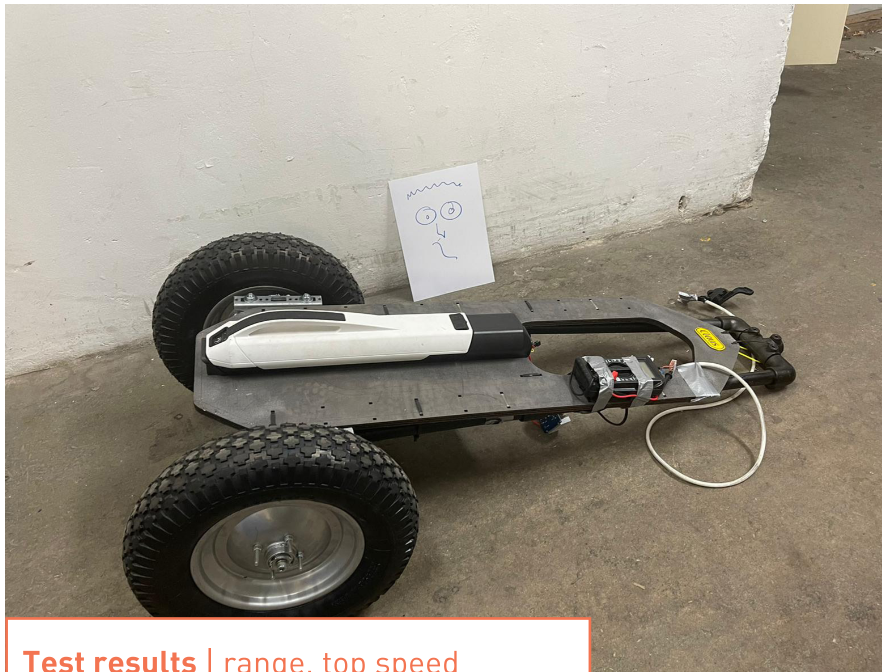
Discussion

The prototype houses a second hand motor and therefore it is not known how many hours the motor had already run for and whether the internal gearing and bearings of the motor were still up to standards. A motor with a lot of wear could have resulted in worse efficiency characteristics.

Over the course of the iterations several other aspects of the technical prototype were optimized as well such as the dashboard and the motor suspension. This might have resulted in an improvement of test results in the latest iteration.

Li-ion batteries with a low capacity typically have a lower max. current discharge rating as the individual cells are only wired in series. This might have been the reason that the motor did not get enough power in iterations V2 and V3. Using batteries with a higher capacities typically consist of cells that are connected in parallel as well which result in a higher max. discharge rating. The setup of V2 and V3 can be repeated with powertool batteries with a higher capacity to test this hypothesis.

The continuous discharge current test indicated that the motor draws 10 Amps at a continuous speed. Therefore, the batteries should have a discharge rating of at least 10 Amps.



This version (V4) of the technical prototype houses a 36 V, 8,8Ah e-bike battery

Motor - Battery configurations

V1
Single powertool battery (18V ; 1,5Ah | 4Ah)
Hub wheel motor (24V - 260 W)

V2
Single powertool battery (18V ; 1,5Ah)
Transaxle motor (24V ; 250-300 W)

V3
2x powertool battery (parallel)(18V ; 3-5,5Ah)
Transaxle motor (24V ; 250-300 W)

V4
E-bike battery (36V step down to 24V) ; 8,8Ah
Transaxle motor (24V ; 250-300 W)

Test results | range, top speed

V1
1,5 Ah → ±1500 meter, top speed ±6kmph
4,0 Ah → ±5000 meter, top speed ±6kmph

V2
1,5 Ah → ±50 meter, top speed ±6kmph (est.)

V3
3 Ah → ±50 meter, top speed ±6kmph (est.)
5,5 Ah → ±50 meter, top speed ±6kmph (est.)

V4
100+ meter, top speed ±6kmph (est.)
±10A cont. discharge current at full speed

Current Status | Overview

This table gives an overview of the current testing status of Claus. For every sub-component or system it is pointed out which aspects still need additional attention and which aspects are already proven with the earlier presented user tests.

The first column points out the sub-system, component or topic.

The second column ('Proven') indicates what aspects of the sub-system are proven in the earlier presented user tests. The third column ('To Be Proven') indicates what aspects still need additional testing to move to a final design.

Finally, the fourth column ('To Be Designed') indicates what aspects of Claus are not yet designed. These aspects need to be designed and proven still.

The last two columns of this table are used to inform the **Validation - Discussion | Recommendations** chapter

	Proven	To Be Proven	To Be Designed
Coupling point	Coupling and steering mechanism with Hebie F1 Anhangerkupplung	Structural integrity - FEM analysis	Integration and design of quick release in the coupling point sub-assembly. Connection of ball connector to hand truck. Integration of cup connector in the coupling point sub-assembly
Frame		Structural integrity - FEM analysis	
Handlebars		Structural integrity - FEM analysis Ergonomics of carrying Claus with the handlebars	Fasteners
Wheels	Size in relation to comfort and steering characteristics		
Batteries	Sufficient power provision to control the motor	Range of technical prototype (V4)	Electronic and mechanical connection to the battery box
Motor	Sufficient power to bring person and cargo in motion upto 6kmph	Efficiency	
Dashboard	Interface with which the driver can control the speed	Braking on the motor with an electronic brake button on the dashboard Front light on the dashboard	Electronic brake button on the dashboard Quick attach and release to both the hand truck and Claus Front light integrated into the dashboard
Electronics	Central processor that controls the motor and inputs		Sufficient housing, PCB design Software for driving characteristics optimiziation
Look & Feel		Perception of user-base. An elaborate user-test can still be performed	
Hand truck	The combination of Claus with a conventional hand truck that is used in delivery work.	Extensive research into the combination of Claus with different types of hand trucks.	Custom hand truck specifically tailored to Claus in order to optimize ergonomic performance. Additions for ergonomic optimization
Storage	Similar volume to the hand truck. Loading and unloading is similar to the hand truck.	Stability of the vertical position considering the current weight distribution.	

Discussion | Recommendations

To get Claus to the next level, several factors still need to be designed and tested. In the previous chapter an overview is provided of what aspects are proven and what aspects still need to be validated. In this chapter recommendations are provided for future development of the aspects that still need additional attention.

Pilot study

A delivery company will only purchase Claus if it makes last-mile delivery more efficient. Therefore it has to be tested in a real world environment whether delivery workers are willing to use Claus and whether it really offers a significant time advantage. This chapter presents a rough proposal for a small pilot study.

To test whether Claus offers a significant time gain, a test route with real delivery addresses can be set up that a test subject has to service with a delivery van and actual parcels. Two runs, one with and one without Claus should be done by the test subjects to compare the total time that was spend on delivery. To test on what threshold distance the delivery worker will go through the effort of connecting Claus to the hand truck, the run with Claus can be used to observe this distance.

Research Questions

Q1 What is the threshold distance of one leg at which users start to use Claus in addition to the hand truck?

Q2 What is the total time difference between a delivery run with and without Claus?

Dry run

Materials
Delivery van, 10 mid-sized parcels, hand truck

Context
10 addresses in city centre with limited mobility access.
Between 8:00 am and 5:00 pm

Objective
Deliver all packages on their corresponding addresses. Test subjects can choose the route and the available tools however they like.

Claus

Materials
Delivery van 10 mid-sized parcels, hand truck, Claus

Context
10 addresses in city centre with limited mobility access.
Between 8:00 am and 5:00 pm

Objective
Deliver all packages on their corresponding addresses. Test subjects can choose the route and the available tools however they like.

Dashboard

The dashboard is not yet designed. The dashboard that is displayed in the images is an impression of what the dashboard can look like roughly. However, some functionalities such as the braking lever and the quick attach mechanism are not yet integrated into a suitable embodiment.

In the image above a recommendation is made for quick attaching the dashboard to the frame by using a magnet and a form closure. When the dashboard is not in use and when Claus is not coupled to a hand truck, the user can quickly and easily store away the dashboard on the frame.

For quickly and easily attaching the dashboard to the hand truck three mechanisms are proposed on the right.

Braking

In the current design, braking is done with a separate button on the dashboard that is supposed to electronically stall the motor in a controlled manner. However, this is not integrated in the functional prototype and therefore is not tested yet.

A proposal for the integration of the brake lever is done on the lower right of the facing page.

Clamp

An integrated clamp in the dashboard can be used to secure the dashboard to the hand trucks handles. The adjustment screw on the clamp makes sure that there can be variation in the diameter of the hand truck handle.

Interface

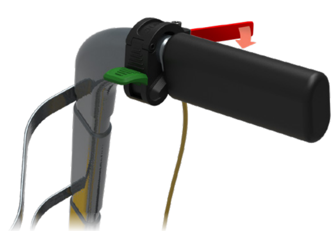
This solution consists of an interface that is installed once on the hand truck handle by the user. Consequently, the interface receives the dashboard by using a form closure, magnet, or other quick attachment manner.

Cord & plug

In this solution the dashboard is permanently mounted to the handles of the hand truck. Once the users have to attach Claus, they only have to plug in a cord to the dashboard.

Brake button

This is an impression of a possible brake button. The button is clearly red to communicate the function. Furthermore, it resembles a mechanical brake also to communicate its function to the user.



Batteries

As mentioned earlier in the 'package' chapter, the battery configuration is not yet defined. This chapter elaborates on yet to be performed battery tests.

A powertool battery configuration was tested with the technical prototype, but no conclusive result was found that indicated that powering Claus with powertool batteries was not possible at all. More research can be done with powertool batteries to find whether it is possible or not. For example, the front opening of the frame can be used as an additional battery box to wire two extra powertool batteries in parallel for more capacity and a higher discharge current. Also, the powertool battery tests were conducted with two 18V 1,5Ah Wesco brand batteries. The possibility exists that these batteries could not provide enough discharge current to the motor. Batteries with a higher discharge current might solve the encountered power issues.

The battery specifications guide that was presented in the 'package' chapter is purely theoretical and is not validated with real batteries and prototypes. If range tests will be performed with different types of batteries the specifications guide can be validated and calibrated accordingly.

A configuration in which multiple powertool batteries were wired in parallel was tested on the technical prototype. This setup encountered problems, but is was unclear whether these problems originated from the battery characteristics or whether they originated from the wiring setup. As other proposals also rely on parallel wired batteries more tests have to be done on battery winding to validate the parallel wiring setup.

Tailored hand truck

The current design is focussed on compatibility with different brands of hand trucks. However, for an optimal ergonomics, either a specialized hand truck or extension modules for hand trucks can be developed. In the image on this page multiple suggestions are made for optimizing ergonomics and user experience.

Business Model

Next to the retail price there has not been any attention to the business model of Claus. Since Claus is focused on delivery workers and delivery companies, a B2B sales strategy is probably the most appropriate.
Another possible scenario would be to develop a subscription model around Claus. In this scenario Claus is used by delivery companies for a monthly or yearly fee. Since the subscription company keeps ownership over Claus, the company can continuously gather data to improve Claus and also offer their customers tailored products and services.

Look & Feel User test

The look & feel of Claus is not yet validated with its intended user base. However, the look&feel might be an important characteristic of the product on which the delivery workers make the decision to use it or not. Therefore, an elaborate user test concerning look&feel should still be performed.

FEM analysis

Since the structural architecture of the technical prototype differs from the envisioned architecture, there is no indication yet whether the envisioned production method of the frame is sufficient in terms of structural integrity. Therefore, a FEM analysis should be performed on the frame and on other structural elements of Claus to assess whether the sheet thickness, production methods and material choice is appropriate. Furthermore, these FEM analyses should be validated with physical prototypes.

Production analysis

The chosen production methods are not yet validated.

The designs of the various components are based on ergonomics, look & feel and general functionality. However, these designs are not yet validated in terms of manufacturing. The current form of the frame for example is constructed with general knowledge about the production technique, but is not yet validated by a manufacturer.

Regulations and rules

Rules and regulations for LEV's differ per country and is a grey area regarding vehicles that do not directly fall into a specific vehicle category. In the last decade there has been an enormous increase in LEV's and therefore the rules and regulations are lagging behind. For the development of Claus Dutch and European regulations were consulted, but they were not studied in detail nor practiced in detail. For further development of Claus, these regulations should be studied in greater detail. Some relevant rules and regulations are presented in this chapter.

European law has regulation for Quadricycles (Regulation (EU) No 168/2013) However , these regulations do not apply to quadricyles with no seat. The Dutch government did a proposal for future regulation, since in the Netherlands LEV regulations are still non-existent as well. LEV regulations are likely being introduced in 2023 in the Netherlands. In the figure below a proposition is presented for these regulations (Infrastructure and Water Management, 2021).
In this project these regulation proposals are taken as starting point for some criteria. Based on the current concept Claus is likely to fall into 'Categorie 1b' (Category 1b).

Uitgewerkt toelatingskader lichte elektrische voertuigen

	Categorie 1a	Categorie 1b	Categorie 2a	Categorie 2b
	e-(bak)fiets volledige trapondersteuning <55 kg	alle andere LEVs dan 1a < 55 kg	goederenvervoer > 55 kg	personenvervoer > 55 kg
Wijze van toelating en toezicht				
Toelatings-regime	Zelfcertificering	Goedkeuring	Goedkeuring	Goedkeuring
Toezicht-regime	Op de markt	Op de fabricage	Op de fabricage	Op de fabricage
Uitgangs-punten	EU Machinerichtlijn / EN 15194	EU 168-2013 / Bijz. Bromf. / EN 17128 / Duitse norm + integrale risicobeoordeling	EU 168-2013 / Bijz. Bromf. + integrale risicobeoordeling	EU 168-2013 / Bijz. Bromf. + integrale risicobeoordeling
Eisen voor toelating tot de weg				
Max. afmetingen LxBxH	2 wielen: 3 x 0,75 x 2 m; > 2 wielen: 3 x 1 x 2 m	2 x 0,75 x 1,50 m	3 x 1 x 2 m	3 x 1 x 2 m
Max. constr. snelheid	≥ 6 km/h en ≤ 25 km/h	≥ 6 km/h en ≤ 25 km/h	≥ 6 km/h en ≤ 25 km/h	≥ 6 km/h en ≤ 25 km/h
Toegestane max. massa	Max. rijklaar <55kg, TMM 200 kg	Max. rijklaar <55 kg TMM 140kg	Max. rijklaar 270kg of 425kg bij 4 of meer wielen, TMM 565kg	Max. rijklaar 270kg of 425kg bij 4 of meer wielen, TMM 565kg
Vermogen	< 250 W	Zomer 2021	Trapondersteuning: < 250W, Geen trapondersteuning: Zomer 2021	Zomer 2021
Aantal personen	1 bestuurder, max. 2 passagiers	1 bestuurder	1 bestuurder	1 bestuurder, max. 8 passagiers
Eisen voor gebruik op de weg				
Kenteken	Geen kenteken	Kenteken	Kenteken	Kenteken
Verzekering	AVP / AVB	WAM	WAM	WAM
Helm	Nee	Nee	Nee	Nee
Rijbewijs	Nee	Nee	AM	AM
Minimum leeftijd	Nee	16 jaar	18 jaar	18 jaar

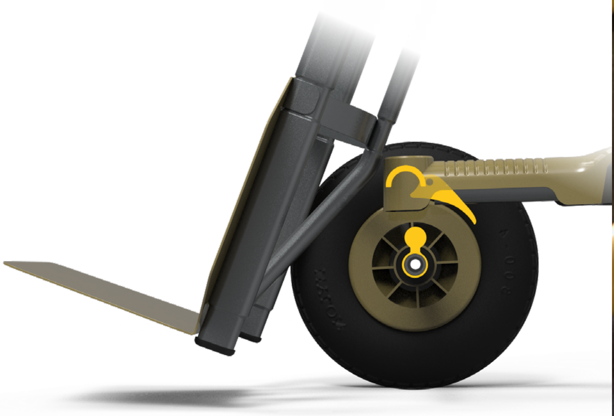
Dutch proposal for rules and regulations on LEV's

Coupling point

The general mechanism and workings of the coupling point are described in chapter **Actualization - Package - Coupling point**. Aspects like the safety release and the ball joint connection of the coupling point are still underdeveloped and should be explored in future research.

The consumer should be able to adapt a hand truck for connection with Claus by permanently or semi-permanently attaching a ball joint to the central wheel axis. Since hand trucks slightly differ in dimensions across brands, this ball joint should account for different axis diameters. Furthermore, a connection should be established that prevents the ball connector to rotate over the axis when there is force applied to it.

The prototypes proved a ball joint connection as displayed to the right to be an efficient manner of connection. In all the prototypes the cup was attached to Claus while the ball was attached to the hand truck. Since this has been a very decent connection during all the tests, no additional tests were done with a configuration in which the ball was attached to Claus and the cup to the hand truck. Tests can still be done to assess whether this alternative configuration works as well.



Electronics

The electronics can be optimized for better driving characteristics and overall better user experience. For example, the latest version of the technical prototype accelerates and decelerates at very fast which results in uncomfortable driving. This can be solved by either using more appropriate hardware such as a better throttle or it can be solved by software that controls the motor power.

Product Family

As the hand truck was the initial seed for the ideation of Claus, this report always presents Claus in combination with the hand truck. In retrospect, as Claus does not have any features that are hard-wired to the hand truck, Claus might act as a drive train module for other products as well. In the image below, some proposals are done for other products that can connect to Claus. Some of these proposals might be a bit farfetched, but the main goal of the visual is to explore the possibilities of Claus as an all-round drive train module.

On the right page some proposals are done to extend the product family of Claus by producing other types of power modules. A step is proposed for light-duty work or for the consumer market, while a scooter-like module is proposed for business purposes and for longer distances.

Ideally, the power modules can be mixed and matched with the several types of cargo modules for a wide range of possibilities.

Drive train

This is the module that is presented in this report. It has an electric drive train and a deck which the user stands on.

Step

This is a visualization for a passive module. It functions as a kick scooter and therefore does not have electronics.

Comfort scooter

This is a visualization for a more comfortable electrically assisted module. The user has a seat and footrests. This might be beneficial for longer distances.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motorhuis

EPILOGUE

Acknowledgements

I want to express my appreciation for the following people. Thanks to their help the project would not have reached its current status .

I want to thank my parents for their support in borrowing their car, and financing my academic career through paying tuition and helping me to purchase study aids.

I want to thank Judith for her mental support for the multiple times I needed it and for providing some extra pair of hands in the workshop.

I want to thank the support of the PMB staff at the Industrial Design faculty for giving me prototyping advice and helping me to produce parts.

I want to thank my academic supervisors, Sander Minnoye and Joris van Dam for their countless councils and for asking critical questions that helped me to move on.

Finally, I want to thank the team of DNAMX. I want to thank Frank Mahn for his friendly advice and patience with me at the office. I want to thank Jorrit Schoonhoven for his direct and crucial feedback in during all the sessions in Bergen op Zoom. I want to thank Stefan Akkerman for thinking along with me and for kicking of the sketching phase. I want to thank Stanley Quitz for his help at the workshop and for teaching me his life lessons. I want to thank Bart Bluemink for all the work behind the screens.

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