APPENDICES

DESIGN FOR our future

TU Delft

Appendix A - Original Brief

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Ameln

initials: C.E. given name: Coen

student number: 4453247

street & no.: [redacted]

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ◯ Dfl ◯ SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ◯ Honours Programme Master

specialisation / annotation: ◯ Medisign ◯ Tech. in Sustainable Design ◯ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: A.L.M. Minnoye dept. / section: SDE, MF

** mentor: J.J.F. van Dam dept. / section: SDE

2nd mentor: Frank Mahn

organisation: DNAMX

city: Rotterdam country: The Netherlands

comments (optional): Whereas both team members have usefull knowledge of advanced production methods, Sander Minnoye can help me out with the design process and Joris van Dam can help me out with prototyping.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair ______________________ date 06 - 03 - 2022 signature Sander Minnoye Digitally signed by Sander Minnoye Date: 2022.03.06 18:58:40 +01'00'

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ________ EC

Of which, taking the conditional requirements into account, can be part of the exam programme ________ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ______________________ date - - signature ______________________

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name ______________________ date - - signature ______________________

Design of an automotive industry inspired platform for utility bicycles

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 21 - 02 - 2022

19 - 08 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

European urban infrastructures are undergoing an interesting transformation due to political trends. The European Green Deal states that the European Union must reduce emissions from road transport by 70% before 2050. As a result, European cities are investing in a more sustainable infrastructure which is forcing citizens and businesses to rethink the way they move from A to B. For example, cities are curbing traffic by introducing congestion zones and low-emission zones. Also, cities are promoting other forms of transport such as cycling by building bicycle freeways.

This shift in infrastructure results in people and businesses having to rethink the way they use utility vehicles to fulfill their current mobility needs. A telling example is the last-mile delivery sector. With their current fleet of delivery vans, logistic companies are experiencing problems due to poor accessibility while the demand for deliveries has skyrocketed. Another example is that young families want to avoid congestion and polluting vehicles while bringing the children to school and while doing groceries. For these costumers, a mobility solution that is better adapted to the transforming infrastructure can solve the problems they are currently experiencing. In addition, it can help to solve the problems that automotive manufacturers are experiencing. The industry is facing decreasing car sales partly due to the decreased popularity of automobiles in urban areas. The industry can profit by diversifying to new forms of mobility that bridge the gap between mobility needs and modern infrastructure.

The solution proposed in this project is a platform for utility vehicles that is inspired by electric cargo bicycles. The design of the platform should allow for production with highly automated automotive production methods to involve the automotive industry and to reduce the costs per unit.

The design of the platform will be inspired on electric cargo bicycles since these already answer a part of the mobility needs in the modern urban context. For logistic companies electric cargo bikes offer a solution because they can transport a relatively large number of packages without getting stuck in traffic jams. For young families the same applies for transporting children and groceries. In addition, electric cargo bikes are a good political outcome as they do not directly emit greenhouse gasses or particulate matter.

A shared platform has the potential to serve a large market share since it is common to a multitude of final products. As a result, a platform can be produced in large volumes while spreading the development and manufacturing costs over the total range of final products. In addition, mass production of the platform enables the possibility to move bicycle production to European automotive factories. These facilities have the potential to reduce the manufacturing costs even further thanks to short production cycles and a high level of automation.

In conclusion, the aim of this project is to develop a concept for a utility vehicle platform that is inspired by electric cargo bikes. To keep production costs low and to provide a new market for the automotive industry, the platform must allow for manufacturing using production methods from the automotive industry.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: The Volkswagen MEB-platform is an example of how platforms are used in the automotive industry

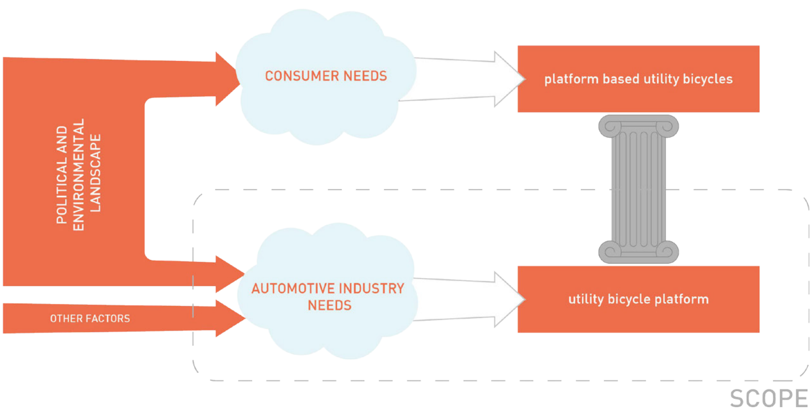


image / figure 2: Scope

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

This project studies the opportunity to develop an affordable platform for utility bicycles by utilizing automotive production methods.
The goal of this project is to conceptualize an embodiment design of such a platform to showcase how automotive production methods can be utilized to develop affordable, new means of mobility. In addition, the platform should offer automotive manufacturers an alternative or addition to their current portfolios, since the automotive industry is facing decreasing car sales.

A side effect that should be avoided is that the stringent quality requirements of the automotive industry result in an increase in production price. Also, the investment costs of automation and machinery should weigh out against the production volume to prevent an increase of the price per unit.

In the light of time limitations and personal learning goals, the focus lies on the problems for the mobility industry that arise during the production of the platform. Therefore, the mobility needs of the end-costumers shall be explored to a lesser extend. However, since those needs do partly define the embodiment of the platform, these needs are substantiated with assumptions that are supported by examples from the industry, current trends on mobility, and trends on urban infrastructure. Next to the needs of the various end users, these assumptions cover the political needs, and the needs of the automotive industry as well.

(See image 2 for visualisation)

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The conceptualization of a physical platform that acts as a foundation for various electric utility bicycles that serve diverse market segments such as young families, last-mile delivery companies and shared mobility companies. The production costs of the platform should be kept low by adopting production techniques from the automotive industry.

Prior to the conceptualization phase, market research will be done in which assumptions on the need for the platform are made on basis of examples from the industry, current trends on mobility, and trends on urban infrastructure. Finally, finite element analysis and CAD-software will be used to asses the manufacturability and the structural integrity of the product.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 21 - 2 - 2022

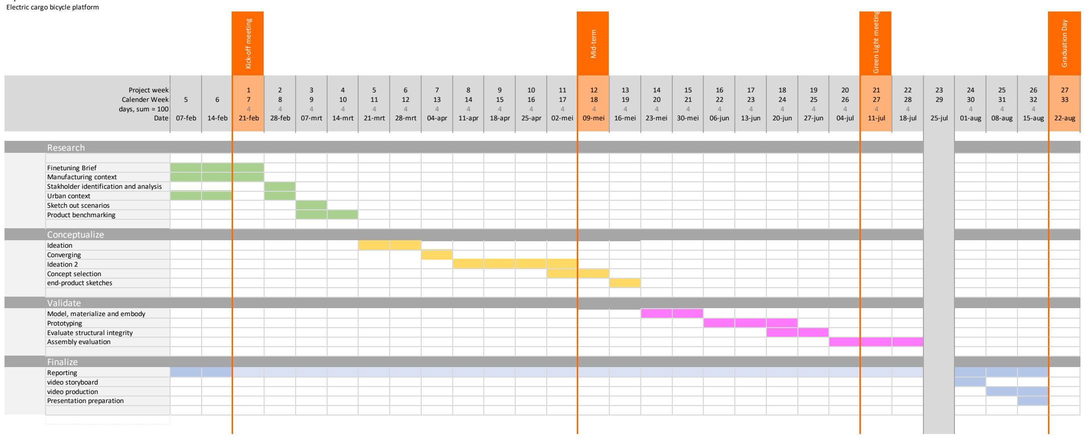
19 - 8 - 2022 end date

Graduation planning

Coen Ameln - 4453247

Supervisors
Frank Mahn - mentor DNAMX
Sander Minnoye - chair TU Delft
Joris van Dam - mentor TU Delft

Topic
Electric cargo bicycle platform



The planning of the project is built around a research stage, a conceptualization stage, a validation stage and a finalization stage. Because prototyping and validation are a substantial part of my motivations and ambitions, I want to spend plenty time on the validation phase.

Prior to the kick-off meeting some research is already done on the urban and manufacturing context. After the kick-off meeting the research phase will be continued by more context research. The completed research analysis will be the foundation for the conceptualization phase.

In the product conceptualization phase idea generation will be done on basis of the assumptions from the prior research. The double diamond method will be used to get to the final concept. Converging ideas will be informed by an estimation of manufacturability, diversification potential, and overall costs. Once a final concept is chosen, its potential will be illustrated by some rudimentary concepts for end-products that showcase the possibilities of the platform.

The objective of the validation phase is to prevent the need for fundamental alterations to the concept in a later stage. To do so, a validation is done on structural integrity by doing finite element analysis and prototype testing. Also, CAD-tools and an assembly evaluation will be used to evaluate the feasibility of the chosen production methods.

During calendar week 29 I have planned a week-long holiday. This week also marks the end of the validation phase. After this holiday I can reflect on the past design work to finish the final deliverables. If the schedule allows it, I might want to make a short presentation video of the final product.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I would like to finish my master degree with a project in which I can both apply my current skillset in confidence and learn new skills at the same time. The design of a bicycle platform is an appropriate project to reach this objective. I am accustomed to the design of physical products but at the same time it challenges me to design with advanced production techniques. Furthermore, I think that the mobility market offers a lot of interesting work for designers, both now and in the future.

Competences to prove

- The ability to integrate function, manufacturability and business perspective into a convincing design.
- Convincing presentation and demonstration of the results.
- Prototyping for structural and functional validation.

Ambitions and personal learning goals

- Learn to design with complex shapes in both the context of design sketching as well as in the context of CAD-modelling.
    - I have learned the basics of design sketching in both university courses and prior internships. However, I did not follow additional sketching courses and I have the feeling that I have a lot to learn in this domain. In this project I want to broaden my sketching skills.
    - The same goes for CAD-modelling. I am familiar to the basics, but my skills regarding modeling complex shapes is limited. In this project I want to broaden my CAD-skillset.

- Finding a personal design method which I feel comfortable with.
    - In previous design projects I used a wide variation of design methods. However, most of the time implementing these methods felt forced and unnatural. In this project I am hoping to finetune my personal way of working and I am hoping to define my personal way of working to a greater extend.

- Take my embodiment design skills to a higher level.
    - Embodiment design is one of my main motivations for industrial design. However, my confidence is lacking when it comes to designing parts for mass production. When I am graduated, I want to have a more confident attitude on embodiment design.

- Using CAD-tools to evaluate manufacturing methods and to perform finite element analyses.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Appendix B - Last-mile Delivery Problem

Last-mile delivery problem

The last mile delivery problem is explored through the 5W1H method. With the 5W1H method, the problem is explored through the following series of questions on the problem. *Who* has the problem, *What* is the problem, *Where* is the problem situated, *When* does the problem take place, *Why* does the problem take place, and *How* does the problem manifest itself.

Who

Initially the platform is aimed at multiple use-cases regarding the last mile delivery ecosystem. The direct stakeholders in the last mile delivery context are both the delivery workers and the logistic companies that exploit the vehicles. However, the production of the platform is a significant aspect of realizing these vehicles. As indicated before the automotive industry can benefit from moving into new directions and therefore OEM's and part suppliers are seen as an important stakeholders as well. Multiple use-cases can be identified in the last mile delivery ecosystem. The figure on the next page identifies thirteen segments of last mile delivery. Ideally the platform offers the possibility to cover all these segments by finishing the vehicle according to the needs of the corresponding stakeholders. It should be noted that each segments in turn have two stakeholders; the delivery worker, and the logistic company. Either one has separate interests. An additional possibility of the platform is to serve private actors such as young families that need to bring their kids to school.

What

The problem of the last mile delivery sector is twofold. To begin with the demand for order delivery has grown enormously in the last decade resulting in more delivery vehicles on the street. In combination with ongoing urbanization this results in congestion in urban areas which makes the situation only worse. Secondly, municipalities are making continuous efforts to make cities safer and less polluting at the expense of the conventional ICE logistic vans. The last mile logistics sector reacts by introducing a multitude of electric vehicles (EV's) on the road. EV's deal with less stringent regulations, especially if they are allowed on the bicycle paths. In this project a complete solution for the whole last mile delivery problem will not be provided. This project entails to develop a vehicle that can act as a part of the solution.

Where

The last mile delivery problem especially occurs in urban areas. This encompasses both dense inner city areas as well as more sprawled suburban areas. However, each city is unique in terms of infrastructure and demographics. This adds to the complexity of a universal solution for the last mile delivery problem.

When

The problem is due to a number of different factors that have taken hold at different times. First, the rise of e-commerce underlies a huge growth in B2C delivery of goods. Thanks to technological developments, a number of different forms of delivery have been added in recent years, such as meal delivery, on-demand delivery and grocery delivery. Due to Covid-19, the popularity of the latter two has increased even more. In addition, more and more citizens and governments are aware of the seriousness and consequences of climate change. As a result, there are new laws and regulations suggesting that the transportation sector needs to become more sustainable by electrifying vehicles and making urban transportation less polluting. (1) An underlying issue that has been around for much longer, but does play a role, is urbanization. It is expected that by 2030 60% of the world's population lives in cities (2). The infrastructure of cities cannot cope with the huge numbers of new residents, making the traffic situation worse.

Why

As mentioned before, each city is unique and therefore each solution should be unique as well. However, it requires enormous efforts and investments to specifically design a solution for each scenario. Current efforts to solve the problem entail stepwise improvement of the situation. Solving the problem will likely require joint investments of both municipalities and the industry to move to systematic change.

How

The urban landscape is transforming with a high pace. The logistic companies capability time to react and invest in the ongoing change is too low. Due to the enormous pace with which the urban and logistic landscape has undergone transformations, the industry did not have the capability to timely react. In addition, the logistic industry is not the only actor that is responding too late. Logistic companies are situated in a complex network where municipalities and automotive manufacturers play a significant role as well. This whole network is responsible for timely reacting to the problems at play.

24 proposed solutions by the World Economic Forum (2)

(1) Delivering the European Green Deal. (2021, August 7). European Commission - European Commission. Retrieved August 18, 2022, from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#making-transport-sustainable-for-all

(2) World Economic Forum, Deloison, T., Hannon, E., & Huber, A. (2019, January). The Future of the Last-Mile Ecosystem.

Appendix C - Manufacturing Methods

Automotive production plants are the pinnacle of modern mass production. Not only are automotive OEM's on the forefront of innovating products, but they are also on the forefront of innovation on manufacturing. Since the introduction of the first mass production line of the T-Ford, OEM's are continuously optimizing their supply chains and production processes in order to minimize production costs and to stay ahead of the competition. Typically, 300-400 cars are produced every day in a single factory, requiring a finished vehicle every 60-90 seconds. To make production even more complicated, almost none of the vehicles are identical because specific clients demand specific customization options. By identifying these processes of the automotive manufacturing domain, an overview of relevant loval production methods is composed.
In this chapter the production techniques and assembly methods in the context of high tech automotive industry are elaborated on. To conclude this chapter an overview of frequently used production methods and a series of guidelines and recommendations for the final design are presented.

Assembly

The assembly line is the most complex stage of automotive production. The high capital investment of keeping an inventory and warehouse forces the automotive industry to handle parts following the Just-In-Time (JIT) principle, which is derived from the Toyota Production System. In a JIT supply system parts are delivered to the automotive plant only when they are directly needed in the assembly line, so no additional resources are spent on the inventory of parts. JIT-supply comes with high complexity since the internal and external supply chain has to deal with complicated part logistics and very strict delivery times. Due to this principle a very limited amount of parts are manufactured in the actual OEM factory. Only those parts and sub-assemblies which are difficult or expensive to transport are produced in the automotive plant. In this chapter the production techniques and assembly methods in the context of high tech automotive industry are elaborated on. To conclude this chapter an overview of frequently used production methods is presented.

Cell vs. line

In general, the layout of an assembly plant can have two different configurations, known as cell assembly and line assembly. In a line assembly setup, the product moves from workstation to workstation undergoing a production step at each stage. The advantage of line production is that a multitude of production activities can be executed at the same time over the length of the full line. This ensures that a fully finished vehicle can be released every 60 to 90 seconds. However, setting up the facilities for in line production requires

large factories and a huge capital investment. In addition, reconfiguration of the line for new products comes with high costs since the whole production line needs to be adjusted.
Cellular production on the other hand is a more agile approach to vehicle production. In a cellular assembly setup a certain amount of robot arms or factory workers produce the whole product in one dedicated cell that can have the size of a tennis field. In this setup the robot arms or factory workers fulfil multiple functions and thus require tool changes after almost each assembly step. A higher production volume can be achieved by operating a multitude of cells in parallel. In this way, cellular assembly facilities can accomplish high production volumes while minimizing reconfiguration costs for new products.

Line factory layout

In a typical line automotive factory the production of a vehicle proceeds in four separate stages in four dedicated production areas. In line of order these dedicated production areas are: the press shop, the body shop, the paint shop, and the assembly line. In the press shop sheet metal is being formed to produce panels for the so called 'body-in-white' of the vehicle. The reason that body panels are made in-house is because transportation of panels from a separate supplier to the plant is expensive due to their awkward geometries and the strict surface quality requirements. The body panels are subsequently processed in the body shop where they are joined together to form the body in white. Once the body in white is completed it proceeds to the paint shop where multiple layers of paint are applied. Finally, in the assembly line the vehicle is finished according to customer demand. The employed production methods of these stages will be elaborated on in the 'production methods' chapter.

Line feeding

The countless customization configurations for vehicles poses the challenge to feed the right parts at the right time to the assembly line. For example, when a white car passes one of the trimming workstations, the assembly worker or robot should be provided with the corresponding white interior sub-assemblies or components. When a black car follows, the black interior components should be provided.
In order to feed the assembly line accordingly, three methods are employed in the industry; line stocking, kitting, and sequencing. These methods are coined for line production, but in essence they apply to cellular production as well.

Line stocking is the most simple method. An assortment of various model-specific components are transported to a specific workstation where the worker himself is responsible for picking the part that corresponds to the model that passes the line.

Kitting is technically more advanced. Prior to transportation to the assembly line, an assortment of model-specific parts is gathered in a container which travels along multiple consecutive workstations on the assembly line. This assortment is called a 'kit' and is especially composed to serve a specific model on the assembly line. Since the assembly workers and robots at a specific workstation can only pick a single model-specific part they don't have the responsibility to pick the right model-specific part.

In the sequencing method the parts are collected in a specific order from a storage area prior to their arrival at the assembly line. The parts are presented at the assembly line this particular order which corresponds to the order of vehicles on the assembly line. This method makes sure that the assembly workers or robots pick the part corresponding to the model on the assembly line.

Mixed model assembly line

In mixed model assembly lines a variety of products can be made on the exact same production line without affecting the continuity of the production line. By utilizing this approach the automotive industry is capable of quickly reacting to specific orders while keeping tooling reconfiguration costs low.
Mixed model assembly lines build on the prerequisite that a set of product components is common to each end-product and that this set of components is customizable by the selection of pre-defined options. In product design this principle is applied to allow customization of a specific model to a clients requirements without setting up an additional production line. Examples in the automotive industry are additional heated seats or an optional sunroof that can be built in just as easily as their alternatives. Since the mid-90's automotive OEM's have taken this approach to a new level by introducing automotive platforms. The utilization of platforms made it possible to produce multiple models of different brands in the same mixed-model assembly line. Typically, the automotive platform shares the under body, the engine compartment and the floor components. An example of a recent platform is the MEB-platform for electric vehicles by Volkswagen. This platform is utilized by Volkswagens Zwickau production plant to produce Audi, Volkswagen and Skoda models on the same line without major adjustments to the line.

Quality requirements

Built quality and especially surface finish quality is of paramount importance in the automotive industry. Technological advancements made a lot of automated quality inspection possible, sometimes even during the production process. However, some quality inspection can not yet be automated and require highly skilled workers. The main challenges lie in the paint and body shop where even minor flaws can have a significant effect on the appearance of the overall paint job or finishing of the car. With the emergence of new visual inspection technologies and AI-related solutions automation of this kind of inspection is near reach. However still automation requires high investment costs, significant floor space for machinery and good engineering skills for implementation.

Positioning

In order to position parts correctly for assembly, fixtures and clamps are used in the industry. Very often these fixtures require special engineering and therefore come with high additional costs. Standardization of these fixtures would be beneficial for OEM's. The challenge for designers and engineers is to design in such a way that the product requires a minimum amount of fixtures. When fixtures can not be eliminated, the design should allow for easy fixing on the fixtures. Preferably the work piece is fixed by gravitational force rather than by mechanical forces, because mechanical clamping requires additional actions that need to be performed by either workers or robots. (1) When it comes to precisely positioning parts on an assembly in an automated environment high tech visual or tactile systems are required. The preferred technique in the industry is tactile sensing since it is direct, quick and relatively cheap compared to visual sensing. However, an

(1) Boothroyd, G., & DeWhurst, P. (2022). Product Design for Manufacture and Assembly (3rd ed.). T&F INDIA.

important downfall of tactile sensing is that it can only provide local views and that it can damage fragile parts. These factors have to be considered in product design.

Production methods

This chapter contains a description of production, joining and colouring methods in the automotive industry. The main source of this chapter is the book Manufacturing & Design by Tempelman and Ninaber (1)

PRODUCTION

Resin transfer moulding

A recent breakthrough in the automotive industry is the mass production of carbon fibre composite components by using resin transfer moulding (RTM). The complete passenger compartment of the BMW i3 is made with resin transfer moulded body panels. A great number of welding robots in the body shop can be made obsolete with this production technique because a significant part of the body in white can be put together with exclusively adhesives. In addition, a significant weight reduction for the total vehicle is established, resulting in an increased driving range. RTM composites are composed of a matrix, usually a thermosetting plastic, and fibres, which come in a multitude of materials. The composition of the materials and proportions define the final material properties of the end-product. In a RTM process fibre reinforced composite components are made by laying pre-pegged fibre mats in a mould cavity which subsequently is filled with liquid resin. When the resin is cured, it has encapsulated the fibre mats and the part is ready for further finishing. It is essential that the liquid resin fills the entire mould because otherwise the structural and aesthetic characteristics are not ensured. Since short cycle times are required in the automotive industry the resin is forced in the mould under high pressures up to 150 bar to speed up the process (2). Another technique requiring less pressure and thus less expensive moulds is ‘pressure RTM’ which utilizes a semi closed mould to facilitate faster resin flow. When the required amount of resin is added, the mould closes entirely. Audi developed their own version of pressure RTM with which they can acquire a cycle time of under 5 minutes for a complete part. (2) Note that this cycle time is still significantly long for an automotive production line although considerably fast relative to other RTM-process. A second drawback of RTM is the poor recyclability characteristics of the end-product.

(1) Tempelman, E., Shercliff, H., & Eyben, V. B. N. (2014). Manufacturing and Design: Understanding the Principles of How Things Are Made (1st ed.). Butterworth-Heinemann.

(2) Sarfraz, M. S., Hong, H., & Kim, S. S. (2021). Recent developments in the manufacturing technologies of composite components and their cost-effectiveness in the automotive industry: A review study. Composite Structures, 266, 113864. https://doi.org/10.1016/j.compstruct.2021.113864

Extrusion

In the automotive industry extrusion profiles are used for structural parts of the body in white such as engine bracket and load bearing structures. Extrusion profiles are frequently used in combination with other production techniques to establish a definitive geometry. For example, the lateral roof frame of the Audi A2 is a hydro formed extrusion profile with additional machining steps (1). Aluminium extruded profiles are very affordable thanks to the high volume potential and efficient production. However, post processing such as machining and hydro forming often require expensive machinery and dies, making it only suitable for high volume production.

Tailored blanks (2)

To locally improve component properties blanks are sometimes processed prior to the matched die forming process. In the industry this process is referred to as 'tailored blanks'. Tailored blanks can be deployed to either reduce overall weight or to improve local structural integrity. Four different sub-groups of tailored blanks are defined in the industry - tailor welded blanks, patchwork blanks, tailor rolled blanks and tailor heat treated blanks.

Tailor welded blanks are blanks that are composed of multiple sheet metals differing in material or in thickness. The blanks are either but-welded or lap-welded depending on the material thickness and welding technique. The weld line can be either straight or curved, but the latter obviously comes with higher costs. A drawback of tailor welded blanks is that the design of the dies is more complex. Depending on the welding technique the stress and strain of the weld seam during the forming process should be carefully considered in the design.

Patchwork blanks are pieces of sheet metal which are locally reinforced by means of another piece of sheet metal welded or glued on top of it. Obviously the same difficulties apply to tailor patched blanks as to tailor welded blanks. The design of the die and the part is critical to ensure overall formability and to prevent weld defects.

Tailor rolled blanks aim to achieve the same benefits as patchwork blanks and tailor welded blanks albeit with only a single sheet of metal. The thickness of the blank is controlled by locally rolling the blank under pressure. The main benefit of this approach is that formability of the blank is more manageable thanks to the continuous thickness transitions as opposed to the sudden thickness transitions of other tailored blanks. However, the sheet thickness variation is limited to straight lines since the rolling process can only proceed in a straight line. Another drawback of tailor rolled blanks is that the material properties are influenced due to strain hardening, sometimes resulting in reduced formability.

Tailor heat treated blanks are blanks that are locally heat treated to improve local formability. This technique is especially useful for hard to form design features in combination with poor formable materials such as aluminium and high strength steel. Heat treating blanks is often very challenging since it is difficult to keep the heat treatment localized due to the heat conductive characteristics of blank materials. Also it is hard to determine the exact heating spot and length for the desired result.

(1) Pan□, G. M. (2020). Developments of Audi Space Frame Technology for Automotive Body Aluminum Construction. Applied Mechanics and Materials, 896, 127–132. https://doi.org/10.4028/www.scientific.net/amm.896.127

(2) Merklein, M., Johannes, M., Lechner, M., & Kuppert, A. (2014). A review on tailored blanks—Production, applications and evaluation. Journal of Materials Processing Technology, 214(2), 151–164. https://doi.org/10.1016/j.jmatprotec.2013.08.015

Casting

Traditionally the body in white is made of steel sheet metal. Audi however, challenged the industry by introducing the completely aluminium Audi Space Frame at the beginning of this century. In order to reduce part count and to increase local strength, the Audi Space Frame introduced aluminium castings. These aluminium castings efficiently replaced a multitude of sheet metal parts thanks to the complex forms that could be accomplished. If designed well, these castings could bear significantly high loads and fulfil multiple functions at the same time. More recently, Tesla introduced aluminium castings for entire undercarriages of their models by employing highly specialized high pressure die casting machines. Thanks to the introduction of this technique, a great number of sheet metal parts and a part of the production line can be made obsolete. The main challenge of integrating casted parts in automotive design is reducing the cycle time. Casting parts are required to be thin-walled in order to cool and solidify as fast as possible. On the other hand, very thin parts are difficult to design due to the complex flow of material in the mould. An easy step would be to fill the mould with high pressure, but this is obviously on the cost of mould price. Another drawback of high pressure moulding is the poor porosity of the parts due to turbulent material flow.

The second challenge of casted parts is that conventional joining methods can not easily be applied to join castings to sheet metal. A possible solution is to use casting inserts in the casting process. Bolts can for example be included in the mould which will be encapsulated in the eventual part.

Hydro forming

As its name suggests hydro forming makes use of pressurized water to form metal components. Most often it is used in combination with thin-walled tubes. These tubes are filled with water which is pressurized under very high pressures. The metal tube consequently expands until it hits a surrounding mould. Since the whole tube is evenly pressured the end-result is a heterogeneously formed thin walled tube. Due to the high pressure and specialized equipment hydro forming is mainly used for very high volume production. Another nuisance is that the initial tube often has to be pre-bend in order to fit in the mould and to produce more complex geometries.

Hydro forming

To produce metal body panels, the automotive industry employs matched die forming. In matched die forming a piece of flat sheet metal is rammed in between two dies with corresponding geometries to form a body panel in a matter of seconds. Prior to forming, the raw sheet metal is degreased and a rough shape is cut out, referred to as a blank. Multiple technologies such as laser cutting, water jet cutting or oxyacetylene cutting are utilized in the industry to cut blanks, depending on the material and manufacturing plant After the part is formed it still has flanges and excess material which needs to be removed to achieve a finished body panel. Either a plasma, laser, or water jet CNC cutter trims down the edges and optionally creates additional cut-outs.

Generally automotive body panels are relatively flat to make the drawing process easier. This specifically applies to aluminium parts because it has a poorer formability. Matched die forming of steel body parts is generally only suited for very high production volumes since the tool steel dies are very expensive. Therefore it is recommended to share matched die formed parts among multiple models instead of having a separate part, thus expensive die, for each model.

Sheet metal bending

For non-aesthetic, functional parts such as motor brackets or load bearing structures, simple single-curved sheet metal parts are sometimes sufficient. Sheet metal bending is very affordable, simple to automate and relatively easy to design for. However, this simplicity repays itself in poor structural integrity in relation to double curved parts and also poor aesthetic characteristics due to its limited form freedom. Secondly, single bent sheet metal parts are subject to spring back. A recent development of single curved sheet metal design is the design of the Tesla Cybertruck. Whereas conventional automobiles consist of a frame with body panels, the Cybertruck makes use of an exoskeleton completely made out of bent parts. The exoskeleton panels will be made out of special grade stainless steel sheet metal. In this case the material choice dictates the design, since forming thick stainless steel sheet metal into double curved parts is hard to execute on a mass scale.

JOINING

Welding

In the automotive industry welding is an essential joining technique for manufacturing cars. Almost every body in white is built with welded joints. Due to the limitless variation in materials and alloys a large number of welding techniques is applied in the industry. In this chapter the main welding techniques used in the automotive industry are summed up.

In spot welding a local spot weld is established by clamping two electrodes with a high current on sheet metal lap joints. Spot welding is probably the most frequently used welding technique thanks to its versatility, speed and simplicity. The number of spot welds in an average car are usually in the thousands. A downfall of spot welding is that it can not produce a continuous weld. A non-continuous weld offers less stiffness and moreover increases the chance of leakages. Also, spot welding can only weld lap joints which are accessible from both the front and the back. In order to prevent leakages, adhesives are often used in combination with spot welds. Welding of aluminium with resistance spot welding is possible although it is difficult due to the high thermal and electrical conductivity of aluminium. (1)

Over the recent decades laser welding has become popular in the automotive industry. As the name suggests, in laser welding a laser beam is focused on the work piece that is powerful enough to vaporize the material. The vaporization of the material results in a narrow and deep cavity, referred to as a keyhole. Thanks to the keyhole the penetration of laser welding is very deep while the heat affected zone is relatively narrow. This ensures a weld seam with good visual quality, low thermal distortion and high stiffness. On top of that, laser welding is a welding method that can be done with access from only one side. Laser welding can produce continuous welds at relatively high speeds (5-8 m/min)(1), making it ideal for automotive purposes. Laser welding is most often used for high volumes in a highly automated context, because automated operation is necessary.

If a weld seam is required with very good mechanical properties friction stir welding is the process of choice. In friction stir welding, a fast rotating tool travels along the joint of two welded pieces, and plastically deforms the material thanks to the generated heat and motion. In this way, the softened material is joined together

(1) Davies, G. (2022). Materials For Automobile Bodies. ELSEVIER INDIA.

way, the softened material is joined together without the need to melt the material. In the automotive industry the method is known to be used to join multiple extrusion profiles together. More complex profiles can be created in this way that are either impossible or too expensive to extrude.

Arc welding is the process of welding materials together by use of an electric arc between the work piece and the tool that creates enough heat to melt the welded materials. In the automotive industry MIG (Metal Inert Gas) welding is frequently used when resistance spot welding is considered not stiff or continuous enough. Due to the high heat and large heat affected zone that arc welding causes, distortion can happen in the work piece quite easily. This especially poses problems for thinner sheet metals in which inconsistencies can cause holes in the work piece called blow-outs. TIG welding (Tungsten Inert Gas) welding can be used as an alternative for these hard to weld work pieces. Another benefit of TIG welding is that is does not require a filler material. Manual arc welding requires a skilled worker making it expensive and time demanding. Automated arc welding is difficult to engineer, but for high volume production it is definitely possible.

Adhesives

Adhesive bonds come with several advantages such as a sealed joint, a decrease in vibrations and the possibility to join different materials together. Adhesives bonds are used for the attachment of trim components, but also for more structural parts such as sheet metal components in the body in white. The passenger cell of the BMW i3 is made from fibre reinforced composite panels which are joint together using solely adhesives.
Traditionally adhesives are unsuited for high volume production because they take a long time to set under difficult circumstances and require much preparation of the to be joined material. A combination of resistance spot welding and adhesives can be used to create a sealed weld with the structural benefits of spot welds.

Threaded fasteners

Threaded fasteners such as bolts and screws are often used to join different materials that can not be welded or glued. Although threaded fasteners are a wide spread fastener for many kinds of applications, in the automotive industry it is not the prioritized fastener of choice due to difficult automation and pre-processing steps such as carefully drilled holes. A potential benefit of threaded bolts is that they are appropriate for repeated disassembly or reconfiguration. In a design where the specific place of a sub-assembly or parts is required to be adjustable, threaded fasteners are appropriate because the location of the component can be adjusted during or after the production process.

Self piercing rivets

Traditional rivets have the same drawback as threaded bolts in the sense that a hole should be drilled prior to the assembly of the fastener. A recent development in the automotive industry is the invention of self-piercing rivets. Self-piercing rivets are rivets that are punched into sheet metal components and thanks to their design the sheet metal material deforms in such a way that the rivet, and the two sheets are clinched together. Application of a self-piercing rivet is very simple because the only tool that is needed is a press. Furthermore, application of such a rivet can be done very fast. An additional benefit of self-piercing rivets is that the aesthetic appearance is very good. The head of the rivet sits flush with the joined sheet metal.

Clinching

Clinching is the process of joining sheet metal materials by locally deforming the sheet metal parts in such a way that they physically interlock. Only a simple press and die is required for clinching which is the main benefit over riveting. Because no additional fastener is needed it provides a significant benefit over rivets or threaded fasteners.

COLOURING

Paint shop

The paint shop of automotive plants consists of several consecutive stages in which various layers of paint are applied. Although the painting process can be automated to a high extend, paint defects are still very common in the automotive industry. Due to these errors and due to the high diversity in applied colours, the logistics of paint shops are increasingly complex. Since the continuation of the production line is critical, the industry takes the smooth reworking of defects very seriously. The introduction of product buffers prevents the entire production line from pausing, since the affected vehicle can be easily replaced by a functional product from the buffer batch. Defect inspection and quality control is done both by automated robots as well as by highly specialized production workers. Furthermore, the variation of colours poses problems for the maintenance of the paint shop as well. The automated robot arms are equipped with paint guns specifically for a single colour. A variety of colours on the production line requires either exchange of the painting tool or a multitude of robot arms. Both options are costly and the latter would occupy valuable floor space as well.

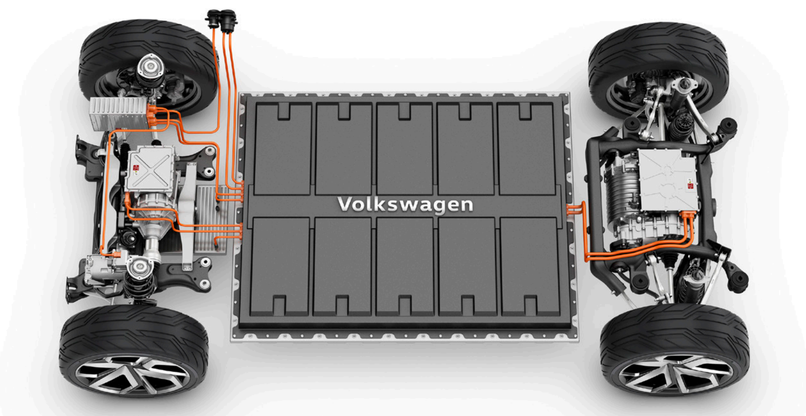
Alternatives

An alternative to painting in the paint shop is to apply colour in earlier stages of the production process. For example, colour can be applied in the production stage of body panels when they are made from injection moulded plastic. In this case the metal parts of the vehicle still needs painting to prevent corrosion. However, since the variation of colour is applied in the non-metal part, the metal only is required to be paint in one specific colour, significantly reducing the complexity of the paint shop. Another approach is to make the entire vehicle of a non-corrosive material. For example, the Tesla Cybertruck is made of stainless steel, eliminating the need for any additional material processing.

METHOD	TECHNIQUE	SUB-TECHNIQUE	costs	Automation	Speed	Form freedom	weight	application
production	Resin transfer moulding		4	3	2	2	5	lightweight body panels
	casting		3	2	2	5	2	form freedom and structural parts
	extrusion		1	4	5	3	3	structural beams
	Matched die forming		2	4	5	2	4	metal body panels
	pipe/ extrusion bending		1	5	4	1		bending extrusion profiles and tubing
	hydroforming		4	3	3	4		structural beams with additional form freedom
joining	weld	laser weld	3	4	3			Large production volume, one side access, deep penetration
		Friction stir	5	4	3			Joining small parts made of reactive metals
		resistance spot welds	1	5	5			fast and simple joining
		Arc welding	3	3	3			
	rivets	self-piercing	3	5	5			Fast, simple joining without the need for a pre-drilled hole
		normal rivets	1	2	5			Permanent, fast joining of different materials
	adhesives		3	3	3			watertight, vibration free joints. Joining of seperate materials
	threaded	cast inlay bolts	3	2	5			joining casted components to other components
		bolts	1	3	4			Joining seperate materials. Suited for disassembly
		screws	2	3	4			Fast joining for simple manual labour
	Form closures	snap fits	1	5	5			Joining strong, low stiffness materials and easy assembly
		clamp fits	1	4	3			Semi-permanent joining
		seaming	3	4	4			Joining metal sheets on the edges
		clinching	2	5	5			Joining metal sheets at a single point
colouring	paint shop		5	3	1			Colouring the body in white in a dedicated factory division
	plastics		1	5	5			Colouring parts during the production
positioning	fixtures		3					Holding parts in place in the assembly line
	clamps		2					Holding parts in place in the assembly line
	tactile positioning		3					Positioning parts based on pressure
	visual positioning		5					positioning parts based on camera
Tailored blanks	tailor heat treated blanks		3					
	tailor welded blanks		3					
	tailor rolled blanks		3					
	tailor patched blanks		3					
	inspection		4					
assembly	line stocking							
	kitting							
	sequencing							

Additional drawbacks	comments
Specialized setup	BMW and Arrival succesfully employed RTM on a mass scale
cooling time	Tesla uses so called megacastings which eliminated 70 deep drawn panels of the body in white
reduced form freedom	Audi uses extrusions in the Audi space frame
	Bending extrusion profiles offers more form freedom for extrusion profiles
Often additional production step is required	
For large parts, expensive machinery	
two side access	
Apart from 'pop' rivets, rivets require two side access	
application under complex circumstances	
more expensive mold engineering	
disassembly issues	
Only injection molded parts	
very expensive set-up	
color freedom is dependent on the design	
expensive and product specific	
Requires additional assembly step	
Additional production step prior to the press shop	

Appendix D - Platform Cases



Volkswagen MEB-Platform

The MEB platform is designed to cover the full market spectrum of the Volkswagen portfolio. The platform does not only cover the portfolio of the VW brand, but it provides a production foundation for models of other brands as well, namely; Seat, Audi and Skoda. The platform is by no means a fully finished driving undercarriage for a car. Rather it is a set of modular components that can be configured to build a specific vehicle model. This set of modular components includes mostly technical chunks of the vehicles such as the drive train, battery pack, suspension and electronics. While some of these modules are identical for each model, some other modules come in several variants or dimensions, for example to provide the possibility to control the wheel length basis, battery range, or motor performance. Also, the product architecture provides the possibility to add optional functionalities such as a front axis motor in addition to the rear axis motor.

The strategic benefit for Volkswagen is that development of new models can be accelerated thanks to the already existing technical infrastructure of the MEB-platform. In addition, VW's assembly lines do not require severe alterations when a new model is introduced. Finally, and the bulk supply of components can decrease production costs. Since the customers can easily configure vehicles according to their personal wishes without added costs, the platform also adds value for the consumer.

An important notice is that the MEB-platform is only a platform to a certain extend. The Volkswagen brand portfolio includes very diverse vehicles that are built on the MEB platform. For example, the ID.BUZZ is built on the MEB platform as well as the ID.3. The whole passenger compartment and bodywork of these two models is drastically different. The interfaces of the bodywork components and passenger compartment sub-assemblies are product specific and do therefore not comply with the earlier defined characteristics of a platform.

Scooter Platform Concept

This is a concept for a platform that can be used to build a variety of electric scooters. The strategic idea of this platform is to achieve competitive advantage by sharing components and sub-assemblies and thereby lowering production costs. In addition, this platform aims to add value to the customer since every single model is tailored to a specific use-case.

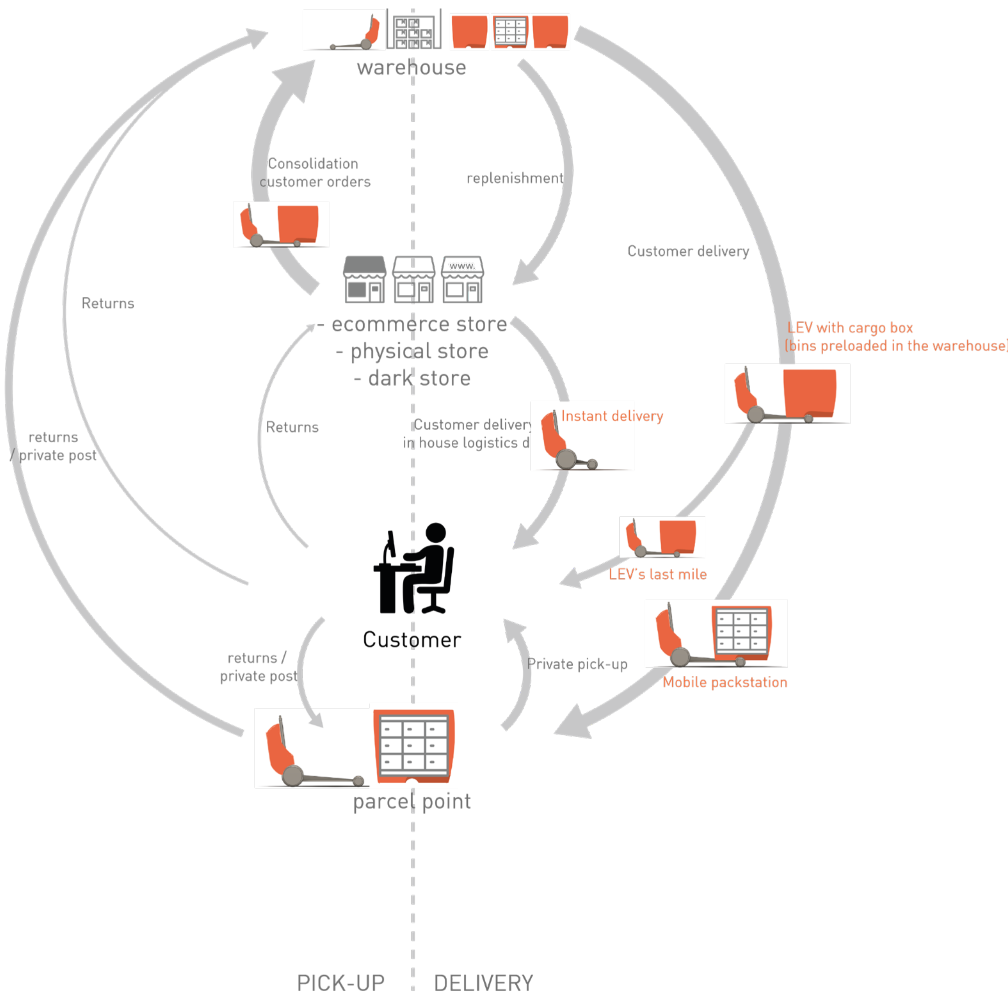
Developing a platform for smaller products with less sub-functionalities can sometimes result in the opposite of the desired effects. The design of this platform demonstrates the dangers of a platform strategy that is taken too far. In the worst case this approach may result in an increase of production costs relative to a non-platform approach.

In order to design a well functioning modular platform, the engineering team has to subdivide the product into a collection of sensible chunks with their own sub-functionalities. These chunks will then be designed in such a way that they will be modular and interchangeable thanks to their standardized interfaces. Subdividing a product into modules and specific sub-functionalities presents the danger of turning the a well integrated structural product into a loose collection of sub-assemblies. Engineers and designers subsequently have to think of solutions to connect these modules again to achieve the same structural integrity, functionalities and aesthetics. Due to these engineering detours, more parts, more weight and more functionalities end up being added to the product. The costs associated with this may not outweigh the initial cost reductions and the customer ends up having a less efficient product.

This concept for a scooter platform might have those same pitfalls. While most conventional scooters get their structural integrity from tubular frames, this scooter platform can't rely on this solution since a tubular frame can not be subdivided. The structural integrity relies on transferring forces through the interfaces of the modules which asks for special engineered strong connections, adding weight and costs. A specific example of such a pitfall is the design of the steering mechanism. The designers state that a special hub steered wheel is implemented to prevent the need for a headset. A headset is undesired since it travels through multiple modules, making integration a cumbersome task. In short, a complex and expensive steering mechanism is implemented, because the conventional affordable steering mechanism was not suitable in the platform approach.

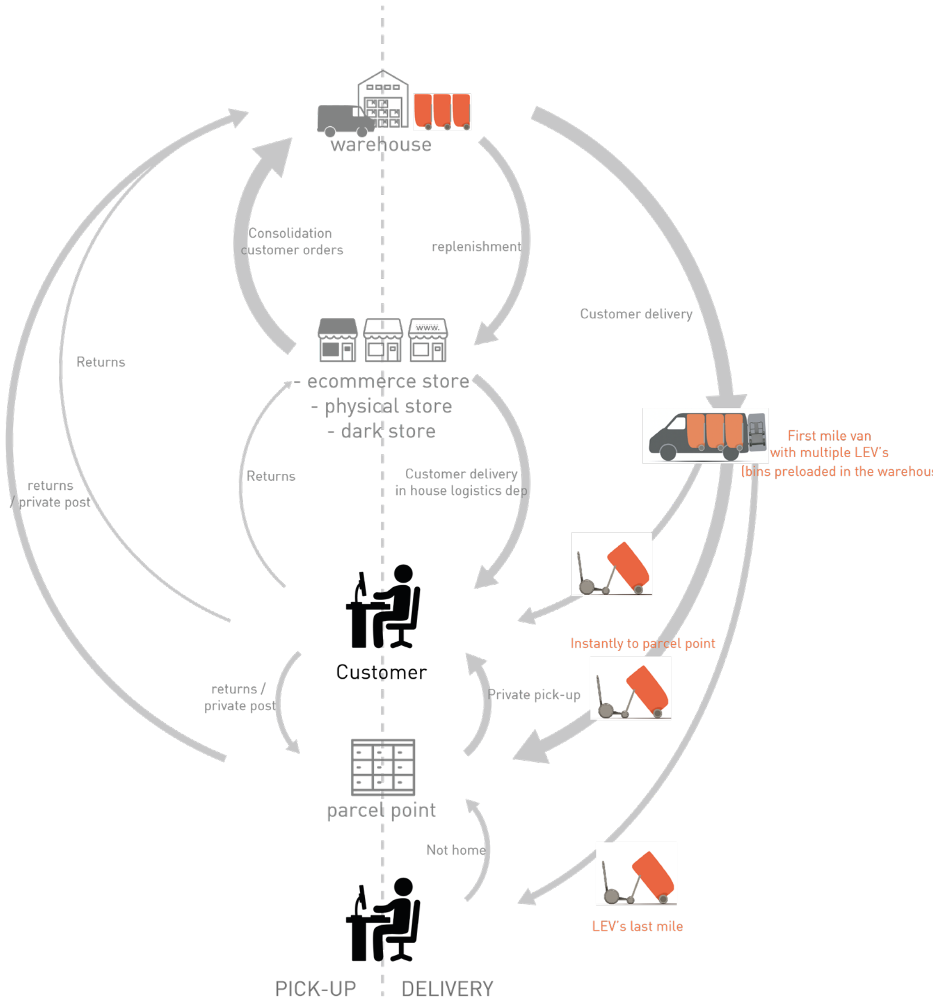
The reason that the automotive industry is able to pull this off is because the modules serve a very specific task and have a clear limited functionality and embodiment.

Appendix E - Future Scenarios



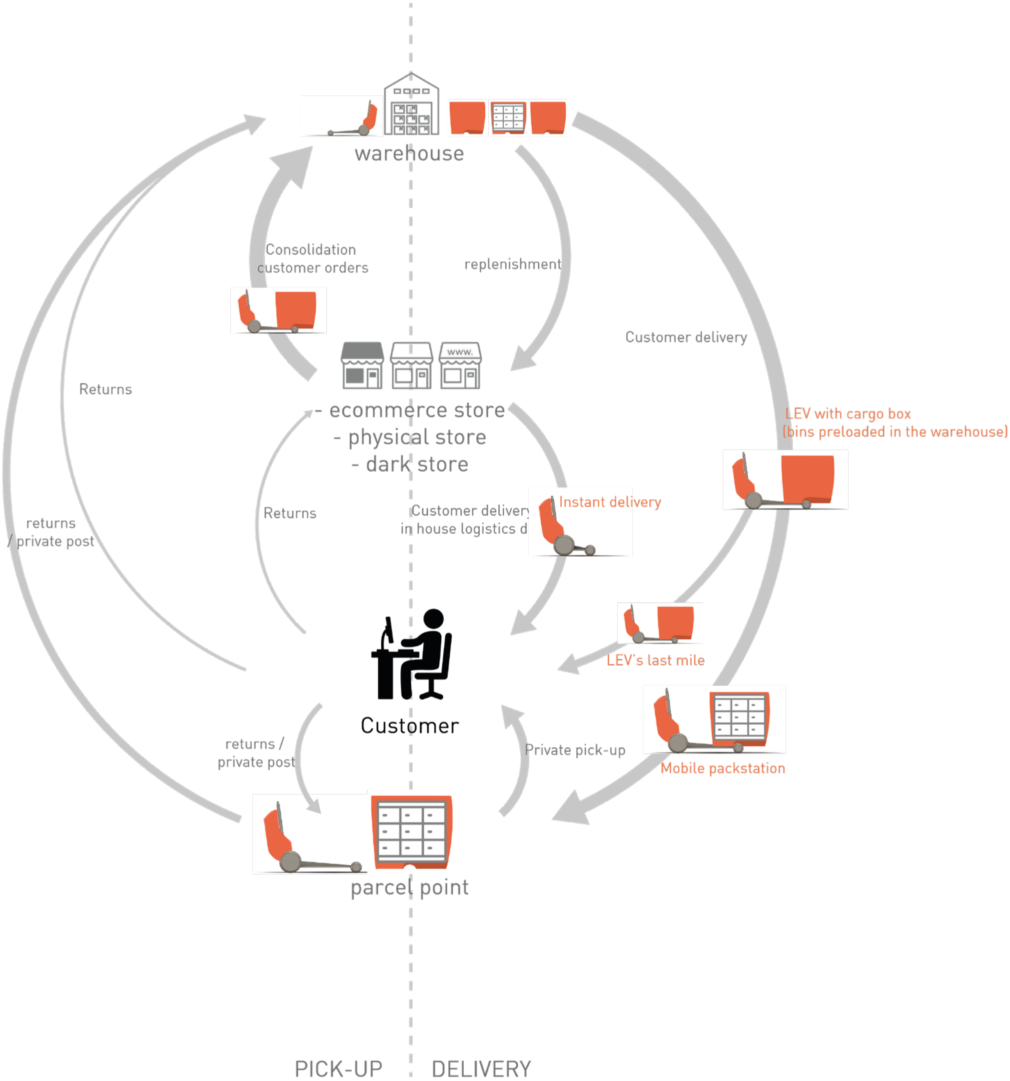
SCENARIO 1
LMD vehicles tailored to use-case

LMD as it is with better vehicle design tailored to the specific use-case. In this scenario nothing changes to the whole logistics chain except for better designed vehicles that are especially tailored to the specific LMD use-case. The platform can act as a foundation for a multitude of these vehicles.



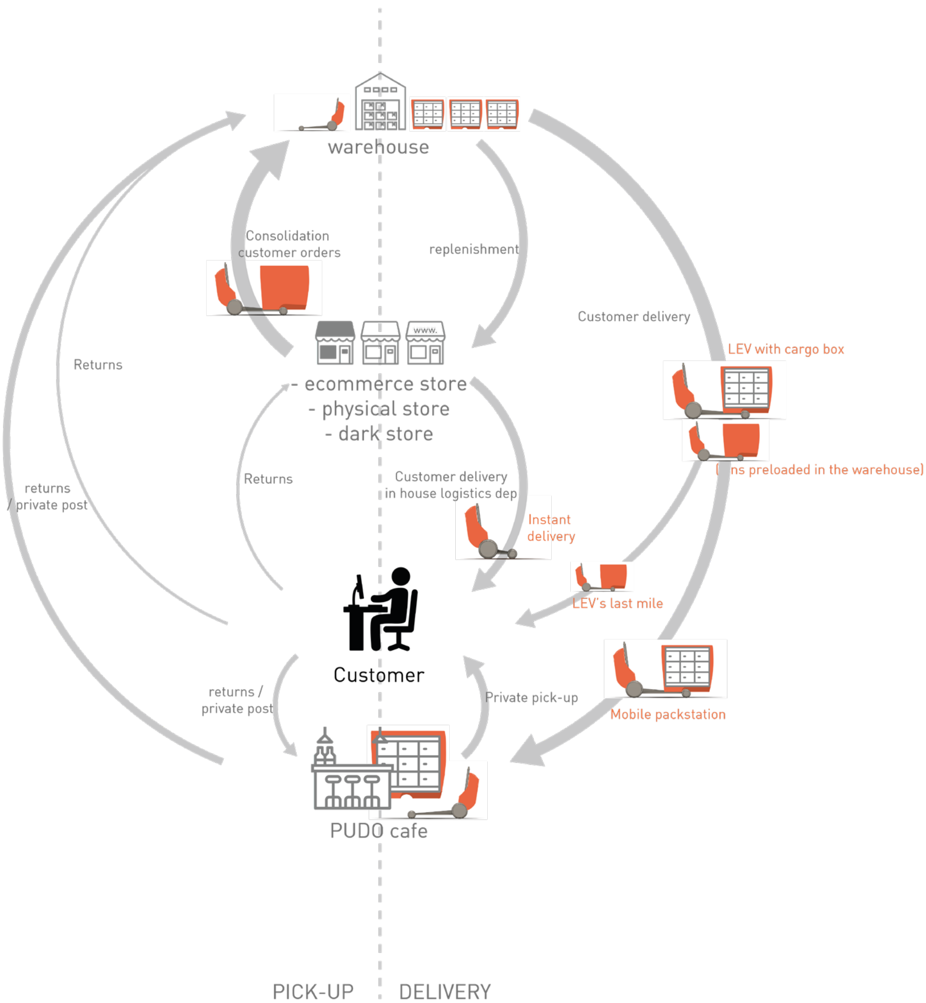
SCENARIO 2
Van and electrified hand truck

Combination of vans and LEV's. In this scenario conventional (or electrified) delivery vans are loaded with a couple of electrified hand trucks and with pre-loaded cargo containers that can be attached to the hand trucks. The van can drive to a strategic calm location from where on out the hand trucks can further distribute the cargo in the denser, busier areas of the city.



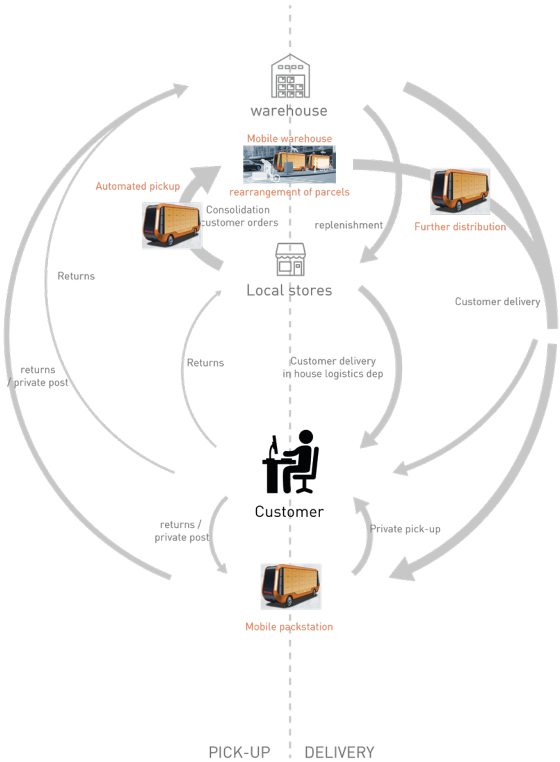
SCENARIO 3
Mobile packing stations

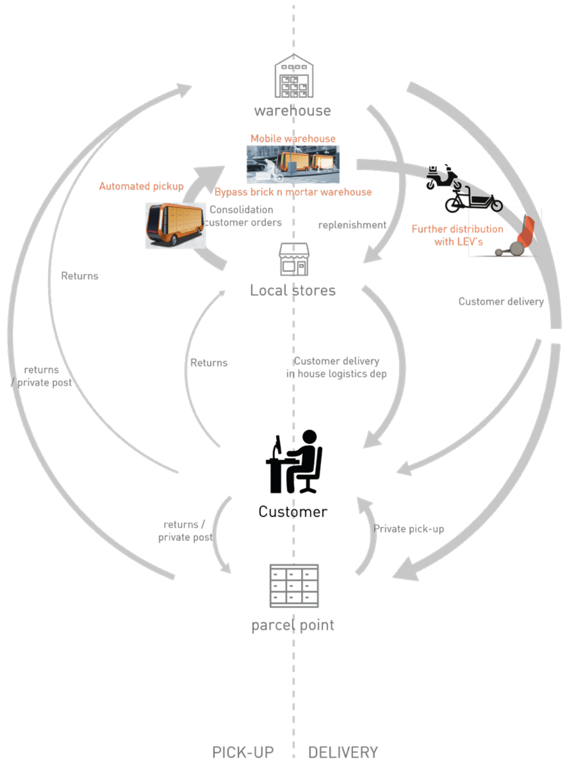
Mobile packing stations. In this scenario LEV's drive pre-loaded parcel lockers to strategic locations in the city. The LEV can unload the parcel locker on the spot and move on to pick up a parcel locker that was placed earlier.



SCENARIO 4
PuDo cafe

PuDo (Pick Up Drop Off) cafés act as parcel points that are opened throughout the day and the evening. Using a cafe as PuDo point adds a social dimension to parcel ordering.



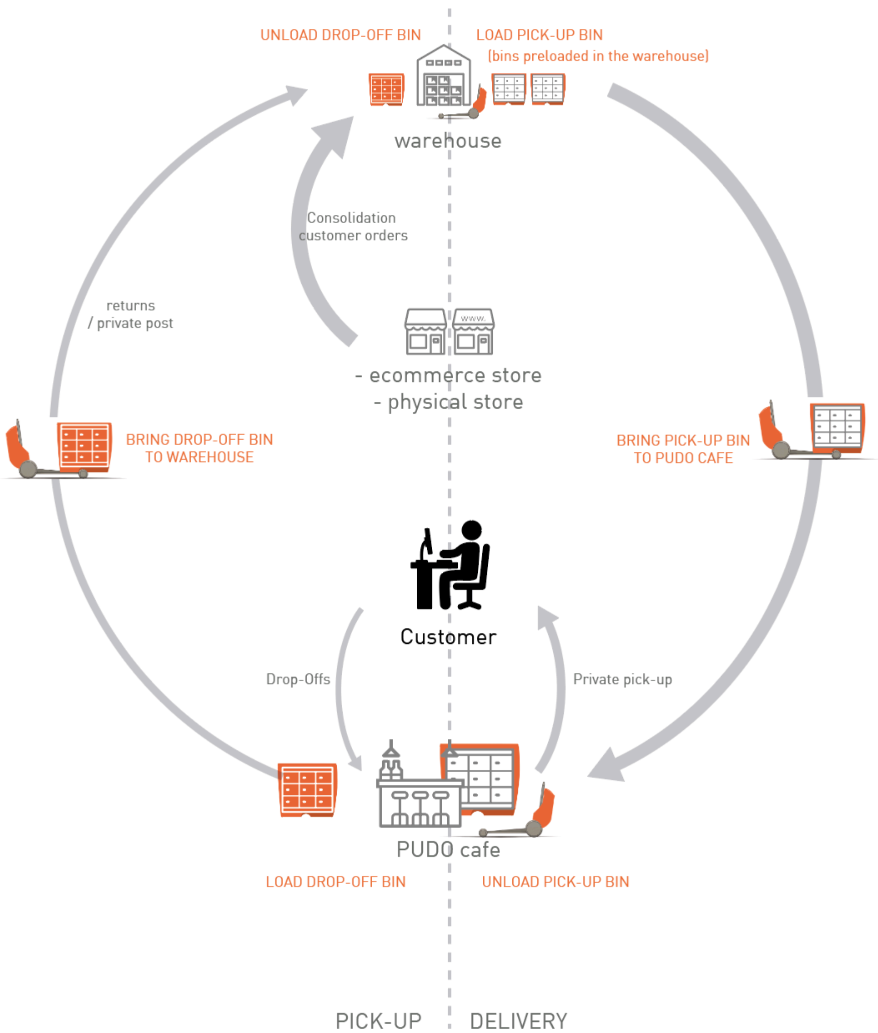


SCENARIO 5
Autonomous vehicles

Autonomous pick-up of local orders. This is a scenario that I explored in an earlier project. The general idea is that automated lockers pick up parcels from local shops. Subsequently these lockers collectively drive to a central spot which then acts as a mobile warehouse. From this place further distribution is realized either through bicycle couriers or through mobile (autonomous) packing stations. This is based on the assumption that fully automated driving will be possible in the near future.

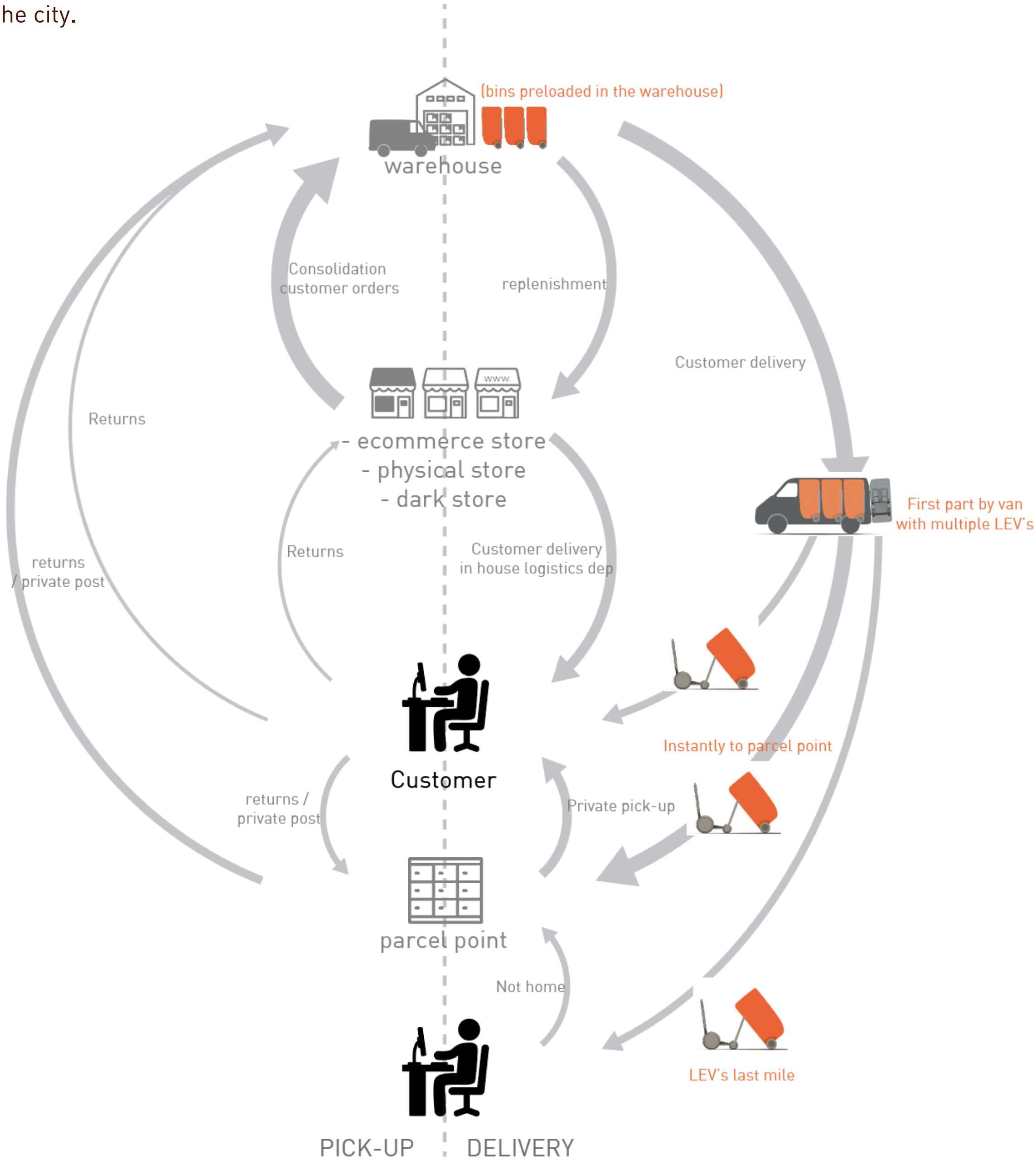
PUDO cafe scenario

The first scenario that was explored was the PUDO Cafe scenario. In this scenario a vehicle is able to load cargo bins filled with customer orders at the warehouse. Next, this vehicle drives off to a hotel, cafe, or restaurant where the cargo bin is easily dropped off. The customer can then pick up his or her parcels from the bin in the cafe. In addition, the customer can drop off packages that need to go in the direction of the warehouse. These drop-off packages can be placed in the same cargo bin. When all the parcels from the bin are picked up, it can be brought back to the warehouse where it is unloaded and loaded for a new cycle. At the PUDO cafe the vehicle can unload a new bin and load an old bin during the same run.



Hybrid van scenario

This scenario consists of a combination of vans and LEV's. In this scenario conventional (or electrified) delivery vans are loaded with a couple of electrified hand trucks and with pre-loaded cargo containers that can be attached to the hand trucks. The van can drive to a strategic calm location from where on out the hand trucks can further distribute the cargo in the denser, busier areas of the city.



Appendix F - Contextual Inquiry

A contextual study with a delivery driver was done. This section presents the context, the observations, relevant interview results and the eventual implications on the vehicle design.

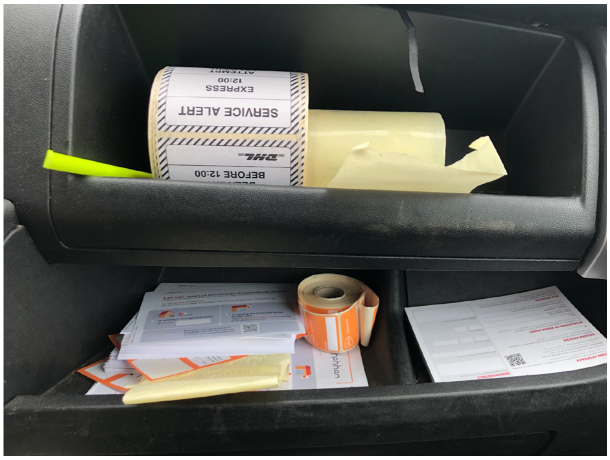
DATA

- Saturday May 1, 2022
- ± 110 km (80 - 150 km in general)
- 196 parcels
- 160 stops
- 3 PostNL stops for not-home deliveries
- 4,5 m^3 ($7m^3$ for business parks - heavier loads)
- 20 - 25 not at home deliveries
- 1 hour break
- **7:55 - 9:00** Loading packages and driving from depot to location
- **9:00 - 16:45** Delivering packages. + Several short breaks.
- **16:45 - 17:20** Drive from location to depot and debrief.

ROUTE: Den Horn, Enumatil, Niekerk, Oldekerk.

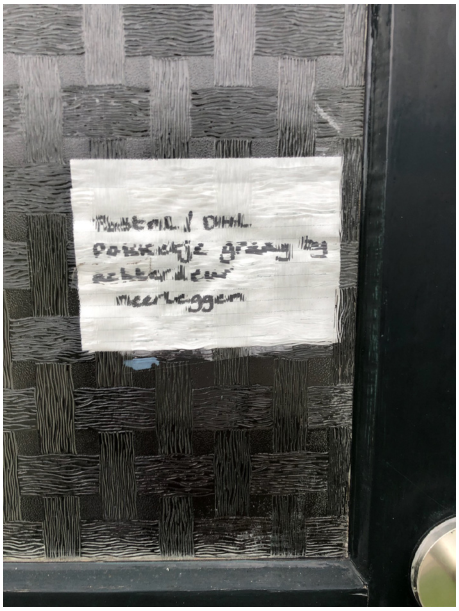
Rick and his van fully loaded with packages. This particular van had scaffolding for packages.

Rick his passenger cabin with a crate of personal belongings and PostNL documentations.



Rick often collected a handful of parcels from the back that had to be delivered on the next addresses. These parcels were stalled on the passenger seat and on the dashboard.

Rick delivering packages. Enthusiastic dogs were not uncommon.



On his route through the outskirts of Groningen, Rick was very much trusted by the recipients. Very often parcels were allowed to be delivered in carports or backyards.

Not-at-home deliveries were stalled in the passenger cabin as well. Three stops at supermarkets were made to deliver these packages at PostNL points. Most of the times Rick did not go through the effort of delivering packages at the neighbours.

A couple of times Rick couldn't find a package, which was annoying due to the time pressure.

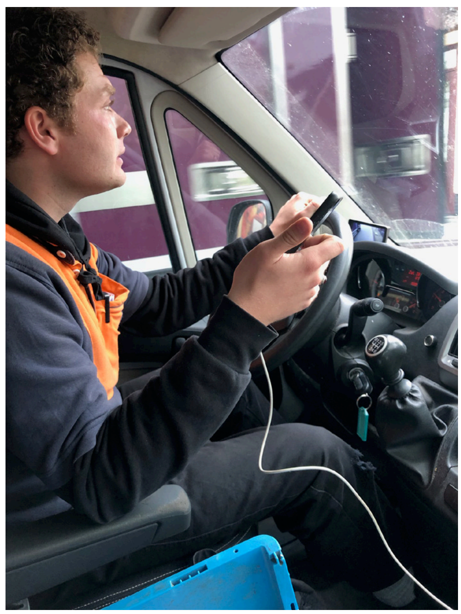
High urgency deliveries

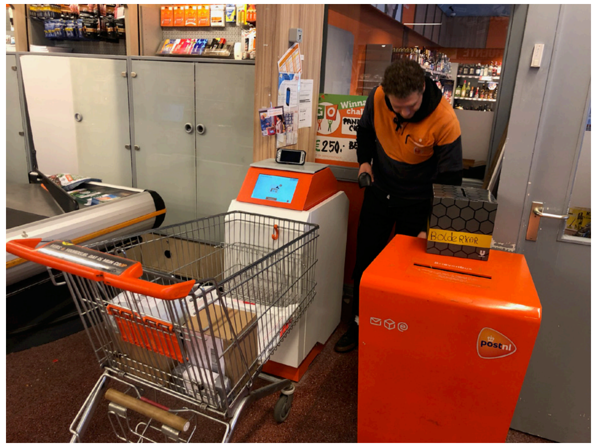
The terminal indicated when and where packages had to be delivered. The delivery drivers are able to install the routes themselves on the beginning of the workday.

The streets were mostly void of other traffic and parking the van in front of addresses was no issue.

Rick sometimes collected a few packages and left them in the very back of the van for easy access once the address was reached. This was only possible once the van was not fully loaded anymore.

Although Rick had served this particular route multiple times, once in a while he had to find the route. He did this on his personal phone while driving.





The not-at-home deliveries had to be delivered at PostNL points. At this route the PostNL points were supermarkets. Rick used a shopping cart from the supermarket to transport these packages to the counter.

Once all the packages were delivered, Rick had to debrief at the depot where he started his day as well. Rick had to proof that his van was empty and he had to declare packages that were not delivered according to plan.

INTERVIEW

- When Rick was doing delivery routes in the city of Groningen he had to either park his van on a street corner and gather 5-10 parcels to walk them to their recipients.
  Or he had to stop his van in front of every address. Most of the times this was more comfortable since he did not have to look for a parking spot and he had to carry only one parcel at the time instead of 5-10. However, Rick mentioned that stopping his van in front of every address was very annoying for other road users and he often had confrontations with those.

- According to Rick the traffic situation in the city largely depends on the time of the day and the type of neighbourhood. During working hours in rich neighbourhoods with double-earners there was likely not very much traffic.

- Rick did not often use a hand truck. 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, Rick mentioned that delivery workers in Amsterdam very often use hand trucks to carry 20-30 parcels through streets and through apartment buildings. According to Rick these delivery workers sometimes travel for 1,5 km with the hand trucks.

- According to Rick the delivery workers sometimes left the hand trucks outside when they entered apartment buildings.

- According to Rick most delivery workers are very very very dumb.

- The average age of the delivery workers in Rick's company was between 20 and 50 years old.

- Most delivery workers did not work for AZ Express for a very long time period. Rick estimated that students with a side job worked there for an average of one year, while older workers worked for 3 years on average.

Appendix G - Dark Store Study

Flink dark store observation

To gain a better understanding on the delivery process of instant delivery businesses, an observational study was done on a Flink dark store. Over the course of approximately one hour, the dark store and the delivery workers were observed. The main insights are described in this chapter.
The study was executed on a Wednesday between 12 pm and 13 pm.

Driver struggling to get his bike outside

Saddle bags and backpacks were used

The cargo bike was not used once

Driver puts paper bags inside saddle bags

Driver struggling to get his bike inside

Smart phone is used as terminal

- The bicycles were stalled inside the dark store when they were not in use. The delivery workers were sometimes struggling with getting their vehicles in and out of the door.

- The groceries were packaged in a small paper bag that the delivery workers transported in either a branded backpack or in saddlebags.

- Prior to putting the paper bags inside the saddlebags, the delivery driver placed the bags on the sidewalk.

- Two types of electric bicycles were used by the delivery workers. Most of the workers drove Radrunners, sporadically an ebike4delivery was used.

- The only bicycle that was placed outside was an Urban Arrow cargo bike with a Dockr cargo box. This bike was not used over the course of the observation.

- The delivery workers used their mobile phones as terminals for delivery. Some workers had a power bank connected to their phone during delivery. Watertight phone mounts were installed on the steers of the bikes.

- During the observation at least 7 delivery workers were counted.

- The delivery workers had one to five minutes waiting time in between rides. The average waiting time was more likely to be close to five minutes.

- The estimated age of the delivery workers was between 16 an 28 years old.

- The duration of the rides was between 10 and 20 minutes.

Radrunner

ebike4delivery.com

Meal delivery observation

During the course of the observation an additional coincidental observation was made on meal delivery services. Both Deliveroo, Uber Eats and Thuisbezorgd came to pick up meals from the restaurant from which the observation was done.

- One delivery worker left his bike and bag outside while he was waiting inside for the food to be prepared.
- The delivery workers were waiting inside for approximately 5 minutes in order for the meals to be prepared.

A Thuisbezorgd worker left his bike and bag outside, while he was waiting for his goods. In the meantime a Deliveroo worker drives off to deliver a meal.

Implications on vehicle design

- Bags or containers on the bicycle prevent the delivery driver to bear loads in a cumbersome backpack.
- Option to mount phone/terminal to the steer.
- Limited vehicle width to stall outside and inside and to easily manoeuvre through doors and sidewalks.
- Option to charge mobile phone with the bicycle battery instead of a power bank.
- Quick lock and unlock of the bike for fast mounting and unmounting.

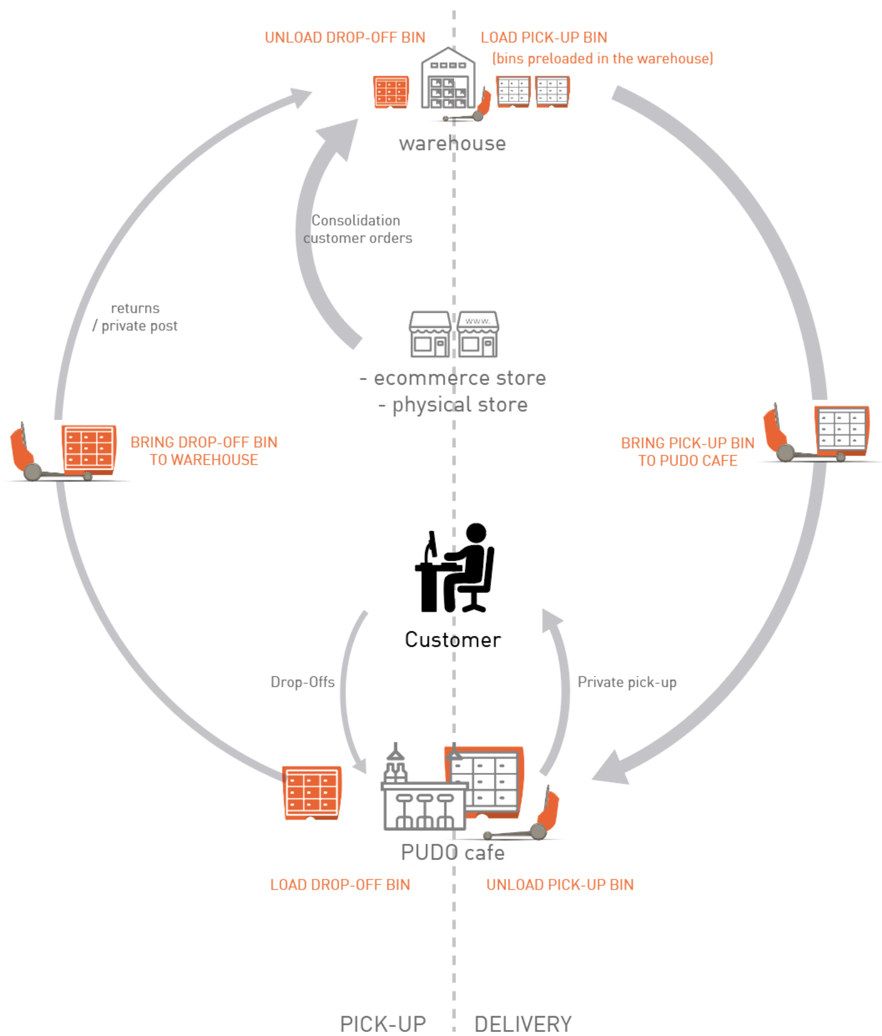
Appendix H - Ideation

Ideation 1

Experimental prototyping was done to generate ideas and to get a feeling for the dimensions and the product architecture. Initial ideas were generated for vehicles based on the scenarios that were described in the prior chapter. Prototypes were then made and iterated upon during the process. Through additions and associations various sub-ideas were generated.

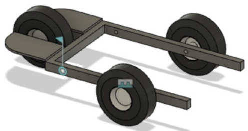
PUDO cafe scenario

The first scenario that was explored was the PUDO Cafe scenario. In this scenario a vehicle is able to load cargo bins filled with customer orders at the warehouse. Next, this vehicle drives off to a hotel, cafe, or restaurant where the cargo bin is easily dropped off. The customer can then pick up his or her parcels from the bin in the cafe. In addition, the customer can drop off packages that need to go in the direction of the warehouse. These drop-off packages can be placed in the same cargo bin. When all the parcels from the bin are picked up, it can be brought back to the warehouse where it is unloaded and loaded for a new cycle. At the PUDO cafe the vehicle can unload a new bin and load an old bin during the same run.



Initial design

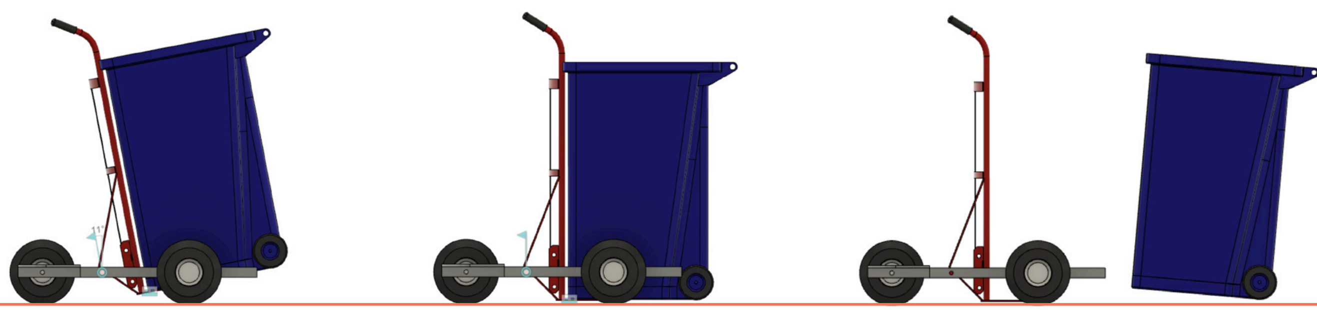
In this scenario it is of importance that the delivery worker is able to load and unload cargo easily and fast to save time and efforts. The vehicle idea for this scenario embraces this function by mimicking a hand truck. A hand truck was taken as a starting point because it is able to quickly load and unload cargo without too much effort. Where the hand truck is designed to transport only cargo, this idea serves a double purpose since it entails it should be able to transport both the delivery worker and the cargo. By shifting the wheels forward and by adding an additional wheel in the back, a stable load distribution of both the cargo and the delivery worker is always guaranteed. The images below illustrate how a two wheeled cargo bin can be easily dropped off and picked up by this vehicle.
The last image hints to the use of the vehicle as a platform. By removing the hand truck, the vehicle becomes a bare cart that can function as other types of vehicles as well.



Platform?

cargo option

Parcel box



Drive

Unload

Further distribution

Prototyping

The first prototyping effort was to place a third wheel behind a horizontally lying down hand truck. This gave an indication of the wheel base and overall length. In this situation the small rear wheel looked a bit odd in comparison to the whole vehicle.

The rear wheel was replaced by a car wheel. Also, an additional hand truck was placed on the horizontal hand truck to give an indication of the hand truck that was illustrated in the initial design. This also made it possible to interact with the prototype by standing up on it and putting hands on the 'steering wheel'. Thanks to the bigger wheel it was also a possibility to sit down.

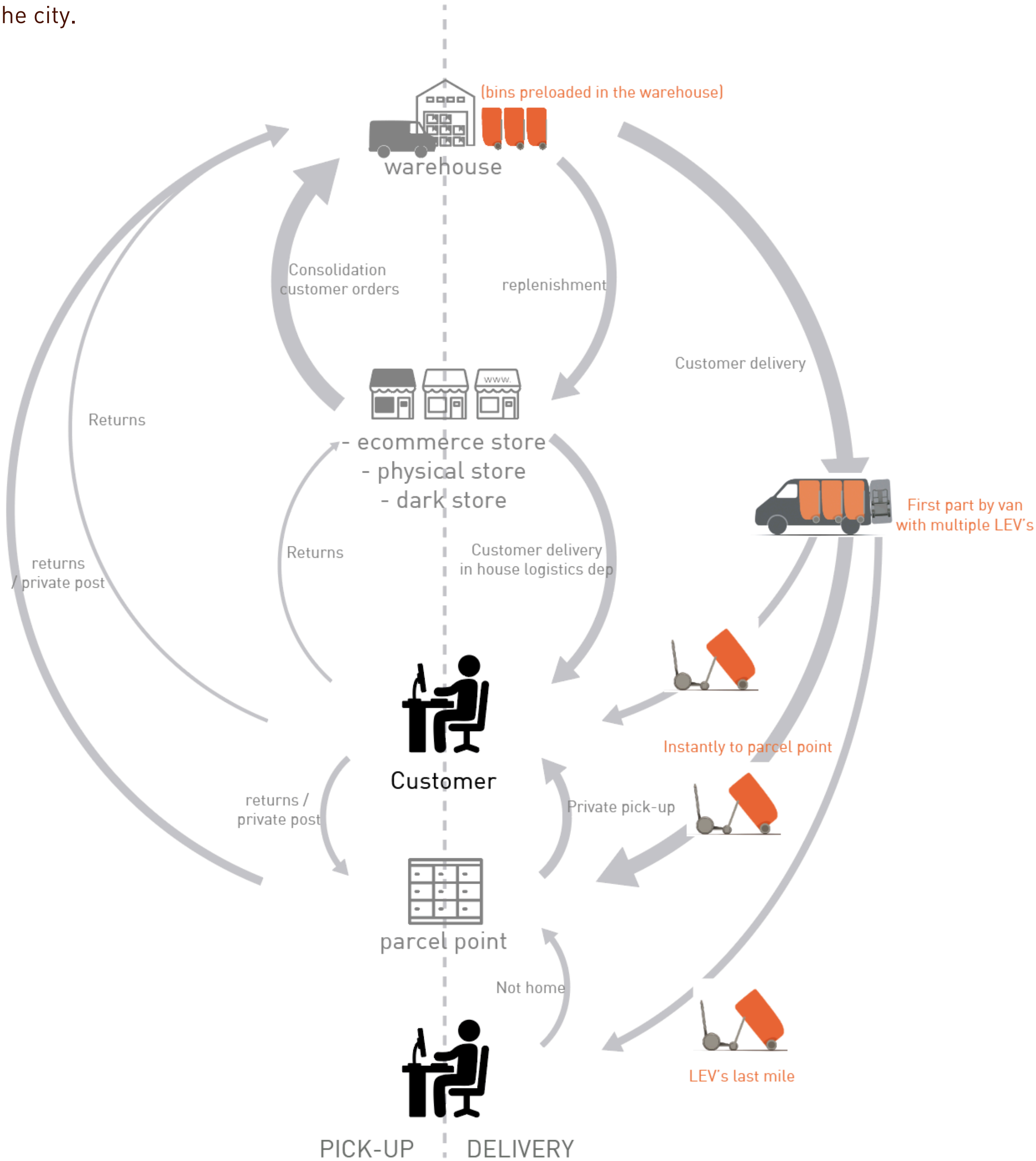
Sitting down initiated the idea to incorporate a chair in front of the rear wheel. However, since a chair takes up a significant amount of floor space, no room is left for the cargo area.

A side-span (snowboard) was added to bring cargo along with the delivery worker. The idea of a non-symmetrical vehicle can be interesting since most of the times a delivery worker only has to access the sidewalk side of the vehicle. For the same reason delivery vans have their sliding doors on the right side.

The additional hand truck was added again to illustrate how the vehicle would look like with the bigger rear wheel.

Hybrid van scenario

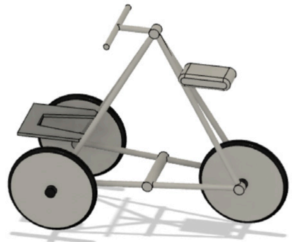
This scenario consists of a combination of vans and LEV's. In this scenario conventional (or electrified) delivery vans are loaded with a couple of electrified hand trucks and with pre-loaded cargo containers that can be attached to the hand trucks. The van can drive to a strategic calm location from where on out the hand trucks can further distribute the cargo in the denser, busier areas of the city.



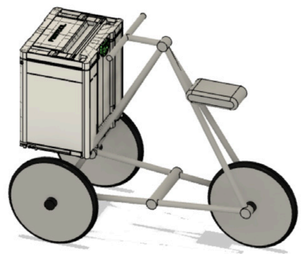
Initial design

This idea consists of a foldable tricycle with two front wheels. It is light weight so that the delivery worker can easily suspend it in the back of a delivery van. Furthermore, in its folded state, it doubles as a conventional hand truck.

Delivery workers are enabled to cover larger distances than they can cover with normal hand truck since this vehicle is faster. The product is equipped with either an electric drive train or a bicycle chain drive train.



Parcel box



Parcel box

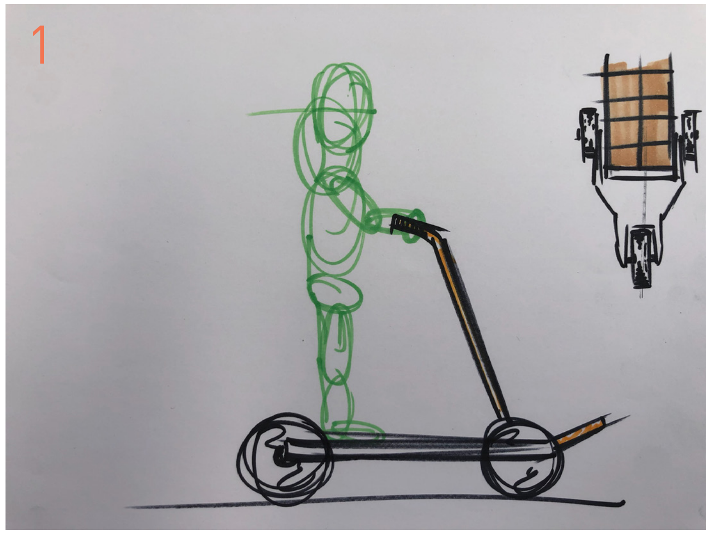
Folded functions as conventional hand truck

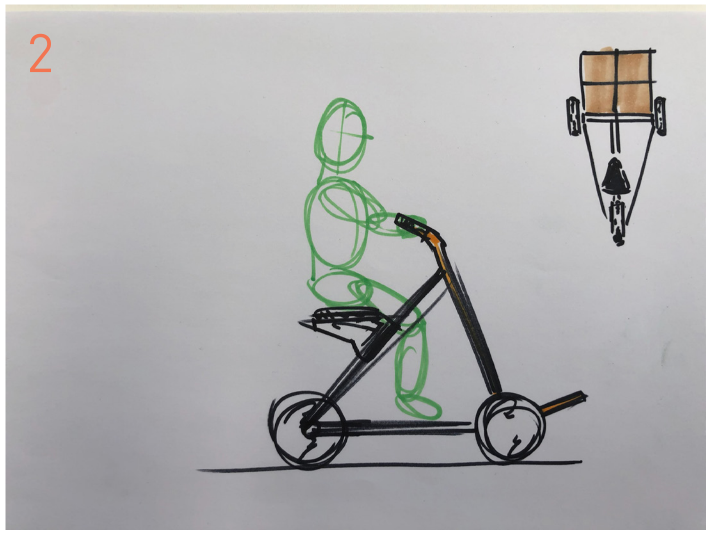
Suspend on van doors

Ideation 2

Three concepts were developed based on the new approach and the new list of criteria. All were based on the hand truck. The hand truck is the basis of all the concepts. In all three concepts additions and adjustments were done on the existing hand truck.

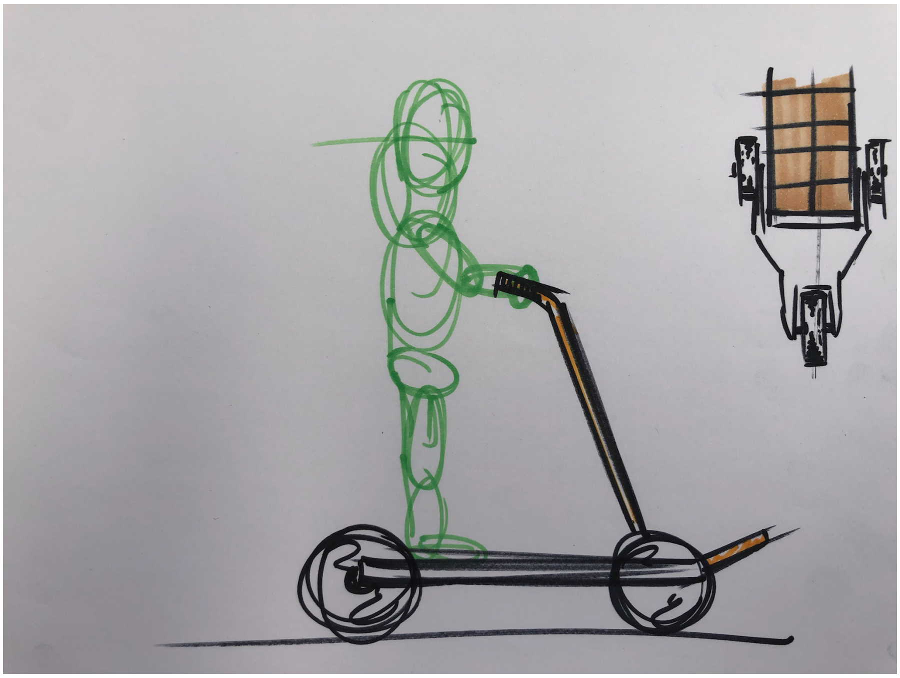
Rapid scale models were made to test the interaction of the delivery worker and the product.

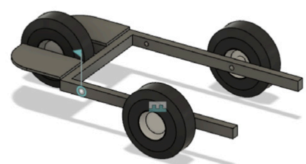


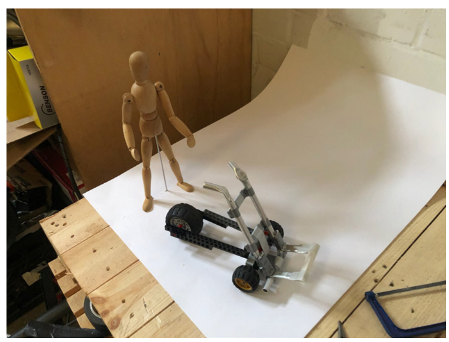


Concept 1 Simplicity

The first concept is based on a prior idea. A one-wheeled addition to the hand truck functions as both a drive train and a standing platform for the delivery worker. The delivery worker can deliver goods with an electrically assisted hand truck.

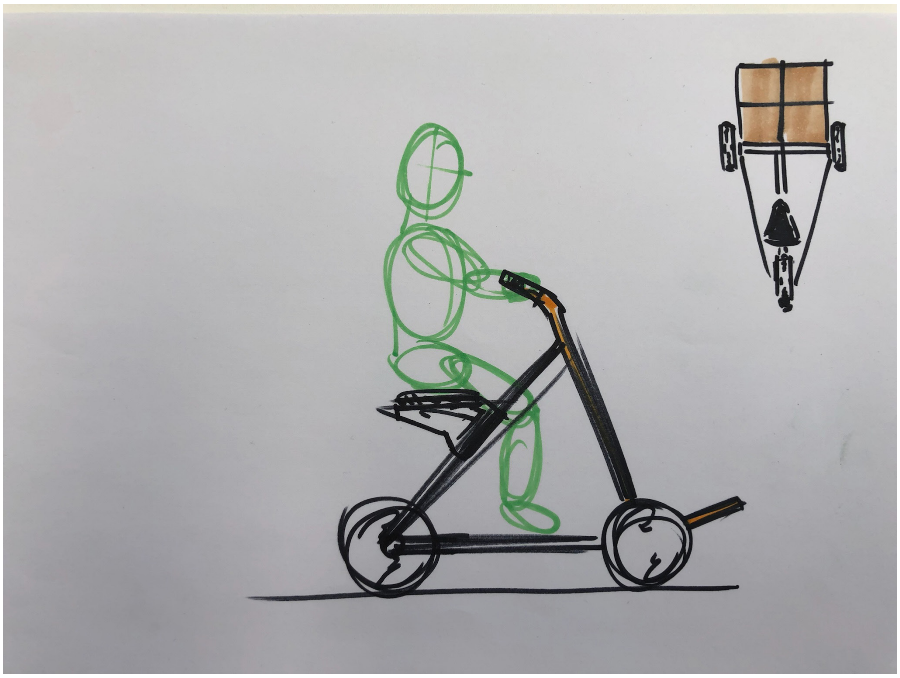


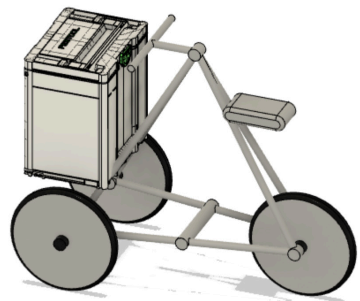




Concept 2 | Rigidity

This idea was based on an idea that I had earlier for a specific scenario. The triangular construction offers structural integrity and it also offers the possibility to add a seat for the delivery worker.





Folding

Driving

Concept 3 | Comfort

The third concept is based on an idea that emerged during an earlier prototyping session. This idea focusses on comfort because the user is able to sit down on the hand truck.

Folding ?

Conclusions conceptualization

Concept 1:
Simplicity might add customer value in the sense that the delivery worker is able to quickly hop on and hop off. This concept might be especially suited for the very last meters in the supply chain.
Range suggestion: 0 - 50 m

Concept 2:
This concept provides structural integrity thanks to its triangular construction. The seat might add some comfort for the delivery worker. This might be beneficial for slightly longer distances.
Range suggestion: 500 - 1000 m

Concept 3:
The delivery worker has a comfortable seat that allows him or her to drive longer distances. However, the vehicle has poor folding characteristics and a cargo area is hard to implement.
Range suggestion: 1 - 5km

Selection

The three concepts were assessed based on the main criteria. Thanks to its simplicity and small footprint the first concept scores better than the other two.
However, the other two concepts have some beneficial characteristics that might come in handy for the eventual concept as well. For example, the comfortability of the second and third concept might enable the delivery worker to drive longer distances.

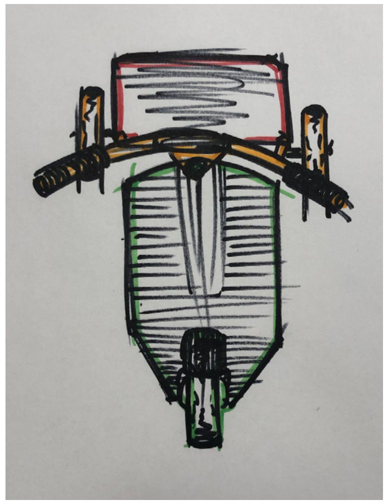
An attempt was done to merge the good characteristics of all the concepts into one concept.

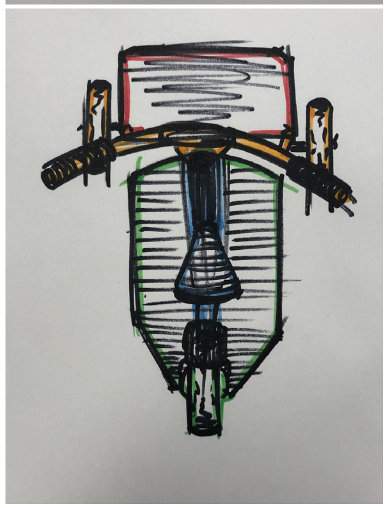
		Concept 1 Simplicity	Concept 2 Rigidity	Concept 3 Comfort
1	The customer is able to adapt the vehicle to his or her specific demands by using modules	3	3	3
2	2. The delivery worker is able to manoeuvre the vehicle through areas that are hard to reach with delivery vans	5	4	2
3	The vehicles do not hinder citizens with noise or air pollution	5	5	3
4	The vehicles make the job of the delivery worker less physically demanding.	4	4	4
5	Local production	5	5	5

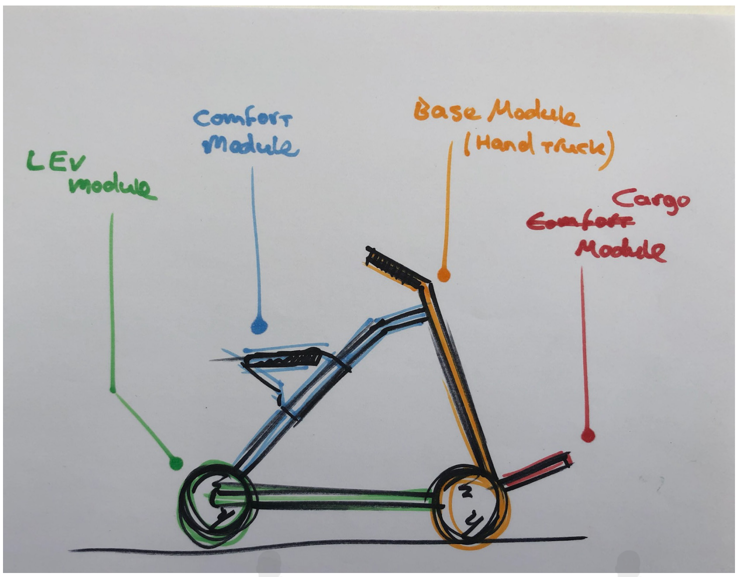
Eventual Concept

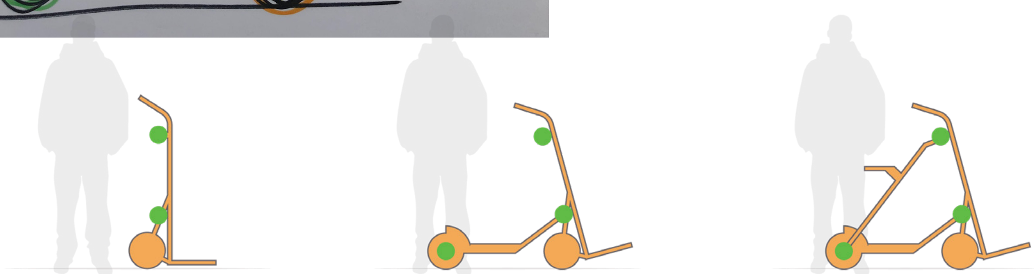
The eventual concept is a modular hand truck that allows the customer to compose a hand truck vehicle to his or her specific demands. (See image). The basis of each vehicle variant is a simple hand truck that is similar in function and size to a conventional hand truck.
If the customer requires an electrified version he or she can choose to add the 'Drive Train Module '(LEV module in the image). If the customer requires more comfort, for longer distances for example, he or she can add the 'Comfort Module'.

The 'Cargo Module' is part of the actual hand truck. The Cargo Module might become an interchangeable module that is tailored to the specific type of goods that the delivery worker is transporting. For example, a insulator box cargo module can be made for meal delivery and a heavy duty cargo module can be made for transporting heavy goods such as refrigerators.









Hand truck as usual

very short distance

Additional Drive train module

medium distance

Additional Comfort module

long distance

Appendix I - Experimental Prototyping

A technical prototype is being built to see how the joints and modules can come together. This prototype also gives an indication of the (folding) dimensions of the vehicle. While the previous prototypes were bulky and messy this prototype is more neat. The prototype was made with a folding bike frame and therefore the crank and drive train are still assembled. This will not necessarily be the case in the eventual concept.

(Right) earlier prototypes
(Down) technical prototype

Due to the three-wheeled architecture of the vehicle, it demanded a more technical approach to the steering mechanism. In the photo below it can be seen that the current steering mechanism results in a tilt to the wrong side when steering.

Several alternatives were explored for the steering mechanism. Most alternatives were technically too complicated, resulting in added part count, weight and assembly steps. Other alternatives would have resulted in a decrease of comfort.

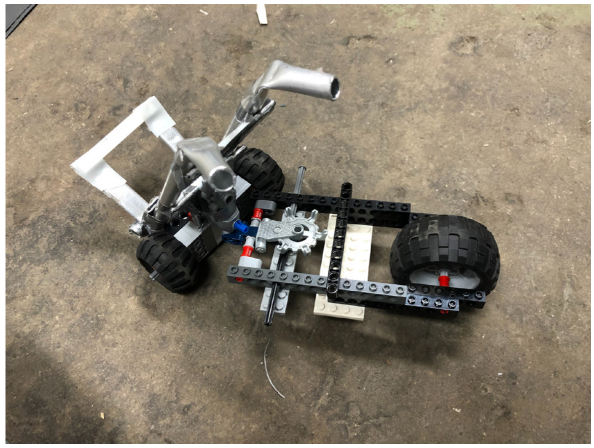
To narrow down the scope of this project and nevertheless develop a feasible product, it is decided to leave out the comfort module for now. The focus after the mid-term will lie on the hand-truck and the drive train module.

Without the comfort module the steering mechanism becomes less complex since there is only one contact point. The proposed mechanism for this connection is a ball joint similar to a tow-bar and trailer.

Steering resulted in leaning to the opposite side

Coupling point

Two concepts for the coupling point were explored. These two concepts were compared to each other on the basis of several criteria. The first concept explores how the vehicle can be realized with only one wheel in the drive train module. The second concept explores the implications of an additional wheel in the drive train module.

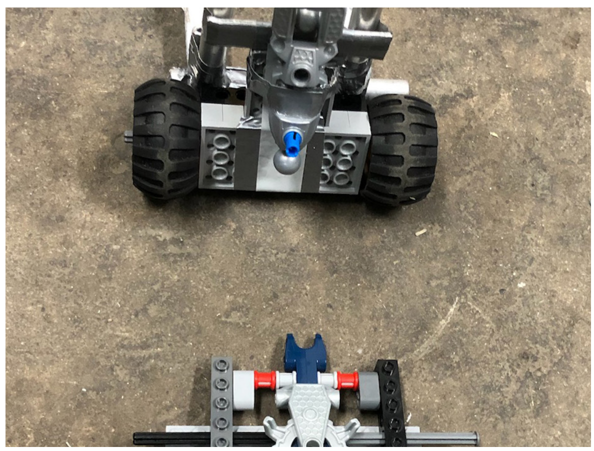


Single wheel drive train

The most significant benefit of a single wheel in the drive train is that the architecture of the module can be kept simple and straightforward. However, the single wheel poses a stability challenge since the stable area of the drive train is dictated by only two points, namely one at the wheel and one at the coupling point.

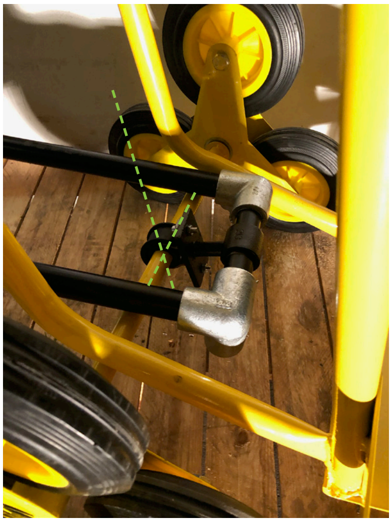
An instable drive train module is detrimental to the drive experience and might pose safety issues. An additional prototyping step was done to explore whether some stability could be gained in the coupling point.

Stable area indicated by green line



Ball Joint/hinge

Stability could be gained from the coupling point by resting two bars on the wheel axis of the cargo module (hand truck in the picture). The coupling point itself allows for vertical rotation and tilting of the hand truck while the two horizontal bars limit rotation of the drive train module in the horizontal plane. The two additional support result in a triangular stable area (see image). However, for optimal stability the user has to stand in the triangular area which might result in a elongated drive train module. In addition, the complexity of the joint/hinge is increased in this solution. This is why a second option with two wheels is explored.



Double wheel drive train

An additional wheel in the drive train results in a triangular stable area with the wide base in the back. This allows the user to stand in between the two wheels without worrying about balancing him or herself. The coupling point can be less complex since the it does not have to ensure stability in any direction. A ball joint, or caravan coupling can be used to ensure the connection. The drawback of an additional wheel is that it generates extra weight and that the layout of the the drive train has to be reevaluated.

(Left) Stable area

(Right) coupling point

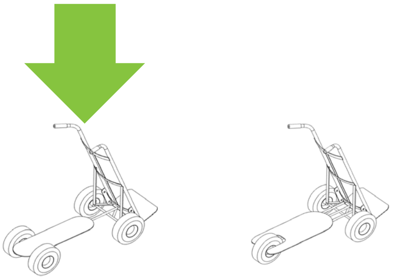
(Left) Stanley driving a Stanley

(right) Me decoupling the drive train module

Selection

A matrix was made that compares the two concepts on basis of several criteria. The most important criteria are at the top, namely comfort for the driver.

The choice was made to pursue the two wheel strategy since it promises to add more value to the delivery driver.



	Two wheels	One wheel back	Two wheels	One wheel
Comfort / disconnect	4	4	More stability, but more weight	Less stability
Comfort / Stability	5	2	Stability in between wheels	Small stable area
Length	5	3	In between wheels for stability	In front of wheels for stability
Weight	3	4	Heavy wheels	Slightly more weight due to complex coupling point
Maneouvrability / Steering	3	3		
Price	3	3		
Part count	3	3	Complexity in drive train	Complexity in coupling point
Power efficiency	3	5	If two motors, less efficiency	
Maintainence	3	3		

Drive train

Powering the vehicle with two rear wheels poses problems since both wheels must be powered for a decent driving characteristic.

Three methods for powering the rear wheels were identified. These three methods were assesed on the basis of several criteria that are listed in the first column below.

The transaxle motor was chosen as the most appropriate method for powering the vehicle as it scores best on most of the cirteria.

Third wheel

	Double hub motor	Transaxle	Third wheel
Comfort / disconnect	3	3	3
Comfort / Stability	3	3	3
Weight	3	4	2
Maneouvrability / Steering	4	4	3
Price	2	4	3
Power efficiency	3	4	4

Appendix L - Urban Context

» City infrastructure

The introduction of the car brought huge advantages for citizens thanks to the possibilities it gave 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. As a response, the European Union forces municipalities to move towards new modes of transportation in order to benefit the transition into more sustainable alternatives. Innovations in the mobility sector are likely to take place hand in hand with the private sector, since they have the knowledge to innovate and the assets to realize new modes of transport. The role of the municipality is to prepare and adapt the infrastructure for this oncoming change. Automated vehicles (AV), robo-taxis, and new modes of shared mobility often depend on appropriate infrastructure. To ensure a smooth, efficient and safe operation of these transportation systems, the municipality will have to regulate traffic in an intelligent manner.

Intelligent traffic systems

Intelligent traffic systems gather and process data to support decision making in traffic management. The main challenge with these systems is to gather a broad spectrum of relevant data and process this in real-time in such a way that it is relevant for a variety of actors. For example, individual vehicles might want to achieve info on the best parking spot, city administrators want to achieve relevant data for policy making, and traffic controllers want data for optimizing traffic flow with traffic lights.
For the collection of data an intelligent traffic system relies on roadside sensors, connected vehicles, and mobile data (1). Currently, vehicles and roadside sensors do not provide sufficient data to support intelligent decision making. However, most likely in the future more and more vehicles are being connected and municipalities will invest in roadside sensors to realize meaningful intelligent traffic systems as the European Committee recommends cities to invest in these technologies.

Smart parking

An interesting application of intelligent traffic system is guiding vehicles to a nearby parking spot. By integrating multiple sensor technologies municipalities can closely monitor the occupation of parking spots in the city. An example is Streetline which is a company that uses machine learning in combination with magnetometers, CCTV, light sensors, and mobile applications to monitor parking spaces. In addition to providing vehicles information on parking availability, cities can also introduce dynamic pricing in order to manage the curb. Curb management is the effective use of curb space by allocating different functions to the curb throughout the day. For example, loading zones during the early morning, bus stops during peak hours, parklets during lunchtime and metered parking spots for the remainder of the day. A certain area of the curb can also be reserved for shared mobility purposes such as pick-up and drop-off points for electric bicycles.

Congestion pricing

The European Committee states that economical incentives should be considered to drive the transition to more sustainable urban mobility (EC, 2020). An example of one of those incentives is congestion pricing. In London congestion pricing is introduced to prevent the overflowing of streets. When a vehicle enters the zone the owner has to pay 15 pounds. When the system was introduced, the yearly vehicle count was reduced by almost 15% (2)

Lane allocation

In a future scenario in which AV's, robo-taxis, shared mobility and private vehicles collectively use the streets AV's will likely not be utilized to their full potential due to the complex and unexpected behaviour of other road users. In a recent report McKinsey stated that in such a scenario congestion levels could even rise (3). To avoid this scenario municipalities can introduce thought through lane allocation. An example of conventional lane allocation is to provide buses and taxis with a special lane to improve their traffic flow. Another example is the opening of dedicated cycling lanes. In 2016 cycling superhighways were opened in London after which the vehicle count dropped with more than 15% (2). Milan, Paris and Brussels also are working

Artist impression of a new cycling highway in London

(1) Mondal, M. A., Rehena, Z., & Janssen, M. (2021). Smart parking management system with dynamic pricing. Journal of Ambient Intelligence and Smart Environments, 13(6), 473–494. https://doi.org/10.3233/ais-210615

(2) Department of the Built Environment, City of London. (2018, February). Traffic in the City 2018 [Slides]. Cityoflondon.Gov.Uk. https://democracy.cityoflondon.gov.uk/documents/s91800/Appendix%201%20-%20 Traffic%20in%20the%20City%202018.pdf

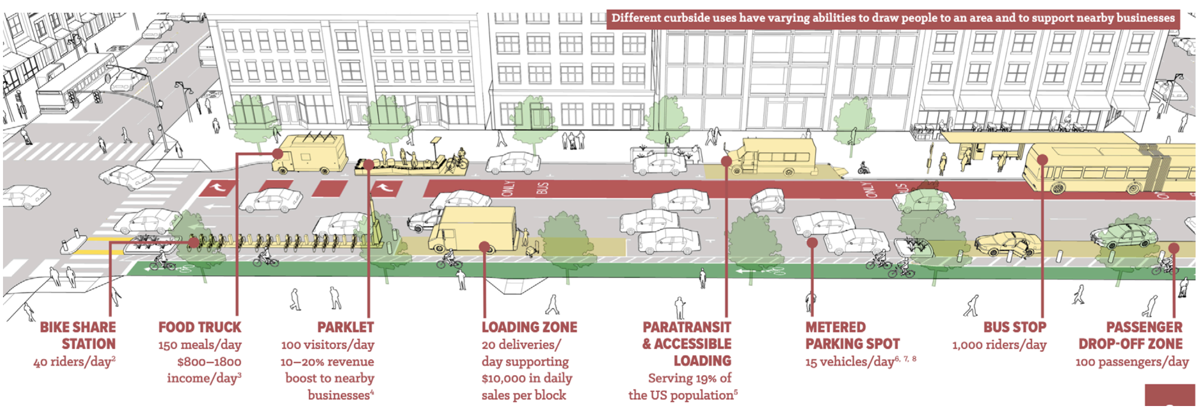
(3) McKinsey & Company. (2016, October). An integrated perspective on the future of mobility. https://www.mckinsey.com/business-functions/sustainability/our-insights/an-integrated-perspective-on-the-future-of-mobility

on converting car roads to dedicated bicycle lanes (1). In the future AV's and automated shuttles might have a dedicated lane as well so that they can drive closely together and make efficient use of the space. Dynamic lane allocation could even further improve this concept, so that specific lanes can differ in functions throughout the day. For example, the same lane can be used in the morning for AV's and public transport, throughout the day for bicycles and pedestrians, and in the evening peak hour for AV's again. The implication for cyclists is that more space and safety is guaranteed and that an optimized traffic flow is established.

Shared mobility regulations

While the European Committee stimulates an enabling environment for game-changing new technologies, some of these new phenomena comes with such speed that they can disrupt certain aspects of urban mobility as well. For example, double parked shared mobility vehicles, or more congestion due to the rising number of e-hailing vehicles. Municipalities have to actively manage these services to prevent congestion and to manage competition (1).
On first sight, it is beneficial for municipalities to have designated parking spots and a limited service-area to prevent sidewalk cluttering and nuisances for other travellers. On second thought however, micro mobility can support cities' ambitions for mobility and sustainability goals. Cities might unlock more potential in shared micro mobility by providing the supportive infrastructure to these vehicles such as allocating conventional parking space to parking space designated to micro-mobility (2). Well thought through curb management by the city can help to minimize nuisance for other travellers. Incentives and vehicle design by micro mobility providers can be beneficial to the collaboration with the municipality. Sophisticated parking regulation can also offer opportunities for the micro mobility provider, such as automatic charging and better maintenance accessibility.
Parking characteristics should to be taken into account when designing a vehicle for shared use from the ground up.

A practical example of lane allocation. (NACTO, 2017)



(1) McKinsey & Company. (2020, June). The future of micromobility: Ridership and revenue after a crisis. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-micromobility-ridership-and-revenue-after-a-crisis

(2) Brown, A. (2021). Micromobility, Macro Goals: Aligning scooter parking policy with broader city objectives. Transportation Research Interdisciplinary Perspectives, 12, 100508. https://doi.org/10.1016/j.trip.2021.100508

» Shared mobility

In the last decade urban areas are being flooded with new modes of shared mobility. New kind of vehicles as well as new kinds of services emerge and are redefining the modern urban landscape. The companies that provide these services often depend on venture capital which makes it possible to scale-up at an enormously high pace. While these providers are huge expanding companies they are still at their infancy. In the coming years these companies will continue to bring changes to the mobility market as car ownership decreases in popularity.

Mobility as a service | MaaS |

At first sight, shared mobility vehicles offer a sustainable and practical alternative for the private owned car. However, no single transport mode is versatile enough to encompass all the needs of these urban dwellers. Multi-modal mobility is a combination of several modes of transport to fulfil the travel requirements of the user. Using multiple platforms can be a nuisance to users, since every mode of transport requires its own software and journey planner. Mobility as a Service (MaaS) aims to eliminate this process by providing the user with a single platform for all the modes of mobility. MaaSLab gives the following definition: "Mobility as a Service is a user-centric, intelligent mobility management and distribution system, in which an integrator brings together offerings of multiple mobility service providers, and provides end-users access to them through a digital interface, allowing them to seamlessly plan and pay for mobility."

Shared micro-mobility

Micro-mobility vehicles make up a great share of the shared mobility fleet. Micro-mobility vehicles such as e-scooters, motor scooters, and electric bikes generally do not operate at speeds more than 25km/h.

Typically, ride sharing services do not develop these vehicles themselves. The vehicles are being bought in bulk for a reduced price after which minor adjustments will be made to adapt them to the likes of the operator. With the shared mobility market growing the introduction of purpose-built vehicles is likely. In order to keep up with the competition more companies will have to adopt purpose-built vehicles in their fleet.

Several modes of shared micro-mobility are prevalent. I.e. two-way dock, free-floating, one-way dock

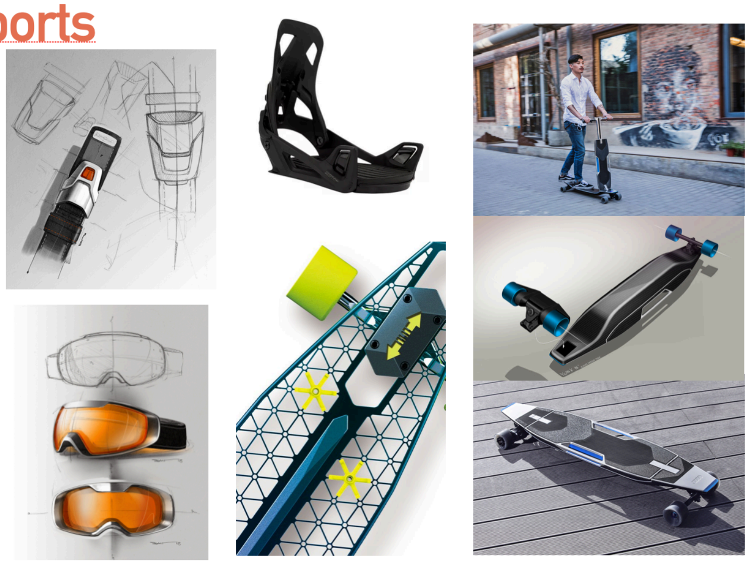
An example of a one-way dock system is the Dutch OV-fiets. After the customer has picked-up the OV-fiets at a manned or unmanned dock he or she can use the bike for a whole day wherever the user wants. Finally the user is supposed to bring back the bike to the same dock. A two-way dock relies on a similar principle. Usually more docks are spread over the service area. The user can drop off the vehicle at each of these docks. Free floating services do not require any dock whatsoever. Usually the user is equipped with a mobile application which indicates the locations of the vehicles. These vehicles are often paid for per minute. The operating area of these vehicles is often geo-fenced, making some areas inaccessible for driving the vehicles and only certain areas fit for parking the vehicles. A downside for the operators of these services is that all their vehicles are spread over the service-area. If maintenance such as charging is necessary the operator is forced to locate each vehicle in its specific location.

Appendix M - Look & Feel

Conclusions

Several collages were made to find an appropriate look & feel for the concept.

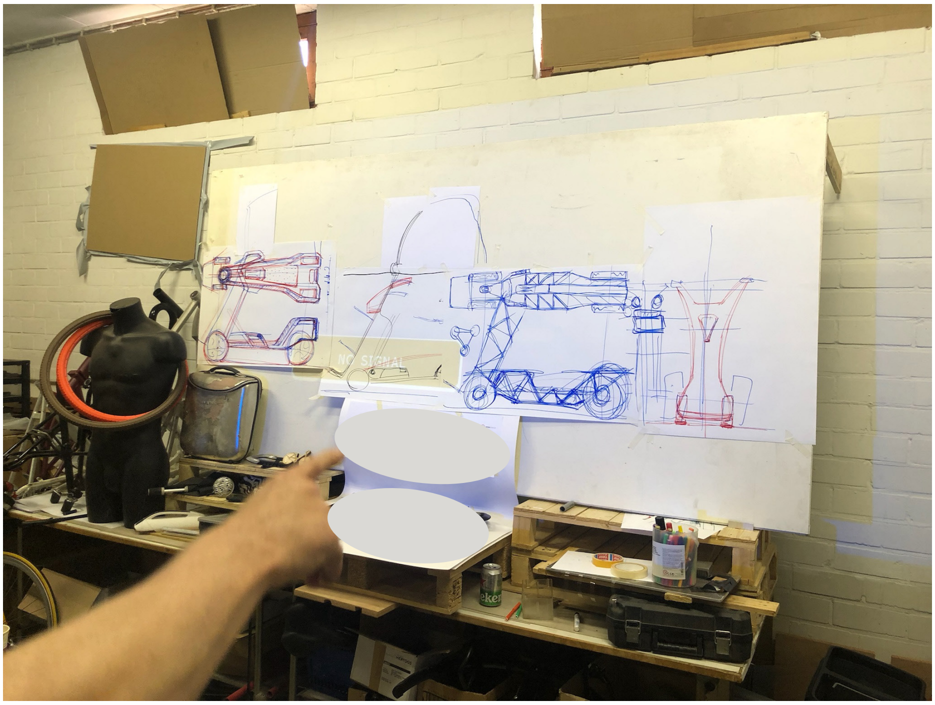
Boardsports



Sporty Tech Functional

Rams

Futuristic Minimalistic Boring



Sketches made in collaboration with
Stefan Akkerman, Jorrit Schoonhoven
and Stanley Quitz