FACULTY OF ENGINEERING
AND ARCHITECTURE

Design of an E-bike specific cargo container system to stimulate sustainable commuting behaviour

Julian Adam
Student number: 01708364

Supervisor: Prof. dr. Marina Emmanouil
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Master's dissertation submitted in order to obtain the academic degree of
Master of Science in de industriële wetenschappen: industrieel ontwerpen

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Preface

This thesis is the crowning accomplishment of my studies Industrial Sciences – Industrial Design. All the skills and knowledge I have acquired and internalised over the last four years converge into this final design assignment. In addition, over the past academic year, I have rediscovered and deepened my passion for bicycles and mobility. As a result, an innovative concept is presented, which could open the door for a fresh and original way of looking at cycling equipment in the context of e-bike and speed pedelec commuting. Thankfully, I was not on my own. Several people were eager to guide and support me along the way.

First of all, I would like to thank my promotor Prof. dr. Marina Emmanouil for her valuable insights and guidance. In particular, I would like to thank her for helping me understand the importance of users in the design process. As a result, I can confidently say that I can communicate with users and extract their valuable knowledge, which ultimately helps define design outcomes. Furthermore, the way she handled the problems involving the external company was very professional. During these extremely stressful weeks, she managed to reassure me and guide me back in the right direction.

Secondly, I would like to thank Prof. Jan Detand for his time and effort. His valuable technical insights helped shape the final concept. Prof. Detand became my mentor after the collaboration with the external company was halted. He was eager to help out and carve out some time to give consult.

Of course, I would also like to thank my teacher, Ir. Yannick Christiaens. Despite his hectic schedule, I could always call upon his expertise and experience as a hard-core bicycle enthusiast. He helped me redefine this master's thesis's context and was able to steer me in the right direction with his hands-on approach.

I would also like to thank the hundreds of people who participated in the questionnaires, interviews and user tests. Without them, the final result would undoubtedly have looked very different. Thank you for your feedback and valuable insights!

Of course, I would like to thank my friends for providing the occasional, but much-needed distraction.

Most importantly, I would also like to thank my family for supporting me throughout the course of my education. After graduating high school, it was hard for me to find a new direction in life, but you helped me make the right choice. Thank you for cooking delicious meals, for tolerating a house filled with prototypes and for heartening me in highly stressful and uncertain times!

Julian Adam

Abstract

English

Over the last 15 years, the sales of electronic bicycles (e-bikes) and speed pedelecs (fast e-bikes, up to 45 km/h) have increased enormously. E-bikes, and speed pedelecs, in particular, show a significant potential of achieving a modal shift away from the car.

However, several barriers need to be overcome for the e-bike and speed pedelec to become a ‘365-days’ vehicle, such as luggage transportation, specific clothing and locking.

The problem with current bicycle cargo containers is that they are not adapted to e-bikes and speed pedelecs. Valid criteria for regular bicycles, such as low weight and low price, are less relevant for the former. By acknowledging this different context, the door is opened to design an innovative cargo container.

To ensure the voice of speed pedelec and e-bike users is heard, they are included in every step of the design process. First, two exploratory surveys are used to identify user needs. One (n=30) is directed towards the general public, and the other (n=219) towards speed pedelec users. Second, one survey and nine interviews (n=9) are performed to validate generated concepts and prototypes.

A mixed-methods approach was used for all surveys, while the interviews were purely qualitative.

As a result, several new user needs are identified, such as storing everyday carry (EDC) and a helmet. Furthermore, the provided security of the final concept significantly expands the possible use cases of speed pedelecs and e-bikes, rendering them more versatile and convenient.

Dutch

De afgelopen 15 jaar is de verkoop van elektronische fietsen (e-bikes) en speed pedelecs (snelle e-bikes, tot 45 km/u) enorm gestegen. Vooral e-bikes en speed pedelecs laten een aanzienlijk potentieel zien om een modal shift weg van de auto te realiseren.

Er moeten echter verschillende barrières worden overwonnen om de e-bike en speed pedelec een '365-dagen'-voertuig te laten worden, zoals bagagevervoer, specifieke kleding en vergrendeling.

Het probleem met de huidige fietscontainers is dat ze niet geschikt zijn voor e-bikes en speed pedelecs. Geldige criteria voor reguliere fietsen, zoals laag gewicht en lage prijs, zijn voor de eerstgenoemde minder relevant. Door deze andere context te erkennen, wordt de deur geopend om een innovatieve vrachtcontainer te ontwerpen.

Om ervoor te zorgen dat de stem van gebruikers van speed pedelecs en e-bikes gehoord wordt, worden ze bij elke stap van het ontwerpproces betrokken. Ten eerste worden twee verkennende onderzoeken gebruikt om de gebruikersbehoeften te identificeren. De ene (n=30) is gericht op het grote publiek, de andere (n=219) op gebruikers van speed-pedelecs. Ten tweede worden één enquête en negen interviews (n=9) uitgevoerd om gegenereerde concepten en prototypes te valideren.

Bij alle enquêtes is een mixed-method approach gehanteerd, terwijl de interviews puur kwalitatief waren.

Als gevolg hiervan worden verschillende nieuwe gebruikersbehoeften geïdentificeerd, zoals het opbergen van alledaagse draagtas (EDC) en een helm. Bovendien breidt de geboden veiligheid van het uiteindelijke concept de mogelijke gebruiksscenario's van speed-pedelecs en e-bikes aanzienlijk uit, waardoor ze veelzijdiger en handiger worden.

Design of an E-bike specific cargo container system to stimulate sustainable commuting behaviour

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***Abstract*—Over the last 15 years, the sales of electronic bicycles (e-bikes) and speed pedelecs (fast e-bikes, up to 45 km/h) have increased enormously. E-bikes, and speed pedelecs, in particular, show a significant potential of achieving a modal shift away from the car.**

However, several barriers need to be overcome for the e-bike and speed pedelec to become a '365-days' vehicle, such as luggage transportation, specific clothing and locking.

The problem with current bicycle cargo containers[1] is that they are not adapted to e-bikes and speed pedelecs. Valid criteria for regular bicycles, such as low weight and low price, are less relevant for the former. By acknowledging this different context, the door is opened to design an innovative cargo container.

To ensure the voice of speed pedelec and e-bike users is heard, they are included in every step of the design process. First, two exploratory surveys are used to identify user needs. One (n=30) is directed towards the general public, and the other (n=219) towards speed pedelec users. Second, one survey and nine interviews (n=9) are performed to validate generated concepts and prototypes.

A mixed-methods[2] approach was used for all surveys, while the interviews were purely qualitative.

As a result, several new user needs are identified, such as storing everyday carry (EDC) and a helmet. Furthermore, the provided security of the final concept significantly expands the possible use cases of speed pedelecs and e-bikes, rendering them more versatile and convenient.

***Keywords*—sustainable commuting behaviour, cargo container, speed pedelec, e-bike, Design Thinking,**

I. Introduction

E-bikes and speed pedelecs are on the rise [1]. For example, in Belgium, 34.774 more e-bikes were sold in 2020 compared to 2019, which is an increase of 18% [2]. A study by the European's Cyclists' Federation has shown that greenhouse gas emissions of e-cycling are in the same range as ordinary bicycles, which is ten times lower than the amount coming from driving a car [3]. These figures indicate that significant environmental benefits could be achieved through the modal shift from car to bicycle.

E-bikes and speed pedelecs have evolved from regular bicycles and share many characteristics. However, they are also fundamentally different from regular bicycles due to their pedal-assist: they weigh more, cost more and reach higher speeds. Unfortunately, current cargo container manufacturers fail to acknowledge the opportunities this different context offers, and 'e-bike specific' cargo containers are, in essence, no different from those sold for regular bicycles.

There are several problems with the current cargo containers, especially in the context of e-bike commuting. The most crucial problem is probably the complete lack of security: nor their contents nor the containers themselves are easily secured or locked to the bicycle. This deficiency limits the possible use cases of the e-bike, as commuters often carry a laptop and other valuables.

Second, current cargo containers (bicycle panniers) are almost always top-loading: a single, large compartment where the cargo is 'thrown' in. Thus, the objects are stacked onto each other, and it is hard for the user to keep an overview or retrieve a specific item.

Third, current bicycle panniers do not provide decent protection of their contents in case of a fall or crash. Again, this is relevant because items like a laptop or tablet are often transported during the commute.

Fourth, the increased speed of the speed pedelec (and e-bike) requires a cargo container that is more robust than its regular bicycle counterpart. According to the World Economic Forum, the condition of the road surface in Belgium is appalling [4]. All those potholes and road vibrations are problematic for bicycle equipment and require, e.g. a sturdy attachment system.

In conclusion, this extended abstract covers the design process of a convenient [5], versatile cargo container system, which is specifically designed around commuting and aims to draw people away from the car, resulting in more sustainable (commuting) travel behaviour.

II. Literature Review

A. *Cycling equipment as a promotor of utility cycling*

In recent years, the interest in examining key factors linked to utility cycling has increased dramatically along with the interest of cities to increase this specific type of cycling (utility cycling is any form of cycling performed as a form of transportation, rather than as a hobby or sport [6]). As a result, several key factors are already extensively studied, such as distance and bicycle infrastructure. However, there is a severe lack of research on the role of bicycle equipment in promoting utility cycling. This deficiency is surprising because cycling equipment may significantly affect the comfort, feasibility, safety, and convenience of cycling and, as such, positively impact an individual's choice to cycle [7]. The same findings are mentioned in the book 'City Cycling' [8].

In this book, several 'problems' associated with utility cycling are also mentioned. The need to carry cargo or

[1] The term 'cargo container' is a name for anything that serves as a 'container' to hold freight on the bicycle.

[2] A mixed-methods approach implies both qualitative and quantitative information was obtained.

passengers, frequent stops and starts and exposure to theft were the most interesting ones.

B. Barriers to cycling

E-bikes and speed pedelecs can remove some of the barriers to cycling thanks to their pedal assist. For example, excessive sweating due to physical activity is prevented, longer travel distances and shorter travel times are possible [9].

However, other barriers remain, such as low perceived traffic safety and reliability and luggage carrying capacity. The speed pedelec also requires more planning, such as checking the forecast before packing rain clothes and is less flexible than the car [10].

C. Modal shift and behavioural change

Studies have shown that e-bikes and speed-pedelecs have a significant potential of achieving a modal shift away from the car [9]. Behavioural change was researched to determine how users (e-bike commuters) could be steered in the direction of the positive behaviour (e-cycling) and away from the unwanted behaviour (car use) [11] [12].

The main lesson learned is that habit is the strongest predictor of behaviour [12]. A strong habit towards e-cycling was promoted by expanding the possible use cases (beyond commuting) of the e-bike through the innovative functions of the cargo container. As such, the e-bike owner is less likely to fall back on the car for transportation.

III. Methods

A. Methodology

The methodology used during this master's thesis combines the 'Design Thinking' [13] methodology and the 'generic product design process', defined by Karl T. Ulrich and Steven D. Eppinger [14].

First, in general, Design Thinking was used throughout this thesis by applying the five themes that characterise it: inherent user focus *(empathy-building and user understanding)*, problem framing *(challenging, reframing, and widening the problem)*, visualisation *(making ideas tangible and visual)* and experimentation *(testing different solutions)* [13]. More specifically, the Double Diamond model [15] was used, which consists of four phases: Discover, Define, Develop, Deliver. The first 'diamond' is about 'designing the right thing', and the second diamond is about 'designing the thing right'. The model is based on a process of divergence and convergence.

Second, guidelines from the generic product design process were used as a solid theoretical background, e.g. during identification of user needs and target specifications.

B. Discover and Define

The 'Discover' And 'Define' stages are combined here because the border between them is not always prominent.

The 'Discover' stage started with looking into online customer reviews of benchmarks to better understand the market and its users. Then, the subject of the 'bicycle cargo container' was expanded as much as possible, looking at all kinds of different cargo containers. Five different cargo containers were selected based on their widespread use or the exciting viewpoint they could offer (detachable bicycle panniers (single), fixed bicycle panniers (double), bicycle crate, top case and shopping trolley). Next, an initial analysis of these benchmarks was performed, discovering their weak and strong points.

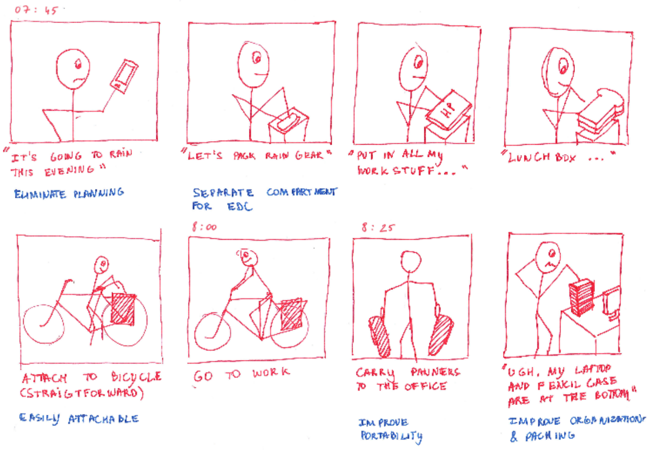


Figure 1: Storyboarding

Storyboarding [16] was another used method, helping to understand some pain points present in current cargo containers.

The primary insights gathered from customer reviews, benchmark analysis and storyboarding were then used to devise the first two surveys. The first survey was directed towards the general public and distributed on the author's Facebook page. The second survey was directed towards speed pedelec users and was distributed on the Facebook page of Speed Pedelec Vlaanderen.

The first survey had two main parts. The first, 'Means of transport', was used to gauge how respondents used different transportation modes and determine their relative (dis)advantages. The second, 'Supermarket visit', was meant to determine a reasonable cargo container volume and score the benchmarks defined in the 'Discover' stage in the context of a supermarket visit. Strong and weak points were determined for each of the benchmarks.

The second survey included these same first two parts, and a third part was added, 'personal cargo container'. This part allowed the respondents to comment on their own cargo container and validated some of the author's assumptions.

The first surveys (1 and 2) were also used to identify the user needs. Customer remarks were written on a post-it note as a like, a dislike or a suggestion for improvement. Then, these were grouped into primary and sub-primary needs.

Because these user needs statements were still expressed in the 'language of the customer', and had a subjective quality, product specifications were defined. Each specification consists of a *metric* and a *value*. The metric is a *measurable* statement, and the value is the actual *number* that accompanies this metric and is labelled with the correct *unit*.

A persona is another method used to represent the target group as an actual, specific (and fictitious) person [17]. These personas were used to communicate the target audience more clearly with stakeholders, and they helped keep the end-users in mind in subsequent design stages.

Finally, a problem decomposition was performed in the 'Define' stage, based on the sequence of user actions (user journey mapping). The problem decomposition helped divide the research question (main problem) into smaller sub-problems that could be solved separately.

C. Develop

In the 'Develop' stage, much ideation was done on the previously defined sub-problems. During ideation, two main methods were used: sketching and prototyping. The low fidelity prototypes were used to help decide the embodiment of the final, comprehensive prototype.

The final prototype was used to perform user testing. In the last survey, several video fragments were used to show how the prototype functioned, as in-person testing was still ill-advised. This final survey had 73 respondents and was distributed on the author's Facebook page and several Facebook groups. The median age of respondents was 43 years old. This survey aimed to check the different features of the cargo container system prototype and determine areas of improvement and strong points.

Figure 2: testing of rear and front container, respectively

Interviews were performed as well. First, a pilot interview was used to get rid of teething problems. Subsequently, an alternative concept was generated. Finally, eight people (n = 8) were interviewed about the final prototype and the alternative concept. They were all fellow design students aged 21, except one person aged 22. The sample population of these interviews was very different from the target audience due to covid-19 restrictions. However, overall, the interviewees could empathise well with this target audience, and the results were valuable.

D. Deliver

In the final 'Deliver' stage, Siemens NX was used to model the final concept with CAD. These models were used to prove the final concept could be produced, and renders were made to show how the final product would look if it were produced.

IV. Results

A. Discover and define

The first survey remained online for six days and had 30 respondents. The median age of respondents was 23 years old. The second survey remained online for three days and had 219 respondents. The median age of respondents was 50 years old.

The respondents were asked to indicate their preferred cargo container in the context of a supermarket visit. The detachable bicycle panniers score best with 37.5% and 43.3% in the first and second survey, respectively. Overall, the top cases scored worst. The shopping trolley came in second for the second survey.

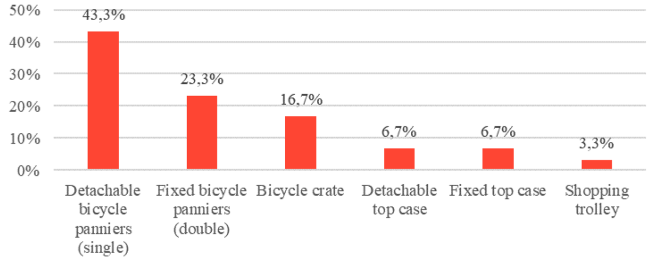


Figure 3: Preferred cargo container (survey 1)

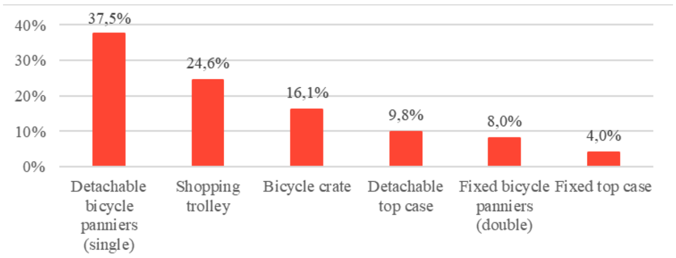


Figure 4: Preferred cargo container (survey 2)

An idea stemming from some answers of the first survey was assessed in the second survey: the possibility to store a helmet and rain gear dry and safe on the bicycle.

Table 1: Storing rain gear (locked and dry) on e-bike

No added value at all	*No added value*	*Neutral*	*Added value*	*Large added value*
6%	6%	8%	33%	47%

Table 2: Storing helmet (locked and dry) on e-bike (in possession of cargo container)

No added value at all	*No added value*	*Neutral*	*Added value*	*Large added value*
2%	7%	15%	35%	41%

Next, the question "In what areas would you improve or change your current cargo container?" was asked to the respondents already in possession of a cargo container. The five most mentioned areas are identified in table 1.

Table 3: Areas of improvement

Security	*Ease of use*	*Volume*	*Waterproofing*	*Firmness*
43%	19%	12%	10%	9%

At the end of the 'Define' stage, the decision was made to focus on a hard-shell solution.

B. Develop

A cargo container can be attached to the e-bike in many locations (figure …) The cargo container placement was determined first, before progressing and developing different concepts.

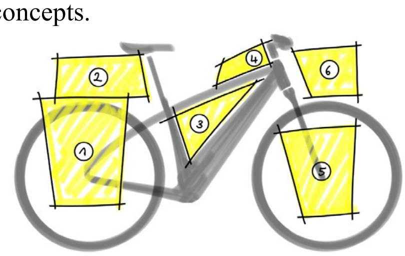


Figure 5: cargo container placement possibilities

Several elements were considered when determining the ideal load placement: aerodynamic drag [18][19][20], the ease of attaching and detaching, aerodynamic side forces [21] and the location of the centre of gravity. The last two were considered the most important as they influence the stability of the e-bike. Finally, the choice was made to design cargo containers for locations one and six, both at the front and the rear of the e-bike. Thanks to this placement, the ideal weight distribution of 60/40 on the rear/front wheel could be maintained [22].

There are essentially two ways to attach a front container to a bicycle. The first is to attach it to the steering assembly, and the second is to attach it directly to the frame. Two low fidelity prototypes were made to test these configurations with a weight of 4 kg. The attachment to the e-bike's frame was chosen because it barely affected stability or handling, contrary to the attachment to the steering assembly. It was also decided to use a smaller front wheel for the target e-bike.

Figure 6: testing front load attachments

A known problem with rear cargo containers is 'heel strike', or the cyclist's heel catching on the container. Several possibilities were investigated, including moving the container upwards, backwards, chamfering the container and mounting the container at an angle. Mounting the container at an angle presents some significant advantages and was therefore chosen. A prototype was made and used to test this solution.

Figure 7: expandability of rear container

One of the user needs was an adjustable volume. As a result, a way to expand and reduce the rear cargo container's volume had to be found. A bellow combined with a slider mechanism was invented, allowing two volumes: 16 l and 24 l.

Figure 8: final prototype mounted on demonstration bicycle

Finally, a comprehensive prototype was built and both containers were installed on a bicycle. Several videos were made, clarifying the envisioned user journey and presenting the cargo container's main features. These videos formed the backbone of the fourth survey. The main features and characteristics are discussed below:

The ***first main feature*** is that the complete cargo container system is hard-shell. It was anticipated that this would increase the perception of the provided security.

The ***second main feature*** is the provided security: the front container is permanently attached to the bicycle, and the rear container can be locked to it. The contents of both can also be secured with a lock.

The ***third main feature*** is the protection of contents: the cargo containers are both waterproof and provide better protection to the contents in a fall/crash than regular bicycle panniers. This feature is especially relevant in the context of commuting, where often a (valuable) laptop is transported.

The ***fourth main feature*** is the ability to store one's helmet, rain gear or EDC (everyday carry) in the front container.

The ***first additional feature*** is the bellow and slider system, enabling expanding and shrinking of the rear container.

The ***second additional feature*** is the rear container's organizability: first, it is front-loading. Most 'roll top' panniers are top-loading, allowing for items to be 'thrown in'. An identified shortcoming of this type of loading is the lack of organisation, which is why the front-loading option was chosen to allow for straightforward organising at home or work. Second, a laptop compartment and an internal divider panel, meant to keep the rear container's contents from falling out when opened on the bicycle, are provided.

The ***third additional feature*** is the improved aerodynamic drag: the total frontal area is decreased compared to a conventional pannier setup. It is expected that this will increase the e-bike's battery range.

One of the essential aspects of the fourth survey is to gauge the people's reaction to the hard-shell cargo container.
The fourth survey was used to validate these features.

First, the hard-shell was evaluated. Considering all respondents, the soft-shell and hard-shell both scored 38.4% of votes, while for the general survey, 30.0% of respondents preferred the hard-shell (table …).

Table 4: preference hard-shell vs soft-shell cargo container (target audience)

Softshell	*Hardshell*	*Unclear / no preference*
47.5%	30.0%	22.5%

Second, both the security of locking the container to the bicycle and locking its contents were rated.

Table 5: added value of provided security

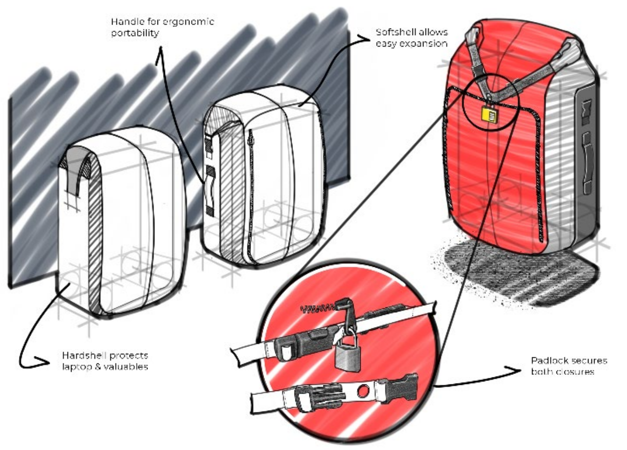
	No added value at all	*No added value*	*Neutral*	*Added value*	*Large added value*
Contents	2.7%	1.4%	5.4%	23.0%	67.6%
Container	2.7%	1.4%	6.8%	25.7%	63.5%

Third, the respondents had to indicate which cargo container seemed most safe to them.

Soft-shell pannier	Hardshell cargo container	No preference	Other
23%	44.6%	24.3%	8.4%

Next to the final survey, the final prototype was tested in person, and final interviews were performed. In total, nine people were interviewed.

After a pilot interview, the front-loading feature of the rear container was questioned. As a result, an alternative concept was generated for the rear container and compared to the final prototype in the following eight interviews. This alternative concept was a combination of a hard-shell and a soft-shell, provided top- and front-loading, and provided some security.



The subsequent interviews proved the strengths of the final prototype, but several respondents preferred the alternative concept. Its most significant advantage was the roll-top, allowing top-loading on the bicycle.

After a brainstorm, a solution was found: making the final concept 'diagonal-loading'. Instead of tilting the flap when on the bicycle, the whole cargo container is tilted, and the flap is firmly attached to the bicycle's rack.

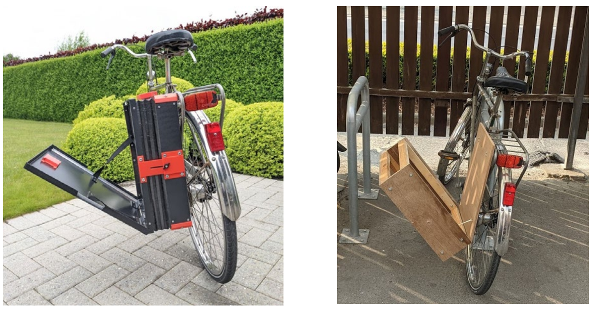


Figure 9: front-loading (left) vs diagonal loading (right)

V. Discussion

A. *Discover and define*

The top case benchmark was included in the surveys to see how respondents react to a lockable hard-shell cargo container. However, it was not very popular among the respondents. Why? The respondents' explanations uncovered the following problems with this benchmark: it is too small, its centre of gravity is too high, causing instability, and it always takes up a lot of room (not foldable). These problems could be fixed, but they were just not addressed in the current benchmarks.

From the first and second survey, it became clear that the security of cargo containers was the most significant area of improvement (43% of comments on possible improvements were about security). As a result, the customer need "The cargo container and its contents are protected from theft" was considered the main focus of this thesis.

Because the shopping trolley scored so well among speed pedelec users, a trolley function was ideated upon. However, in subsequent design stages, the idea was abandoned because the appreciation among users differed significantly. In addition, this feature would have further increased the weight and purchase price of the final product.

The car often houses 'just in case' items, such as a spare wheel, a toolkit, a shopping crate or a map. A spare wheel and a toolkit are not needed outside of car trips, so they always remain with the car. Then why do cyclists always have to carry their repair gear, rain clothes and helmet with them? Wouldn't it be more convenient to be able to leave these items on the bicycle? The respondents agreed that this would be a helpful feature and were very enthusiastic about the idea. Fulfilling this need to store everyday carry (EDC) was the main focus of the front container.

At the end of the 'Define' stage, it was decided to focus mainly on developing a hard-shell cargo container. This decision was based on several factors. First, it allows for easier integration of locks (resulting in increased usefulness). Second, the rigid material provides an added sense of security. Fourth, the cargo container's contents are better protected in case of a crash or fall. Finally, the higher production cost and weight compared to regular soft-shell panniers are less relevant in the context of e-bikes and speed pedelecs.

B. *Develop*

The final survey showed that the hard-shell feature was generally well-received. Many people thought this feature presented enough advantages to prefer it over the soft-shell. The results showed a lower preference for the hard-shell among the target audience compared to all respondents (38.4% vs 30.0%, respectively). A preference of 30% was still considered a great result, as there are not many direct competitors for hard-shell cargo containers on the market.

Probably the most significant result obtained from this fourth survey is the appreciation of the provided security. The results were highly positive, as around 90% of respondents thought this was an added or large added value, proving that a major area of improvement in current cargo containers, the security, was largely eliminated by the final prototype.

Almost twice as many people considered the final prototype safe than regular soft-shelf panniers, primarily thanks to the width of the cargo container being easier to estimate. When soft-shell panniers are heavily loaded, it is sometimes hard to estimate how wide they are, and since the cyclist does not see them, this can decrease the feeling of safety, as the fear of catching onto something increases.

The interviews showed a problem with the final prototype: its lack of top-loading possibilities. The alternative concept filled this gap but scored a lot worse in other areas. As a result, the principle of 'diagonal-loading' was invented, which is expected to solve this problem. This 'diagonal-loading' should be tested with users to validate the principle.

VI. Conclusion & further work

This master's research is about the research, design and development of a versatile, convenient bicycle container system. Throughout this research, the Design Thinking methodology was used, with an emphasis on the user. Thanks to this user involvement, it was possible to generate an e-bike cargo container system tailored to its users' wants and needs. Implementation of this concept could mean a decent first step in developing the e-bike and speed pedelec into a '365-days' vehicle.

The final concept minimises some of the advantages of the car, such as security, convenience and the protection of its contents. Furthermore, some of the identified problems with current cargo containers, such as a lack of robustness and consideration of aerodynamics, are also solved. Finally, the final concept is adapted to the relatively new context of e-bikes and speed pedelecs, unlike current cargo containers.

The final concept also excels in its sustainability aspect. The e-bike only emits about one-tenth of the greenhouse gases cars emit. Furthermore, the e-bike makes the environment more liveable: it is pleasant to live in a city filled with bikes instead of cars. Design for disassembly was also taken into account, allowing easy maintenance and separation of material currents at the end-of-life.

The final concept is not yet finished due to time limitations: the front container still needs to be modelled, and a complete concept needs to be rendered. Other further work could include: producing a high-fidelity prototype to test some of the aspects of the final concept, such as the diagonal loading, and do final user tests to see if the final concept holds up in actual use. Second, a cost calculation should be made to determine the final cost of the cargo container system.

In conclusion, by decreasing the relative advantages of the car through the cargo container, car commuters are more likely to shift to speed pedelec and e-bikes for commuting. If this results in a strong habit towards cycling, the modal shift from car to bicycle may be nearby.

Acknowledgements

First, I would like to thank Prof. dr Marina Emmanouil for her feedback and guidance. Second, I want to express my gratitude to Prof. Jan Detand and Ir. Yannick Christiaens for their valuable insights and guidance. Last, I would like to give my appreciation to the hundreds of people who participated in this study.

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Table of contents

List of abbreviations and symbols

e-bike	electronic bicycle
pedelec	pedal electrical cycle
TU	Test User
ABS	Acrylonitrile Butadiene Styrene
PP	Polypropylene
PC	Polycarbonate
EDC	Everyday Carry

1. Introduction

1.1. Context & initial problem statement

Over the last 15 years, the sales of electronic bicycles (e-bikes) and speed pedelecs have increased enormously [1]. In Belgium, 34.774 more e-bikes were sold in 2020 compared to 2019, which is an increase of 18% [2]. The majority of the e-bikes sold (94% of all e-bikes) are regular e-bikes with pedal assist[1] up to 25 km/h. The remaining portion (6%) are e-bikes that give more power and support speeds up to 45 km/h [3]. High-speed e-bikes, or so-called speed pedelecs, have some advantages over regular e-bikes in their potential of achieving a modal shift away from the car. Their main advantage is that they can maintain higher speeds (up to 45 km/h). In congested areas, this means that a commute by speed pedelec has similar travel times to those of the car or public transport. Furthermore, thanks to their higher motor power and assistance speed, larger (commuting) distances are possible [4].

However, according to a study on the potential of the speed pedelec in achieving a modal shift, the speed pedelec still fails to overcome many barriers to cycling. The authors argue that the speed pedelec should be developed into a '365-days' vehicle by further removing some of these barriers, 'such as luggage, clothing or locking'. One of the advantages of the car is its luggage-carrying capability [4]. That is why the cargo container developed during this master's research tries to help improve some luggage transportation capabilities of e-bikes and speed pedelecs, such as safely securing the transported items.

The term 'cargo container' will be used throughout this thesis and means a 'container' to hold freight on the bicycle. It could be anything, such as a single pannier, bicycle crate, basket or trunk bag.

Currently, **there are no cargo containers on the market that fulfil the specific needs of speed pedelec users**. This absence is surprising because several significant differences between speed pedelecs and bicycles make the classic bicycle panniers less suited for speed pedelec use. Many so-called e-bike specific cargo containers are just rebranded bicycle cargo containers, meaning that, in essence, these cargo containers are no different from those sold for regular bicycles. They are just marketed differently. Suppose cargo containers for e-bikes and speed pedelecs *were* adapted to users' needs and *could* be used in many different scenarios. In that case, owners could be a lot more tempted to use their e-bike or speed pedelec more often and leave their car. In the end, more sustainable mobility (and commuting) could be achieved. More sustainable mobility can be achieved by a decrease in travel distance, an increase in the use of public transport, and a decrease in car use.

For example, it is not self-evident to store an extra battery in a conventional bicycle pannier for those who want to cover large distances. One of the problems is that E-bike batteries can be heavy. For e-bikes, the Ortlieb E-mate provides a separate compartment to store an extra battery.

[1] 'Pedal assist' e-bikes are different from 'throttle' e-bikes in that the motor will **only** engage when the cyclist is pedaling. In contrary, the motor of 'throttle' e-bikes can be activated without the cyclist pedaling (through a throttle).

Figure 1: Ortlieb E-mate pannier with battery compartment

One of the most critical problems is that cargo containers lack security: nor their contents nor the containers themselves are easily secured or locked to the bicycle. This deficiency limits the possible use cases of the e-bike, as commuters often carry a laptop and other valuables. Users are likely to feel uncomfortable leaving behind such valuable items, which results in them carrying around their cargo container everywhere, even when they do not need it.

Another problem is the robustness of current cargo containers: the increased speed of the speed pedelec requires a cargo container that is more robust than its regular bicycle counterpart. Moreover, according to the World Economic Forum, the condition of the road surface in Belgium is appalling [5]. Furthermore, up to 50 % of the cycling paths along regional roads are in poor condition [6]. All those potholes and road vibrations are problematic for bicycle equipment and require, e.g. a sturdier attachment system.

Finally, some other complaints are identified: panniers often do not provide many options in terms of organisation. For example, many panniers provide one large compartment where the cargo is ‘thrown’ in (top-loading). Thus, the objects are stacked onto each other, and it is hard for the user to keep an overview or retrieve a specific item.

More and more people are using their e-bike or speed pedelec to commute to work. However, the car, which is the direct competitor of these e-bikes, presents some significant advantages. For example, a car is very convenient, meaning that it makes life comfortable, and causes no difficulty for one’s schedule or (changing) plans [7]. However, this master’s thesis aims to make it **more tempting for regular car commuters to switch to an e-bike or speed pedelec**. Therefore, these relative advantages should be removed, or at least decreased as much as possible. This way, not only might e-bike and speed pedelec commuters use their car less frequently, but it may also become more tempting for regular car commuters to switch to an e-bike or speed pedelec as their primary vehicle. A study by the European’s Cyclists’ Federation has shown that greenhouse gas emissions of e-cycling are in the same range as ordinary bicycles, which is ten times lower than the amount coming from driving a car [8].

To conclude: e-bikes and speed pedelecs have evolved from regular bicycles. However, even though these two-wheelers are fundamentally different from regular bicycles, speed pedelec or e-bike specific cycling equipment, such as cargo containers, have not seen much progress and innovation. Thus, while cycling equipment has evolved to fulfil the needs of the average cyclist (e.g. being lightweight), it is not suited anymore for its ‘new’ users, namely this relatively new group of e-cyclists. Furthermore, the shift to e-cycling would be great for the environment, as its greenhouse gas emissions are only one-tenth of those stemming from driving a car.

1.2. Stakeholders

Firstly, this master's thesis is carried out internally as a research project within Ghent University, specifically at the Department of Industrial Systems Engineering and Product Design. The Industrial Design Center is the venue of this department, and its machine park was used to create several prototypes for this research.

There are several stakeholders regarding e-bikes and speed pedelecs. The direct stakeholders are directly in contact with the designed product, while indirect stakeholders are not. These indirect stakeholders are not consulted during this master's thesis because they are of minor importance.

Direct:

- E-bike commuters (target audience)
- Speed pedelec commuters (target audience)
- Bicycle repair-and salesmen and -women

Indirect:

- Fellow road users (cyclists, pedestrians, cars)
- Fellow citizens (a more pleasant environment by decreasing car used and increasing e-bike and speed pedelec use)

According to a Norwegian study on the e-bike's role in overcoming barriers to bicycle use, the people who cycle the least are the most interested in buying a speed pedelec [9]. The authors of that research suggest an increase in speed pedelec uptake is unlikely to reduce regular cycling. These findings indicate that increased e-bike use mainly shifts people away from motorised transport, which is beneficial to the (living) environment. In conclusion, e-bike and speed pedelecs targeting car users could provide the most significant sustainability gains. For these people, every e-bike trip substitutes for a car trip and not a conventional cycling trip. [10] According to [11] and [12], the most significant potential to replacing cars lies in promoting pedelecs for commuting.

1.3. Research question

As mentioned in the context and initial problem statement, switching from travelling by car to travelling by (e-)bike presents a significant environmental improvement. However, the car still presents significant advantages, one of which is its convenience.

Habit is one of the strongest predictors of behaviour, as is discussed later in the chapter 'Literature review'. A habit is the automation of a particular process and is influenced by past behaviour. Many people also have a specific commuting habit, e.g. a student who usually cycles to campus or a bank clerk who rides his car to work. Ultimately, the goal of this thesis is to form a strong habit towards e-cycling to work. The context of commuting is chosen for two reasons. First, it gives the research a clear and specific focus. Second, it is hypothesised that commuting with an e-bike or speed could increase e-cycling in general by forming this commuting habit.

These factors have led to the research question: "How can sustainable commuting behaviour be stimulated by designing an e-bike specific, *convenient* cargo container."

1.4. Methodology

Design Thinking (the Double Diamond model)

Design Thinking is "an innovation methodology that supports the solution of wicked problems in terms of innovative products or services [13]." The term 'wicked problem' needs to be explained first to understand this definition. The term was coined in the 1960s by Horst Rittel, a design theorist and professor. He described wicked problems as a "… class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision-makers with conflicting values and where the ramifications in the whole system are thoroughly confusing [14]." In other words, complexity and conflict are inherent to wicked problems[15]. A wicked problem is hard to pin down and ambiguous. It is characterised by its indeterminacy[2] [14].

This indeterminacy in wicked problems and design thinking is opposed to the determinacy of science, which has been developed to deal with 'tame' problems. On the one hand, determinate problems have a clear start- and endpoint and are solved linearly. On the other hand, indeterminate, wicked problems have no clear starting point or endpoint. They need to be solved iteratively to account for the complexity and conflict that inevitably arise when 'solving' such a problem [15].

Design Thinking presents several design activities, methods and design phases. However, the methodology does not prescribe an order to these 'design steps[3]'. The reason is that this way, the designer can choose the best-suited design steps in a specific situation and be resilient against the unexpected discoveries that are inherent to the process of solving wicked problems [13].

The Design Thinking methodology knows different models, such as the model proposed by the Hasso-Plattner Institute of Design at Stanford (d.school) [16], and the Double Diamond Design Thinking model, which is a 4-step model of 4 D's developed by the British Design Council [17]. These models have different names, and they emphasise different aspects of Design Thinking, but in essence, all describe very similar phases. One study on design thinking tries to provide a different, more general framework characterising Design Thinking and proposes five themes that characterise Design Thinking: user focus, problem framing, visualisation, experimentation, and diversity [16].

The first theme revolves around an inherent **user focus** expressed in the *user's understanding and involvement* in the design process and *empathy building*. During this master's thesis, the user was involved in every design stage to deliver a design relevant to the target user. Several methods were used for this, resulting in a mixed-methods approach resulting from a quantitative and qualitative data collection: four questionnaires were distributed, and ten interviews conducted. The surveys were used to gather both qualitative and quantitative data. Gathering qualitative data through questionnaires was necessary because of COVID-19 limitations regarding in-person communication. The interviews were conducted to gather qualitative data only.

The second theme is **problem framing** and refers to the way designers try to *challenge, reframe and widen the problem* instead of trying to solve it. Reframing the problem has happened several times during this thesis. In general, this framing and reframing of the problem was sometimes challenging to process, as people intuitively do not like uncertainty.

The third theme is **visualisation**: making ideas *tangible* through low-resolution mock-ups or *representations*. Many storyboards, simple sketches and low-fidelity prototypes were made during this master's research.

The fourth theme is **experimentation**: *testing different solutions* and trying things out in an iterative way.

Finally, the fifth theme is **diversity**: diverse teams guarantee that *several perspectives* are taken into account. In addition, the different competencies of the team members ensure a final design that is as 'complete' as possible. This master's thesis was realised through consults with the internal promotor and several other mentors, and so different viewpoints were integrated.

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[2] Indeterminacy is the state of not being measured, counted or clearly known [76].
[3] The term 'design step' is an umbrella term for design methods, activities and phases [13].

These themes are implemented in a more specific model: the Double Diamond model, as explained below and shown in figure 2.

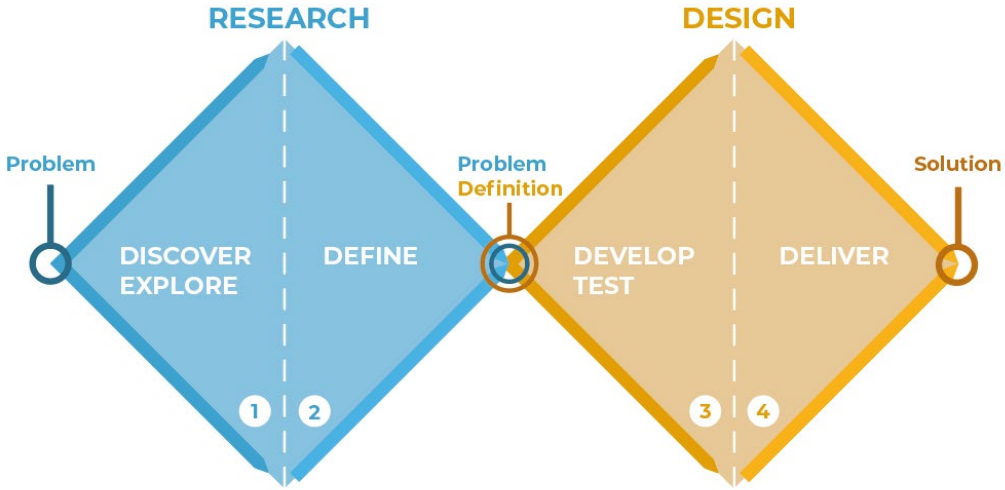

Figure 2: Double diamond methodology, adapted from [17]

In this model, there are four stages, the four D's: Discover – Define – Develop – Deliver. The first diamond is more about the research and understanding and defining the 'problem' at stake that precedes the second diamond. This second diamond represents the solution design stage, which refers to developing prototypes and testing. One could say that the first diamond is about 'designing the right thing', while the second diamond is about 'designing the thing right'. By 'designing the right thing', one avoids that the wrong problem or question is solved in the second diamond, resulting in a useless final design. 'Designing the thing right' is about how the solution to that problem comes about [18].

This design process is one of divergence (Discover, Develop) and convergence (Define, Deliver). By diverging, the problem can be understood better and explored deeply. Converging, on the other hand, enables focused action. As explained, wicked problems are solved through design thinking, and the complexity of these wicked problems requires an iterative approach. That is why it is usual to go back to a previous stage of the Double Diamond and cycle through the entire process again.

Ulrich & Eppinger

Finally, the generic product development process presented in the book 'Product design and development [19]' by Karl T. Ulrich and Steven D. Eppinger is used to provide a solid theoretical background for performing several of the steps involved in the Design Thinking process. For example, the customer needs are identified using this book and the guidelines it provides.

The generic product development process itself is different from the Design Thinking methodology in that it provides a linear approach to product development that is less flexible. The focus is more on direct implementation in the business context and allows less freedom than the Design Thinking methodology [19]. The process itself is not followed during this master's research, but some of its tools are used (to define user needs and specifications and generate concepts). Furthermore, elements like planning and production ramp-up are not present in this master's thesis (figure 3).

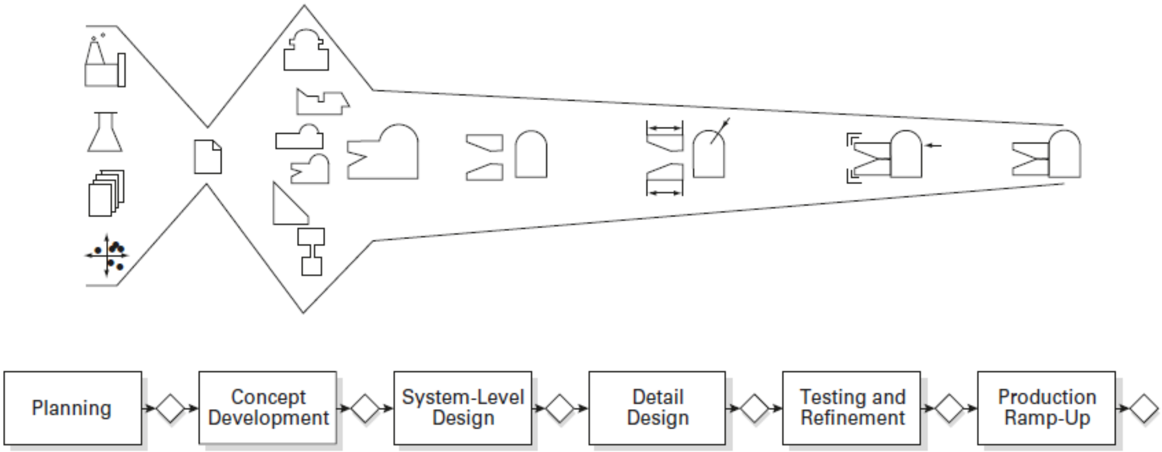

Figure 3: Generic product development process by Urlich & Eppinger

2. Discover

The ‘discover’ stage starts with a literature review of the topic of bicycle cargo containers. In the literature review, there are three first main themes: What? How? and With what? (medium) First, the ‘What?’ dives a little deeper into the problem. Second, the ‘How’ defines how this problem could be tackled. Third, the ‘With what?’ is about the cargo container itself: the medium that aids in tackling the problem. There are two other topics under literature review: aerodynamics (influencing safety, among others) and security. These are separate from the first three but added here because of their theoretical character.

Next, the market is researched to understand the weak and strong points of current cargo containers. Storyboarding is also used to understand the user journey, and finally, several surveys and their results are also discussed. The conclusions drawn from the surveys are mentioned in this ‘Discover’ stage. For convenience, some ‘narrowing down’ of the different concepts is also included (in reality, this would belong to the ‘Define’ stage).

2.1. Literature review

One element of the first stage (Discover) is to understand (rather than assume) what exactly is the problem. How can designer assumptions be prevented? Usually, a designer has some prior knowledge about the subject (in this case: e-bikes, speed pedelecs, commuting and bicycle cargo containers). However, this prior knowledge is not always completely correct and may be biased. A literature review is a way of absorbing and synthesising the information already present in literature and reinforcing this personal knowledge. The researcher takes a critical look at the information gathered. Furthermore, one of the objectives of a literature review is to identify gaps in current literature. Finally, it has to present the literature in an organised way [20].

The problem at hand is multifaceted, and a literature review is one of the tools that can help in attacking this complexity by providing a scientific base on which can be built further.

Modal shift – Barriers & motivators (What?)

Although e-cycling is less physically straining than regular cycling, one primary motivator to use a pedelec or e-bike is physical activity. Next to this, there is a mental aspect: to clear one’s head for the day ahead and feel mentally free [21][22]. Other motivators include time gain, predictability and free choice of route [23].

The e-bike in general, and speed pedelec in particular, have been researched in relation to a modal shift away from the car. A modal shift is a shift in travel or transportation mode (a ‘way’ of transportation). Some examples include the train, car, bicycle or boat. Consequently, a modal shift is a migration from one mode to another, e.g. from using the car to using the train while commuting. A modal shift is seen as a way to counteract negative aspects of road transportation, such as air pollution and congestion. [24]

Utility cycling is any form of cycling performed solely as a means of transportation rather than as a hobby or sport. Utility cycling is the original type of cycling and the most performed cycling type worldwide. In addition, utility cycling is the most environmentally friendly form of cycling, as it replaces other, less sustainable transport modes, such as the bus or the car [25].

However, there are several barriers preventing people from using their bicycles for utility cycling. First and foremost, several kinds of weather conditions like wind, rain, hot/cold temperatures present a significant obstacle to utilitarian bicycle use, such as the cyclist getting wet, cold, or sweating excessively [23]. Other barriers include the time it takes to cover long distances, infrastructure, traffic safety, battery range, lack of luggage carrying capacity, and flexibility [4]. E-bikes (and speed pedelecs in particular) can remove some of these barriers, such as the effects of severe wind. In the latter condition, the cyclist does not have to increase his effort because of the pedal assist, and so, fatigue and excessive sweating are eliminated. Furthermore, higher speeds can be maintained (up to 45 km/h on a speed pedelec), resulting in lower travel time to a destination and increased travel distances.

However, several barriers have to be overcome to achieve higher (e-)bike uptake. These include high purchase cost, low perceived traffic safety and reliability, but also luggage carrying capacity. It is also a lot harder to adapt to unexpected situations when travelling with an e-bike. Therefore, planning is needed with an e-bike, such as carrying rain gear when necessary [23].

Behavioural change – Intentions & habits (How?)

The ultimate goal of the cargo container is to help enable a modal shift (from the car) to the speed pedelec and e-bike. The aim is not to completely replace the car, but to enable using the e-bike or speed pedelec in situations where previously, only the car would be considered a reasonable option. For example, a weekly grocery run is hard to perform by (regular) e-bike or speed pedelec. Other trips, such as commuting, visiting friends and family or doing small grocery shopping, could be performed by speed pedelec or e-bike and are targeted in this thesis. As mentioned earlier, obstinate car users are the target group with the most potential to achieve this modal shift.

However, one study found that people with a 'strong' habit towards a particular travel mode acquire less information and use less elaborate choice strategies when compared to those with a weak habit [26]. Weak vs strong habits can be explained with a simple example in the context of car use: say someone has to buy a loaf of bread at a bakery 500 m away on a sunny day. The person with the weak habit, on the one hand, is likely to walk or cycle to the bakery. The person with the strong habit, on the other hand, is likely to take the car [10]. The study's author elaborates on this by stating that it is not surprising that people who have a weaker habit and thus already combine the car with other modes of transport are more open to trying alternative modes of travel and more willing to use. These findings entail that the developed cargo container should present a considerable advantage over the car to convince both people with weak and strong car use habits.

Of course, to understand behavioural change, first behaviour in and of itself needs to be understood. In this regard, there are several models and theories. The Theory of Planned Behaviour (TPB – figure 4) [27] and the (Extended) Model of Goal-directed Behaviour ((E)MGB – figure 5) [28] are most used. This literature review focuses more on the (E)MGB since it is more recent than the TPB. These models were used to understand better the different drivers behind the wanted behaviour (e-commuting by bicycle or e-cycling in general).

The MGB considers several additional areas over the TPB: motivational, affective (positive and negative anticipated emotions) and automatic processes (frequency & recency of past behaviour). In addition, the EMGB adds another factor, namely goal desire: the desire to achieve a particular goal will influence the desire to perform a particular behaviour (behaviour is a means to a goal (end)) [29].

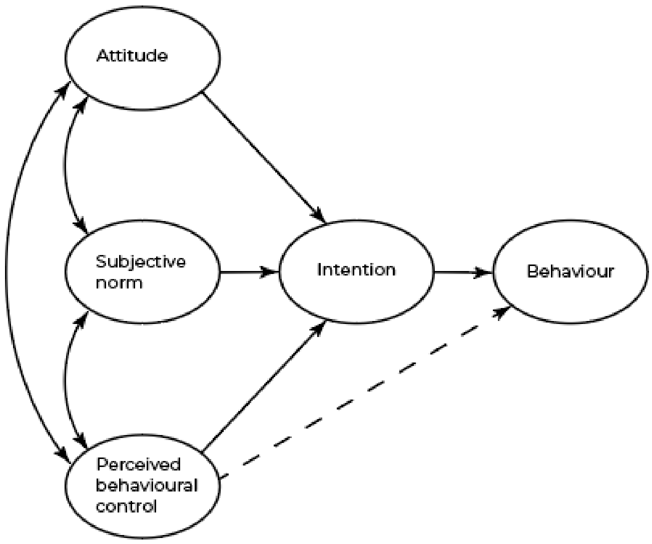

Figure 4: Theory of Planned Behaviour (adapted from [27]*)*

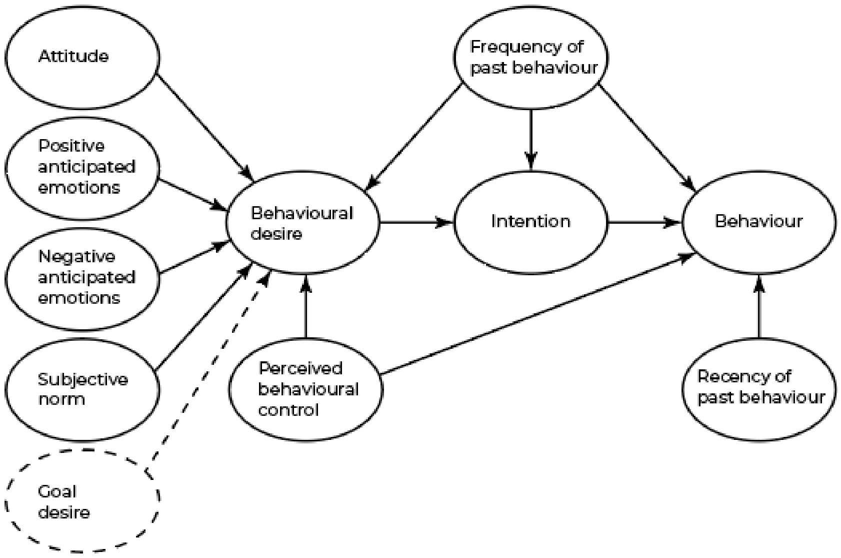

Figure 5: Extended model of goal-directed behaviour (adapted from [28]*)*

The following part is an overview of the different factors that influence behaviour and their possible implications in the context of this master's thesis.

These different factors were researched in their impact on this master's research.

There is an influence of individuals' affective states (their 'emotion') on action: individuals try to move towards positive affective states (**approach**) and away from negative affective states (**avoidance**) [30]. In psychology, an affect is an emotion or sentiment concerning a specific situation or event [31]. These findings are also reflected in the MGB [28]. Applied to a **modal shift**, this implies that negative emotions associated with the current travel mode may trigger the exploration of other travel modes. Therefore, by minimising negative emotions and maximising positive emotions, speed pedelecs and e-bikes could become a very tempting alternative for the car. One example of this is traffic: e-bike users are far less influenced by traffic than car users. Thus, the frustration of being stuck in traffic (negative state) is replaced with, e.g. the feeling of being mentally free (positive state).

Behaviour is influenced by past behaviour, accounting for the automation of certain processes (**habits**). A habit is a learned act that forms an automatic response to certain situations and can help obtain goals or end-states. [26] Habit is the strongest predictor of behaviour and contributes significantly over and above perceived control and intention. For example, these findings imply that even though a person intends to cycle to work, a strong habit might intervene and prevent this. There are two possible options to change habits. Firstly, to obstruct the execution of the unwanted habit. A second option, however, is to do the opposite and to promote wanted habits. Once individuals experience the benefits of executing the target behaviour, the probability of repeating this behaviour increases. Thus, a new, positive habit is formed. In the context of this research, a strong habit towards e-cycling was promoted by expanding the possible use cases (beyond commuting) of the e-bike through the innovative functions of the cargo container. As such, the e-bike owner is less likely to fall back on the car for transportation.

Another important factor is **perceived behavioural control**: this refers to the person's belief that the behaviour is under his or her control. It is often assessed by the difficulty or ease of the behaviour in question [32]. In the context of this master's research, this perceived behavioural control could be increased, e.g. by augmenting the perceived 'ease' of (grocery) shopping by bicycle, filling the cargo container, attaching the cargo container to the bicycle and so on. Finally, attitude and subjective norm are also factors that influence behavioural desire (in the TPB, this influences intention). Attitude means precisely that: how is the person's attitude towards a specific behaviour – "Do I want to do this?" On the other hand, subjective norms refer to the perceived support or approval from a person or group of people concerning a particular behaviour – "Do other people want me to do this [33]?" For example, during the 'Develop' stage, a trolley function concept was developed. One of the reasons many people did not like this concept is because of these subjective norms. They thought the trolley would make them look like a 'granny', or the trolley was seen as not masculine enough.

Luggage container (With what?) (Medium)

While doing research, it was found that there is a lack of literature in terms of existing products for bicycles that serve as bicycle cargo containers (cargo solution). Among the few sources, a Danish study (by CycleLogistics) was found, which provides a comparison between different brands and models of both cargo bicycles, as well as cargo containers (for regular bicycles) [34]. This study was used to help validate the identified user needs, such as the need for stability and the ease of attaching the cargo container or filling it.

In recent years, the interest in examining key factors linked to utility cycling has increased dramatically along with the interest of cities to increase this specific type of cycling (utility cycling is any form of cycling performed as a form of transportation, rather than as a hobby or sport). As a result, several key factors are already extensively studied, such as distance and bicycle infrastructure. However, there is a severe lack of research on the role of bicycle equipment in promoting utility cycling. This deficiency is surprising because cycling equipment may significantly affect the comfort, feasibility, safety, and convenience of cycling and, as such, positively impact an individual's choice to cycle.

The same findings are mentioned in the book 'City Cycling' by John Puchner and Ralph Buehler [35]. While the focus has been on infrastructure, for the most part, bike planners have given little attention to the role of bicycle equipment, stating that the 'risk of theft already limits the adoption of improved designs' [35]. In this book, differences in needs when riding for utilitarian purposes are listed. The most interesting are the following: the need to carry cargo or passengers, frequent stops and starts, exposure to theft. These three aspects can be seen as interconnected: while grocery shopping, carrying the groceries by bike is necessary. Furthermore, if multiple shops are visited, the bicycle will be left alone, meaning that both the bicycle and its cargo are exposed to theft.

In conclusion, the security of the bicycle container might be one of the most important aspects to include in its design because the lack of it is limiting the possible uses of a bicycle.

Aerodynamics

When cycling, the cyclist and his bicycle are subject to aerodynamic drag. This aerodynamic drag is present because a body (the system 'cyclist and bicycle'[4]) moves through a fluid (air). Often, the air itself is not static either. This moving air can best be described as 'wind' and can be separated into two vector components: first, there is the wind in the direction of motion (called **headwind** or **tailwind**, depending on the wind direction). Second, there is a component perpendicular to the direction of motion (called **crosswind**) [36]. As a result of these winds, the system 'cyclist and bicycle' is subject to a drag force and a side force, respectively [37].

Aerodynamic drag is a crucial bicycle design element because it is the primary resistance opposed to motion when cycling on level ground (a flat surface) [38].

The following equation describes the resistive force of drag (R_D) for cyclists [39]:

$$R_D = 0.5 \cdot A_p \cdot C_D \cdot \rho \cdot v_f^2$$

Where:

A_p = the combined projected frontal area of the cyclist and bicycle [m^2]
ρ = the air density [kg/m^3]
C_D = the drag coefficient [/]
v_f = the velocity relative to the fluid (= the air through which is cycled) [m/s].

In cycling, two forms of drag are relevant: skin friction and pressure drag [38]. Pressure drag arises from a difference in air pressure between the front and rear of a moving body. The more turbulence behind the moving body, the larger the pressure drag. This pressure drag is mainly dependent on the general shape and size of the body (cyclist and bicycle).

In the above equation, the bicycle-cyclist system aerodynamic's determinant parameter is the effective frontal area, represented by A_p C_D [m^2] [40]. Thus, the most straightforward way to minimise aerodynamic drag is to decrease the frontal area. The bicycle-cyclist system's frontal area can easily be determined by taking a photograph in a frontal plane. Another way to minimise aerodynamic drag is by streamlining the moving object, thus decreasing the drag coefficient. Streamlining essentially means attaching the laminar flow (disturbed by the front of the object) again at the rear of the object. Thus, the (rear) turbulence is what should be decreased as much as possible.

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[4] In physics, a system is a collection of objects that are identifiable. The surrounding is everything else that is not the defined system [77].

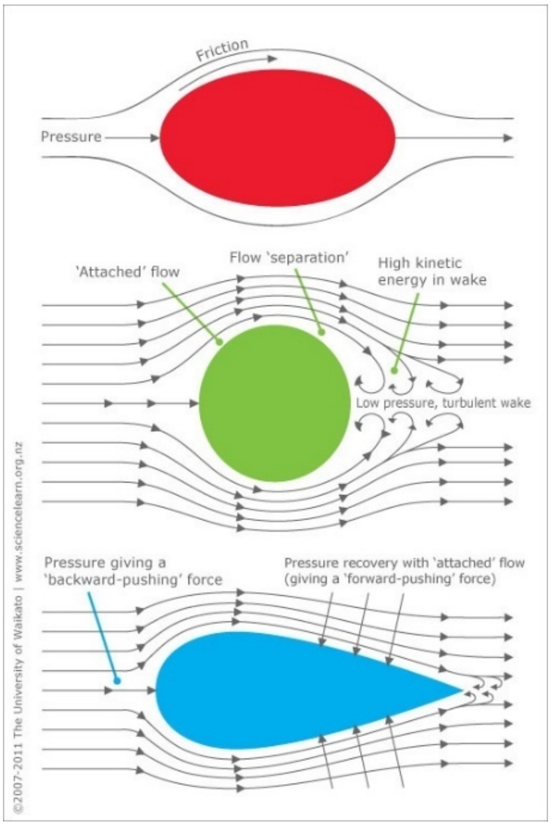


Figure 6: Effect of streamlining (< Cd) on pressure drag (Source: University of Waikato)

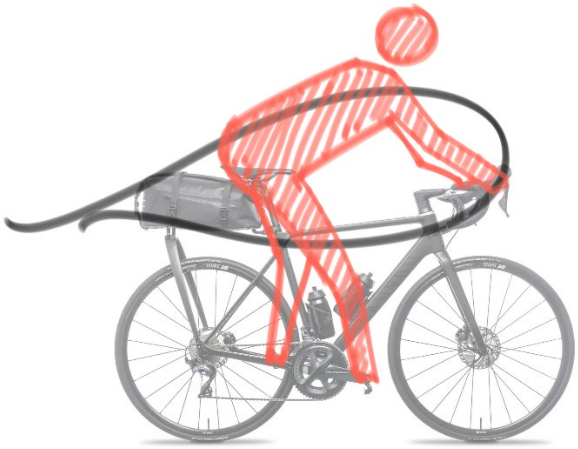


Figure 7: Streamlining by using the Tailfin AeroPack

Tailfin is a producer of high-performance cycling equipment. Not only do they claim their AeroPack is aerodynamic, but it has also been proven. Because the AeroPack makes the 'cyclist and bicycle' system more streamlined, it makes the system 2.5 Watts faster at 25 km/h [41]. How is this possible? This phenomenon is explained in figure 6 and 7: there is pressure recovery by reattaching the laminar flow, essentially pushing the body forward.

As mentioned, the cyclist and bike are not only subject to a drag force but also a side force. The drag force is widely studied, as it is an undoubted performance parameter. The side force that is caused by crosswinds, however, seems to be considered less critical. However, crosswinds can significantly impact a cyclist's performance, stability, and safety [37].

Here, an important term is the yaw angle: the angle the wind makes with the cyclist's direction of travel. Large yaw angles, especially, have a severe impact on the cyclist's stability and should be taken into account while designing bicycles and cycling equipment.

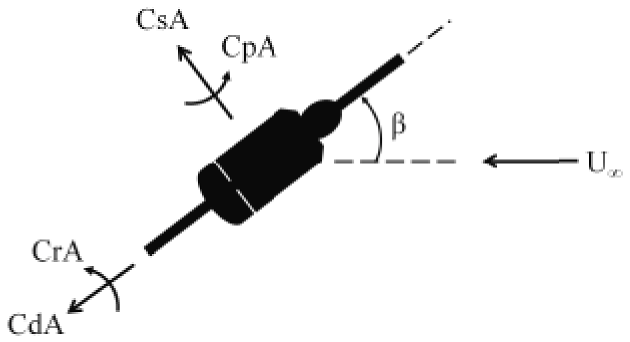


Figure 8: Free body diagram, showing CdA, CsA and CrA, and the yaw angle beta and the wind direction U [37]

There is a strong correlation between the rolling moment coefficient C_rA (figure 8) and the side force coefficient C_sA (comparable to the effective frontal area, C_dA, but for side forces). The rolling moment coefficient is mainly determined by the vertical arm of the side force. In other words, the closer to the ground the lateral area is located, the lower the rolling moment coefficient and the lower the side force coefficient.

Furthermore, at larger yaw angles (up to 90°, very heavy crosswinds), the bike has a progressively larger contribution to the total aerodynamic side force. Therefore, decreasing the bicycle's lateral surface area can reduce roll moments and side forces, increasing safety and stability. However, this decrease in lateral surface area is likely to increase the total aerodynamic drag force.

To conclude: on the one hand, the cargo container should be mounted as close to the ground as possible and have a minimum lateral area to increase safety and stability. However, on the other hand, the frontal area needs to be minimised to decrease aerodynamic drag. In general, the cargo container should be located in line with the bicycle as much as possible to prevent a high increase in the frontal area. At the same time, the lateral area should be kept minimal and as close to the ground as possible. Obviously, a trade-off will have to be made between side forces and drag forces, or put more simply, between battery range and (the feeling of) safety.

Security (removing opportunities)

'The opportunity makes the thief' or 'Occasio furem facit' is a well-known expression. It implies that when the circumstances make stealing possible or easy, an 'decent' person is more likely to do so. Consequently, by just applying some safety measures, most of these potential thieves will be deterred from performing the act of stealing. However, to dissuade a determined thief from stealing can be challenging.

In fact, opportunities play a role in all crime [42]. Furthermore, it has been proven that crime can be prevented by reducing opportunities. Most people instinctively know this. Otherwise, no one would lock their car and house or take any other kind of precaution.

Rational choice theory is a theory that states that "… all action is fundamentally 'rational' in character and that people calculate the likely costs and benefits of any action before deciding what to do" [43]. Four objectives are presented to reduce crime, derived from this rational choice theory: increasing the perceived effort of crime, increasing the perceived risks, reducing the anticipated rewards, and removing an excuse for crime. Each objective has its own set of techniques that are opportunity-reducing. There are sixteen techniques in total [42].

Increase the perceived effort of crime

1. Harden targets
2. Control access to targets
3. Deflect offenders from targets
4. Control crime facilitators

Increase the perceived risk of crime

5. Screen entrances and exits
6. Formal surveillance
7. Surveillance by employees
8. Natural surveillance

Reduce the anticipated rewards of crime

9. Remove targets
10. Identify property
11. Reduce temptation
12. Deny benefits

Remove excuses for crime

13. Set rules
14. Alert conscience
15. Control disinhibitors
16. Assist compliance

Number nine is probably the most often used technique in the context of bicycle panniers and 'cargo containers'. If you want to prevent the theft of a cargo container and its contents, you have to remove it from the bicycle. So the first technique could mean that the cargo container can be locked to protect both its contents as well as the cargo container itself from theft.

Reducing the anticipated rewards of crime could be interpreted in two ways: either the cargo container is made of a solid material, and the thief will not be able to tell if anything is present inside the cargo container. Furthermore, if the pannier is made of a soft material, the thief will see whether or not it is in use, and the anticipated rewards may be more significant. However, a thief's reasoning may also be that the cyclist must use it to transport something valuable because the container is so solid (contrary to regular flimsy cargo containers).

Another valuable insight is found when looking into motorcycle and moped theft. Apart from a lock and a chain, a cover is also a known deterrent for moped thieves. The reasoning behind this is that thieves often 'shop' for particular models. Apart from that, taking off the cover presents a time-consuming obstacle for the thief, and there is no assurance that there are no hidden locks underneath the cover. It is important to remember that thieves are often opportunist and will look for quick and easy objects to steal first [44].

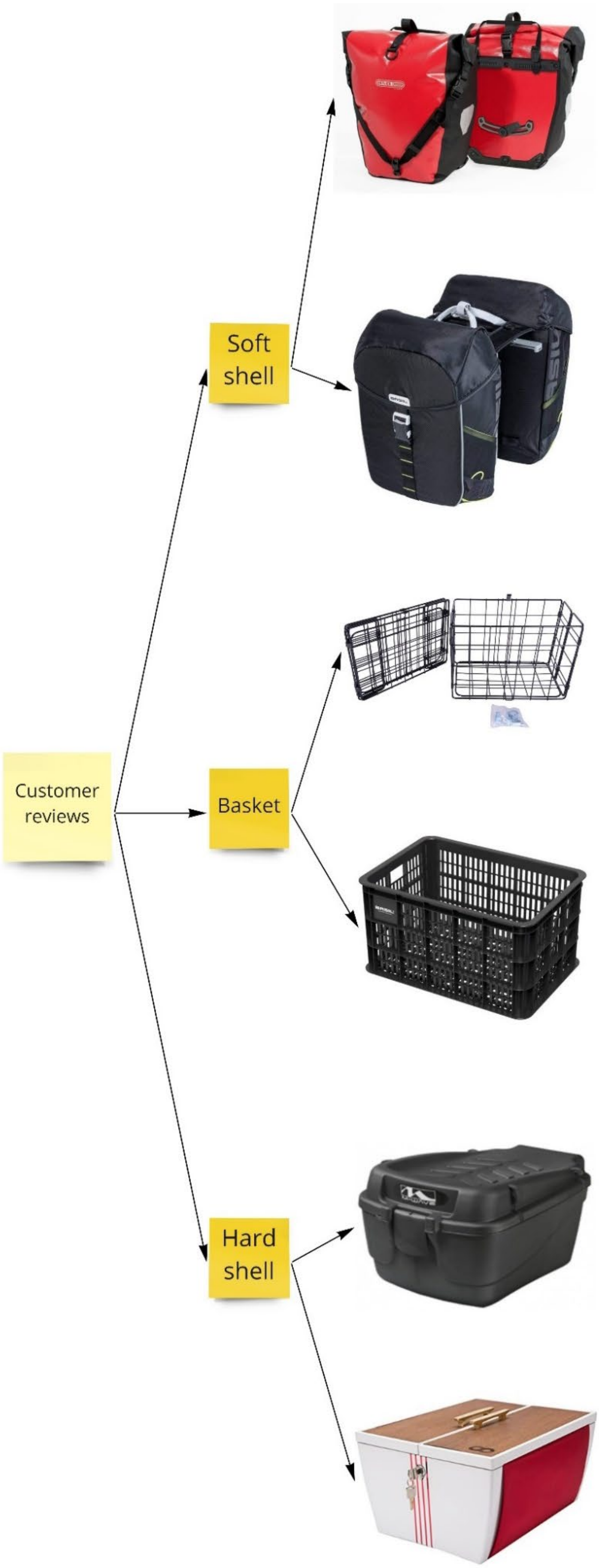
2.2. Understanding the market

Customer reviews

Product innovation is crucial for firms to gain a competitive advantage in the market. However, more often than not, customers are not involved in product innovation processes. Before the advent of the Internet, getting user feedback was no easy task. Currently, however, it is straightforward for users to leave a review online. These user-generated product reviews present a relatively new method of marketing communication and have a word-of-mouth effect [45].

Some reviews of benchmark products found online were used to understand the market and its users better. More specifically, they allowed an initial identification of user needs and frustrations.

The benchmark products, shown in figure 9, were selected randomly (the only requirement being enough online reviews) and categorised into three groups: soft shells, hard shells and baskets. Helpful remarks per product were written as a positive or negative aspect of the depicted product.



Pro:

- "It's perfectly **waterproof**."
- "You can **easily detach them** from the bicycle. This way I **carry the groceries straight inside**."
- "It's **suited for larger items** by **leaving the roll-top open**."
- "It doesn't **rattle**."
- "**Quick-lock system** for **straightforward attachment** to and detachment from the bike."

Contra:

- "It's **not** completely **waterproof**."
- "(About **roll-top access**) It's **not ideal for something like a phone**, but I think that's better suited to a **bike trunk or handlebar bag** anyway."
- "There is **no protection from theft.** Right now I secure these panniers by locking the handles to the rack with a chain lock.

Pro:

- "**MIK system** is very easy to use."
- "Enough storage room for short trips."

Contra:

- "It's **not** completely **waterproof**."

Pro:

- "Inexpensive looking. You can leave these on your bike. I don't think anyone would go through the trouble of stealing them."
- "**When** you're **not transporting cargo**, they stay put tightly and **out of the way**. **Two** baskets is **enough storage** for **one week of groceries**.
- "Very handy for just **dropping your shopping or work bags etc into** with **no fuss**. "

Contra:

- "**Not waterproof** (obviously), but I never ride in the rain so this doesn't bother me."
- "There is **no quick release option**."

Pro:

- "It's **large**. It fits a **well-filled backpack** easily."
- "Always useful to **do groceries** or to put in my bags after shopping."
- "**Not too big** so it **doesn't protrude** too much, unlike some other bicycle crates."

Pro:

- "If there was a **single word** to describe this bicycle trunk, it would be **sturdy**."
- "It's **lockable**. **No more** going out to bars with the girls, while **lugging my helmet around**."
- "... in my case I wanted to **fit waterproofs, bike lock, toolset, and spare tube and tyre**."

Contra:

- "This might **make mounting up harder**."
- "I **won't be adding a lock** as a pair of wire cutters could **easily cut through the plastic bracket."**

Pro:

- "It fits **SO MUCH STUFF**."
- "It makes it easy to carry around my '**just in case' stuff, like a rain jacket, pump, extra tubes**, etc. I just keep it **locked** on my bike at all times."
- "I can **leave everything safely on my bike**."

Contra:

- "It tends to **rattle** on your back rack."
- "You **can't take it** on and **off the bike** at a moment's notice."

Figure 9: Customer reviews of several benchmarks

These results were summarised in an initial identification of customer needs and frustrations:

Needs

- Waterproofing
- Attachability and detachability (straightforward)
- Security (locking)
- Enough volume
- Compact when not in use
- Good quality

Frustrations

- Rattling
- Harder to mount the bicycle

Benchmarking and analysis

While looking into customer reviews of benchmarks, the subject was expanded as much as possible, looking at all kinds of different cargo solutions. Some of the most exciting cargo solutions and the most common ones are synthesised in the brainstorm depicted in figure 10. Brainstorms like these are necessary during the 'Discover' stage to diverge on the topic as much as possible.

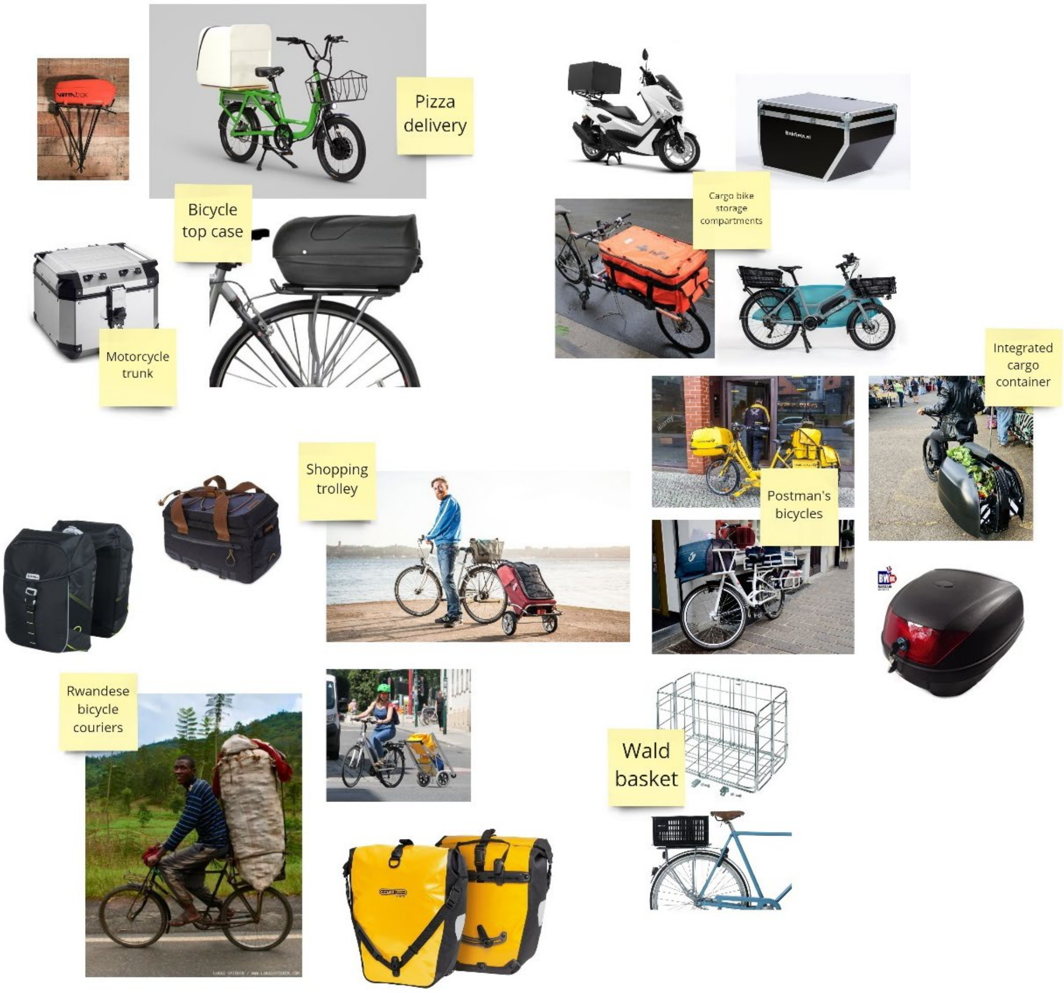


Figure 10: Brainstorm cargo solutions (benchmarks)

Different viewpoints were created by looking into cargo containers for real cargo bikes, scooters, and motorcycles.

In a subsequent stage, five different cargo containers were selected based on 1) their widespread use or 2) the exciting viewpoint they might offer onto this master's research. These benchmarks were then evaluated based on six reasonably objective criteria (ease of use, for example, is left out because it depends on the user: one might find something very convenient while it may appear useless). These initial criteria stem from the customer reviews and personal assumptions and are by no means final. They are represented in radar plots for straightforward interpretation.

The following results were obtained:

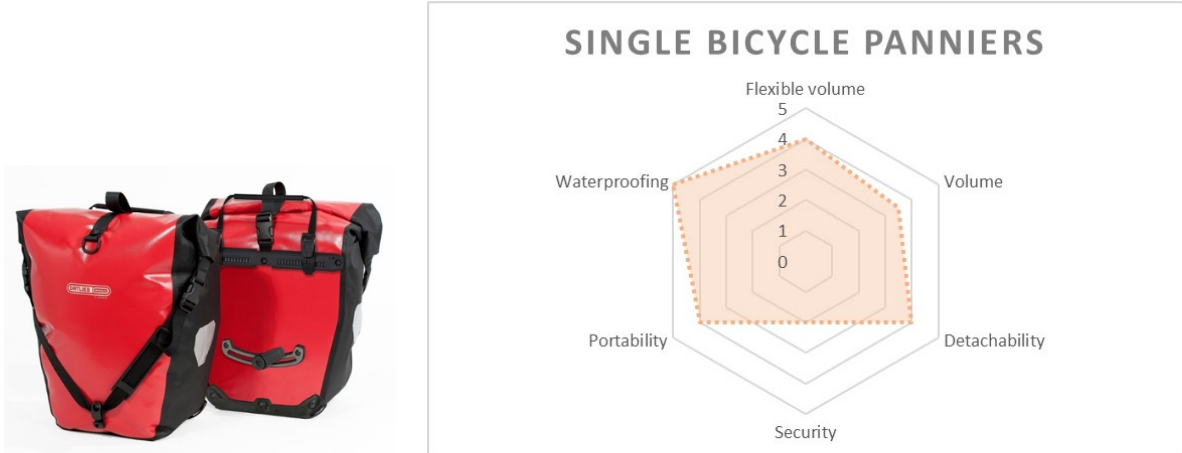


Figure 11: Benchmark 1: single bicycle panniers

The first benchmark was a single bicycle pannier. The model depicted is an Ortlieb Back-Roller Classic. The brand is considered an authority in terms of bicycle panniers – and is widely used by avid cyclists, commuters, tourers, e-bike (and speed pedelec) users. These panniers are entirely waterproof and can easily be attached to and detached from the bicycle's rear rack. Thanks to the roll-top, the volume can be increased when needed. Because the pannier is made from fabric, one is also able to carry oddly-shaped objects. However, neither the bags nor their contents can be easily secured (locked). Portability is quite good, but because the handle is not placed in the centre of the bag, the bottom of the panniers sometimes hits the user's legs.

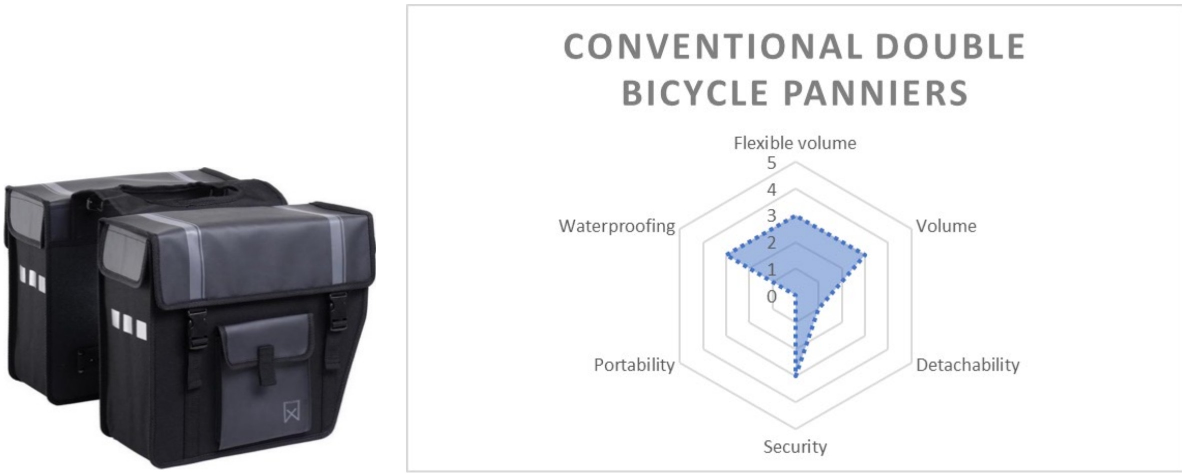


Figure 12: Benchmark 2: conventional double bicycle panniers

The second benchmark was these ‘conventional’ double bicycle panniers. People originally from Belgium or the Netherlands will probably recognise this benchmark as the classic ‘fietstas’. They are still very popular with amateur/leisure cyclists. These are not (easily) detachable, thus also not portable. However, the panniers feature a decent volume, some flexibility in volume, and are usually water-resistant (light rainfall).

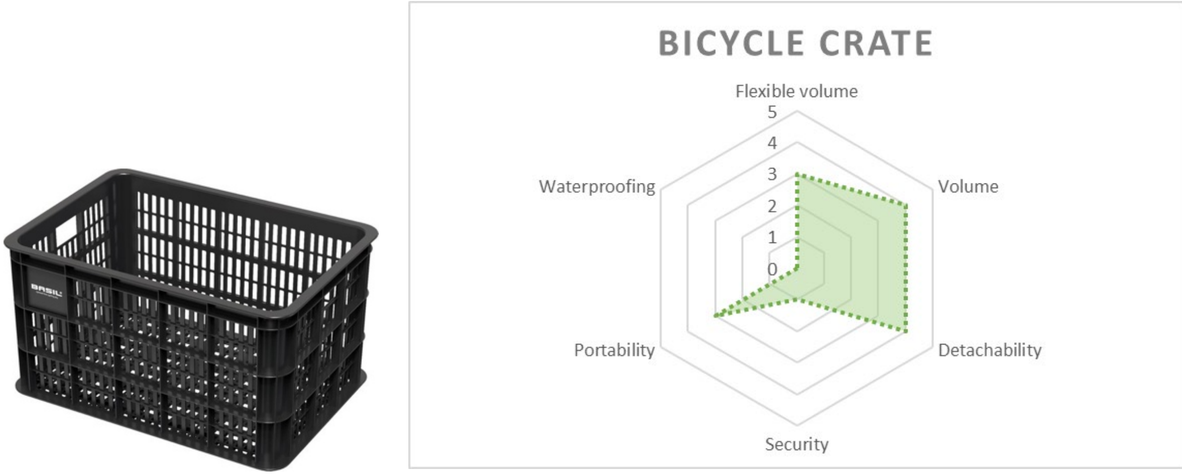


Figure 13: Benchmark 3: bicycle crate

The third benchmark was a bicycle crate (Basil). Usually, this crate is mounted on a front carrier on ‘Dutch style’ bicycles. The bicycle crate is quite portable, easily detached, and can contain a vast (flexible) volume (up to 50 litres) but scores poorly on waterproofing (none) and security (none).

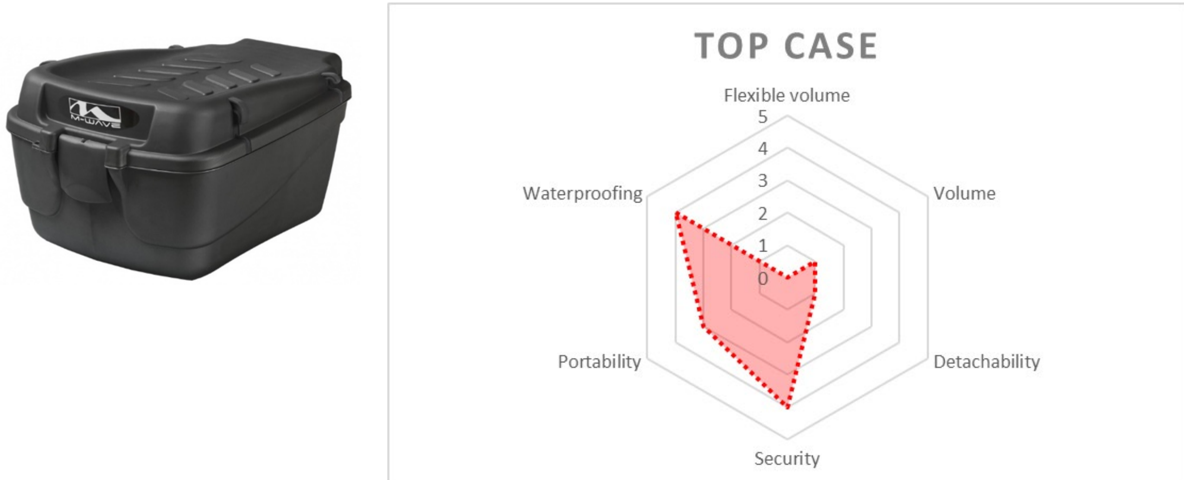


Figure 14: Benchmark 4: top case

The fourth benchmark was a bicycle top case (M-wave). The main advantage of this benchmark is its security. Not only is the top case usually attached to the bicycle rack from the inside, but the cargo container can also be locked, protecting its contents. Because the top case is made from hard plastic, it makes sense to make it lockable (compared to textile: easily cut or torn and more challenging to integrate a lock into).

Figure 15: Benchmark 5: shopping trolley

The final benchmark was an Andersen shopping trolley which can also be attached to a bicycle. This trolley is primarily used on regular bicycles because the stability is not extremely good (there are better trailer alternatives for this). The shopping trolley has some good things going for it: it has a substantial, quite flexible volume, it can be easily detached and attached, and it is very portable. However, waterproofing and security are not optimal, and subjective opinions on the looks are not all positive.

2.3. Storyboarding

Storyboarding is a widely used technique in the film and advertisement industry to pre-visualise a video or animation. However, it is also widely used in product design since it helps the designer to understand the user-product interaction over time and in a specific context [46].

Here, storyboarding was firstly used to empathise with the user by experiencing the visualised interactions. Because the representation is visual, it is straightforward to correct mistakes stemming from the author's assumptions. Users (targeted people and fellow designers) are asked to give remarks and point out inconsistencies. Second, the storyboard is also a reflection tool. It was used in this research to have an accurate, visual overview of the user's actions and their sequence.

Several storyboards were made. The first one was a 'quick and dirty' (low fidelity) storyboard, used to visualise the user journey (red text) and identify some pain points present in the current benchmark (Ortlieb rear panniers – improvements: blue text).

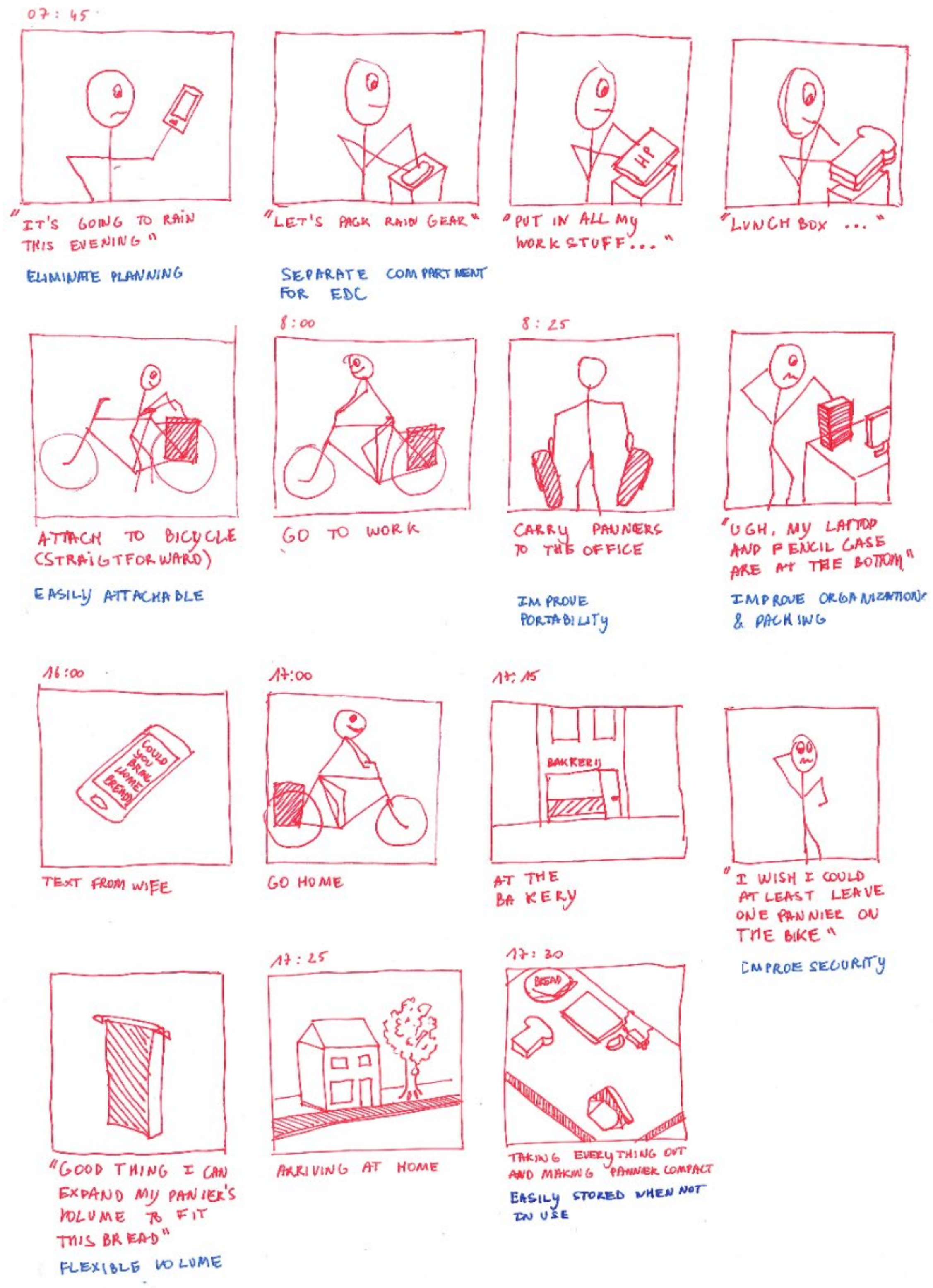


Figure 16: 'Quick and dirty' storyboard: identifying 'pain[5]' points and use sequence

[5] A pain point is a persistent or recurring problem (as with a product or service) that frequently inconveniences or annoys customers [78].

2.4. Survey 1, 2 (&3)

The first survey was directed towards the general public, not specifically targeting e-bike or speed pedelec users nor regular cyclists. The goal of this first survey was to uncover some obstacles which prevent non-cyclists from adopting cycling more. It was also meant to determine the wanted and unwanted aspects of a cargo container. The first survey was distributed on the author's Facebook page and remained open for answers for six days (by then, the interval between responses was more than a day).

The second survey was directed towards speed pedelec users. This survey was similar to the first one but dove a little deeper into the technical aspects of cargo containers because its respondents were assumed to more likely own a type of cargo container already. The second survey was distributed on the Facebook page of Speed Pedelec Vlaanderen. It remained open for answers for three days (by then, more than 200 responses were obtained).

The third survey was directed towards bicycle mechanics. As mentioned in chapter 1.2 (Stakeholders), bicycle mechanics are direct stakeholders who will come into direct contact with the final product. Furthermore, they have a lot of experience and expertise, which may provide valuable insights. This survey was distributed on a Facebook group for bicycle mechanics. It was also sent directly to 25 bicycle mechanics that are found using google maps. Unfortunately, only two bicycle mechanics answered this survey. All the questions asked were qualitative, and none of the responses provided valuable insights. As a result of this tiny sample size, this survey is not included in this master's thesis.

Demographics

Survey 1: There are 30 respondents (n=30), 43.3% is male and 56.7% is female. The mean age is 35.2 ($\bar{x}$=35.2), and the median is only 23 years old (M=23). The standard deviation is 17.0 (s=17.0) [47]. These figures indicate that the population is skewed: more young people filled out the survey than older people.

Survey 2: There are 219 respondents (n=219), 87% is male and 13% is female. These percentages confirm that most speed pedelec users are male [48]. The mean age is ($\bar{x}$=48.7), and the median is 50 years old (M=50). The standard deviation is 10.3 (s=10.3) [47].

Discussion: a cargo container will most likely have to appeal to men in order to be successful.

Means of transport

Survey 1: 73.3% owns a car, 86.7% owns a conventional bicycle, and 26.7% owns an e-bike. Of the respondents, 3.3% owns a scooter or moped, but no one owns a motorcycle or speed pedelec. While regular e-bikes are widely adopted, speed pedelec users are still early adopters.

Survey 2: Among the speed pedelec owners, 87.2% still own a car. Only 7.5% shares a car, and 5,3% does not own a car. The respondents are asked which factors are determinants for taking the car and leaving the speed pedelec. After doing qualitative analysis, it appears that, after comments about the weather, comments related to cargo are made more often. Cargo and the other identified barriers are in accordance with the findings of Van den Steen and Herteleer [23]. Many respondents mention using their car for large groceries and not their speed pedelec because it is more convenient (reasons of stability, wind resistance, and feeling of safety).

Discussion: this quantitative and qualitative data implies no need among current speed pedelec users to do large groceries with their speed pedelec. However, the cargo container should still be sufficiently large to transport small groceries. Furthermore, actual cargo bikes are designed around this large volume, while regular e-bikes and speed pedelecs are not adapted.

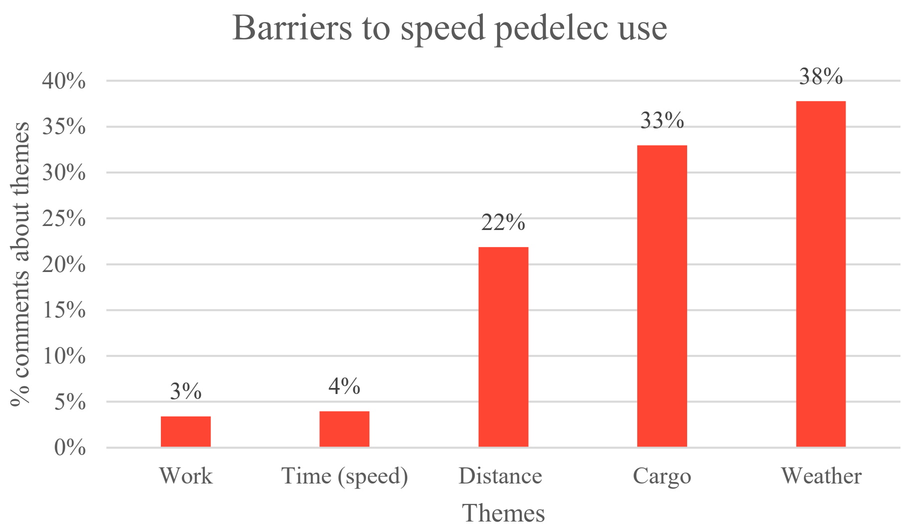


Figure 17: Qualitative analysis: "What factors are determinants for taking the car and leaving the speed pedelec?"

The qualitative analysis is performed using the *Microsoft Excel* software [49]: each comment is read and categorised in separate themes. The themes are created as the qualitative analysis is performed, and this results in 5 separate themes: work, time (speed), distance, cargo and weather. The final percentage per theme is determined by dividing the mention counts for a particular theme by the total number of comments on all themes.

"What do you use your bicycle, e-bike or speed pedelec for?"

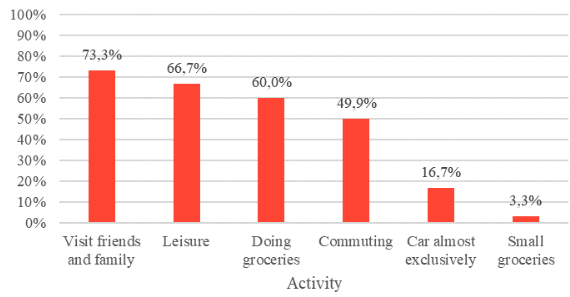


Figure 18: Bicycle and e-bike usage

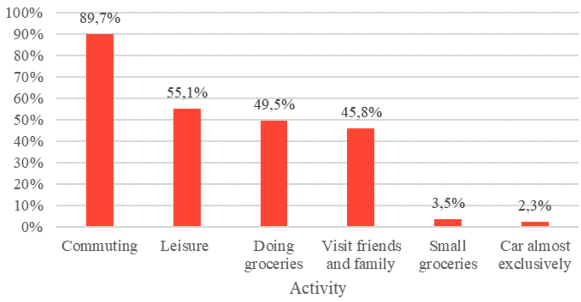


Figure 19: Speed pedelec usage

The results of the survey suggest that the usage of speed pedelecs differs from the usage of regular bicycles and e-bikes. Speed pedelecs are mainly used for commuting (89,7%), while bicycles and e-bikes are used more often for leisure activities (visiting friends and family: 73.3%, leisure 66.7%) than for commuting (49.9%). However, they have in common that they are often used to do groceries. Here again, some people add that they only use their bicycle/e-bike/speed pedelec for small groceries. In conclusion, the cargo container should be easy to use while commuting and enable small (grocery) shopping.

Frequency of use

Comparing the frequency of use of bicycle/e-bike users with speed pedelec users shows that speed pedelec use is more intensive than regular bicycle or e-bike use. The comparison is not entirely valid because other frequency measures are used. However, not one speed pedelec user reported a frequency less than weekly (< once per week), while for regular bicycles and e-bikes, even a monthly frequency is common (26.7%). The speed pedelec data are shown for both males and females because of the population's uneven gender distribution. In general, most male speed pedelec users have a frequency of 5 days a week, while most female speed pedelec users have a frequency of 4 days a week.

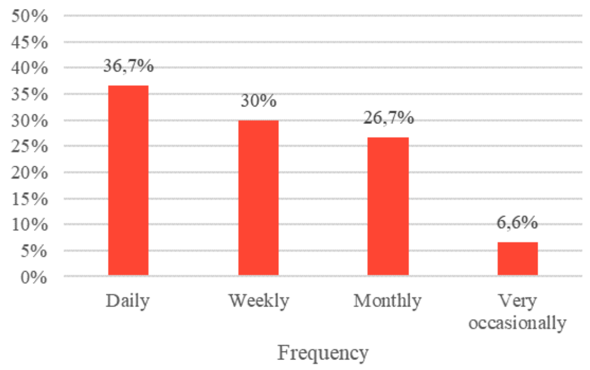


Figure 20: Use frequency: bicycle and e-bike

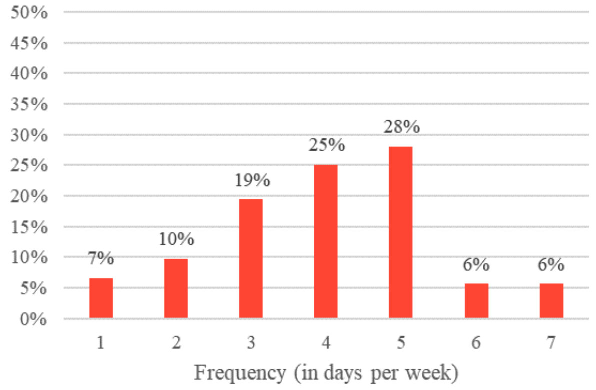


Figure 21: Use frequency: speed pedelec (male)

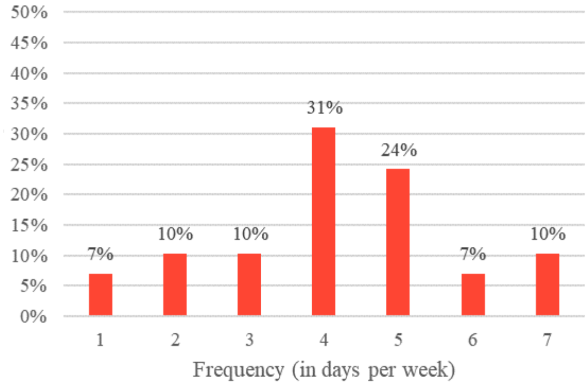


Figure 22: Use frequency: speed pedelec (female)

Supermarket visit

Average volume per supermarket visit

Respondents of both surveys were asked to indicate the volume of groceries bought during an average supermarket visit. Instead of having the respondents indicate a volume in litres, a more practical approach was used: the volume must be expressed in shopping crates or bicycle panniers (both are 33 l in volume).

Figure 23: Shopping crate reference (volume: 33 l)


Figure 24: Bicycle pannier reference (volume: 33 l)

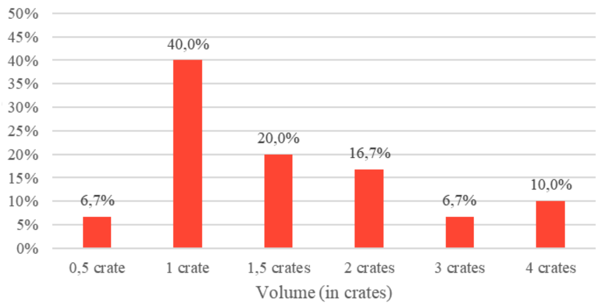


Figure 25: Average shopping volume: bicycle and e-bike

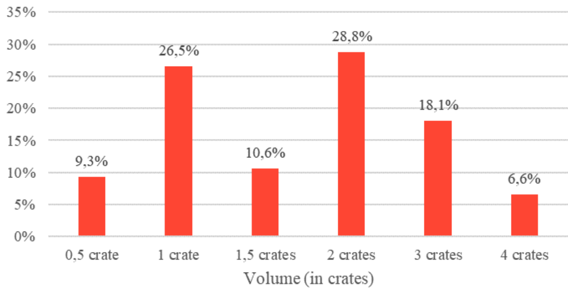


Figure 26: Average shopping volume: speed pedelec

It appears that the speed pedelec users have a higher average shopping volume than the respondents from the first survey. At the very least, one crate or 33 l seems to be the minimum volume. This volume is sufficient for 46.7% and 35.8% of the respondents of the first and second survey, respectively.

The (average) density of the groceries could be estimated using the following formula:

$$\rho_{groceries} = \frac{m_{groceries}}{V_{container}}$$

With $m_{groceries}$ the mass of the groceries (consisting of contents & packaging) and $V_{container}$ the volume of the container, which also includes inevitable air gaps. This average density is estimated by randomly filling a crate with groceries (consisting of both heavy items like tonic water and light items such as a bag of crisps). The groceries weigh in at 16 kg. Because the volume of the container is 33 l,

$$\rho_{groceries} = \frac{16}{0.033}\frac{kg}{m^3} = 484\frac{kg}{m^3}$$

In other words, 1 kg of groceries will take up a volume of about 2 l.

Most bicycle rack manufacturers put a weight limit on their rear racks of 25 kg [50]. Even the renowned rack manufacturer *Tubus* sets a limit of 26 kg on most of their racks because the ISO norm 11243:2016 requires all luggage carriers with a maximum capacity of 27 kg or more to be approved for attaching child seats too [51].

Thus, transporting two crates or 66 l of groceries would be equal to a weight of 33 kg, which is 8 kg more than the upper limit of most bicycle racks. What about one and a half crates? A volume of 49.5 l would translate into a weight of around 25 kg, the upper limit of most racks.

In conclusion, a (very) large volume for the rear cargo containers would be 50 litres, which should not be exceeded. At 1.5 crates, this volume would suffice for an average supermarket visit for 66.7% of the regular bicycle and e-bike respondents and 46.4% of the speed pedelec respondents.

Next, the respondents were asked to indicate their preferred cargo container. The different options were the benchmarks that have already been discussed.

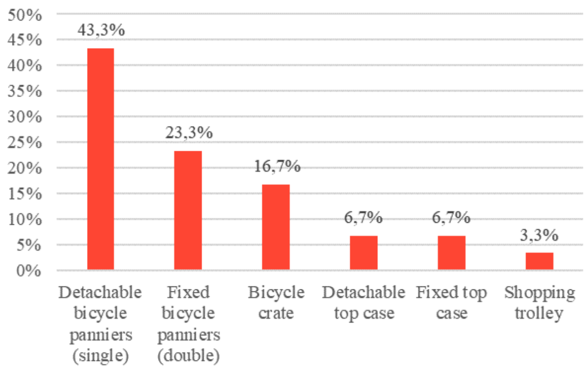


Figure 27: preferred container (survey 1)

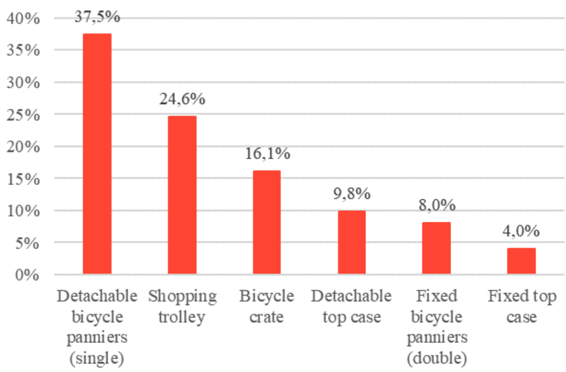


Figure 28: preferred container (survey 2)

There are some similarities and some differences between the results: for most respondents, the single detachable bicycle panniers are the cargo containers of choice. However, the second-best choice differs between the different kinds of cyclists: the regular cyclists and e-bikers preferred the double fixed bicycle panniers, while the speed pedelec users preferred the shopping trolley. Surprisingly, the speed pedelec users seem to dislike the double fixed panniers, and the cyclists and e-bikers seem to dislike the shopping trolley. For both groups, the bicycle crate was the third most preferred option.

The respondents also had to indicate an 'appreciation rating' for each benchmark. The results of the second survey are presented in figure 29.

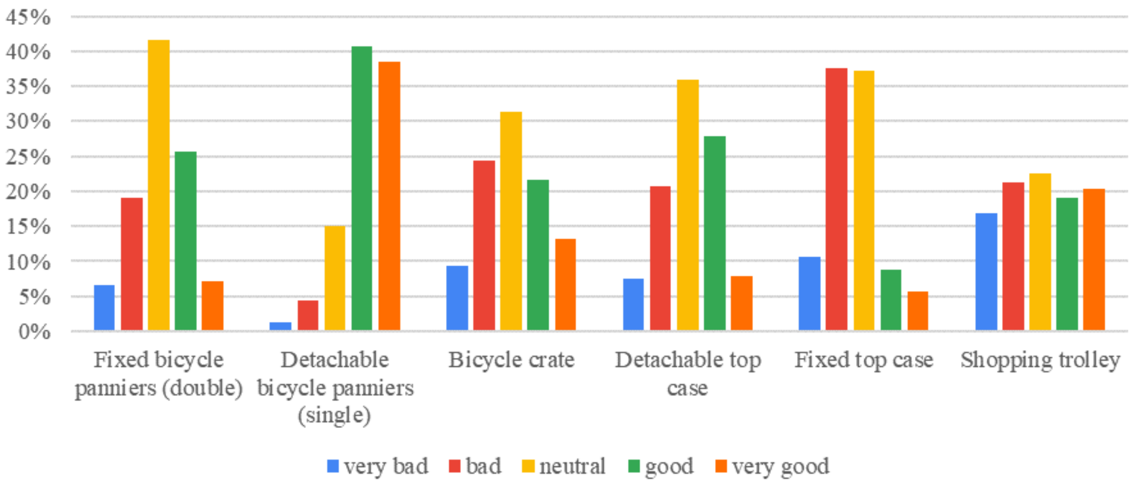


Figure 29: Distribution of benchmark ratings (survey 2)

As can be seen in figure 29, there is quite a lot of variation between the different benchmarks. Firstly, the score distribution of the shopping trolley is more or less flat, meaning many people like this cargo container (very good: scores second best) and many people hate it (very bad: scores worst). The fixed double bicycle panniers distribution is comparable to that of the detachable top case: most people scored these options as ‘neutral’. The fixed and detachable top case results can be compared to get an idea of the importance of detachability, which is the only difference between them. It appears to be essential since the fixed top case scores a lot less than the detachable one.

When looking at the ‘very good’ score, the bicycle crate comes in third.

The ‘winner’ appears to be the detachable single bicycle panniers (e.g. Ortlieb Back Roller). Its distribution is skewed towards ‘good’ (41%) and ‘very good’ (38%).

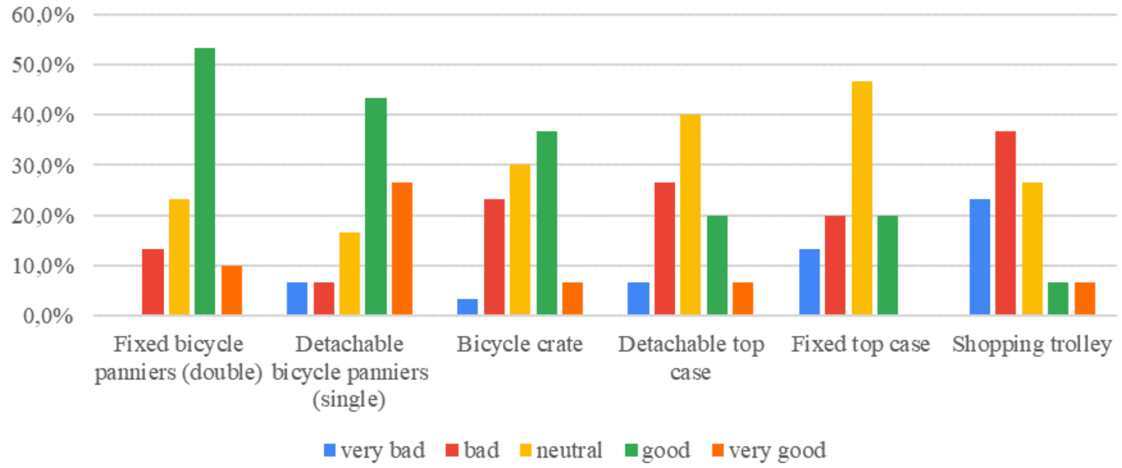


Figure 30: Distribution of benchmark ratings (survey 1)

The distributions for the first survey are harder to read because of the smaller population. Here, the double panniers score much better than in the second survey, and the shopping trolley scores much worse.

The averages are also calculated:

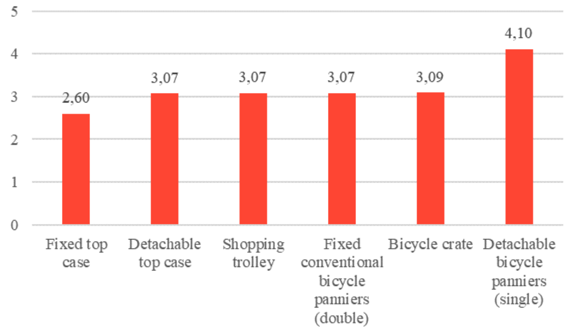


Figure 31: Benchmarks: average (Likert) score (male - survey 2)

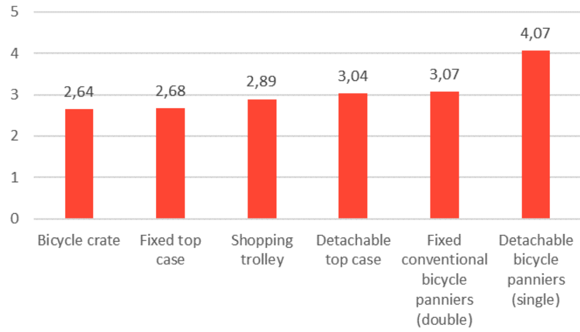


Figure 32: : Benchmarks: average (Likert) score (female - survey 2)

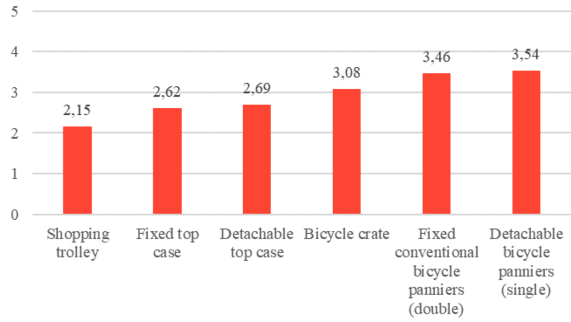


Figure 33: Benchmarks: average (Likert) score (male - survey 1)

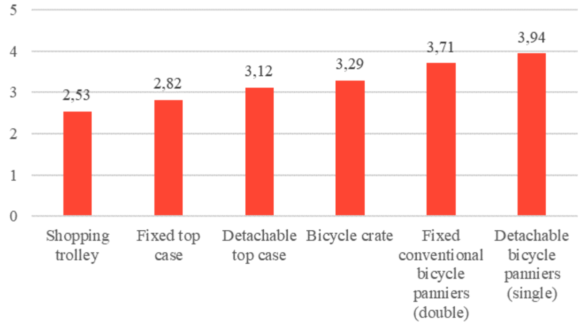


Figure 34: : Benchmarks: average (Likert) score (female - survey 1)

There is a difference between men and women for the speed pedelec users (figure 31 and 32): the bicycle crate comes in second for men (although there is not much difference with the third, fourth and fifth average), but last for women. The respondents were also asked to explain their two lowest scoring benchmarks. As a response, women frequently remarked that they do not like the open bicycle crate because they fear some cargo will bump out. This finding seems to be why this benchmark receives a low score among women. Thus, safety may be a more critical factor for women than for men.

The respondents were also asked to indicate why they prefer a specific solution. Finally, qualitative analysis is performed on these results, and the motivators per benchmark are listed below:

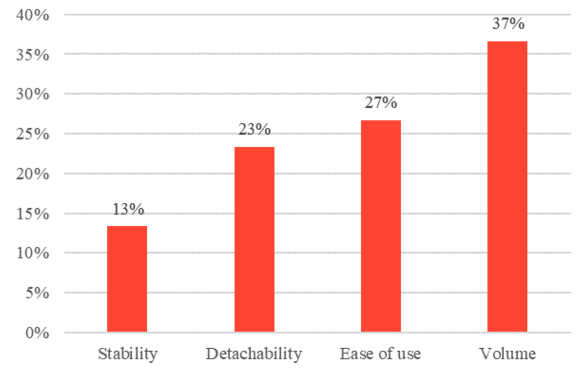


Figure 35: Motivators for choice: shopping trolley

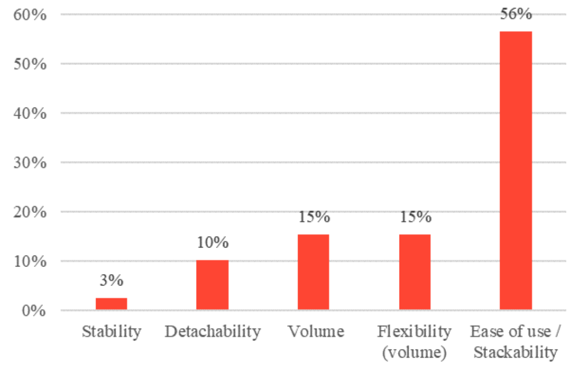


Figure 36: Motivators for choice: bicycle crate

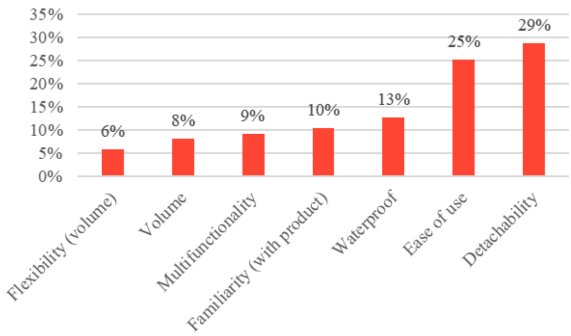


Figure 37: Motivators for choice: detachable panniers (single)

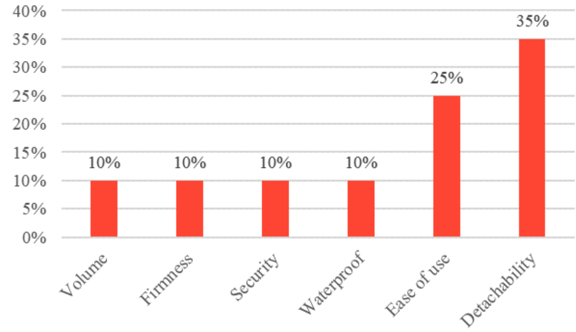


Figure 38: Motivators for choice: detachable top case

The results for the fixed top case and conventional double panniers are omitted because too few respondents indicated them as the best solution. Furthermore, no new themes are discovered for these options (volume, ease of use and waterproofing are mentioned).

A summary of these central themes (motivators):

- Stability
- Detachability
- Ease of use (mostly organisation and attachment)
- Volume
- Firmness
- Security
- Waterproofing
- Multifunctionality (flexible in volume and purposes)

Personal cargo container

This part was only present in the second survey. Its goal was to identify problems with current cargo containers and validate some initial ideas which emerged from the first survey.

The first question tested one of these ideas (all questions were asked in Dutch. Some questions were translated to English for the purpose of this thesis):

“To which extent do you think it would be an added value if you would be able to leave your rain gear permanently (locked) in your cargo carrier – and this way, you do not have to worry about the weather anymore?”

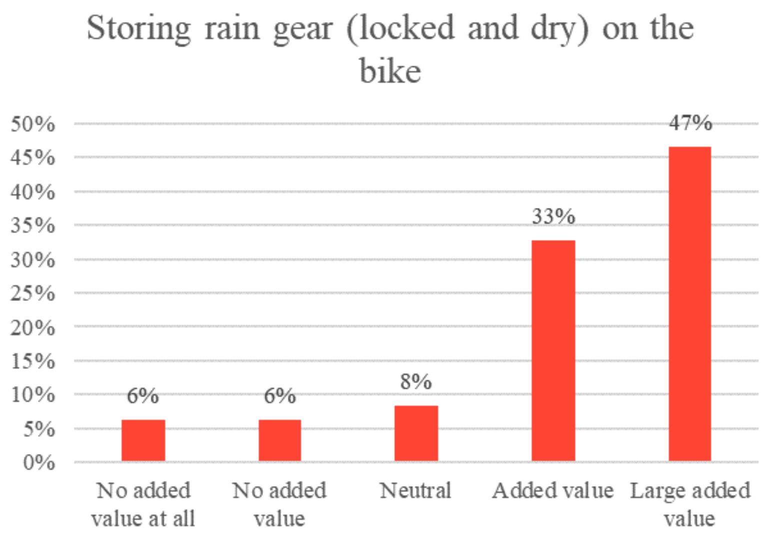


Figure 39: Appreciation of the possibility of storing rain gear (locked and dry) on the bicycle

Thirty-three % (33%) of respondents think this is of added value, 47% even think it is of significant added value. Thus, this function appears to be an unfulfilled need, and therefore, this possibility is a feature that should be included in the final product. Rain gear is an example of everyday carry (EDC). EDC consists of objects someone always has with him or her 'just in case' [52]. Other examples in the context of cycling are an extra inner tube, a multitool, tire levers, or a bicycle repair kit.

Next, the respondents were asked to indicate if he/she owned a 'cargo carrier'. Fifty-nine point seven percent (59.7%) indicate that they do not own a carrier, and 40.3% indicate that they do. It seems not many people use a kind of bicycle panniers, which is surprising because the speed pedelec is mainly used for commuting. Most people carry some (light) cargo while commuting, so this would mean the majority of respondents uses a backpack and not a cargo container attached to the bicycle. After processing the qualitative questions, it appears that a mistake has been made: the term 'cargo carrier' has not clearly been explained, and many respondents think this is the same as a bicycle trailer. 'Cargo carrier' is meant as a general term for anything used to carry cargo by bicycle, such as a top case, a single pannier, a basket. After receiving these results, the term is changed to 'cargo container', which is closer to its actual meaning: an object meant to 'contain' bicycle 'cargo'. A better explanation was provided when taking interviews and surveys in the remainder of this thesis.

The first question tried to uncover improvements or changes the respondents would make to their current cargo container or persuade people to buy one. The respondents were also asked to indicate their current cargo container. The following comments are the most interesting.

Improvements or changes (**users already in possession of cargo container**)

- (Owns: two detachable Ortlieb bags) "In some circumstances, it would be helpful that the panniers are 'fixed' to the bicycle, and only I could remove them. Content security would also be helpful. Right now, **one pannier is used for storing rain clothes**, and this one could always **remain on the bicycle** if it could safely be **secured**."
- (Owns: one snap-on backpack, one snap-on pannier) "For the pannier, a combination **lock** would be helpful. I can fasten the pannier to the bicycle, but it can be opened, and inside I am storing **expensive rain clothes**."
- "I miss **useful compartments**!"
- (Owns: Vaude pannier) "I would apply more **fluorescent patches** and separate compartments to store everything.
- (Owns: fixed cargo container) "I use it to store **rain clothes and repair tools**."

- (Owns: single bicycle pannier) “I would like to **be able to open my pannier more** so that I could pack everything in a more **organised** way.”
- “I think a good idea would be a **U or H-shaped Samsonite-like container** (with **wheels** and **a telescopic handle**) which slides over your rear rack and snaps onto it… **Robustness, reliability and ease of use** are the keywords here.”
- (Owns: Ortlieb panniers) “**Sturdiness and hardness** are completely missing.”
- “A **lock**, both on the **cargo container itself** and **between container and bicycle** (container fixed to the carrier). “
- (Owns: Vaude panniers) “A **fixed lock** would be of added value, as well as an **extra compartment for storing, e.g. rain gear** (right now, I am storing this at the bottom in a plastic bag).”
- (Owns: Ortlieb panniers) “The most significant improvement would be to add a **sturdy lock** to **prevent theft of the rain gear** which is now stored in the panniers.”
- (Owns: Vaude) “I would like to be able to **put my regular backpack in the cargo container**. This way, I would not have to move all its contents to the pannier every time I am commuting by bicycle.”
- (Owns: Vaude panniers) “I would prefer it to be fully lockable, but this does add weight. Vaude panniers are **tapered towards the bottom**, which is **not always helpful while doing groceries**, but it IS **waterproof**.”
- (Owns: single bicycle panniers) “My panniers do not have **a decent handle**, so I would like something to **transport** them more easily.
- “A system **to lock** to the bicycle. Now I am using a small bicycle lock, but this is not **convenient**.”

Improvements or changes (users not yet in possession of cargo container)

- “**Straightforward** and **decent protection** against **theft**.”
- “A **low centre of gravity**, be easily detachable, easy to take into a shop (confer **carry-on luggage**) and lockable.”
- “The possibility to take off the lid? I am thinking about, e.g. **large vegetables like leeks**, which usually does not fit into a closed (hard-shell) cargo container.”
- “The container should be at the same time spacious and compact (**foldable**?), easily **detachable** and at the same time **safely secured** to the bicycle. In addition, its **walls should provide protection** (not solely be made out of webbing).

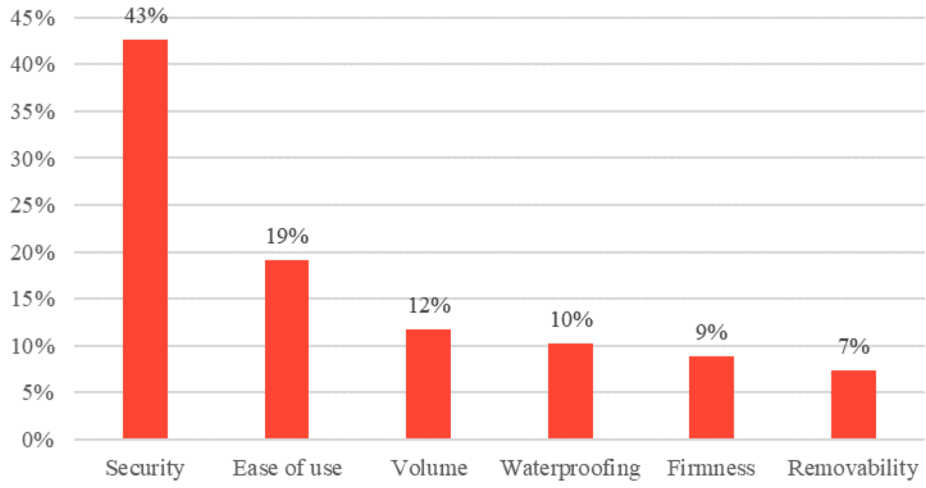


Figure 40: Areas of improvement for existing cargo containers

When the respondents were asked to indicate areas of improvement for their current cargo containers, it became clear that the security of the containers is the areas that can still be improved most (43% of comments on possible improvements was about security). As a result, the customer need "The cargo container and its contents are protected from theft" was considered one of the main focuses of this thesis.

The next question is: "what do you do with your helmet whenever you are not cycling?" Sixty-five point nine % (65.9%) of respondents indicated taking the helmet with them, and 16.5% indicated leaving the helmet in their existing cargo container. Finally, the last 17.6% of respondents wrote an answer themselves. Some of these answers can be categorised into the first two groups. Others provide some interesting insights.

- "I lock my helmet to my bicycle with **a regular bicycle chain lock**."
- "I hang my helmet on my handlebars, but in doing so, it is **always wet when it rains**!"
- "I put it on my handlebars (the helmet is not expensive, and I do not have enough space in my panniers, and it could **easily be stolen** if I did put it in my panniers)."

The same question is asked to those not in possession of a cargo container but in a purely qualitative way. Again, some interesting remarks:

- "The helmet would belong in a **locked case** together **with rain gear**."
- "Is suspended by a hook in the bicycle shed. I **keep it on while doing grocery shopping**, which is **not a pretty sight**!"
- "I take it with me, **attached to my backpack**."

Next, the respondents were also asked to value being able to leave their helmet on their speed pedelec while locked and kept dry.

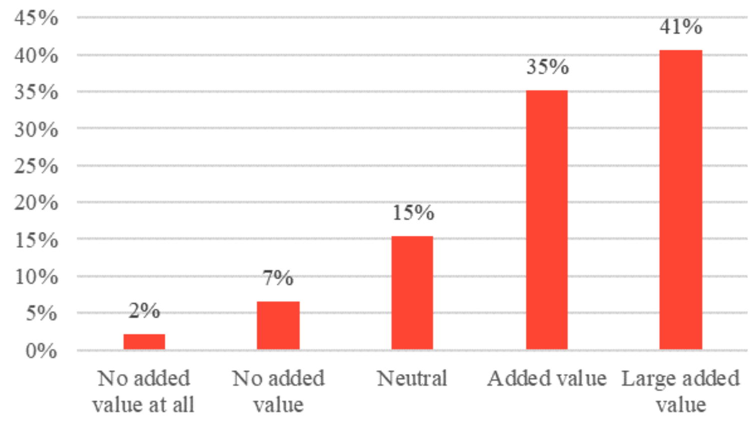


Figure 41: Appreciation of the possibility of storing one's helmet (locked and dry) on the bicycle (in possession of cargo container)

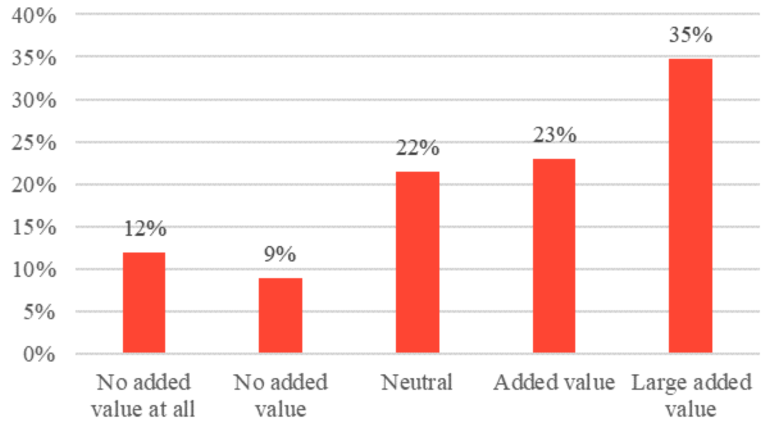


Figure 42: Appreciation of the possibility of storing one's helmet (locked and dry) on the bicycle (not in possession of cargo container)

These results are slightly less optimistic than storing rain gear, but significant nonetheless: this would be a good feature for most people.

Final remarks

Finally, the respondents (of both surveys) are asked if they have any final remarks.

- "No remarks. I am happy about my bicycle panniers. On the one hand, I own a set of Ortlieb Back Rollers (large volume, flexible, the disadvantage is that you **cannot put them down in a practical manner**). On the other hand, I own an Ortlieb Office, which is more rigid and can easily be positioned like a suitcase."
- "Good luck! It is an important matter because transport possibilities/solutions can **determine the choice of bicycle** or brand!"
- "In the Netherlands, you often see **baskets and bags at the front of the bicycle** and the handlebars. I do not have any experience with that, but it is probably **handy**: telephone, access badge, bottle holder."

3. Define

3.1. Identifying user needs

Raw data has to be gathered from users to identify their needs. Usually, interviews, focus groups, or observing the product are commonly used methods to collect this data [19]. However, all these methods are best conducted in person, which is deemed impossible considering the current covid-19 circumstances (see limitations, chapter 8). Alternatively, the raw data is gathered from the qualitative questions asked in survey 1 and survey 2.

These qualitative questions were processed as follows: each customer remark was jotted down on a post-it note. Different colours of post-it notes were used for each survey. As suggested in Ulrich & Eppinger, these were formulated as: a like, a dislike, or a suggestion for further improvements [19].

When a like, dislike or suggestion had already been mentioned in the exact same way, no new post-it note was written. However, when the like or dislike resembled a previously identified need but had a different nuance, this was added as a new post-it note.

The collection of likes, dislikes, and suggested improvements were then grouped into several primary and sub-primary needs. The term 'sub-primary needs' is used here instead of secondary needs because these are simply primary needs that belong to a bigger, more general need. There is no hierarchical difference between the primary and sub-primary needs. In figure 43, the dark yellow post-it notes are the primary needs, and the purple-blue post-it notes present the sub-primary needs. The teal (blue-green) post-its notes are the likes and dislikes mentioned in the first survey. The green post-it notes are the improvements suggested in the second survey, and, finally, the light yellow ones are the likes and dislikes mentioned in the second survey.

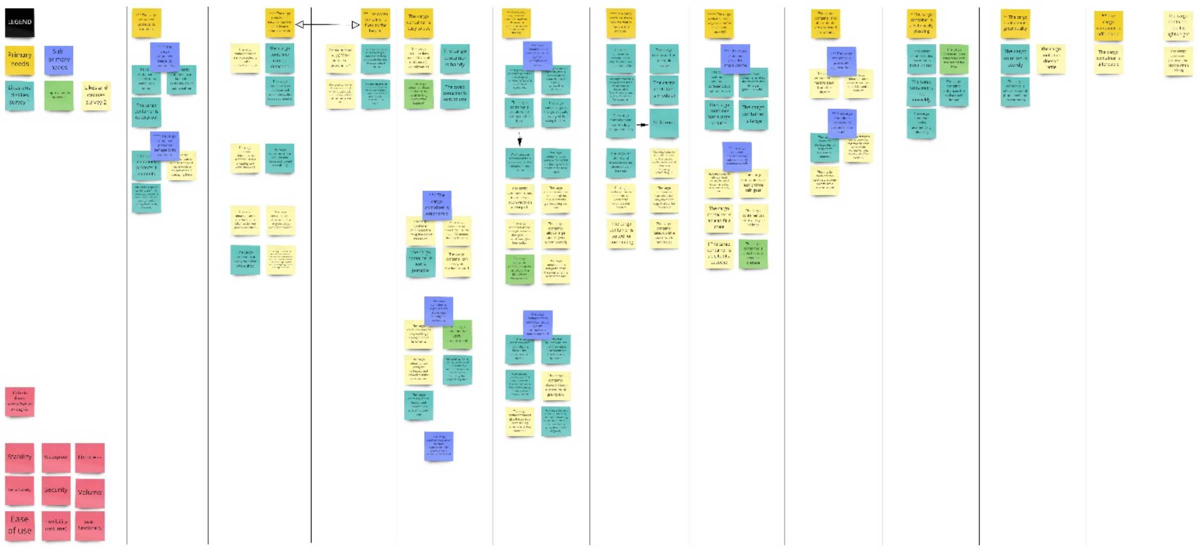


Figure 43: Customers' likes, dislikes and suggested improvements grouped into primary and sub-primary needs

The identified user needs are the following:
(The needs are rated on a three-star (asterisk) scale: user needs with three stars (***) were the most important ones, followed by those with two stars (**), and user needs with one star (*) were considered less relevant. The needs are ordered randomly.)

1 The cargo container protects its contents

   1.1 The cargo container keeps its contents dry (**)

   1.2 The cargo container prevents damage to its contents (***)

2 The cargo container is easy to attach to and detach from the bicycle (**)

3 The cargo container is fixed to the bicycle (*)

4 The cargo container is easy to use

   4.1 The cargo container is ergonomic (***)

   4.2 The cargo container is organised and allows easy loading and unloading (**)

   4.3 The cargo container provides a separate compartment for everyday carry, which can be locked (***)

5 The (loaded) cargo container does not negatively influence the cyclist's perception of safety and stability.

   5.1 The (loaded) cargo container does not influence the cyclist's perception of safety (**)

   5.2 The loaded cargo container does not influence the cyclist's perception of stability too much (**)

6 The cargo container has a volume that is flexible and modular (**)

7 The cargo container has a sufficiently large volume (at maximum capacity)

   7.1 The cargo container provides ample volume (**)

   7.2 The cargo container provides enough volume to carry commonly transported object (*)

8 The cargo container and its contents are protected from theft

   8.1 The cargo container is protected from theft (***)

   8.2 The cargo container protects its contents from theft (***)

9 The cargo container is aesthetically pleasing (**)

10 The cargo container is of good quality (**)

11 The cargo container is affordable (*)

An important note about need 4.1 is that 'ergonomic' denotes the physical ergonomics of the product.

3.2. Identifying product specifications

The identification of customer needs is helpful to develop a clear sense of the issues the user is confronted with and should be resolved by the final product. However, customer needs are expressed in the 'language of the customer' and typically have a subjective quality, e.g. the cargo container is 'affordable'. What may be affordable to one person might be too expensive for another.

For this reason, product specifications are identified. These product specifications are measurable statements about *what* is required from the product. A specification consists of two parts: a value, and a metric. The literal definition of a metric is "a system for measuring something" [53]. Thus, in this case, that means a *measurable* statement. The value is then the *actual numbers* that accompany this metric and is labelled with the correct *unit*. The value can be written in several ways, e.g. with a specific number, an inequality or a range [19].

Preparing the list of metrics

A careful analysis of the user needs has led to the metrics depicted in figure 44.

Metric No.	Needs Nos.	Metric	Importance	Units
1	1.1	Quantity of water and dust entering the cargo container according to IEC/EN standard 60529. (Ingress/International Protection Code)	**	IP rating
2	1.2	Impact testing	**	
3	2	Time to attach cargo container to bicycle	**	s
4	2	Time to detach cargo container from bicycle	**	s
5	3	Is fixed to the bicycle	*	True/false
6	4.1	Is ergonomic (physical ergonomics)	**	Subj.
7	4.1	Handle width	**	mm
8	4.1	Cargo container height	*	mm
9	4.2	Time to find and take out a specific item	***	s
10	4.2	Time to (partially) unload while on the bicycle	**	s
11	4.2	Time to (partially) load while on the bicycle	**	s
12	4.2	Time to (partially) unload at the office or at home	***	s
13	4.2	Time to (partially) load at the office or at home	***	s
14	4.2	Is organised	***	Subj
15	4.3	Provides a separate everyday carry compartment	**	True/false
16	5.1	Ensures a feeling of safety	***	Subj
17	5.2	Centre of gravity of the system 'bicycle and cyclist'	***	mm (X-Y coördinates)
18	5.2	Weight distribution front/rear wheel	***	%
19	6	Possible increase in volume by 'expanding' the cargo container	*	%
20	6	Possible increase in volume by adding parts	**	%
21	7.1	Acceptable volume range of cargo container system	**	l
22	7.2	Able to transport commonly transported objects	**	Subj.
23	8.1	Minimum time needed to steal the locked cargo container	***	s
24		Minimum time needed to steal the locked cargo container's contents	***	s
25	8	Perceived attractiveness to thieves	**	Subj.
26	9	Aesthetically pleasing	**	Subj.
27	10	Material toughness	**	J/m^3
28	11	Product selling price	*	€
29	12	Mass container / volume container	*	kg/l
30	12	Total mass	*	kg

Figure 44: Product specifications

Collecting competititve benchmarking information and setting target values

Table 1: IP rating and its meaning

IP rating		
First characteristic numeral	 X 0 1 2 3 4 5 6	Against ingress of solid foreign objects: Not required (Non-protected) ≥ 50 mm diameter ≥ 12,5 mm diameter ≥ 2,5 mm diameter ≥ 1,0 mm diameter Dust-protected Dust-tight
Second characteristic numeral	 X 0 1 2 3 4 5 6 7 8	Against ingress of water with harmful effects: Not required (Non-protected) Vertically dripping Dripping (15° tilted) Spraying Splashing Jetting Powerful jetting Temporary immersion Continuous immersion

One of the first metrics that needs a target value is the waterproofing of the cargo container. The IP (Ingress/International Protection) Code is a standard that rates the protection against water and dust. The IP code is denoted with 'IP XY', where X and Y are the protection levels against dust and water, respectively [54]. These levels are indicated in the table shown above.

An online search for benchmarks with an IP rating was performed, leading to the following results:

Table 2: Benchmarking IP rating

Brand and model	Basil Urban Dry	Ortlieb Back-Roller (City)	Thule Shield Pannier	Vaude Aqua Back
IP Code	IP X3	IP 64	IP 64	IP 64

Many different brands claim that their panniers are waterproof but often do not back this up with an IP rating. This phenomenon raises some questions about the trustworthiness of these brands, and more importantly, it is an indication that the panniers might be just water-resistant and not waterproof. The brands that are very serious about their product's waterproofing all provide the same IP 64 rating (dust-tight and resistant to water splashes). This rating can probably be classified as 'waterproof' in real-life conditions (it is unlikely that a pannier will be jetted down). Only one manufacturer, Basil, provides another rating, IP X3 (No dust rating and protected against water sprays), which is lower than the IP 64 rating. Bicycle commuters often have to cycle in the rain, so the target requirement is set at an IP 64 rating.

Next is the time to attach the container to or detach it from the bicycle. This metric was hard to determine as it is not a specification that can be easily found online. As a solution, many promotional videos that show the attachment system were watched and used to determine this duration. On average, the well-engineered attachment systems (Vaude, Ortlieb, Arkel) take about 5 to 10 seconds to attach to the bicycle firmly. More 'basic' attachment systems (e.g., simple plastic hooks and velcro) can take up to 30 seconds to attach. As a result, a target requirement for this metric is set at about 5 – 15 seconds.

The handle and its dimensions are some of the most significant elements that influence the physical ergonomics of the product. The width of the handle should be wide enough to fit most people. In Belgium, the average width of the hand is 83 mm. To be sure, the 'holdable' part of the handle should be at least 99mm wide. This way, the handle will be wide enough for 99% of Belgium's inhabitants [55].

The next set of metrics concerning loading, unloading and organisation of the cargo container's contents was hard to quantify. A standardised test (every time the same items) should be executed with several users and for different cargo containers to gather the data needed for this metric. As this seemed cumbersome, a target value is not specified for these metrics.

Again, the target specifications for the location of the centre of gravity is much work to calculate. So instead, simple reasoning is used to rate one option over the other. The target weight distribution front/rear wheel is set at 1/3 of the weight on the front wheel and 2/3 on the rear (see later: chapter 4.1 Ideation, section weight distribution & load placement).

An increase in the volume of the cargo container system can be achieved in two ways: by adding extra containers or by increasing the volume of the existing container. There are different types of cargo containers, which have different expansion possibilities. Some of the original cargo container benchmarks were examined. The first benchmark, double bicycle panniers, may seem expandable because it is made of fabric, but this benchmark does not offer much flexibility or modularity in reality. These panniers often retain their shape pretty well, resulting in a volume about the same empty vs filled (one advantage: the top flap can be left open if necessary). Furthermore, because they are attached, the volume cannot be increased or decreased through modularity.

The second benchmark, Ortlieb panniers, can be very compact when not used because only the rear is made of a rigid material. Next to this, the user can add a second pannier to double the maximum volume if wanted.

The last benchmark, the top case, has no flexibility whatsoever: it is impossible to increase or decrease its volume.

In conclusion, the Ortlieb bags possible expansion of the Ortlieb bags is about 70% of its empty volume, of the Double panniers about 20% and the top case, 0%. Therefore, a target expansion value of about 20% to 40% seems feasible. The target for expansion through modularity is set at 100% (adding a second container).

Figure 45: Benchmark: double panniers

Figure 46: Benchmark: (Ortlieb) single panniers

Figure 47: Benchmark: top case

The difficulty of stealing both the cargo container and its contents are the metrics that determine how theft-proof the cargo container is. Again, a target value is hard to determine for this metric. Looking at the benchmarks in figures 45, 46 and 47, there are some differences. The double bicycle panniers are hard to steal since they are usually (semi) permanently attached to the rear rack with, e.g. velcro. Basil uses the MIK system for double panniers. This system protects the cargo container against occasional thieves. However, the 'key' used to unlock the double panniers all used the same elementary key, and this system is mainly used on inexpensive panniers.

Figure 48: Basil MIK adapter plate and simple key

Figure 49: Ortlieb anti-theft device for QL2.1 bags

An anti-theft device for Ortlieb panniers can be bought separately but is cumbersome to use. Only the top case provides *some* security to its contents: it is usually bolted to the rear rack and often features the option to attach a padlock.

In conclusion, most bicycle cargo containers have a severe lack of theft-proofing and slowing down the thief, say 30 seconds, would already be a significant improvement.

3.3. Personas

A persona is a tool to provide "… abstractions of groups of real customers who share common characteristics and needs" [56]. A persona represents the group target users as an actual, specific person, which is fictitious. A persona can take on different shapes, but they all have specific benefits in common. The most significant advantage of using personas is that they help focus the product's design on the target customer's actual needs and wishes. The increased focus on the customer helps overcome the gap between consumers and designers and challenges some of the designer's assumptions. Furthermore, it helps prevent the designer from referring to himself while designing by constantly considering and involving the actual end-user [57].

A study on the benefits of product design sums it up nicely: "Products that satisfy 100% of the needs of a few personas will have a great chance of success than products that serve 10% of the needs of the all-encompassing 'everyone' [53] ."

During this master's research, the personas were used as a tool to communicate the target audience more clearly with stakeholders. Furthermore, the author used the personas to keep the end-user in mind and refresh what was important about the target audience.

"Over the last few years, I am getting more and more fed up with being stuck in traffic. That's why I am considering buying a speed pedelec. As an engineer, time efficiency is essential to me."

Marc Vanneste

- Age: 50
- Work: Project Engineer at TEN Kortrijk
- Family: Wife Riet and two children, Lotte & Jacob, who are university students
- Location: Moorslede (commute: 25.4 or 23.1 km one way, depending on route)

He is looking to buy a speed pedelec, but has doubts about cargo transportation possibilities:

- He often leaves items in his car, which is not really possible on a speed pedelec out of fear of theft.
- He has used bicycle panniers in the past, but feels like their lack of organisation makes taking out specific items at work difficult.
- He takes his work laptop home and is afraid of damaging it (and losing files) in case of a fall.
- Thinks bicycle panniers are too flimsy and do not 'look good'.

He wants to buy a speed pedelec because:

- He is tired of being stuck in traffic, especially because time efficiency is essential to him.
- He wants to clear his head before and after work, but cycling to work is not an option because he lives too far away.

Wants from a speed pedelec cargo container:

- Protection of his laptop.
- Safety of the container's contents.
- Robustness and solid appearance.

"I own a Gazelle Grenoble e-bike I frequently use for commuting. However, I often fall back to using my car because some functionalities are just missing."

Kathleen Vandamme

- Age: 46
- Work: Bank clerk at Belfius Gullegem
- Family: Husband Bart and three children: Tim, Tom and Liese. Tim is already in university, but Tom and Liese are in their final years of high school
- Location: Heule (commute: 4.1 or 4.5 km (single) depending on route)

She thinks current cargo containers are:

- Not suited for doing multiple stops. When returning from work, Kathleen often stops at the local bakery, butcher and supermarket. However, she does not want to take her work items with her but cannot leave them on her e-bike out of fear of theft.
- Too broad, which often makes her feel unsafe when crossing or overtaking other cyclists.
- Not convenient enough. She used to have a front basket on her old bike but misses the same accessibility and extra storage on her e-bike.
- Often not waterproof, unless one buys the Ortlieb or Vaude bags, but she does not like the aesthetics of those.
- Not well-attached to the rear rack: the weight often shifts in the panniers, and the hooks are not solidly attached. These aspects give Kathleen a feeling of instability.

Wants a better cargo container because:

- She feels like some of her trips are perfectly doable by bicycle, but the negative aspects of current cargo containers make her use the car more often than she would like.

Wants from an e-bike cargo container:

- Security: preventing theft of the cargo container or its contents.
- Durability without making the cargo container too expensive.

3.4. Problem decomposition methods

Most frequently, problems are decomposed using a functional **decomposition** method. Here, black boxes are used, between which material, energy and signal flows are present. Another method is to decompose the problem by key customer needs. This method is mainly used for products where form (and not working principles or technology) is the main problem. Finally, a problem can also be decomposed by using user journey mapping, a (visual) representation of the user's steps while using the product [19].

User journey mapping (sequence of user actions)

The method used here is problem decomposition by sequence of user actions. This method seems ideal since the product is not highly technical but requires a lot of user interaction.

Looking back at the research question: "How can sustainable commuting behaviour be stimulated by designing an e-bike specific cargo container?", what exactly is the main problem here? The problem is that e-bikes and speed pedelecs have evolved from regular bicycles but still use their original bicycle equipment. This changing context provides a crack in the door for innovation, so the lack thereof is a pity.

Some of the changes in the context are the following:

First of all, the price: the price of a speed pedelec is relatively high. The price of most e-bikes is in the range of €1.500 - €3.000 [58], and the price of most speed pedelecs even varies between €4.000 and €6.000 [59]. However, the average price of a traditional bicycle is a lot lower, at around €400 [60]. In addition, an average cargo container (40 l) costs about €100. Putting things in perspective, this means that the ratio cargo container/bicycle is about one to four. Now, taking that same cargo container (€100), this only consists of 1/22ths of the average e-bike and 1/50ths of the average speed pedelec. In conclusion, the average e-bike or speed pedelec user will likely be willing to pay more for a cargo container, provided that this container does feature improved functionality.

Secondly, weight is also less of an issue: the weight of an e-bike is relatively high. Most e-bikes weigh between 24 and 28 kg, battery included (speed pedelecs even more than that). In comparison: most traditional bicycles weigh between 14 and 21 kg [61]. Furthermore, not only do e-bikes already weigh more, but the pedal-assist also ensures that this extra weight is hardly noticeable. Hence, the weight of the cargo container itself is less critical than on a regular bicycle, where extra weight is transported solely by the power of the cyclist.

In general, two different use cases are possible in the context of cargo containers. In the first, the cargo container remains attached to the e-bike or speed pedelec at all times. In the second, the cargo container can easily be detached from the e-bike or speed pedelec. These use cases can be represented schematically, as shown in figure 50.

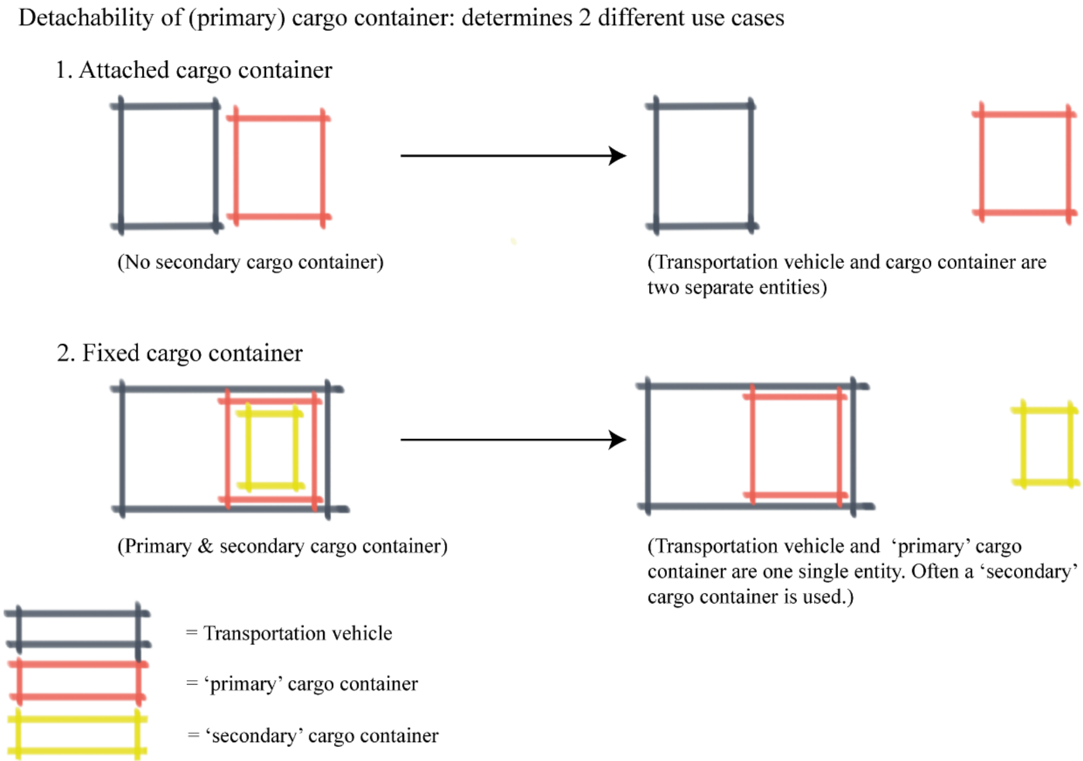


Figure 50: Schematic representation of different use cases

The schema is drawn in the following way: every rectangle represents a specific entity. If a rectangle is inside of another (larger) rectangle, it is a part of it. For the first use case, the cargo container is attached to the bicycle rack, but it is still a separate entity as it can be detached easily and is not an integral part of the bicycle.

The second use case is different: here, the primary cargo container is an integral part of the bicycle (not easily detached). Therefore, only a secondary cargo container can be removed from the bicycle. It can also be noticed that the use case for the fixed cargo container is very similar to the use case of transporting cargo by car. In the case of the car, the primary cargo container is the car's trunk, and the secondary cargo container could be anything from a shopping crate to a backpack or suitcase.

As mentioned in the literature review, habit is the strongest predictor of behaviour [28]. In essence, this use case does not change regular car users' habits (when transporting cargo by car), enabling a smooth transition from car to e-bike or speed pedelec.

However, there are also several significant differences between the car and the fixed cargo container: First, the volume of the car trunk is a lot larger than the volume of the cargo container. The car trunk of a Volkswagen Golf, for example, has a volume of 380 litres [62]. On the other hand, regular double bicycle panniers have a volume of about 40 litres. Safe to say, this difference is enormous.

Second, the car trunk is an integrated entity, meaning that by no means it could be detached from the car itself. On the other hand, the fixed bicycle cargo container is usually not an integrated entity. In most cases, it is attached to a rack and can be detached somehow, although equipment might be needed for this.

Third, The car trunk can be locked. However, the fixed cargo container usually cannot be locked unless it is in the form of a hard-shell top case.

User **journey maps** are made for three different scenarios to decompose the problem into sub-problems. This decomposition is done both for the car (similar to a fixed bicycle cargo container) and for the detachable bicycle cargo container (single bicycle panniers). For simplicity, locking the cargo container is left out because it is already identified as a sub-problem.

The first scenario is considered the 'base' scenario. Here, differences are indicated between the two types of containers. For the second and third scenario, differences within a specific cargo system are indicated. In particular, the first scenario describes a situation where the displacement only happens between two points: departure point A and arrival point B. Hence, there is only one destination. The second scenario describes a situation where the displacement happens between a departure point A and an arrival point B. However, there are also intermediate stops (e.g. C, D, E). During these stops, no luggage from the cargo container is needed nor added to it. Finally, the third scenario presents a variation to the second scenario: luggage is added at one or multiple intermediate stops. (A more readable version of this user journey mapping can be found in appendix 10.2)

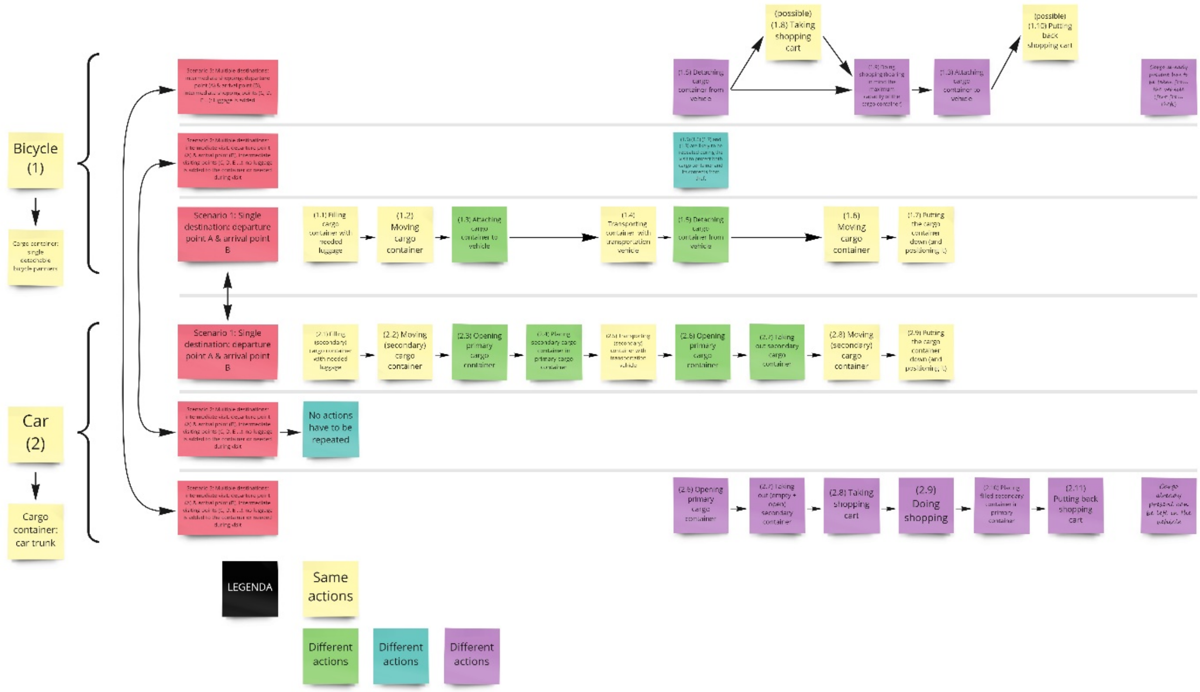


Figure 51: Problem decomposition through scenarios and user journey mapping

This problem decomposition through user journey mapping uncovered several problems. First, the car's advantages over the e-bike had to be reduced through the cargo container. Second, there are also some advantages of the e-bike that could be highlighted through the cargo container.

User journey mapping also helped to make some of the problems stated in the introduction (planning and security) more tangible and prove that they are indeed problems that would increase the versatility and convenience of the e-bike and speed pedelec.

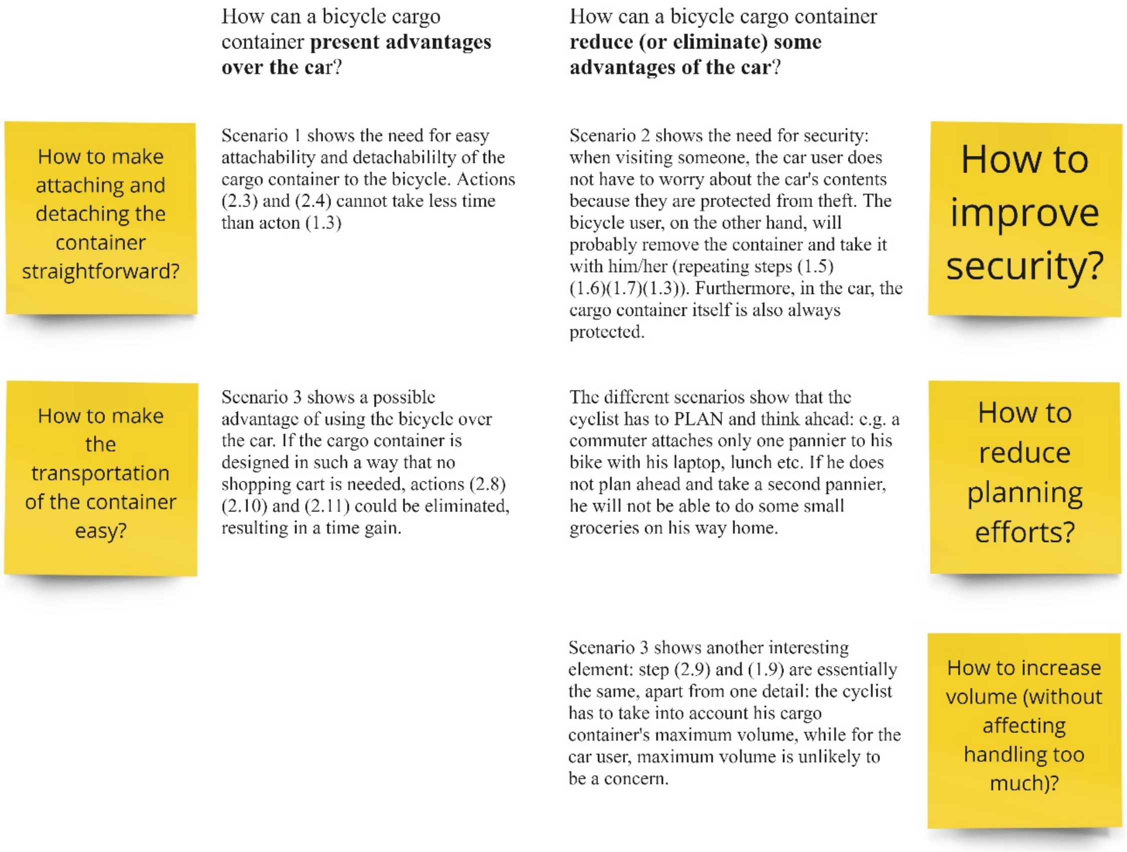


Figure 52: Further identification of problems (car vs e-bike)

4. Develop

4.1. Ideation

The ideation is meant to explore different possibilities and ways to fulfil a specific user need. The most used ideation methods in this master’s thesis are sketching, prototyping and CAID (Computer-Aided Industrial Design).

Some remarks about the prototypes: prototypes can be classified along two different dimensions. The first dimension is about the extent to which a prototype is analytical as opposed to physical. While physical prototypes are tangible artefacts, analytical prototypes are represented in a non-tangible, usually mathematical or visual, manner. The second dimension is about the extent to which a prototype is comprehensive as opposed to focused. A focused prototype is meant to test one or a few elements of the final product. However, a comprehensive prototype implements most if not all the attributes of a product [19].

For each of the depicted prototypes, their classification is specified.

Ideation is a process that belongs best in the ‘Develop’ stage. However, it also happens in other stages of the design process. Below are some ideation sketches that are already produced in the ‘Define’ stage. These sketches are quick representations of an idea that has come to mind and might be used in later stages.

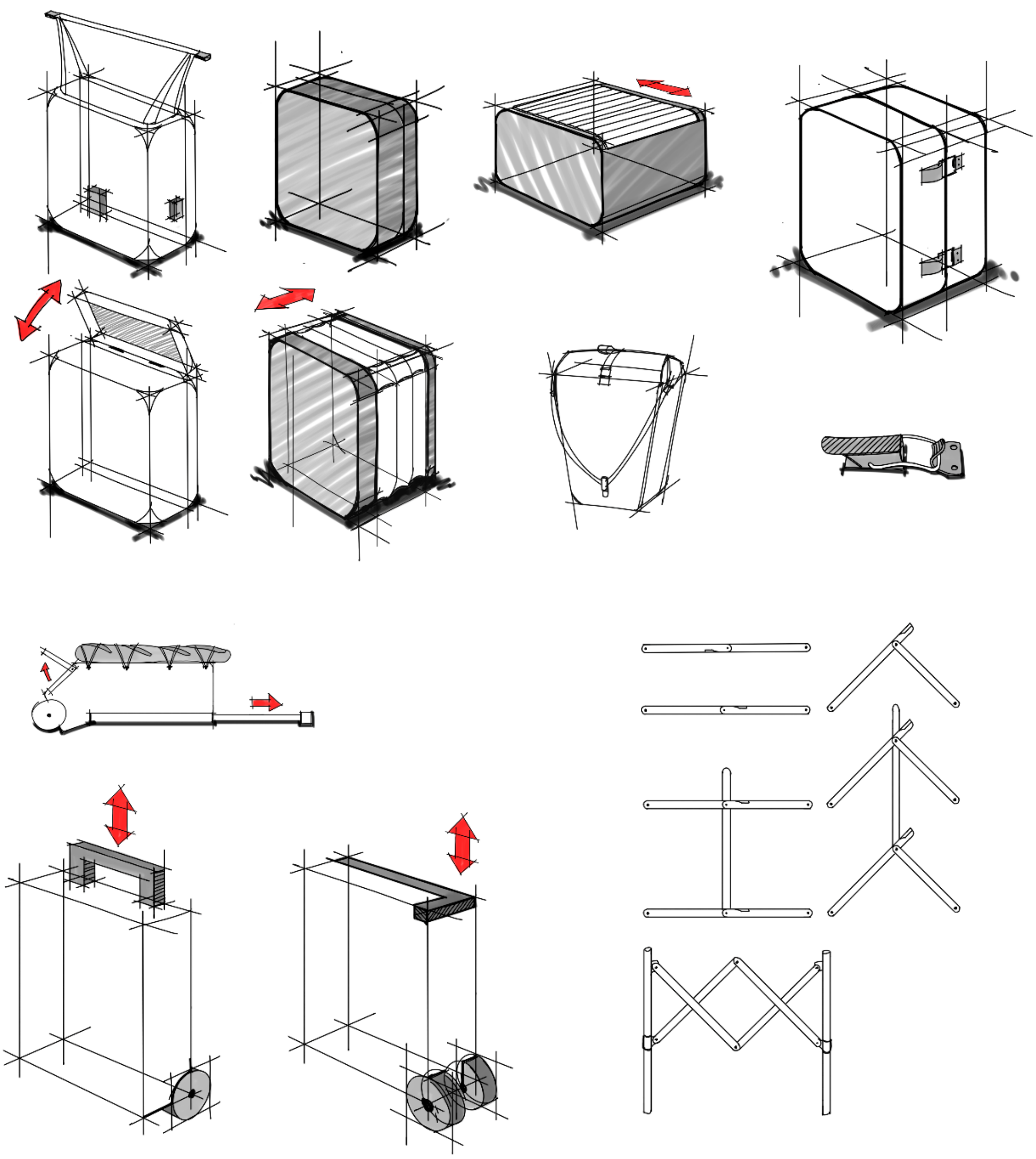


Figure 53: Initial sketches from previous phases (Discover and Define), mainly about expandability and trolley function

Weight distribution & load placement

There is not a consensus about the ideal weight distribution on a bicycle. Some say 50/50 front/rear distribution should be maintained. Others say 55% of the weight on the rear, and 45% of the weight on the front is ideal [63]. According to Lennard Zinn, a renowned bicycle technician, frame builder and tech writer, 2/3 of the weight on the rear wheel and 1/3 of the weight on the rear wheel are more realistic numbers and are satisfactory [64].

Concerning weight distribution, it is helpful to look into bicycle touring guidelines: it is good to maintain the same weight distribution of around 60% rear and 40% front for the carried cargo. Furthermore, carrying too much weight on the bicycle is dangerous because the bicycle's handling could be upset. The front of the bicycle is a lot lighter relative to the back, and this can cause it to be almost uncontrollable (oversteering), especially over rough roads [65].

Along with the weight distribution issue, there is also the question about cargo placement. First of all, the weight should be located as close to the ground as possible, explained in figure 54.

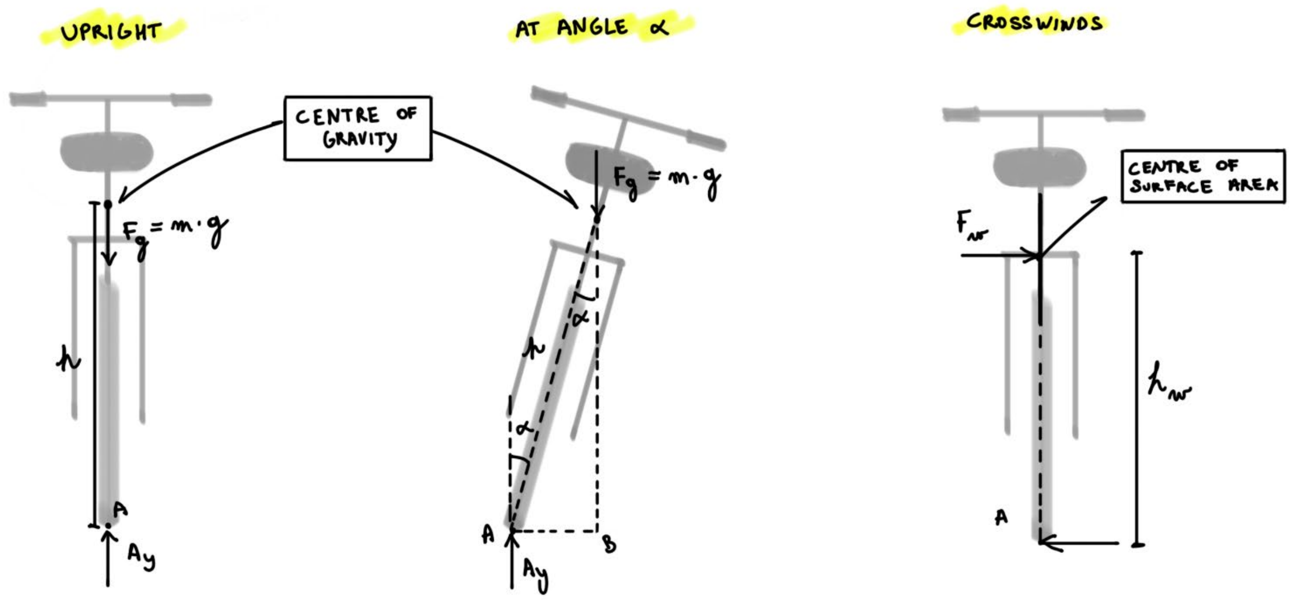


Figure 54: Effect of the centre of gravity and the centre of side surface area on stability

In its simplified form, it comes down to the following: when the bicycle is leaned at an angle α, the centre of gravity is no longer directly above the wheels, and a moment arm M_A is formed. To keep the bicycle upright, the rider (unconsciously) counteracts this by steering into the lean.

The moment arm is calculated.

Calculating AB:

$$\sin(\propto) = \frac{AB}{h}$$

$$AB = \sin(\propto) * h$$

Calculating the moment around A:

$$M_A = m * g * \sin(\propto) * h$$

In conclusion, the moment arm increases as the mass of the system bicycle/rider/load, the height of the centre of gravity, or the lean angle α increases. Thus, for the transportation of fixed weight, this moment arm will increase as the height of the centre of gravity increases.

The moment arm needs to be minimised as much as possible because it wants to increase the lean angle α and essentially tries to tip over the bicycle.

Furthermore, there is another reason why the cargo containers are best placed close to the ground: the aerodynamic side forces (mentioned in the literature review) provide an additional moment arm around A (figure 54):

$$M_A = F_w * \ h_w$$

Finally, placing a cargo container high up on the bicycle will negatively influence the stability because of the high centre of gravity. It is also more dangerous than a low-placed cargo container in (heavy) crosswinds, which can be even more dangerous due to the unpredictable nature of wind.

First, the options can be arranged in ascending centre of gravity:
Option 5 < Option 1 < Option 3 < Option 2 ≈ Option 6 < Option 4.

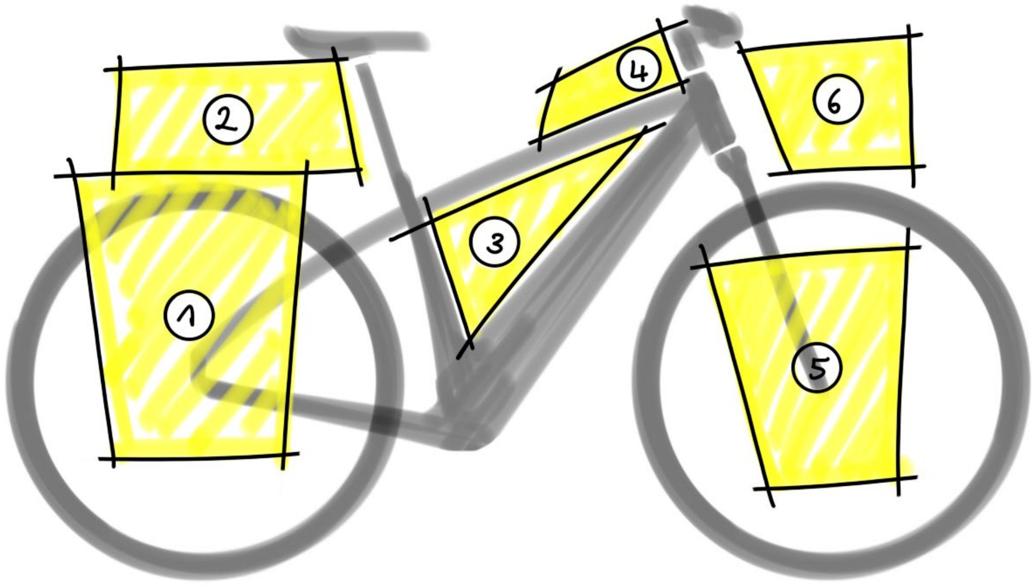


Figure 55: Cargo container placement possibilities

Second, the aerodynamics of the different options are considered. In this context, it is helpful to talk about bikepacking and bicycle touring aerodynamics. Bikepacking is "the synthesis of all-terrain cycling and self-supported backpacking" [66] and is very similar to bicycle touring. However, primarily, it differs in the terrain: when bicycle touring, the terrain is mostly paved roads, while for bikepacking, the terrain can be much more diverse. Furthermore, panniers and racks tend to rattle on rough roads, and ground clearance is necessary.

As a result, the cargo is attached to the frame differently by bikepackers than by bicycle tourers. For example, on a touring bike, panniers are most used, both front and rear (option 1 and 5), while bikepackers use several smaller containers, more in line with the bicycle (option 2, 3, 4 and 6). Because these containers do not protrude as much, the frontal area is kept minimal, and so is the aerodynamic drag.

The different options can be arranged in sequence of increasing aerodynamic drag [67] [68]:

Option 2 (*) < Option 3 ≈ Option 4 < Option 6 (**) < Option 5 ≈ Option 1
(*) Possibly even decreases the aerodynamic drag, as mentioned
(**) Only slightly less aero than option 3 & 4

As mentioned in the literature review, drag forces and side forces are essential in aerodynamics. Thus, the effect of side force should also be quantified. Some assumptions are made: lower on the bike = better, larger volume/side surface ratio = better. The options are scored from one to five, with one being worst.

Option	Placement score	Volume/side surface score	Total score
1	4	5	9
2	2	3	5
3	3	1	4
4	1	1	2
5	5	5	10
6	2	4	6

Thirdly, the different options can also be rated regarding their ease of attachability and detachability, in ascending order of ease:

Option 1 < Option 2 (*) < Option 5 (**) < Option 6 (**) < Option 4 < Option 3
(*) Provided that this cargo container is mounted on top of a rear rack and not attached to the saddle.
(**) This sequence is open for discussion, as it depends on how the cargo containers are attached to the bicycle. In general, removing something from the front is probably harder when parking the bicycle in a bicycle storage facility.

The cargo containers can also be categorised according to the weight distribution front/rear.

Table 3: Weight placement

Option	**Front/rear/centred**
1	Rear
2	Rear
3	Centre
4	Centre
5	Front
6	Front

Other elements worth noting: the third option, the ‘frame bag’, is highly dependent on the bicycle's geometry (frame triangle). Hence, the frame bag has to be tailored to the bicycle’s frame, and with e-bikes and speed pedelecs, this location is often already used to store the battery. Furthermore, on ladies’ bikes, there is no ‘triangle’.

Figure 56: No frame triangle on ladies' (step-through) bicycles (source: Gazelle)

Figure 57: Frame triangle is used for battery storage (source: Klever)

Another important note is about the fifth option: attaching the cargo container to the front fork. E-bikes and speed pedelecs often have sprung front forks and are not suited for attaching a load onto it. Therefore, mounting the cargo container in the sixth location is also impossible when using sprung forks unless the container is attached to the bicycle’s frame. Furthermore, if the weight is attached to the front fork, it must be evenly distributed to prevent dangerous handling.

Lastly, as can be deducted from questionnaires 1 and 2, the first option is currently the most frequently used option on e-bikes and speed pedelecs.

Table 4: Average weighted score load placement

Option	Aerodynamic drag (/5)	Aerodynamic side force (/5)	Centre of gravity (/5)	Detachability (/5)	Average weighted score (/5)
1	2	4.5	4	5	3.95
2	5	2.5	2	4	3.15
3	4	2	3	1	2.5
4	4	1	1	2	1.8
5	2	5	5	3	4
6	3.5	3	3	3.5	3.2

The average score is weighted, with the aerodynamic side force and centre of gravity weighting 1.5 and the others weight 1. This, because the stability of the e-bike or speed pedelec is considered the most crucial factor.

Looking at these results, placing the cargo container in the first (most used) position makes much sense, as it also scores second-best by a tiny (3.95/5 vs 4/5) difference.

The third and fourth option does not score very good (the third option is not even an option for the reasons mentioned above). The fifth option scores best, but attaching a load to the fork of an e-bike or speed pedelec is impossible for the reasons mentioned above.

The second and fifth option is left. However, the weight distribution should be kept 2/3 of the weight on the rear wheel and 1/3 of the weight on the front wheel. If both cargo containers are located on the rear of the bicycle, the rear wheel will be too heavily loaded. That is why the sixth option is chosen in combination with the first one.

Front load stability

Prototype: physical / Focused

On a bicycle, a front-load can be attached to the bicycle in two ways. Firstly, it can be attached to the bike's steering assembly. Secondly, the front load can be attached to the frame itself.

Both ways of attaching the load to the bicycle come with their own set of advantages and limitations. A frame-mounted front load does not directly affect the handling characteristics and makes for a more stable ride. When doing benchmark research, it becomes clear that most e-bikes use this mounting system (Riese & Müller Multicharger, Ahooga Modular Bike, VanMoof S3 Front Carrier). Because e-bikes and speed pedelecs achieve higher speeds than regular bicycles, the handling cannot be compromised. However, because the load is not attached to the steering assembly, there are some interference issues.

First of all, the bicycle's cables might rub against the front rack. Second, and more importantly, the load cannot be very high because this would make the bicycle unable to turn, as shown in figure 58.

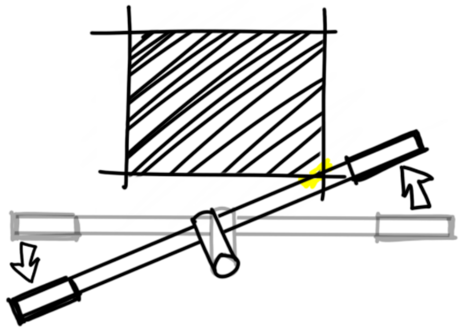


Figure 58: Handlebar hitting front load when turning

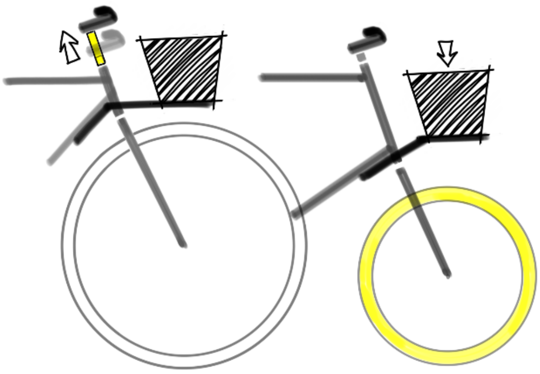


Figure 59: Two options to increase handlebar clearance

A solution for this problem is to raise the bicycle's stem (resulting in a more upright riding position) or to decrease the front wheel's size.

Figure 60: Front load attached to steering assembly

Figure 61: Front load attached to frame

Both setups are tested with several users on the same test bicycle (not an e-bike). A 'quick-and-dirty' solution is made for the frame-mounted setup: the cargo container is attached to bent rebar rods, clamped to the downtube with hose clamps. The cargo container itself consists of an ice cream box filled with sand. The weight of the sand is 4 kgs.

The author uses the test bicycle with the front load permanently attached for daily use. Whenever possible, friends and family are asked to take the bicycle for a short ride and comment on the front load.

Figure 62: Author testing different mounting systems

This results in the following findings and comments: when the front load is attached to the steering assembly, handling is greatly affected. One test person (male, 21 years old) underestimates this effect and nearly crashes the bicycle while making a tight turn.

On the other hand, another test person (male, 21 years old) is surprised that the handling is barely affected when the front load is attached to the frame itself. This person himself owns a bicycle with a front carrier attached to the steering assembly and continues to explain that he stopped using this front carrier after transporting a crate of beer and feeling very unsafe.

Exterior attachment

One of the initial survey respondents mentioned that he likes his Ortlieb panniers because it allows him to transport some objects with an unusual shape. He also gave a specific example: “I often buy a baguette at the local bakery, with a hard-shell cargo container that would not be possible.”

As a result, different methods of attaching items to the cargo container are investigated. Usually, a similar attachment system will exist of a kind of ‘straps’ and a kind of hooks to strap those onto.

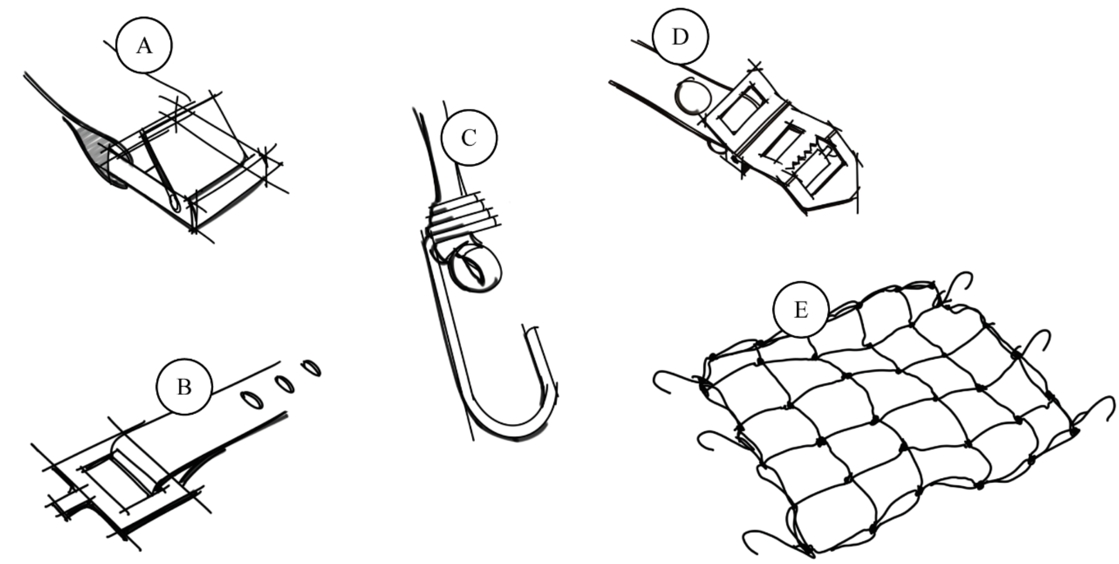


Figure 63: Ideation of possible straps

Many different straps can be used: cam-lock straps (A), bungee cords (C), toe straps (D), voile straps (B) and even whole nets (E).

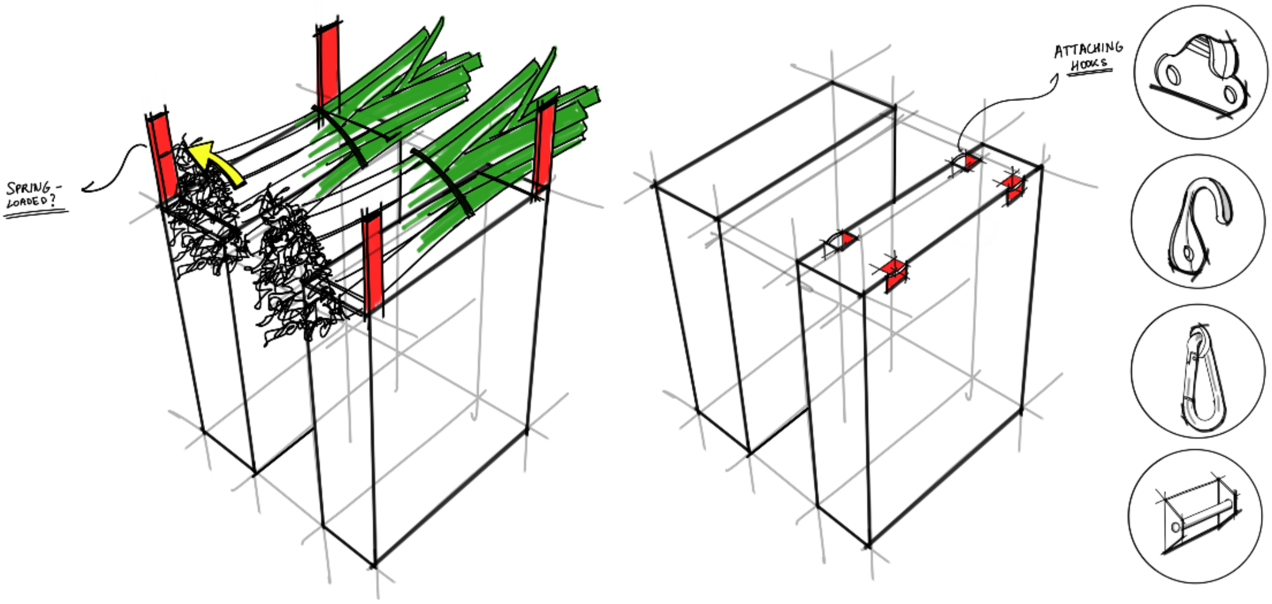


Figure 64: Ideation of cargo container hook attachments

Another option is to integrate spring-loaded plates on top of the containers that clamp the load (e.g. a bundle of leeks) down. If straps are used, hooks are also needed to tie those down. Different kinds of hooks can be used. Some are open, and others are closed. Carabiner hooks combine the best of both worlds: they can be opened when wanted but stay closed when needed. The advantage of an open hook is that the strap does not need to be threaded through it but can just be tensioned over it. The advantage of a closed hook is that the strap is less likely to come loose than with an open hook. However, the carabiner has a disadvantage: it might rattle because it is attached to the cargo container in a hinged manner and not entirely fixed.

Portability & Trolley function

First of all, the trolley function is discussed. As mentioned in the problem decomposition, a fixed primary cargo container combined with a removable secondary cargo container is different from a single removable cargo container in the way it is used.

While the car has many advantages, transporting this secondary container can be pretty cumbersome. Here, the e-bike cargo container could present an advantage by implementing a trolley function, which is especially useful in the context of (grocery) shopping. A comparison is made through storyboarding to explore the differences between the two use cases in this specific context.

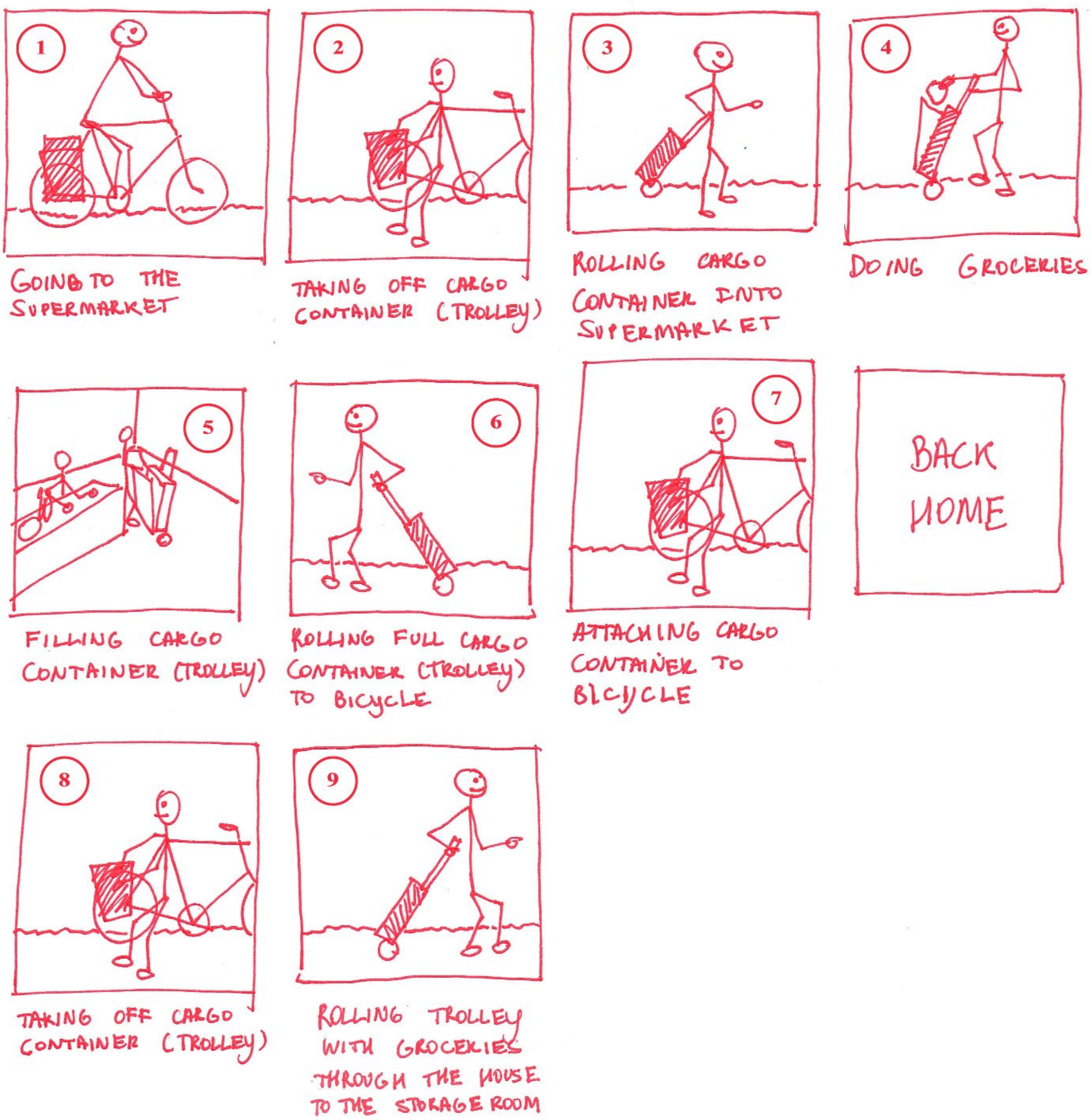


Figure 65: Storyboard: shopping with the e-bike trolley (cargo container)

Figure 66: Storyboard: shopping by car

Shopping by car requires more steps than shopping by bicycle with the trolley cargo container attached (12 steps vs 9 in figure 65 and figure 66, respectively). The cargo container trolley eliminates the steps that include taking and putting back the shopping cart (steps 4, 9 and 10) because this cart is unnecessary. Another advantage of the cargo container shopping trolley becomes apparent when the user arrives home: while the car user has to carry the (heavy) crates and bags to the storage room, the cargo container trolley can just be rolled, decreasing stress on the user.

These advantages, combined with the relatively positive results of the first questionnaires, lead to the ideation of possible trolley solutions. However, incorporating the trolley function into the rear cargo container is no easy task, as it is prone to interfere with the locking mechanisms and attaching hooks.

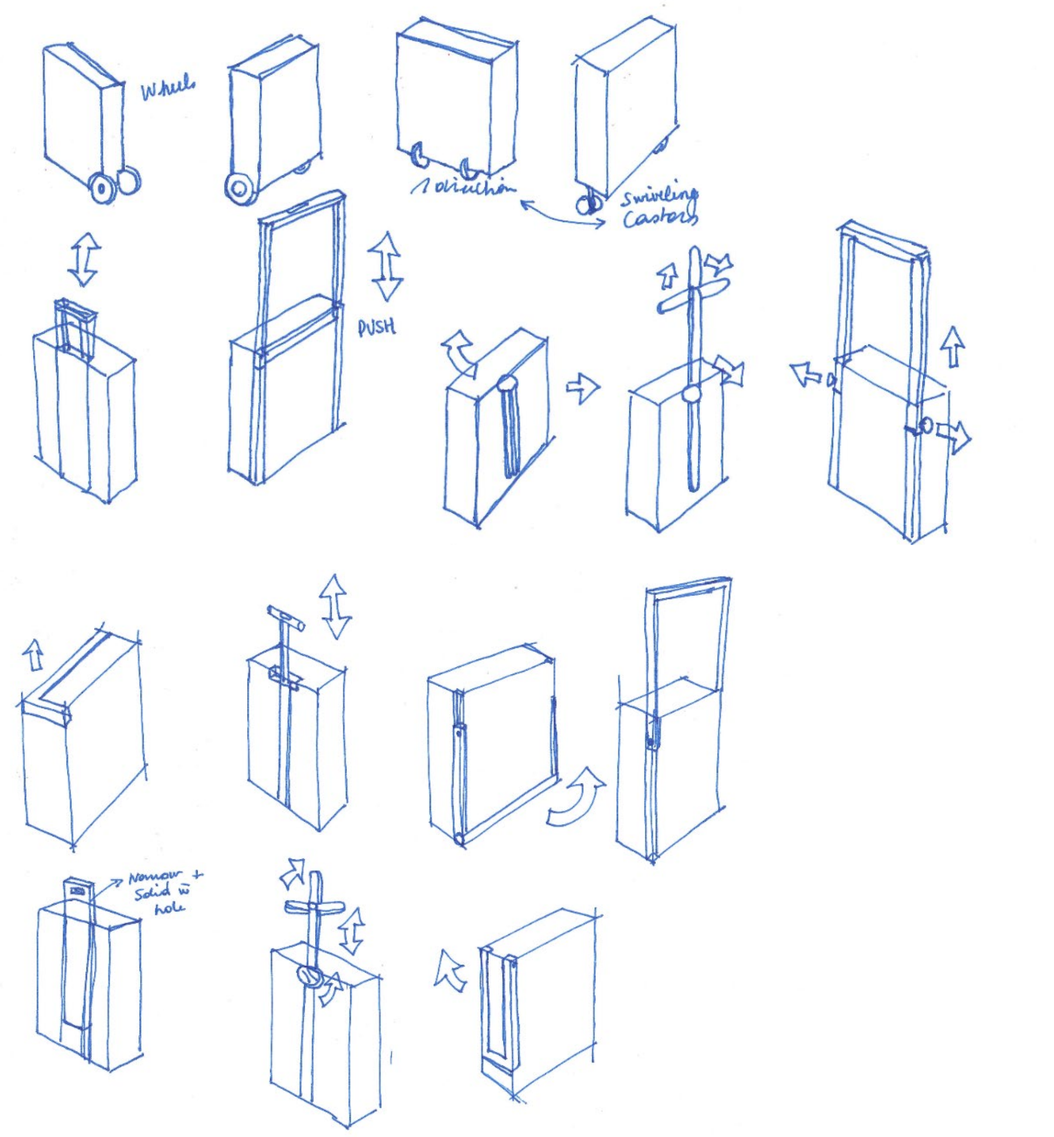


Figure 67: Ideation of wheel placement and shape, handle placement and shape

Several prototypes are made as well, on a scale of 1:1, to check some of these possible configurations. They are made out of wood to ensure their strength (needed so the containers can be tested with weight). The prototypes consist of a frame made of pinewood and faces made out of 10 mm plywood. The sides of the containers can be exchanged with wider ones, giving a cargo container the following dimensions: 350 mm * 450 mm * 100 mm / 150 mm. The 'non-expanded' volume is then 15.8 l and the 'expanded' volume 23.6 l.

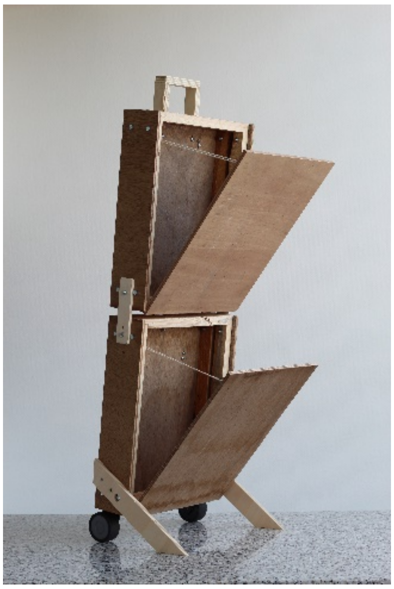


Figure 68: Prototype trolley (wheels on the back, two stacked on top of each other)

Figure 69: Prototype trolley (wheels on the side - alternative handles)

Figure 70: Prototype trolley (wheels on the side)

Figure 68 shows a trolley most people will be familiar with, placing the wheels on the cargo container’s broad side. Here, the trolley consists of two cargo containers that are stacked onto each other. This way, the volume is doubled, and the user has to roll around only one trolley instead of two when he/she wants to transport larger volumes.

The second and third picture shows a trolley where the wheels are placed on the cargo container’s narrow side. This configuration can often be seen on vintage luggage cases, such as this one from Samsonite (figure 71).

Figure 71: Vintage Samsonite luggage case (wheels placed on the narrow side)

This last configuration presents some advantages over the first one in the context of a bicycle cargo container. First of all, the wheels do not protrude towards the bicycle's rear wheel. Second, the impact on the container's internal volume is minimal because the (telescopic) handle can be mounted on the side of the cargo container.

However, it is suspected that the narrow wheel placement of the second configuration (picture 2 & 3) will negatively impact the stability of the trolley. Therefore, some tests are executed with these prototypes to investigate differences in their stability. It becomes clear that the placement of the wheels on the side of the cargo container is not ideal. The wheels are spaced over 10 cm (narrow position of the cargo container), which is a very short wheelbase. That is why the 'trolley' has a severe tendency to tip over in turns and when the wheels are not level.

The prototype in figure 68 is tested with several different loads and rated in terms of how the stability and the weight feel.

	(kg)		(kg)
Weight empty prototype (total)	7,2	Weight large brick	3,6
Weight empty protoype (bottom)	3,6	Weight small brick	0,9
Weight empty prototype (top)	3,6		

		# large bricks	# small bricks		totaal (kg)	Score stability (/5)	Score weight (/5)	Total score (/10)
Case 1	Top	3		Total weight (bottom)	14,4			
	Bottom	1	2	Total weight (top)	9			
				Total weight (combined)	**23,4**	3,5	3	**6,5**
Case 2	Top	3		Total weight (bottom)	14,4			
	Bottom		2	Total weight (top)	5,4			
				Total weight (combined)	**19,8**	4	3,5	**7,5**
Case 3	Top	2	2	Total weight (bottom)	12,6			
	Bottom			Total weight (top)	3,6			
				Total weight (combined)	**16,2**	5	5	**10**
Case 4	Top	2		Total weight (bottom)	10,8			
	Bottom		2	Total weight (top)	5,4			
				Total weight (combined)	**16,2**	4,5	5	**9,5**

Figure 72: Different load cases and their effect on the feeling of stability and weight

The total weights for the cargo container and its load are 23.4, 19.8, 16.2 and 16.2 for the different cases. The 'trolley' is not tested with a weight higher than 25 kg, for reasons mentioned above. There is also a difference between the weight in the bottom and top container. As the bottom container is closer to the ground, much weight placed here affects handling less than in the top container. However, this uneven distribution also entails that the weight will be unevenly distributed left vs right on the e-bike.

The third case hits the 'sweet' spot between weight and stability. When the weight is shifted more towards the top (4th case), stability decreases. At a total weight of 19.8 kg, stability is still okay, but the trolley gets heavy. Finally, 23.4 kg (case 1) is not comfortable anymore: the weight is too much, and the stability is affected. In conclusion, the weight of this trolley should not exceed around 16 - 19 kg.

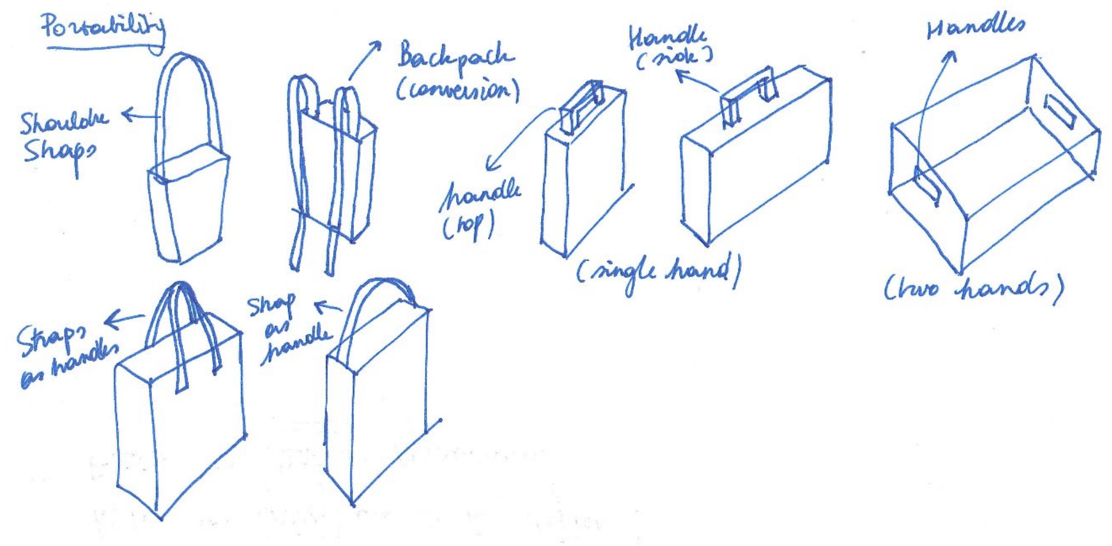


Figure 73: Portability options

There are other ways the cargo container can be carried around comfortably. The shoulder strap and the backpack (conversion) are attractive because they carry the weight on the shoulders, which is less straining for the user than carrying around the cargo container in his/her hands. However, some of the options depicted are not ergonomic. A simple handle strap, for example, will cut in the user's hands if the cargo container is heavily loaded. An ergonomic handle might be a better choice by ensuring the user has a good grip on the cargo container and prevents pain after long periods of use.

In the context of commuting, one might wonder what the 'average' distance is between the location where the e-bike or speed pedelec is stored and the actual work location. In addition, the shoulder and backpack straps present a difficulty in that they need to be tucked away or fixed so that they do not catch in the rotating wheel, which could have disastrous consequences.

Another complexity of the backpack solution is the presence of the attachment hooks. These will have to be covered by a soft material to prevent them from poking into the user's back.

Figure 74: Two Wheel Gear convertible backpack/pannier

As will be shown later, an ergonomic handle is implemented in the final prototype. This final prototype does not feature a trolley function to prevent a prototype that is too complex and requires too much effort to build. Users were asked about this trolley function separately (a separate ‘quick-and-dirty’ prototype was shown).

Heel strike

One of the most significant problems with rear panniers is the ‘heel strike’. This phenomenon is well-known in the bicycle touring milieu. The problem is that the cyclist is unable to put the rear panniers far enough backwards, resulting in the cyclist (occasionally) hitting the pannier with his or her heel during cycling.

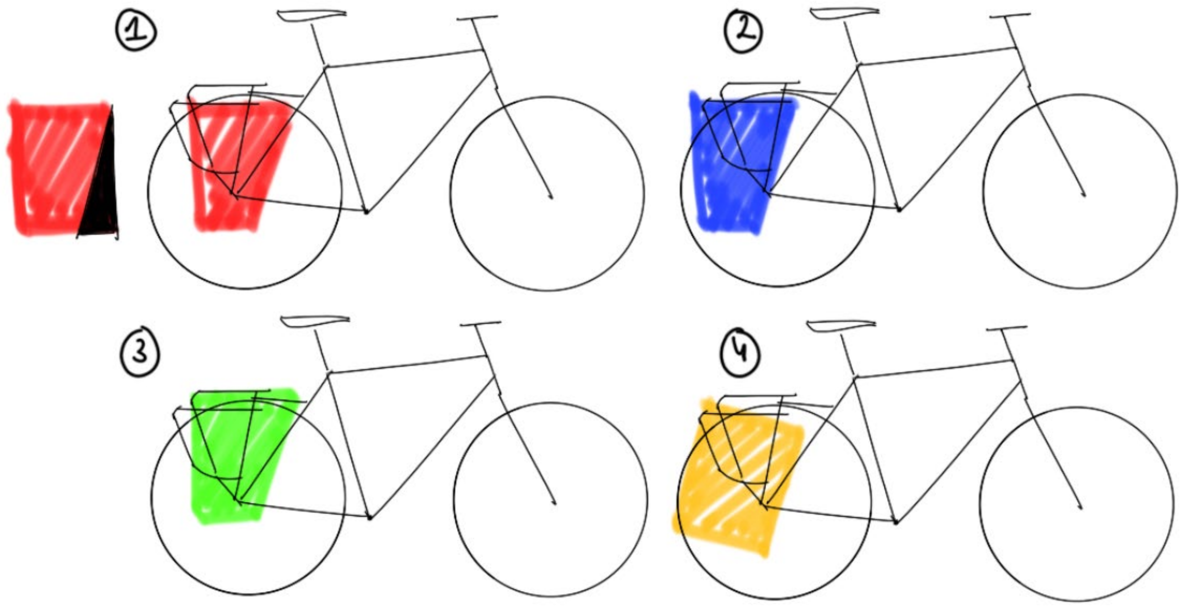


Figure 75: Heel strike: possible solutions

The first image shows a situation where heel strike is likely to appear, even though the pannier already has a chamfered edge to minimise the problem. The pannier could be mounted further backwards to fix the problem, as depicted in the second image. Another possibility is to mount the pannier up higher, as can be seen in the third image.

However, mounting the pannier further back will move the centre of gravity behind the rear axle, compromising handling. Moving the pannier up will also move the centre of gravity up, negatively influencing stability and making the bicycle top-heavy.

A different solution is proposed here. The pannier is no longer mounted level on the rear rack but at an angle (fourth image of figure 75 and figure 76). The same effect is achieved as chamfering the edge in the first image while keeping the volume maximal. After taping an LED light to a cyclist’s heel (size EU 44), disengaging the chain, and using a long exposure photograph, the trajectory of the heel and the regions where a heal strike pose a problem become clearer.

Figure 76: Angled cargo container

Figure 77: Long exposure photograph + LED show heel strike trajectory

Another aspect that minimises heel strike is the bicycle's geometry, more precisely the chainstay length (figure 78).

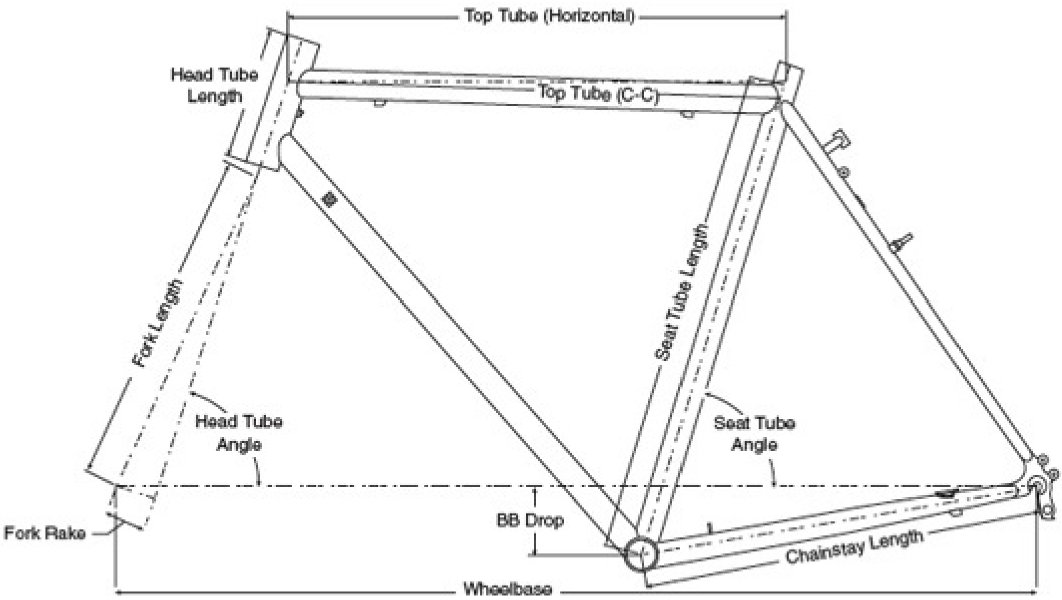


Figure 78: Bicycle frame geometry

The chainstay length is the distance from the centre of the bottom bracket to the centre of the rear wheel axle [69]. This measurement is one of the elements that determine the handling of a bicycle. A shorter chainstay length effectively reduces the turning radius and provides quicker handling. The centre of mass of the bicycle is also shifted further back, often to balance a more aggressive rider position. In contrast, a bicycle with longer chainstays usually has more stable handling and makes the ride feel smoother than is the case on a bike with short chainstays.

Specific types of bicycles often fall within a certain range of chainstay lengths. For example, road bikes usually have a shorter chainstay length of 405 mm to 415 mm [70], while touring bikes usually have longer chainstays.

Table 5: Touring bike chainstay lengths

Touring bike	Chainstay length (mm)
Trek 520	450
Specialized AWOL Expert	455
Koga GrandTourer-S	460
Vivente Anatolia	464

When looking at some randomly chosen touring bikes (table …), it can be seen that, in general, touring bikes have long chainstays. All chainstay length figures are taken directly from the manufacturers' website.

Touring bikes have to take into account heel strike, which is one of the reasons why longer chainstays are preferred on touring bikes.

Unsurprisingly, a typical range of chainstay lengths for e-bikes and speed pedelecs is hard to find since these are relatively new types of bicycles. As a result, the author himself has to determine a 'typical' chainstay length for these types of bicycles. The following e-bikes and speed pedelecs are selected randomly.

Table 6: Speed pedelec and e-bike chainstay lengths

Speed pedelec	Chainstay Length (mm)	Regular e-bike	Chainstay Length (mm)
Klever X Speed	459	Flyer Gotour 6	480
Klever B Speed	478	Trek Verve+ 4	502
Stromer ST3 Sport	473.7	Cube Town Hybrid	540
Kalkhoff Endeavour 5.B Excite	485	Gazelle Grenoble	480
Trek Allant 8s	487		

As can be seen in table… both speed pedelecs and e-bikes have long chainstays. A chainstay length in the range of 470 – 500 mm seems average. Not only does this make the two-wheeler more stable (ideal at higher speeds), but it also provides the added benefit that heel strike will be very unlikely when rear panniers are fitted.

Expandability

Making an expandable cargo container is not an easy task, especially considering waterproofing and security factors. An initial brainstorming session is held, but this does not appear to be very productive. As is suggested in Ulrich & Eppinger, a search for existing patents can be valuable [19]. After doing an internet search, several examples are found (figure 79).

Finally, a concept that uses a bellow and a slider mechanism is found, inspired by some of these different patents. This system can easily be made waterproof, is expandable from the exterior of the cargo container and keeps the whole rear cargo container rigid.

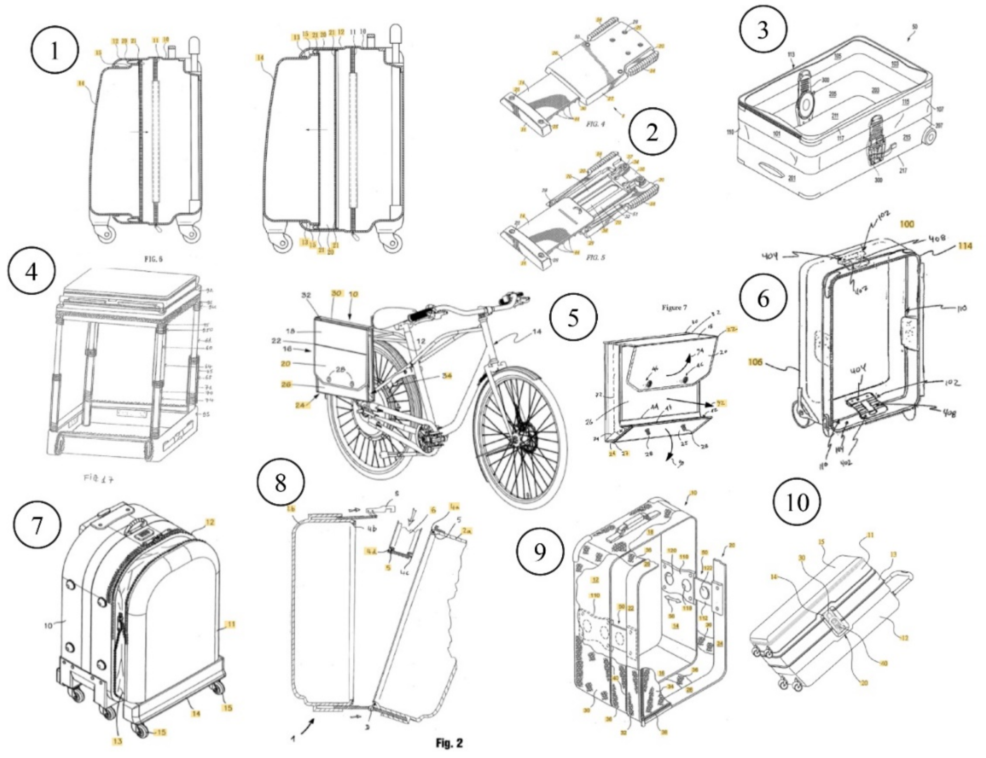


Figure 79: Collection of patent images used as inspiration

Figure 80: Prototype bellow and slider mechanism (expandability)

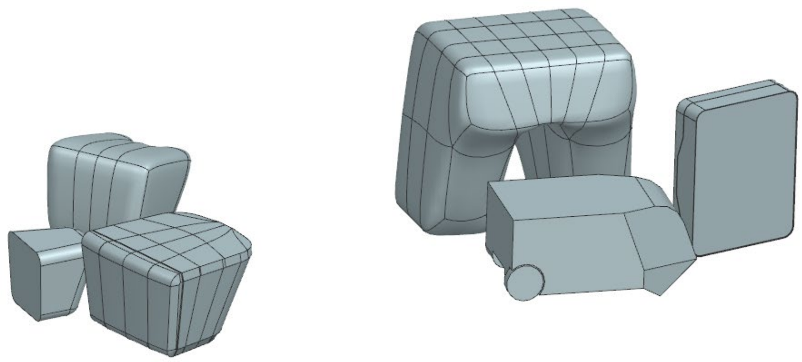
Prototype: physical / Focused

Several prototypes are produced to make ideas concerning the expandability of the cargo container more tangible. These prototypes are made on a scale of 1:2.

To the left, an adaptation of a conventional ‘bellow’ structure [71] is depicted. The bellow structure is interesting because, on the one hand, it enables the expansion and reduction of the cargo container volume. On the other hand, its structure functions as a monocoque[72], minimising loss in the cargo container’s strength. Furthermore, there are no zippers to break, and waterproofing is straightforward.

Whether the bellow structure is collapsed or expanded could be determined by a slider which fixes one half of the cargo container relative to the other.

CAD models



Some of the models used to check proportions (solid modelling) and quickly render some more organic ideas (subdivision modelling).

4.2. Final concept & prototype

Prototype: physical / Comprehensive

The ‘final’ prototype is a comprehensive prototype that combines the previously tested and reviewed focused prototypes and is meant to test with users and get feedback. It is a functional prototype, but not much attention has been given to the actual design (aesthetics are not really relevant at this point).

The ***first main feature*** is that the complete cargo container system is hard-shell. It was anticipated that this would increase the perception of the provided security.

The ***second main feature*** is the provided security: the front container is permanently attached to the bicycle, and the rear container can be locked to it. The contents of both can also be secured with a lock.

The ***third main feature*** is the protection of contents: the cargo containers are both waterproof and provide better protection to the contents in a fall/crash than regular bicycle panniers. This feature is especially relevant in the context of commuting, where often a (valuable) laptop is transported.

The ***fourth main feature*** is the ability to store one’s helmet, rain gear or EDC (everyday carry) in the front container.

The ***first additional feature*** is the bellow and slider system, enabling expanding and shrinking of the rear container.

The ***second additional feature*** is the rear container's organizability: first, it is front-loading. Most 'roll top' panniers are top-loading, allowing for items to be 'thrown in'. An identified shortcoming of this type of loading is the lack of organisation, which is why the front-loading option was chosen to allow for straightforward organising at home or work. Second, a laptop compartment and an internal divider panel, meant to keep the rear container's contents from falling out when opened on the bicycle, are provided.

The ***third additional feature*** is the improved aerodynamic drag: the total frontal area is decreased compared to a conventional pannier setup. It is expected that this will increase the e-bike's battery range.

Figure 81: Prototyping the rear carrier

Figure 82: Carrier for the front container

Figure 83: Front container attached to e-bike

Figure 84: Different features of the cargo container system

4.3. Prototyping sustainably

Sustainability is an essential aspect of design, and more and more designers are considering sustainability, which is a good thing. However, while products are more sustainable than they used to be, this trend is often overlooked during prototyping.

Before starting to prototype, several resolutions are made by the author:

- The prototypes should be designed for disassembly, meaning that all material currents can easily be separated when the design process is finished.
- The prototypes should reuse (discarded) materials as much as possible instead of using 'virgin' materials.

Design for disassembly

The principle of design for disassembly is implemented as much as possible.

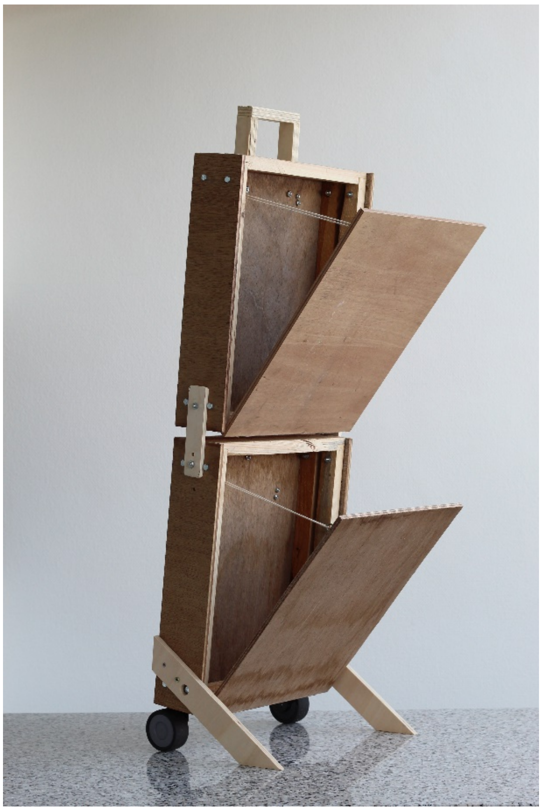


Figure 85: Low fidelity prototypes (wood), assembled with fasteners

An example of this is the low fidelity wooden prototypes. A wooden frame is used to which two side panels and one front panel (with hinge) are attached, all with bolts and screws. This frame allows easy disassembly when the prototype is no longer of any use. It also allows for different iterations to be made on the same basis (changing the wheels and hooks placement, different handles, stacking, different side panels to increase width), leading to less wasted material.

Figure 86: Final prototype assembled with fasteners and rivets

The final prototype (rear) is also constructed with this principle in mind. Where possible, bolts and screws are used to connect different parts of the prototype. Where impossible, the parts are connected with pop rivets. Although this is not as easily disassembled as bolts and screws, it is still very straightforward to drill out the rivets and ensure that all the different materials can be separated for recycling.

Another aspect of design for disassembly is to avoid using glues as much as possible. Thus, none of the prototypes' parts are connected using glue. The only part with hard-to-separate material currents is the expandable bellows, made from duct tape and aluminium strips, but this is inevitable.

Reuse & recycling of materials and objects

Many of the prototypes are made from reusable materials or existing objects.

Figure 87: Old and cheap beaty cases at Kringloopwinkel Kortrijk

The front container, for example, is made from an old beauty case found in the 'Kringloopwinkel', a local thrift store in Kortrijk. These old beauty cases already feature many criteria: hard-shell, lockable, with a latch mechanism, and not too big (around 10 to 15 l). It makes a lot more sense to 'hack' one of these than to prototype a completely new one.

Figure 88: Torn sleeping mat used to line the inside of the rear container (final prototype)

Figure 89: Repurposed closet walls

Found at the 'Kringloopwinkel', this sleeping mat (shown in figure 88) had many tears and was not usable anymore. Instead, it was used to line the inside of the rear cargo container (final prototype) to prevent rattling. This foam is hard to find new, and it does the job as well, as it is the same material as is used in laptop bags. This material is closed-cell polyethene foam. It does not absorb water as it is closed-cell and is lightweight.

Another example is all the wooden prototypes. These were made (mostly) from plywood sheets. The author salvaged these used sheets, which would otherwise be thrown away (construction waste). Although tolerances are not as good as with a fresh plywood sheet, CNC routing & assembling the front carrier was no problem.

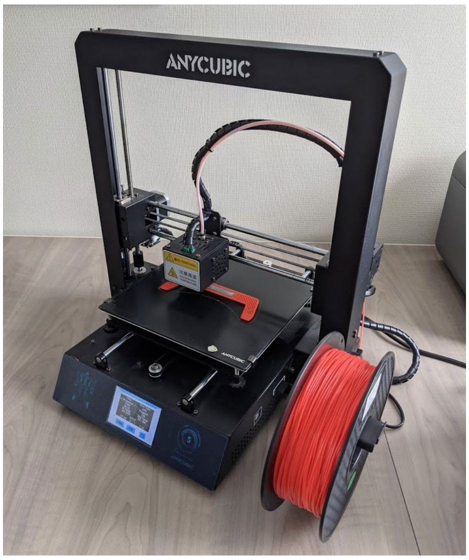


Figure 90: 3D printing: minimising material waste

3D printing was used to produce the red parts of the final prototype. The amount of failed prints was minimized by thinking their design through and designing for 3D printing. Thus, not much support was used or wasted, making this a sustainable prototype production method.

Apart from the examples mentioned above, the front weight distribution prototypes use repurposed rebar and empty ice cream boxes. The cardboard prototype uses paper tape to attach everything, essentially keeping this one material.

Of course, the actions taken to make the prototypes sustainable are futile if, finally, they are not disposed of correctly. Therefore, after handing in this master's thesis, the author will separate the material currents of the low fidelity prototypes and dispose of them correctly. On the contrary, the final prototype will not be destroyed because it still needs to be added to the author's portfolio. If the prototype is not needed anymore after a few months/years, it will also be dismantled and disposed of suitably.

4.4. User testing

As mentioned in the previous sections, the purpose of some of the prototypes was to test ideas with users and get feedback. Several methods are used to test these prototypes, including a fourth survey and interviews.

Survey 4

Demographics

This survey has 73 respondents (n=73), of which 62.2% is male and 37.8% is female. The sample mean age is 41.3 ($\bar{x}$=41.3), and the median is 43 (M=43), suggesting a symmetrical distribution of the data. The standard deviation is 14.0 (s=14.0) [47].

The cargo container's target audience consists of speed pedelec and e-bike users, who use their e-bike (among others) for commuting. The survey is distributed on Facebook, both targeted (speed pedelec and e-bike groups) and universal (author's Facebook page).

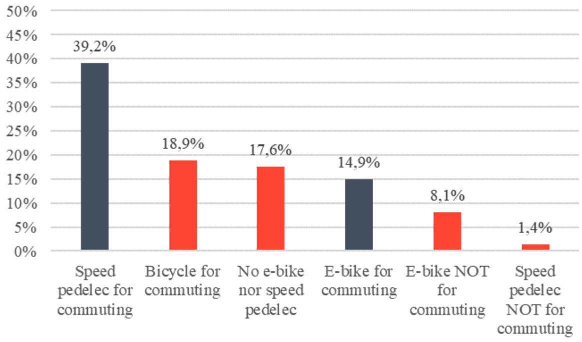


Figure 91: Categorisation respondents (%)

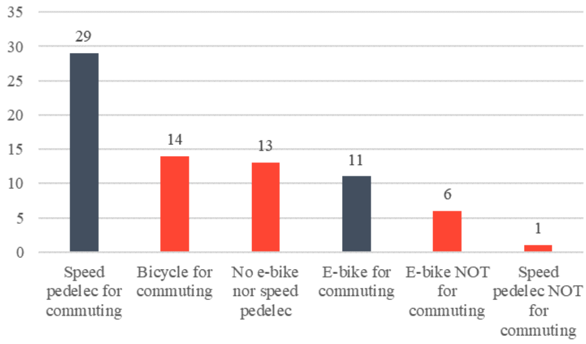


Figure 92: Categorisation respondents (in absolute numbers)

Most of the respondents belong to the group 'Speed pedelec for commuting' (n=29). The other target group, 'E-bike for commuting', contains fewer respondents (n=11). The rest of the groups, 'Bicycle for commuting' (n=14), 'No e-bike or speed pedelec' (n=13), 'E-bike, not for commuting' (n=6) and 'Speed pedelec, not for commuting' (n=1), do not belong to the target audience.

General

The respondents were asked to indicate what they transport (if applicable) during their commute to prevent making assumptions.

Laptop and lunch boxes are the two items that are mentioned most often. Actually, of the target audience (speed pedelec and e-bike commuters), 47.5 % mention transporting laptops during their commute. This number is significant and must be taken into account.

Current 'cargo container'

Of the 40 respondents who directly belong to the target audience, 14 specifically mention Ortlieb panniers as their current 'cargo container'. This number shows the importance of the Ortlieb bags as the primary benchmark. Most of the others use other single panniers, double panniers, a backpack or a trunk bag.

Front cargo container

The respondents have to indicate their appreciation of this front container's volume after showing some video fragments of the container in use. Sixty point eight % (60.8%) Says the volume is OK. More respondents think the volume is too much or far too much than respondents who think the volume is too little. From this, we could say the volume should probably not be increased. However, decreasing the volume might take away some of its functionalities, like storing a helmet.

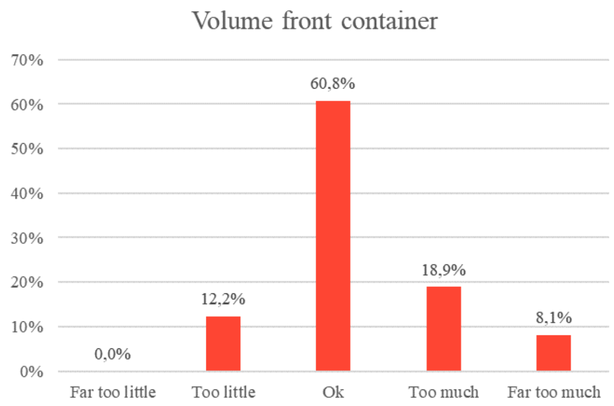


Figure 93: Volume front container

Evaluation of functionalities

Several functionalities of the front container are presented and validated with the respondents. The first functionality is storing a helmet and rain gear on the bicycle safely and protected from the elements. The second functionality is storing items that are usually carried on one's body in the front container while cycling (e.g. smartphone, wallet, tote bag, purse).

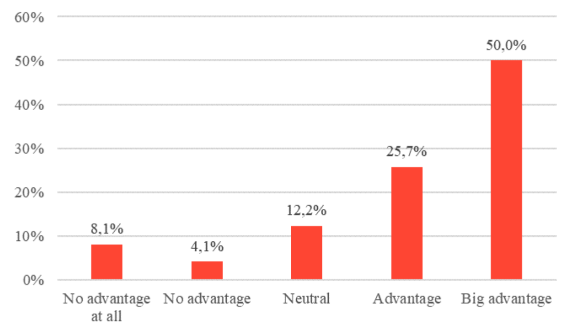


Figure 94: Evaluation of helmet storing functionality

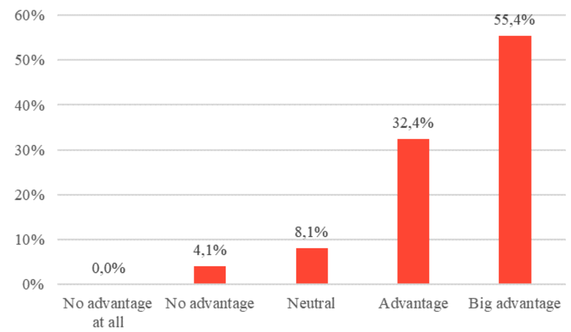


Figure 95: Evaluation of rain gear storing functionality

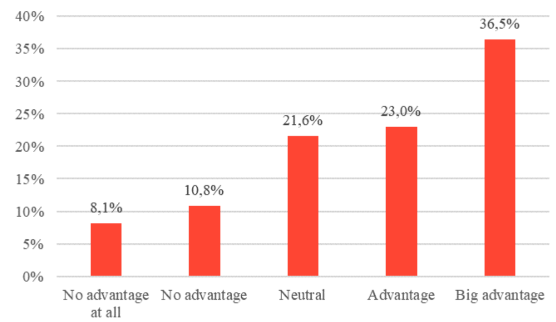


Figure 96: Evaluation of EDC storing functionality

All the functionalities present an advantage over conventional cargo containers. Storing a helmet (advantage or big advantage for 75.7% of respondents) and especially storing rain gear (advantage or big advantage for 87.80% of respondents) seem to represent the most significant advantage.

The respondents are asked about their opinion on the front cargo container. Their remarks are represented in four categories: strong points, weak points, improvements/alterations and reservations. While clearly stated that the prototype shown was just functional and should not yet be rated for its aesthetic qualities, many respondents got caught up in its aesthetics qualities. These respondents did not find the prototype attractive and did not consider any of the advantages it could offer. For these less relevant comments, (LR = Less Relevant) is added.

What would you carry in this front container?

Again, to prevent making assumptions, the respondents must indicate what they would carry in the front container. Most of the items are already identified, but it is good to see them confirmed.

Strong points

- It increases the storage capacity even further
- It provides a dry storing space
- It is similar to a classic bicycle basket but waterproof and secures its contents
- It is very convenient for rain gear and possibly an extra lock
- It does not really influence bicycle handling
- It is a big advantage to always have those small items like repair gear always with you
- It is highly visible because it is in front of you (less worries about it catching on something)

Weak points

- It is not aesthetically pleasing (LR)
- It is harder to steer when the weight is large (Not true, see user testing)
- It is not aerodynamic (Probably referring to making the design more streamlined)
- It is in the way of light, brake cables,… (Not sold as an aftermarket item, but integrated with the bicycle)
- It is too small for a speed pedelec helmet
- It is too big
- It is dangerous
- It might negatively influence vision

Improvements / alterations

- To streamline the design more (LR)

- To make it possible to take it off with a click system
- To let the lid open to two sides (enabling opening when on the bicycle)
- To make the lid removable (convert to a basket)
- To add compartments and/or webbing
- To make it possible to customise it (different colour and size options)
- To mount this container in the rear and on silent blocks (shock-absorbing)
- To add a smartphone or GSM attachment
- To add an extra backup battery in this container
- To change the direction of the container (turn it 90° narrow becomes wide and vice versa)
- To make it possible to open the lid sitting on the bicycle itself / from behind.

Reservations

- Not convinced that the effect on handling is minimal
- Not sure if parking in a regular bicycle parking is still possible

Rear cargo container

The rear cargo container is a front-loading cargo container and not a top-loading cargo container, which is usually the case for regular panniers. Front-loading and top-loading containers both have their advantages and disadvantages. The first question aims to check if respondents think this is useful in the provided context (main focus on commuting).

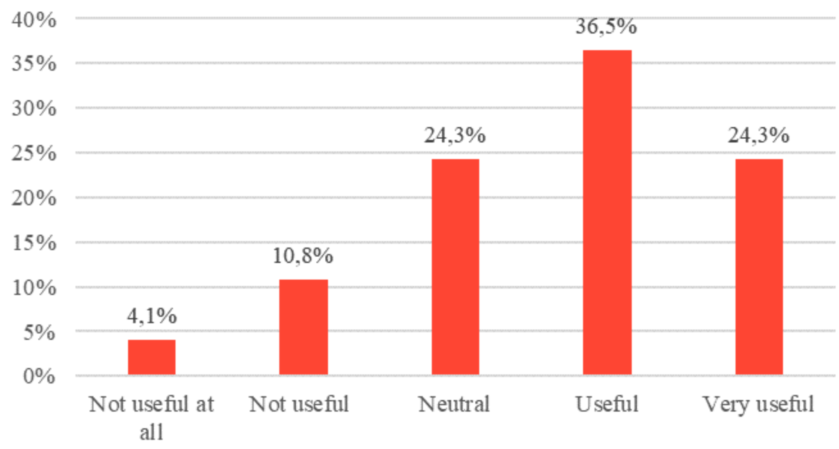


Figure 97: Rear container organisation and loading usefulness

It appears most respondents do find this way of loading useful (36.5% useful and 24.3% very useful). Fourteen point nine % (14.9%) thinks this way of loading and organising the contents is not useful, and 24.3% is neutral about its usefulness.

Safety is among the most critical topics. Safety can be seen in two ways: the safety of the cargo container's contents and the cyclist's safety.

During the first round of surveys (survey 1 and 2), some respondents reported that they did not feel safe (perception of safety) with large or heavily laden rear bicycle panniers. The reason for this was a fear of the panniers 'catching' onto something. One of the reasons for this fear could be that the rear panniers' width is hard to estimate since they deform a lot. The hardshell cargo container eliminates this problem because it cannot expand past a certain width.

The respondents were asked to which extent this cargo container would make them feel safe.

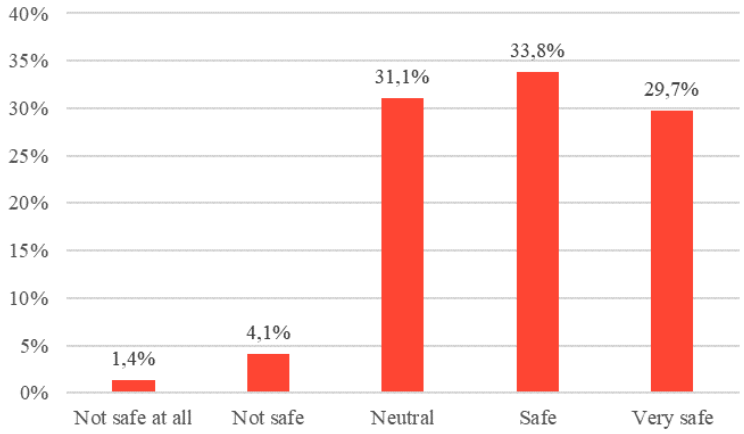


Figure 98: Perception of safety: prototype rear cargo container

Because this result does not make the comparison with regular softshell panniers, respondents were also asked which seems most safe to them.

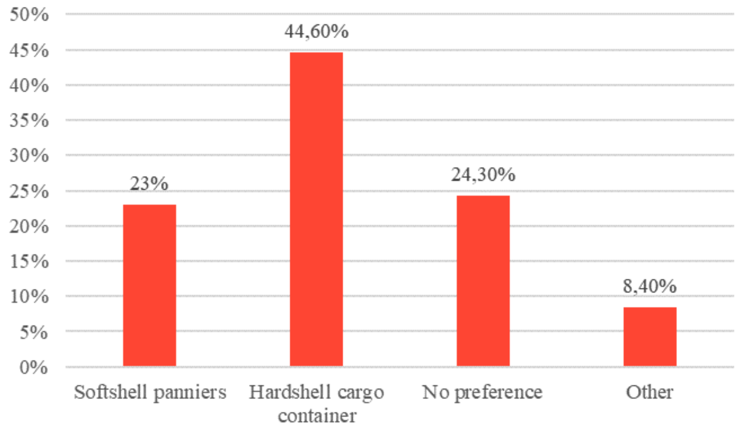


Figure 99: Preferred cargo container in terms of safety

This graph proves that people feel like the hardshell cargo container is safer than softshell panniers. Among the other comments, one respondent mentioned the following: "The contents will be better protected better in the hardshell cargo container, but in the case of a fall, this hardshell cargo container could also cause more damage to the cyclist". This is a good remark and something to take into account for the final concept.

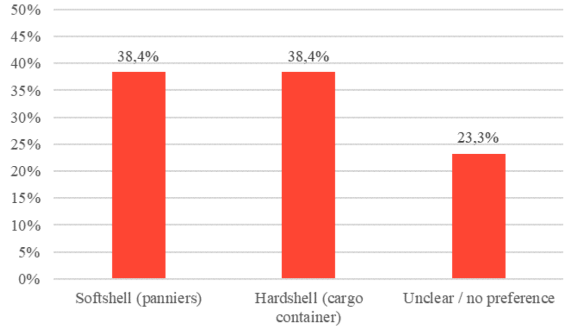


Figure 100: Preference softshell (panniers) vs hardshell (cargo container)(general)

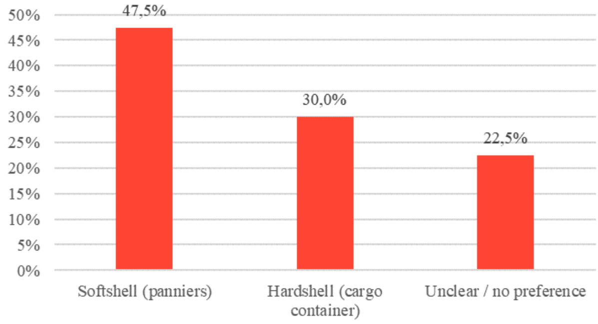


Figure 101: Preference softshell vs hardshell (target audience)

In general, there is no clear preference for the hardshell or the softshell. However, when looking only at the target audience, the softshell (47.5%) is preferred over the hardshell (30%).

The respondents are also asked to state why they prefer one over the other. A summary of their responses:

Softshell (cfr. panniers)

- Flexibility: more flexibility (e.g. when shopping), also gives in more from the inside out (less damage to contents)
- Weight: lighter than a hardshell
- Aesthetics: looks better (not very relevant)
- Volume: top can be left open (Ortlieb) when you are carrying a very large volume
- Damage: if the hardshell catches on something, the damage (to the container itself) would be a lot bigger. It would also be possible to hurt yourself or others with the hard cargo container.
- Furthermore, a hardshell might protect its contents better but a softshell is more likely to have less damage in case of a fall.
- Unknown, unloved: no complaints about current bicycle panniers
- Rattling: less rattling because of loose items
- Storage when not in use: takes up less room

Hardshell (cfr. cargo container)

- Waterproofing: not every softshell is waterproof
- Security: more confident to leave items behind because it can be locked, safer
- Protection of contents: protects the contents more (especially important when the laptop or other fragile/expensive items are transported)
- Volume: easier to navigate through a bicycle storage facility
- Cleaning: easier to wash/clean when dirty
- Ease of use: seems easier to use (also in terms of storage space and loading/unloading)
- Durability: a softshell is more susceptible to tears, hardshell seems more durable
- Aerodynamics: the narrower, the more aerodynamic (softshell: deforms too much under heavy load)
- Organisability: easier to organise everything, more suitable for commuting

Other comments

- Depends on the price
- Would prefer a combination of both

Security

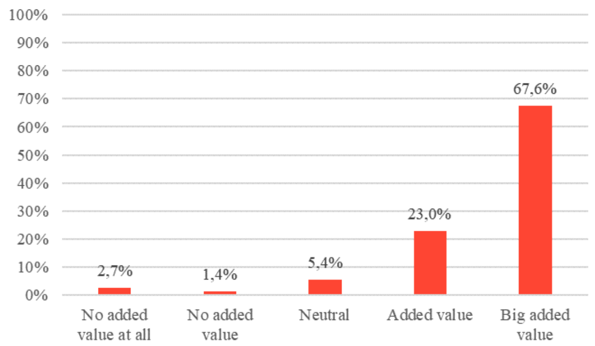


Figure 102: Rating of added security (contents)

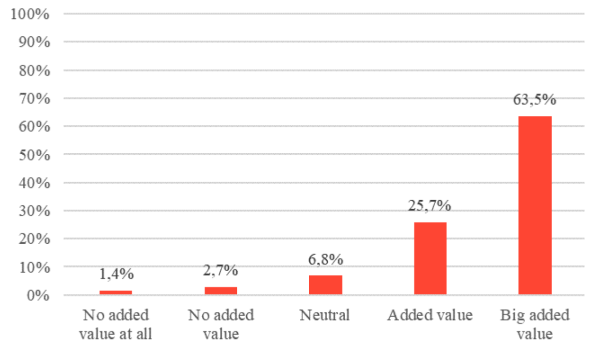


Figure 103: Rating of added security (cargo container to e-bike)

The respondents widely appreciate the added security, which is one of the user needs this prototype puts much emphasis on. Almost all respondents think this improved security is of an added or significant added value.

The willingness of users to leave their items behind is one of the aspects which determines the user journey. To see if people would trust the security of the cargo container enough, they have to indicate if they would also dare to leave valuable items (like a laptop) behind. As shown in figure 104, this yields some very varied results. The numbers represent a Likert-scale rating, from 1 = I would never dare this to 5 = I would not have any problem with this.

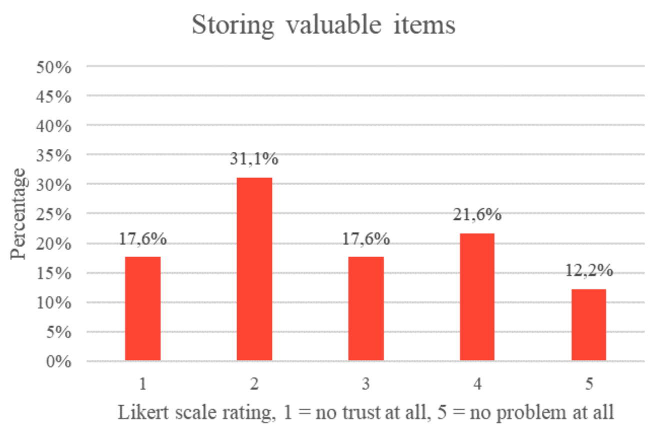


Figure 104: Security (trust in storing valuable items)

From these results, it could be concluded that the provided security of the current cargo container might be overkill. If the users do not feel safe enough to store valuables no matter how secure the container is, the cargo container could probably do with weaker security. Most respondents would not feel comfortable leaving behind valuable items like their laptop. The storyboarding needs to be performed once again to see if this problem can be resolved.

Again, the respondents are asked about their opinion on the front cargo container. Their remarks are represented in four categories: strong points, weak points, improvements/alterations and reservations. While clearly stated that the prototype shown is just functional and should not yet be rated for its aesthetic qualities, many respondents got caught on this. For these less relevant comments, (LR) is added.

Strong points

- Volume: it can be compact (narrow) if you want but allows for more storage in the large setting

- Durability: it seems sturdy, hard shell
- Organisation: easy to organise items inside, laptop holder is a big advantage, compartments
- Security: it can be locked, not only to the bicycle but also the cargo container itself (contents)
- Ease of use: it can be transported easily, trolley function would be a plus (vs backpack: wet back)
- Aerodynamics: it seems like the aerodynamics would be good
- Protection of contents: a hardshell does better than a softshell

Weak points

- Flexibility: it does not provide as much flexibility as panniers do
- Weight: it seems on the heavy side (heavier than softshell panniers). This might wear out the rear rack quickly
- Stability: started using a backpack because the side-mounted container influences stability
- Aerodynamics: it seems like this is not aerodynamic & would catch much wind (side wind)
- Aesthetics: does not look good (LR), make more streamlined.
- Durability: reaction to falls (while cycling or when parked), cold/heat, uv radiation, moisture and dirt in the hinges

Improvements / alterations

- Attachment system: needs to be well thought out. Are you providing something against paint damage?
- Charging: it would be interesting to have a cable opening so that the expensive bicycle charger can be left in the container
- Stability: make it a double system: one on each side (LR, people can just buy two)
- Heel strike: chamfer corner (LR, the container would be mounted at an angle)

Reservations

- Waterproofing: how watertight is the harmonica system?
- Security: could you cut open the harmonicas system?
- Volume: too wide in city traffic (narrow passageways)?

Trolley function

The trolley function is one of the ways to improve the portability of the cargo container. Now, (commuting) business people often carry a rolling laptop case or briefcase. The same functionality could be present in this cargo container system by adding wheels and a telescopic handle. Furthermore, this could also allow the container system to double as a shopping trolley. This way, it is not the user who carries the weight, but the cargo container itself fully supports it.

However, this system has some downsides: it adds weight to the cargo container and takes away some volume. In addition, the production cost will also increase because of the extra components, leading to a higher asking price. The results are pretty diverse: to some people, this may provide an added value, but to others, this presents no added value at all.

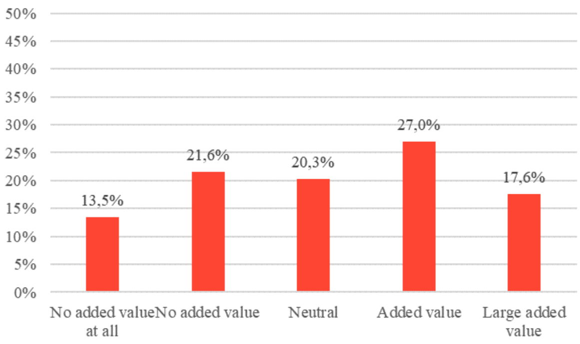


Figure 105: Trolley added value? (speed pedelec)

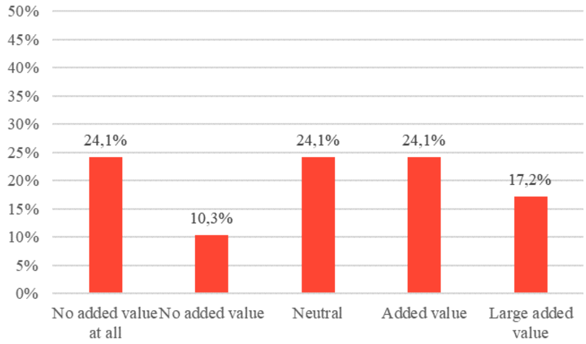


Figure 106: Trolley function added value? (general)

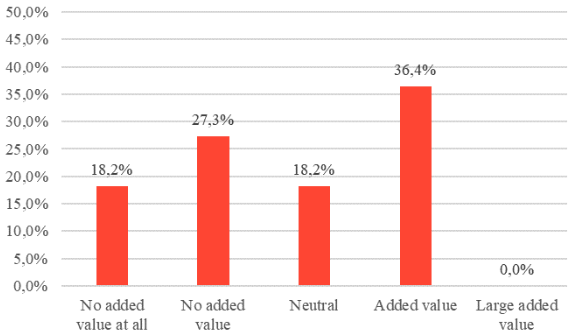


Figure 107: Trolley added value? (e-bike)

These results are valid for the general survey population and the commuting e-bikers and speed pedelec users. In conclusion, the benefits of a trolley function may not outweigh the downsides. The trolley function would add a high cost while, in the meantime, narrowing down the target audience. Furthermore, the added weight (the cargo container is already quite heavy) might scare people off.

Transportation (off the bicycle)

The respondents were asked to write down their preferred way of transporting the rear cargo container. There are several different responses, but overall, they fall into four categories: as a trolley, by the ergonomic handle, as a backpack, and by the ergonomic handle and shoulder strap.

Transporting the cargo container as a backpack is probably the most ergonomic option because it strains the body less. The backpack straps can be located on the front or the rear (where it attaches to the rear rack). Integrating the straps on the front while maintaining pleasing aesthetics might be difficult. Furthermore, padding will be needed to guarantee the user's comfort. In any case, taking out the straps will present an extra step in the user journey. Integrating the straps on the rear will probably be almost impossible because of the attachment hooks. It seems that the only solution here would be to have a separate adapter (padded plate and straps) onto which the user has to hook the cargo container. These actions add even more steps to the user journey.

Some reservations about the trolley system have already been discussed in the section above.

At last, there is the possibility to add a shoulder strap to take some of the load away from the arms and hands. This option has to be investigated because the strap needs to be easily tucked away while on the e-bike.

Whole system

The respondents were asked to indicate which of the two containers they found the most interesting and explain why. How both front and rear containers are evaluated and discover more strong and weak points is the goal of this question. Qualitative analysis is used to get the results in figure 108.

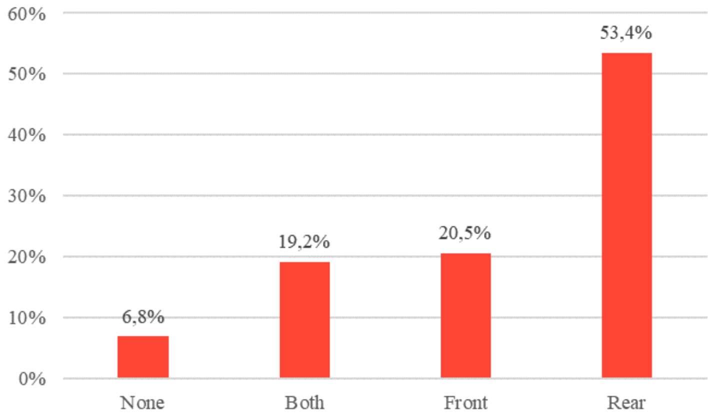


Figure 108: What do you think is the most exciting container?

The front container is seen more as an addition to this rear container, and this is reflected in these results. When having to choose, most respondents pick the rear container. It is positive to see that almost 20% says both. These people understand and value the advantages of the system as a whole.

Some other comments:

Front:

- "It is not yet being sold this way. It is unique."
- "It could be great to include a smartphone holder and a charger."
- "This would allow me to store my helmet safely."
- "Easy to use from the bicycle."

Rear:

- "Presents more possibilities to store items."
- "The rear container will serve my needs best: transporting a laptop safely."

Both:

- "I think they are both exciting, especially because they can be locked."
- "The combination of both presents advantages."
- "Using the rear for commuting and groceries, and the front for a helmet."
- "They both have their function in the system. The front presents easy access, and the rear provides ample volume."

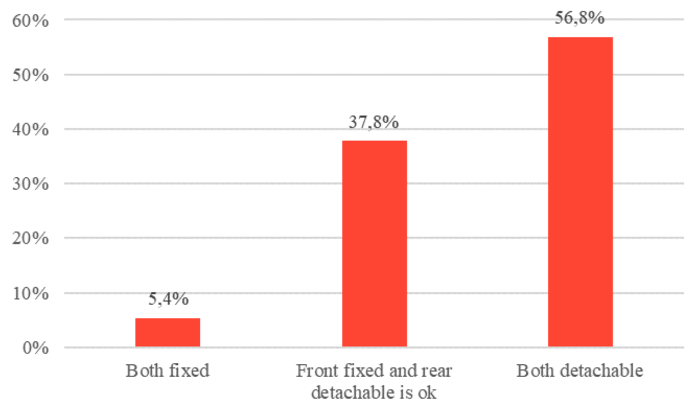


Figure 109: Detachable or fixed cargo containers?

Most respondents want to see that botch containers would be detachable. Only four respondents would like to see that both containers are detachable. As presented, front container fixed and rear container detachable appeals to 37,8% of the respondents. These results are somewhat as expected. The ideal situation would indeed be to make both containers detachable. However, this would present an added cost for the front container (the security still needs to be guaranteed). This detachability would entail extra locks, and the attachment system cannot be integrated into the system.

Pilot interview

Before fully committing to doing several interviews, the prototype is tested with one speed pedelec user. This person is interviewed to help eliminate some teething problems. The interviewee is a 27-year-old woman who daily commutes 32 km one-way. Her current cargo container is a pair of Ortlieb Back Rollers, and she rides a Trek Super Commuter speed pedelec.

Observing the test user (TU) while cycling is hard, so observations are mainly done while the TU is still stationary.

The test user has to perform several scenarios and was asked primarily qualitative questions. The full transcript of this interview can be found in the appendix 10.1 – pilot interview. In addition, the author of this thesis got permission to use picture of the user.

Figure 110: TU tries out the rear cargo container

The findings of this interview can be summarized in positive, negative and neutral statements by the TU.

Positive

- "It is good that the weight is located relatively low because right now, the centre of gravity of the Ortlieb Back-Rollers sits a lot higher" (about rear container)
- The TU thinks the added security is a significant advantage

Neutral

- The TU personally is more attracted to a fabric cargo container
- The TU would like to be able to use the cargo container as a backpack
- The TU states all the locks should use the same key and explains that she prefers a combination lock as she always loses her keys
- The TU does not feel like her Ortlieb bags affect her stability and feels no difference with the prototype cargo container
- The TU does not feel like the cargo container is less safe or safer than her Ortlieb bags (with safety, injuries to herself or other cyclists in case of a fall is meant)
- "The cargo container is heavier than the Ortlieb panniers. It is not very heavy, but there is still a noticeable difference. It would be better if the cargo container were slightly lighter"

Negative

- "I do not see myself walking around with a suitcase, personally. The hard shell is not an advantage because it reminds me of high-school teachers who used those typical Samsonite suitcases, which would make me feel stiff and old-fashioned"
- The TU would not feel comfortable leaving a laptop in the locked cargo container right now.
- Sometimes, the TU adds a jacket to the container during cycling and feels like this would be difficult to achieve with the prototype because it is front-loading. In addition, the TU adds that she feels like items would be falling out of the cargo container, as she has a lot of 'junk' in the cargo container
- "Indeed, you could make the attachment panel from a rigid material, but the front would probably be better off being made from a more flexible material. This way, you do not need the bellow system, and you can pack a lot more. Furthermore, this way, you can fold the cargo container to a very compact size when you are not using it"
- The TU does not see the advantages of the front container: she does not carry tools, and she looks at the forecast in the morning to determine if she has to bring rain gear or not. She says she would "feel like an old lady", using this front container, and that it is too big. The possibility of storing her helmet in there does not seem to convince her
- The TU would like to increase the volume of the rear container and make it more flexible

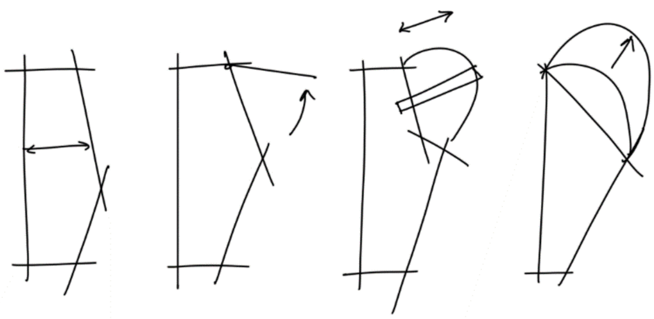
Observations

- The cargo container still needed to be angled to prevent heel strike and allow using the bike's stand.
- The expansion system was still too cumbersome to use. The TU had to pull on the front panel while at the same time tightening the bolts on the side to fixate it. It had to be made possible to perform these actions separately, or one action has to be eliminated.
- The different items the TU carries during her commute are depicted in figure 111. Among these items are a purse, a laptop, a helmet, headphones, clothing (scarf, sweater, jacket), a loaf of bread and some papers.

- The TU was also asked to perform a few scenarios. The first scenario is the following: "*You just arrived at your workplace with your E-bike, and you are about to go inside. Take off your (own) rear cargo container, transport it inside and take an object out of the container.*" Surprisingly, the TU took out **everything** that was in the Ortlieb panniers. By now, the speed pedelec battery charger was at the bottom of the panniers, but it was needed to charge the battery, so everything had to come out. Taking everything out of the prototype cargo container is unnecessary, but the TU still preferred top-loading Ortlieb bags.

Figure 111: Items transported by TU during the commute

Finally, the TU proposed a different cargo container concept: a combination of a hard shell and a softshell and drew some simple sketches.



In general, this TU was not so optimistic about the context, and this worried the author. In conclusion, the biggest problems with the concept were its **limited amount of flexibility**, being **front-loading**, and the provided **security** appeared to be **insufficient for leaving behind valuables**.

Alternative concept

As a result of analysing the biggest problems with the rear cargo container prototype, another concept was generated. The purpose of this concept was to see if the final test users would agree or disagree with findings from the pilot user test and determine if the concept of a completely hardshell cargo container would be viable.

Some of the advantages of the final prototype were incorporated into this alternative concept. First, a hardshell backplate is still present, which continues partly onto the sides of the cargo container. By incorporating these rigid sides, the laptop, which is located in this part of the container, is safer in case of a crash. Second, security was still considered an essential element, and the shoulder strap and zipper can be locked together with a padlock. An integrated lock would have been hard to realise because the fabric is not rigid. Third, the zipper allows the cargo container to be still loaded from the front.

The comments of the pilot test user were also incorporated. First, next to a rigid material, fabric was also used to allow greater flexibility. Second, the alternative concept is top-loading as well, using a roll-top closure.

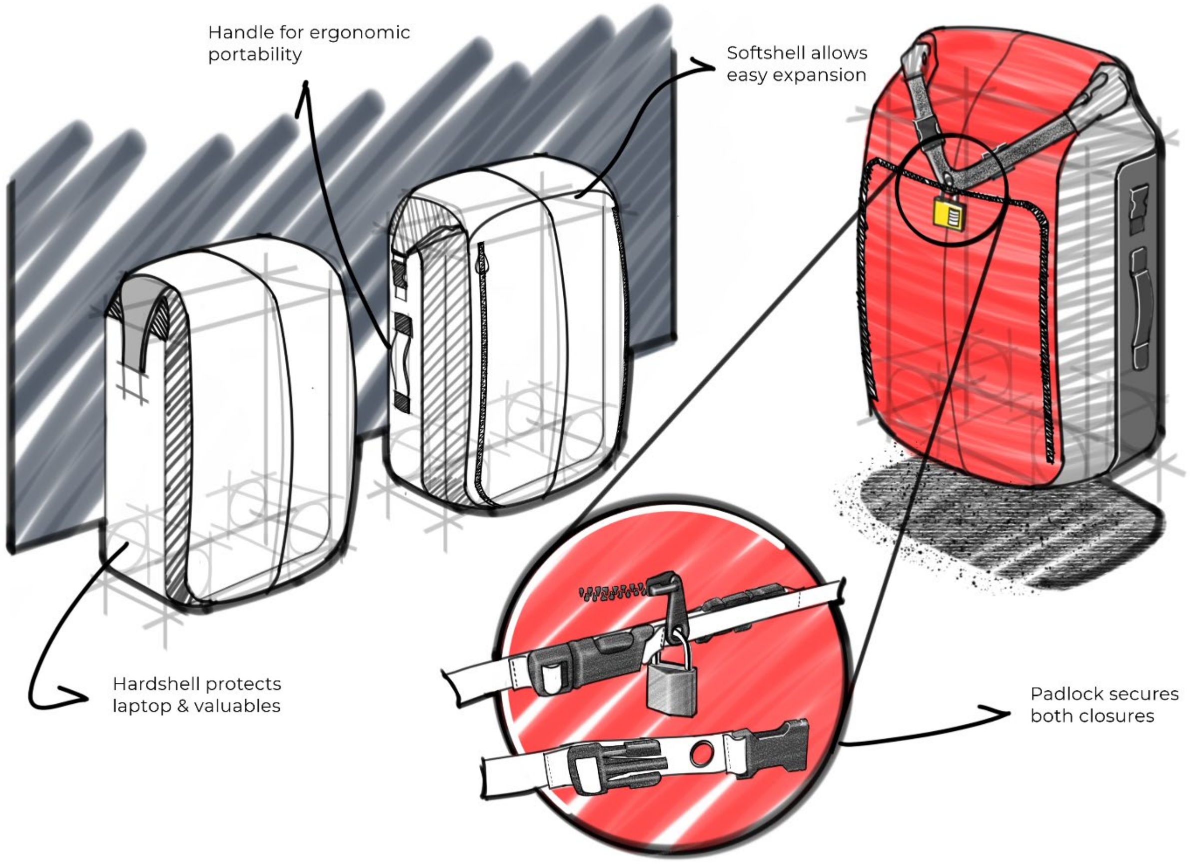


Figure 112: Alternative concept

Interviews

The interviews serve to compare the final prototype and the alternative concept. It is also used to discover problems with the final prototype that have not been identified through the fourth questionnaire. The interview is held using topic guides, which results in a semi-structured interview. By interviewing this way, the sequence of questions and the wording of prepared questions can be changed [73].

The themes that are questioned during the interview are the following:

- Expandability/flexibility of volume
- Organizability and loading/unloading
- Safety/ Protection of contents in case of crash
- Volume (front and rear)
- Number of containers (rear)
- Trolley function
- Waterproofing
- Weight
- Security

- Durability

The transcripts of these interviews are added in the appendix. The most interesting comments are highlighted here.

First, the expandability/flexibility of volume is discussed. Most interviewees think the expandability is sufficient. One interview makes the following remark: “If you would want that kind of flexibility and expansion, then you would buy a Vaude or an Ortlieb. However, if you want something rigid, the hardshell would be the way to go.” Of course, one cannot fulfil everyone’s needs with one single product. This comment confirms the author’s sentiment that a hard-shell container has more potential than designing another softshell. Panniers like the Vaude Aqua and the Ortlieb Back Roller are established values. Therefore it would be tough to compete with them by producing a cargo container that uses a softshell.

Second, the interviewees are asked about their perception of the safety of the rear cargo container. With safety, two things are meant: first, the feeling that the container would cause injuries in case of a crash, and second, how well the contents are protected in case of a fall. None of the interviewed people worried about injuries in case of a crash. However, almost all of them did see the extra protection of, e.g. their laptop, as a significant advantage over regular panniers: “The feeling of safety would be the same as for a softshell. I think this is more of an advantage: if you are crashing while on the bicycle, your laptop will be less likely to be damaged.”

Third, the organizability and way of loading/unloading of the rear container are discussed. Most respondents think the front-loading is an advantage in the commuting context, as it helps keep an overview of the transported items: “I am a very organised person, so I think this is a big advantage.” However, several interviewees see the possibility of top-loading as a requirement. They are more drawn to the alternative concept because of this feature: (about rear cargo container prototype) “I think loading vertically is impaired a little, and this is a problem. I would be tempted to go for regular bicycle panniers then.”

Fourth, the volume was discussed. There were no really pronounced opinions about this. One interviewee remarked: “I like that it is the rear container is this elongated. Regular bicycle panniers are less deep so that you could find items quickly, but because you are using the front-loading mechanism, it is allowed to be longer.” Especially the volume of the front container was discussed. Several respondents indicated that it just had to be large enough to fit a helmet, as this was considered an important feature: “Excellent that you can leave your helmet. I have ridden a moped in the past, and I thought it was terrible that I always had to take my helmet everywhere with me. I did not want to lock my helmet to my moped.”

Next, the number of cargo containers in the rear was discussed. Some people would like to buy two immediately for reasons of stability. Others would start with only one and buy another one if they like it. Eventually, it is up to them to decide, of course.

The trolley function was also discussed. Not one respondent sees this as an added value. The waterproofing, on the other hand, was considered an advantage over cheap panniers. However, the respondents who already owned a waterproof pannier like the Vaude Aqua thought this level of waterproofing was necessary and demanded full waterproofing of a cargo container. These results confirmed the assumption that full waterproofing is an essential criterium for a high-end cargo container.

The respondents reacted differently to the weight of the rear cargo container. Some found it was heavier than expected. Others thought it was lighter than expected. One person commented: “I think it is a little on the heavy side, but on an e-bike, it would matter less because the bicycle weighs a lot more than a traditional bicycle. Furthermore, you would probably make the final product from far lighter materials than this prototype."

Finally, the most crucial aspect of the final prototype was discussed: its security. Most respondents are very enthusiastic about the cargo container's security: "Yes, this is a significant advantage: now I have to take my Vaude everywhere with me, and that would not be the case anymore with this container." While not all respondents would leave their laptop or other valuables in the cargo container, others think it would be no problem if the locks of the final product are very secure: "It depends on how good the locks work. If you really cannot break into it quickly, then yes. However, especially because you cannot cut through this material, I think this would be okay if the locks work well."

The alternative concept scores rather poorly on security. Especially the lack of an integrated lock is not appreciated: "I do not like the padlock. Could you integrate this? I would probably lose this padlock very quickly, so I do not like that." In addition, several respondents think the security of this alternative concept is not sufficient: "Isn't it effortless to cut through this? I would leave my laptop in the hard shell, but I would not leave it in this combination of hard shell & softshell."

In conclusion, the main advantage of the alternative concept is that it is top-loading, but overall the prototyped cargo container does better. Especially the security of the prototype is preferred over the security of the alternative concept.

Final adaptations

As mentioned in the previous section, the main problem with the final prototype is that it is less convenient to load and unload while on the bicycle than regular bicycle panniers, where one just 'throws in' the items. As mentioned, regular panniers are top-loading, and this cargo container prototype is front-loading.

The interviews showed that, for some (minority), this would be a determining factor when choosing between regular panniers and the designed cargo container.

Figure 113: Final prototype: flap opens

Figure 114: Final adaptation: flap is attached

After a brainstorming session, a new idea was found. Instead of having a 'flap' that opens, the prototype is turned around 180 degrees. Now, the flap is attached to the bicycle. This way of attaching the cargo container has several advantages: first, the user's laptop, which was attached to the flap, is now protected even better as it is very close to the bicycle's frame (the furthest away from the street or pavement in case of a fall). Second, when the cargo container is opened, all the contents are tilted, essentially making this a 'diagonally-loading' cargo container. Also, items are unlikely to fall out because of this tilt. Of course, some internal compartmentation will still be needed, e.g. a piece of fabric attached with a zipper, allowing for easy opening at the top but keeping items in place at the bottom. Other examples could be a 'net' keeping everything in place or a more rigid plate attached with Velcro.

This concept needs a little more space to open up than a top-loading cargo container, just like the final prototype. To check if this would be a problem, the author visited several bicycle storage facilities at companies and supermarkets.

Figure 115: IDC storage facility

Figure 116: Dreamland storage facility

Figure 117: WAAK storage facility

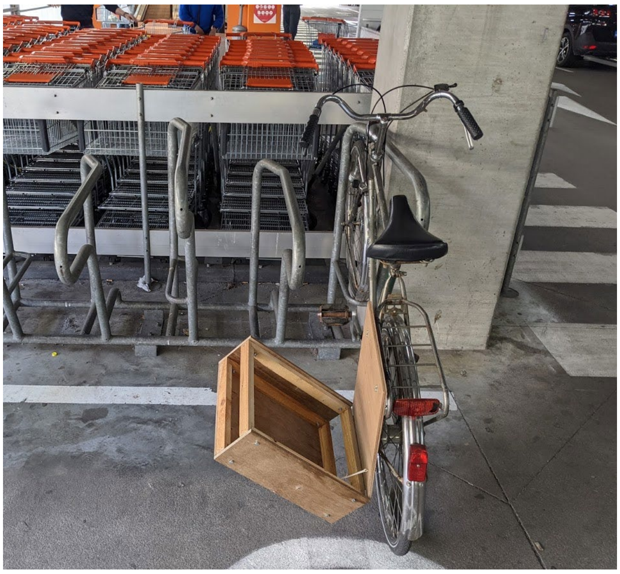


Figure 118: Colruyt storage facility

As shown in figures 115, 116, 117 and 118, the extra space that is needed rarely poses a problem. The most crucial factor for bicycle storage unit dimensions is the handlebar width. If the bicycle storage units are too close to each other, the handlebars and brake cables start interfering, which is very annoying. Most supermarkets and companies seem to acknowledge this and provide enough room per bicycle. Of course, in bicycle storage facilities that are very crowded, opening up the cargo container like this will be more difficult.

To conclude, the developed cargo container is somewhat less convenient for adding and removing items while still on the bicycle. However, because the cargo container is front-loading, organizability is greatly improved. This feature allows quick retrieval of items, avoiding frustration and having to take out every item in the cargo container to find the item the user is looking for. Furthermore, if the cargo container is used as a 'shopping crate', stacking the groceries is much more straightforward.

5. Deliver

As a result of the "Deliver" stage, a final concept is modelled and rendered. Just like the final prototype, the final concept has a front and a rear cargo container. For both containers, the final concept is shown first. Only then, all the choices that have been made are explained. Among these are the material choice and the chosen production methods.

5.1. Rear cargo container

Final concept

The volume of the final concept is about 16 l collapsed, and about 23.6 l expanded. The parts of the final concept were designed for disassembly, e.g. no glues are used, and all screws are the same size.

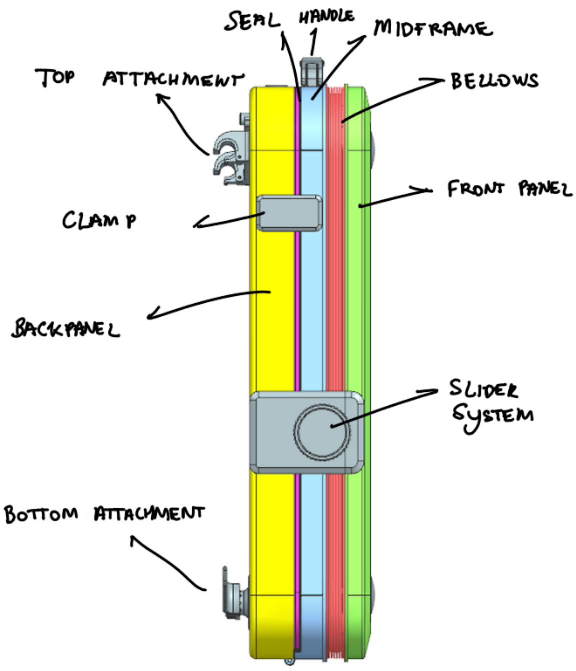


Figure 119: Indication of different parts

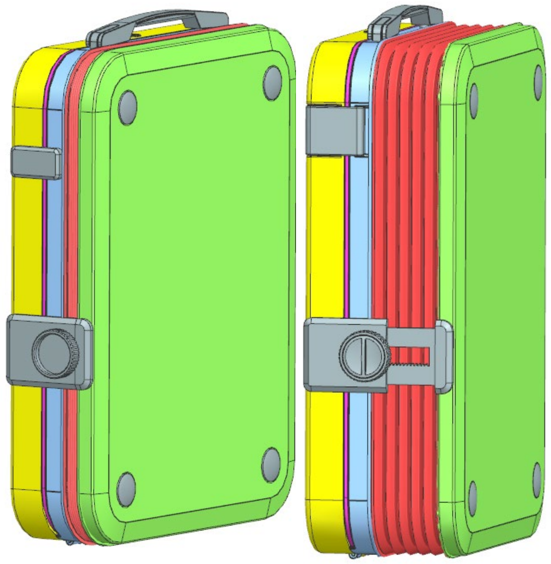


Figure 120: 3D view of final concept (collapsed vs expanded bellow)

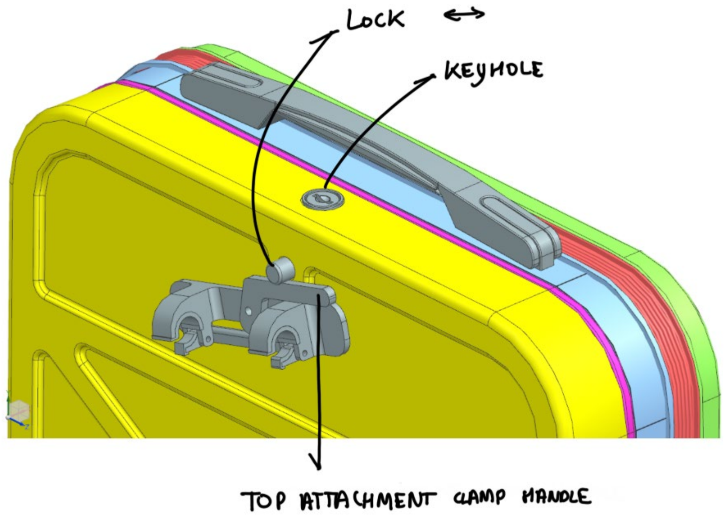


Figure 121: Locking system

Bellow[6]

First, the ‘bellow’ part is examined. The bellow part is a crucial element of this concept as it enables the expansion and contraction of the rear container (around 16 l vs around 24 l). This expansion method is chosen for the following reasons: first, it is not a ‘weak’ element of the cargo container, as would be the case with, for example, a fabric section that can be expanded or contracted with the help of a zipper. The bellow is produced from a ‘hard’ material that is not easily cut. Second, it can be expanded and contracted from the outside of the cargo container, meaning that it does not need to be opened for this action. This exterior expansion is an advantage, especially when, for example, cargo is added while the cargo container is already on the e-bike or speed pedelec. Third, by using a bellow,

[6] A bellow is comparable to an accordeon

the structural integrity of the cargo container is preserved: the ‘triangles’ of the bellow are structurally solid and can take a significant load.

Although these factors are significant advantages, the concept is also not without complications. First, if the bellow is made from a rigid material, how can the needed flex be achieved (every corner of the ‘triangles’ needs to function as a hinge)? Second, if there is a material that is suited for this, how can it be produced?

Figure 122: Living hinges used in the design of a safety razor

Polypropylene (PP) is one of the most commonly used injection moulding plastics. One of its most attractive qualities is that a local thinning of the material can serve as a ‘living hinge’, which is different from conventional mechanical hinges because it is an integral part of the product. In addition, the material properties of PP allow this hinge to be folded tens of thousands of times without it breaking.

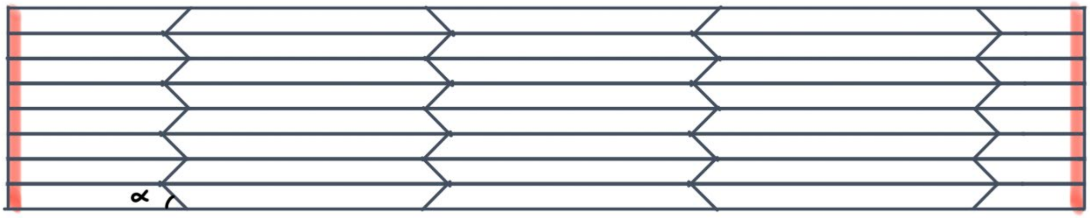


Figure 123: Sheet PP bellow (origami pattern)

Initially, it was researched how this bellow could be produced from a sheet of polypropylene. Then, the living hinges could be produced by stamping the blue lines in figure 123. After this, the bellow would still have to be plastic welded into a closed-loop (the red sides in figure 123). A similar ‘origami’ technique was also used for the final prototype, and it worked well for its rectangular shape. However, as multiple survey respondents and interviewees noted, the pure rectangular shape of the final prototype is not very aesthetically pleasing and a little masculine. These findings meant that the corners of this rectangular would have to be rounded to make sure females would also feel attracted to this rear cargo container. As a solution, a variant of the idea was devised, where the corners were chamfered, achieving a more rounded, feminine aesthetic (figure 124), and it was prototyped to see if it would work in reality. This prototype (figure 125) appeared to be okay.

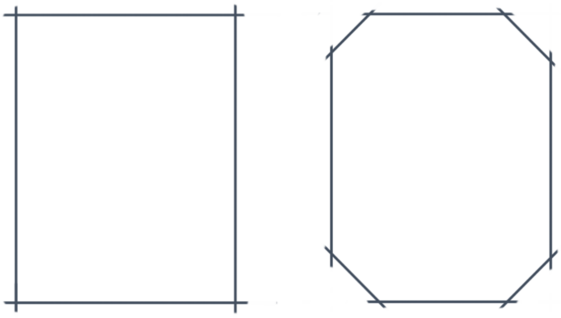


*Figure 124: Original rectangle vs more 'rounded' octagon (350 * 450 mm)*

Figure 125: Prototype octagonal bellow

Because the general shape of the bellow changed from a rectangle to an octagon, the angle α (figure 123) also chaned from 45° to 22.5°. However, when this octagonal shape was modelled in Siemens NX, the author discovered that it was impossible to achieve this 22.5° angle combined with the desired octagonal shape (figure 126).

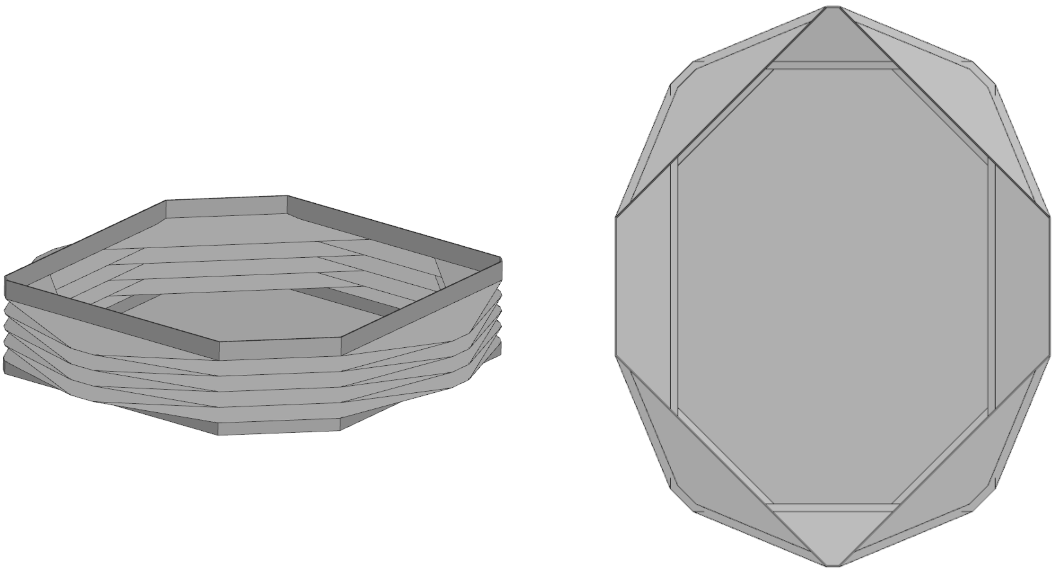


Figure 126: CAD models: octagonal bellow failure

The purely rectangular shape was not considered an option anymore, so a different production method had to be found. After an extensive search for alternatives, an example of a blow moulded expandable PP bottle was found (figure 127)

Figure 127: Blow-moulded collapsible PP plastic bottle

A variant on this blow-moulding technique, 3D manipulation blow moulding, can be used to produce the bellow part as depicted in figure 120.

Back panel, front panel and midframe

The back panel, front panel and midframe are all manufactured using injection moulding. Injection moulding is a technique reserved for mass-produced objects, as tool costs can be pretty high [74]. However, because the rear container is universal, it is expected that it will be sold in the thousands, which makes injection moulding a viable option.

Some design guidelines should be followed when designing a product for injection moulding. To prevent designing a final concept that is impossible to produce using this production technique, these (basic) injection moulding guidelines are followed as much as possible [75] .

Table 7: Design guidelines injection moulding

Maximum wall thickness	The wall thickness directly influences the cooling time that is required and the total materials needed. By keeping the maximum wall thickness as low as possible, both factors can be minimized. The longer the cooling time, the higher the part cost
Corners	All corners should be rounded to improve the durability and aesthetics of the part. If there are changes in wall thickness, a transition should be provided
Applying a draft	A draft is a slight angle (usually one or two degrees) applied to the faces of the mould perpendicular to the parting line, and it is needed to easily remove the pieces from the mould
Ribs	Ribs are a feature in injection moulded parts. They are structural elements that run perpendicular to a plane or wall and are used for stability control. By adding ribs and not design thicker walls, greater structural support can be achieved. Ribs should be about 60% of the nominal wall to prevent sink
Bosses	Bosses are another feature in injection moulded parts. They are included in a design for accepting screws or other fasteners and look like cylindrical, hollow protrusions. A good practice here is to add them to a wall or add a rib so that the bosses remain straight
External/internal undercuts	Undercuts (an indentation or protrusion prohibiting the ejection of the part from the mould) should be avoided as much as possible as they can increase the cost of the mould. If inevitable, the parting line of the mould often has to be adjusted to accommodate this
Threads	Threads should be avoided or placed perpendicular to the parting line

The material used for these parts is, again, polypropylene. This material is primarily chosen by taking a closer look at a critical benchmark: suitcases. In general, suitcases are abused a lot when passing through airport security and handling, so they need to be strong and impact resistant. These material characteristics happen to be crucial for the bicycle cargo container as well (e.g. crashes, bicycle falling). As a result, a few materials are often used: Curv®, polycarbonate (PC), polypropylene (PP) and ABS. Curv® is a thermoplastic material made from stretched and woven polypropylene fibres. It is lightweight and scratch-resistant but also comes at a high cost. Polycarbonate is also lightweight but more flexible and pliable. However, it is also quite expensive. ABS is scratch-resistant, flexible and pliable, but is not as strong as Curv®, PP or PP. Finally, PP is extremely strong, cheaper than the other materials, but also has a higher density, making it slightly heavier.

In the end, PP was chosen, not only for the reasons mentioned above but also for one more significant reason: weldability. Thermoplastics can be welded together on one condition: that they are the same material. By welding together the front panel, bellow, and midframe, these separate parts become one assembly, eliminating the need for seals (needed for waterproofing).

The specific welding method that is used here is hot plate welding. First, the flanges of the parts that need to be joined are heated by a hot plate, and then they are firmly pressed together, creating a weld.

Top and bottom attachment

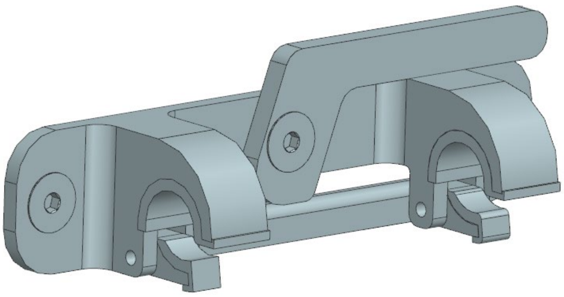


Figure 128: Top attachment

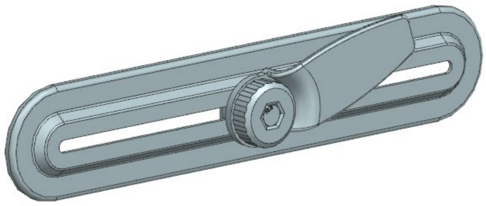


Figure 129: Bottom attachment

The top attachment is CNC-milled from aluminium, and the bottom attachment is injection moulded.

Especially the top attachment is of importance here. In the surveys, several people indicated that one of the problems of current cargo containers is that the paint wears where the top hooks attach the cargo container to the bicycle's rear rack. This wear is formed because the attachment is not entirely rigid. The top attachment presented here is based on a cam lock system that clamps onto the bicycle's rear rack. This system will significantly reduce the wear of the rear rack. It also rigidly attaches the rear container to the bicycle's rear rack, which helps a lot with the bicycle's stability because the centre of gravity of the rear container does not shift during cycling.

Other components

The other components are not discussed in detail here as they are less crucial. The handles are a standard component, and the sliding and latch mechanism are also injection moulded. As mentioned, the end goal of this master's thesis is not to deliver a production-ready model but to prove that the final product can be produced using specific production techniques (e.g. blow moulding of the bellow).

5.2. Final concept (front and rear)

The final concept is a complete cargo container system consisting of a front container of approximately 10 l (large enough to fit a helmet) and one or two rear containers of approximately 16 l (collapsed) or 26.3 l (expanded). The front container still needs to be modelled.

6. Conclusion and further work

This master's research is about the research, design and development of a versatile, convenient bicycle container system. Throughout this research, the Design Thinking methodology was used, with an emphasis on the user. Thanks to this user involvement, it was possible to generate an e-bike cargo container system tailored to its users' wants and needs. Implementation of this concept could mean a decent first step in developing the e-bike and speed pedelec into a '365-days' vehicle.

The final concept minimises some of the advantages of the car, such as security, convenience and the protection of its contents. Furthermore, some of the identified problems with current cargo containers, such as a lack of robustness and consideration of aerodynamics, are also solved. Finally, the final concept is adapted to the relatively new context of e-bikes and speed pedelecs, unlike current cargo containers.

The final concept also excels in its sustainability aspect. The e-bike only emits about one-tenth of the greenhouse gases cars emit. Furthermore, the e-bike makes the environment more liveable: it is pleasant to live in a city filled with bikes instead of cars. Design for disassembly was also taken into account, allowing easy maintenance and separation of material currents at the end-of-life.

The final concept is not yet finished due to time limitations: the front container still needs to be modelled, and a complete concept needs to be rendered. Other further work could include: producing a high-fidelity prototype to test some of the aspects of the final concept, such as the diagonal loading, and do final user tests to see if the final concept holds up in actual use. Second, a cost calculation should be made to determine the final cost of the cargo container system.

In conclusion, by decreasing the relative advantages of the car through the cargo container, car commuters are more likely to shift to speed pedelec and e-bikes for commuting. If this results in a strong habit towards cycling, the modal shift from car to bicycle may be nearby.

7. Limitations

The limitations of this master's thesis are twofold.

First, this thesis was conducted during the COVID-19 pandemic, which led to constantly changing, and unpredictable conditions. At the beginning of the academic year, the end of September, the number of infections was on the rise again in Belgium. As a result, a national lockdown was reintroduced as of the beginning of November: social contacts had to be limited as much as possible and teleworking was mandatory. This lockdown was eased at the beginning of May, but caution is still advised.

As a result, meeting with users in person was virtually impossible but also ill-advised. Therefore, a change in envisioned methods was required: instead of performing in-person interviews, focus groups or observing the product in use, four surveys were distributed, each trying to maximise the information gathered. While a survey is usually a method for gathering quantitative data, a mixed-method was adopted, and next to quantitative, qualitative questions were also asked.

In the second semester, the final prototype had to be tested. Again, a survey was used for this. By implementing short video fragments into the survey (a suggestion by Lore Brosens, PhD student at UGent Campus Kortrijk) to make the questions more tangible and provide a good understanding of the prototype and concept.

Next to this, the final prototype was also tested in person with several users. To prevent unnecessary contact with strangers, these test persons were one teacher (speed pedelec commuter), one family member (e-bike commuter), and eight fellow students (outside of the target audience).

While the interviews with fellow students should not be considered 100 % reliable, the information obtained was still precious, as most of the interviewees were able to get into the skin of the target audience and the personas of Marc Vanneste and Kathleen Vandamme.

Second, this thesis was initially conducted in collaboration with an external company. Unfortunately, this external company started backing out at a certain point, and the contract was ultimately cancelled (at the beginning of April). The reasoning behind this cancellation is the following: at a certain point, the company pushed forward a concept that was completely separate from the work done up to that point. Furthermore, this concept ignored many findings from the surveys and literature review, such as aerodynamics, stability, weight distribution, expandability and detachability. Some ideation was already in place, and this suggested an entirely different kind of cargo container.

The author of this thesis suggested elaborating on both the company's concept and personal ideation and ultimately let the target users decide about the winning concept. However, the external company did not agree with this proposition and insisted the company's concept solely be developed. As this would have undermined this thesis, the collaboration was halted.

Unfortunately, up until then, the ideation and first concepts of the cargo container were designed around the external company's speed pedelec, specifically. This speed pedelec was unusual as it had tiny wheels. This feature presented some advantages over large-wheel speed pedelecs, which were exploited as much as possible. Hence, it was impossible to make the entire cargo container system 'universal', suited to all speed pedelecs and e-bikes. However, the rear container is made as universal as possible and should fit most E-bikes and speed pedelecs. The front container is a container that belongs to a specific bicycle which is designed around a small front wheel.

Finally, this discontinuation meant that much work surrounding the company's speed pedelec had to be destroyed and could not be used in this master's thesis. Thus, in reality, a lot more work had been done. It is simply not shown here.

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9. Appendix

9.1. Transcripts interviews

Pilot interview

Demographics

Gender: Female (Test User)
Age: 27 years old
Distance of commute: 32 kilometres (one-way)
Terrain during commute: primarily paved roads, hilly & flat terrain,)
Current cargo container: Ortlieb backroller
Bicycle: Trek Super Commuter (speed pedelec)

Observation

Observing while the user is testing the cargo container is difficult, so it is done off the speed pedelec.

“It is good that the weight is located relatively low because right now, the centre of gravity of the Ortlieb Back-Rollers sits a lot higher.” This high centre of gravity may have contributed to 3 crashes the test user experienced while on the e-bike. (Originally, it was presumed that falling with a speed pedelec was very unusual, but with the current solution being a hard shell, this might be a problem as it is less likely to survive a fall as good as a soft case solution. The falls always happen when the test user is heavily loaded and in a tight turn, on roundabouts.)

“Why did you choose for a box? You are not meant to take it off the bike, or are you?
I do not see myself walking around with a suitcase personally.”

The test user checks out the expandable storage (Not entirely sure how to open the container at first & some trouble trying to open + fixate at the same time).

There are some problems with the bike stand. First, it is hard to ‘open’ the bike stand (the container protrudes quite a lot at the bottom and is too long. Second, when getting on the speed pedelecs, the test user’s calves hit the bottom corner, which gives an unpleasant feeling. (soft case: not a problem because it is ‘soft’). Note: the cargo container is not yet mounted at an angle here.

Scenarios and tasks

While performing the tasks, the user is asked to use the think-aloud technique (say everything they are thinking)

1) Je bent klaar om naar het werk te vertrekken en plaatst de zaken die je normaalgezien bij je zou dragen (portefeuille, smartphone, eventueel handtas in de voorste container).
   you are ready to go to work, and you are placing the items you would typically carry on you (NOT MENTIONED: e.g. wallet, smartphone, tote bag, purse… in the front container).

TU puts bicycle chain, purse and scarf in the front cargo container.

1) Je bent net toegekomen op het werk met je e-bike en wilt de werkplek binnengaan. Neem de achterste cargo container af, neem hem vervolgens mee naar binnen en haal een voorwerp uit de koffer.
   You just arrived at your workplace with your E-bike, and you are about to go inside. Take off your rear cargo container, transport it inside and take an object out of the container.

The test user takes EVERYTHING out (by now, TU's charger is already at the bottom of the Ortlieb panniers but needs it to charge the speed pedelec battery – so it all has to come out. If TU does not do this, it is almost impossible to find anything in the bags). TU also does not want to leave clothes just used during cycling in the bag & lets them air a little.

Taking everything out of the prototype container might not be necessary (because it is front-loading). However, TU still seems to prefer the top loading containers. One aspect of this is the feeling that TU shows everyone what is in the bag exactly.

TU would not feel comfortable storing a laptop in there (even though it has a cover) and feels that it would be less safe. If there were a separate compartment, this would not change anything. TU would prefer something in fabric anyhow.

2) Je gaat om een brood en laat beide containers op de fiets hangen. Beveilig de achterste cargo container (ga er van uit dat de voorste reeds beveiligd is).
   You are buying a loaf of bread, and you are leaving both containers on the bike. Secure the rear cargo container (presume the front one is already secured).

Sometimes, during cycling, TU adds a jacket to the container and feels like this would be hard to do because the container is front loading.

TU does not seem to think this might alter TU's opinion when proposing a kind of compartments to prevent everything from falling out.

Currently: 'throws' keys into Ortlieb panniers. If the cargo container would have compartments: "Which compartment did I put it in?" TU feels like, while on the bike, stuff would fall out. Strapping the cargo content down would probably not work. TU: I have a lot of 'brol', so this might be cumbersome.

TU would prefer it if the cargo container could be used as a backpack.

Too many different keys is a no-go. (One family of keys! OR combination lock). TU suggests horizontal placement of the cargo container (not vertical placement, but this is impossible because of heel strike – putting the cargo container diagonally but at an angle should solve this problem).

TU: make the attachment panel indeed hard shell, but the front would probably be better off being something a little more flexible. This way, you do not need the accordion system, but you can still pack a lot more. When you look at the Ortlieb: you can fold it to a very compact size when it is empty.

Interview

LEGEND Volume Market acceptance / potential Organizability Security Safety Expandability/flexibility of volume Stability Weight Morphology / aesthetics

- Wat neem je allemaal mee tijdens je pendeltraject?
  What do you carry with you on your commute? (Organizability)

- Waarvoor zou je de voorste bagagecontainer gebruiken?
  What would you use the front cargo container for? (Also to some extent about volume)

TU would prefer one larger container. There is nothing that needs to stay on the bicycle. TU does not bring tools or anything. Rain gear: TU looks at the forecast in the morning, which fixes that problem. Right now: heavy battery (one hand), helmet, and having trouble carrying everything around (Multiple bags would be harder).

Upon arrival, TU goes to the toilet to change clothes.

- Waarvoor zou je de achterste bagagecontainer gebruiken?
  What would you use the rear cargo container for? (Also to some extent about volume)

- Zou je voor de voorste container liever meer volume hebben, minder volume, of vind je het zo wel oké? Waarom?
  Would you like more volume for the front container, keep it as-is, or make it more compact? Why?

TU feels like the container is too big and would prefer something smaller. Indeed, it might be helpful for things like a smartphone. TU would like to put her handbag inside. (puts front container to the bike and says that it looks out of proportion). The TU would possibly prefer a frame bag (that is not wide!). Also, TU would feel like an old lady with a front carrier. Currently: she calls assistance if there is a problem because TU does not know how to fix anything.

- Dezelfde vraag geldt voor de achterste container.
  The same question for the rear container. (Volume)

Make bigger (more flexible).

- Zou je een tweede container achteraan kopen om zo meer te kunnen vervoeren?
  Would you buy a second container for the rear to be able to transport more items? (Volume, market acceptance)

Even though it might make the bike more balanced, TU would probably not buy a second container (more cost + more hassle while transporting (not handy while carrying around)). However, it could be helpful to go shopping. However, the TU does not feel like it would be an excellent option to go (grocery) shopping with (in that case, both TU's Ortliebs are bulging, and TU does not want to squash down anything like fruits or eggs). With the Ortliebs, everything is at the bottom and presses against one another, and it does not 'klots'.

- Wat denk je over de uitbreidbaarheid van de achterste container.
  (*What do you think about the expandability of the rear container?)*

- Nu zou ik willen vragen dat je de volgende zin een score geeft van 1 tot 5, waar 1 helemaal niet akkoord is, en 5 helemaal akkoord is: "Ik apprecieer het dat er een vastgemaakte (vooraan) en een afneembare container (achteraan) zit in het cargo container systeem."
  I would like you to rate this sentence from 1 (strongly disagree) to 5 (strongly agree): " I appreciate that there is a fixed and a detachable container in the cargo container system?"

Helemaal niet akkoord	Niet akkoord	Neutraal	Akkoord	Helemaal akkoord
		X		

- Wat denk je over de verbeterde beveiliging van de cargo containers in vergelijking met de doorsnee fietstas? In welke mate vind je dit een meerwaarde?
  What do you think about the improved security of these cargo containers (compared to regular bicycle panniers)? (Sub-question) To what extent do you think this is of added value?

Helemaal geen toegevoegde waarde	Geen toegevoegde waarde	Neutraal	Toegevoegde waarde	Zeer veel toegevoegde waarde
			X	

At the start, TU was sceptical but now starts to see the point of it. However, the TU would never leave a laptop behind in it.

- Zou je het gevoel hebben dat je bagage en de containers genoeg beveiligd zijn om ze even onbewaakt achter te laten op de fiets?
  Would you have the feeling that your luggage and the containers are secured enough to leave them unguarded on your e-bike?

Laptop: "After a while, maybe yes, I do not think so. I would prefer a combination lock instead of a key lock!" (loses keys very often)

- Wat vond je van de stabiliteit wanneer de containers bevestigd zijn?
  What did you think about the stability with the containers attached?

Right now: she does not notice anything from the Ortlieb bag. With the prototype: no noticeable difference.

- Wat vond je van de stabiliteit en de gebruikservaring van de voorste container?
  What did you think about the stability and user experience (while riding) of the front container?

It is impossible to attach the front container to the test user's speed pedelec, so this is not tested.

- Heb je een veiliger gevoel omdat dit een hard shell is en geen soft shell?
  Do you feel safer because it is a hard shell and not a soft shell?

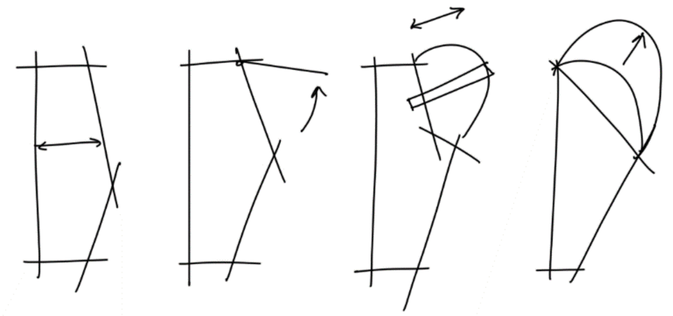
Not less safe but also not safer. The TU would say it is the same.

- In welke mate zie je het als een voordeel dat de cargo containers hard shell zijn en niet soft shell? Waarom verkies je het ene boven het andere?
  To what extent do you think it is advantageous that the cargo containers are hard shell and not soft shell? Why do you prefer one or the other? (Morphology / aesthetics & market acceptance)

Hardshell: "This is not an advantage, because psychologically, it triggers a memory of teachers which had those samsonite suitcases when in high school. It feels a little stiff and a little old-fashioned. Also, there is the feeling, even though it might not be the case, that you can put in less than in a normal pannier. With the expandable accordion, you are fixing the problem, but not really."

- Wat vind je van de vorm van de cargo containers? Hoe zou je de vorm willen veranderen?
  What do you think about the shape of the cargo containers? (Sub-question) How would you like to change their shape?

"The shape of this prototype is maybe not completely logical because you hit the sides with your leg (this is also something that happens with Ortlieb bags, but it doesn't bother TU because it is softshell)." Suggestions: partly semi-hard shell, partly softshell, which can expand easily



- Wat vind je van de esthetiek van een dergelijk cargo systeem? Welke veranderingen zou je willen doorvoeren?
  What do you think about the aesthetics of the cargo container system? Which changes would you make?

Colour: black if it is hardshell and maybe some kind of grey if it is softshell.

- Je hebt even kennis kunnen maken met de optie om van de achterste cargo container ook een trolley te maken. Ik zou je opnieuw willen vragen om de volgende vraag te raten van 1-5, waarbij 1 voor helemaal niet akkoord is en 5 voor volledig akkoord staat. "Ik vind het een meerwaarde dat de achterste container ook gebruikt kan worden als trolley en ben bereid hiervoor een iets hogere prijs te betalen."
  I want to ask you to rate the following statement – again from 1 to 5, with one being strongly disagree and five being strongly agree: "I think it is an added value that the rear container could also be used as a trolley (e.g. to do small groceries) and I am willing to pay a little more for this."

Helemaal niet akkoord	Niet akkoord	Neutraal	Akkoord	Helemaal akkoord
X				

- Wat vind je over het gewicht (leeg) van de cargo containers?
  What do you think about the empty weight of the cargo containers?

"More than the weight of the Ortlieb bags, not very heavy but noticeable. It would be better if they were a little lighter."

- Welke van de twee cargo containers vind je het interessantst en waarom? Waarom vind je de andere minder interessant?
  Which one of the cargo containers do you think is the most interesting to you and why? Why do you think the other one is less interesting?

"The rear one. The front one probably would not be used unless it is tiny. (TU owns rear panniers right now). "

Final interviews

(1)

Gender: **Male**:21 years old
E-bike? **no**
Commuter? **Yes** (distance one way: 2 km)

Prototype

- "It is an advantage that you can store your helmet safely and dry on the bike."
- Security: current bicycle panniers: "You always have to remove them from the bicycle, and you cannot leave anything behind."
- "A bicycle pannier is always ugly, but I like the aesthetics of this hardshell. It can be made to look cleaner than regular bicycle panniers. Maybe put the handle to the sides so that you can use it as a kind of briefcase."
- Volume: "In the front: priority number 1 is that it fits a helmet. The rear is expandable, so that is a significant advantage, and the volume seems OK. Now you have to take your helmet EVERYWHERE, which sucks (it does not always fit into your bicycle panniers)."
- Weight: "No real worries about the weight: it weighs a little more, but not a dealbreaker. I can imagine that the weight would be less for the final product (different materials)."
- Aesthetics: "It looks clean, and I think it is positive that it is a hard shell. In my opinion, it is a big advantage that you can use it like a briefcase because it feels fancier than regular panniers."
- Hardshell: "If you fall, maybe it will break, but if you use a CURV like material, it probably will not break either or be badly damaged. If my laptop is inside it and the bike tips over, I would prefer some damage to my cargo container over my laptop. The cargo container will be cheaper than your laptop, anyway."
- Second cargo container: "I would start with one and possibly add a second one if I am pleased with it."
- Trolley function: "I think only a few people would use it. Maybe if it was an add-on, so that you could fulfil these people's needs, but I would personally not want it. I think trolleys are ugly."
- Front-loading vs top-loading: "I think it is not a dealbreaker that it is not top-loading because you have the partition."
- Durability: "It would be a good feature that the cargo container is modular: if your front flap is broken, you can replace it with a new one. On the other hand, I don't know if the target audience would do that. Chances are they would just buy a whole new container."
- "You cannot really tell that it is a bicycle pannier, so maybe it could be used for travelling as well."

Iteration

- **"Isn't it effortless to cut through this? I would leave my laptop in the hard shell, but I would not leave it in this combination of hard shell & softshell."**
- "I think this iteration is less focused on the target audience who want a professional-looking cargo container. For example, bicycle panniers are always ugly when you carry them around, while that does not have to be the case for this hardshell cargo container."
- "The softshell might have other advantages, but I would go for the hard shell."
- "I think the front-loading zipper function is less relevant because I would never use it. Also, it is less convenient than the prototype because it is softshell."

(2)
Gender: **Male**: 21 years old
E-bike? **no**
Commuter? Yes/no (distance one way: ___)

Prototype:

- "The volume is definitely enough, and it is an advantage that you can expand and decrease it."
- Loading and unloading: "I am a very organised person, so I think this is a big advantage (talking about the front-loading prototype vs regular top-loading panniers)."
- Safety: "I never had any problems with safety for regular panniers, so I do not think this would be a problem."
- Volume in the front: **"Excellent that you can leave your helmet. I have ridden a moped in the past, and I thought it was terrible that I always had to take my helmet everywhere with me. I did not want to lock my helmet to my moped."**
- Second cargo container: "I think I would buy only one because I think one would be sufficient in terms of volume."
- Weight: "It is lighter than it seems. I do not think the weight is too much."
- Security: "I think it is perfect that you can lock it. A regular bicycle pannier seldom has a lock, so if you have to leave anything in there, that will make you feel uncomfortable."
- Leaving laptop behind: "I would never leave my laptop in a regular bicycle pannier, but I would be tempted to leave it in a bicycle container like this."
- Aesthetics: "I think this would go well with the aesthetics of speed pedelecs, the more clean look of a hard shell. Regular bicycle panniers are more for granny bicycles. Bicycle panniers are useful, but not at all pretty."
- Durability: "If you fall with your bicycle or ride against something, it would probably break sooner. On the other hand, if it provides more safety for my laptop, I would not care. I would prefer the cargo container to be broken than my laptop."
- Loading/unloading: "It would be nice to see that it is also possible to use top loading. Some people prefer one or the other, so having both would be a good thing. Top loading is easier to use while the container is on the bicycle."
- Trolley: "It already looks a little like a trolley, but for me, it would not be necessary."
- Waterproofing: "OK"

Iteration:

- Aesthetics: "I think this looks really nice, even more so than the full hardshell. That there is a hard compartment is superb to protect your laptop."
- Security: "The lock looks a lot less professional, less feeling of safety. I would still leave my laptop inside of it for short periods."
- Flexibility: "The added flexibility is a big advantage."
- "A shoulder strap would be added value."

(3)
Gender: **Male** Age: 21 years old
E-bike? **no**
Commuter? **no** (not an avid cyclist)

Prototype:

- Volume: "It is handy that you can expand the volume easily, and you could also "tighten" the contents with this expansion."
- Organisation: "I think this is good: let me give an example: when I go to the baker with my mother's e-bike, and there are some loaves of bread in the bicycle pannier, my keys are often at the bottom, so I have to look for them really hard".
- Hardshell: "Because it is a hard case, it is easier to take out certain items. It retains its shape (when laying down)."
- Safety: "The width is good, no problem. Softshell: Easier to break something inside of it. I would prefer my laptop to be OK and some minor damage to the container over an undamaged container but a broken laptop."
- Front: "Would be an ideal place to store a purse for women and a wallet and keys, smartphone for men. You probably will not do large groceries by bicycle."
- Second container: "It depends on one's own wishes.".
- Loading/unloading: "Top loading might be more useful at times, but front-loading also has advantages. I think the flap would maybe also be good as some webbing, so not a rigid partition."
- Trolley: "Personally, I would not think this is an advantage. Maybe if you had two and you could stack both containers on each other, the volume would be substantial.
- Weight: "Okay, but I expected it to be lighter. I do not think this is a big problem. It depends on how much effect this has on the stability while on the bike."
- Aesthetic: "This hardshell looks better than most common bicycle panniers."

Iteration:

- "Could you carry this on your back? Because then, weight is less of an issue. If it had a shoulder strap, that would also be OK as long as you could secure this strap.
- "Now that I see this, maybe I would prefer it over the full hardshell."
- "I would never leave something expensive on my bicycle. A little bit of security is sufficient, not necessary to have a fixed lock."

(4)
Gender: **Male** Age: 21 years old
E-bike? **no**
Commuter? Yes (distance one way: 1 km)

Prototype:

- “The expandability is good, for example, when you want to store your jacket. I would even always leave it in its fully extended position.” *Explain air resistance*
- Organisability, top or front loading: “The organisability is a significant advantage when you are commuting, but not really when you are shopping with the cargo container. If the flap works well enough, then it could be OK. However, you would need something to put your groceries on top of it or your rear rack. If you are using it as a briefcase, then it would be helpful.”
- Security: “It is a significant advantage that you can lock your contents. When in a city, I always fear theft when I leave stuff in my bicycle’s panniers. It would be even better if you could lock the contents and the cargo container to the bicycle with only one lock. That would already remove one user action.”
- Safety: “The feeling of safety would be the same as for a softshell. I think this is more of an advantage: if you are crashing while on the bicycle, your laptop will be less likely to be damaged.”
- Leaving laptop: “It depends on how good the locks work. If you really cannot break into it quickly, then yes. However, especially because you cannot cut through this material, I think this would be okay if the locks work well.
- Volumes: “ I think the volumes are okay. Are they bigger than regular bicycle panniers? A bicycle pannier is always too small. There will always be occasions where it will be too small. The front container seems a little too big, which I think would bother me and prevent me from buying it. Then I would instead put my helmet in the rear container.
- Trolley function: “This is not an advantage. I even carry my carry-on luggage by hand.”
- Hardshell or softshell: “They both have their advantages. The main advantage of the hardshell would be that the contents are safe and less easy to break into (security).”
- Weight: “The weight is okay. It is not a big problem that it is a little heavier. However, it could be good if you could carry this on your back.”

Iteration:

- **“I do not like the padlock. Could you integrate this? I would probably lose this padlock very quickly, so I do not like that.”**
- “I miss some protection for your laptop in this iteration. I think I prefer the hard shell because I would leave my laptop in it.”
- “I do think that the iteration is easier to use because it is top loading.”
- “If you could make the hard shell look more like a Samsonite case, that would probably look very smart.”

(5)

Gender: **Male**, Age: 21 years old

E-bike? **no**

Commuter? Yes (distance one way: 1,5 km)

Prototype

- Expandability: "I have a Vaude Aqua pannier, and it bothers me that it is always wide, even when there is almost nothing inside. By making this expandable, you are preventing that, and it can be kept relatively compact."
- Organisability: "On the front, you could maybe add another compartment for easy access to keys, e.g."
- Front vs top loading: "Front-loading is a nice feature in the context of commuting if you are carrying folders, e.g."
- Safety: "Add some reflectors so that you are well visible in the final product. Otherwise, no complaints."
- Weight: **"I think it is a little on the heavy side, but on an e-bike, it would matter less because the bicycle weighs a lot more than a traditional bicycle. Furthermore, you would probably make the final product from far lighter materials than this prototype."**
- Volume: "I like that it is this long. Regular bicycle panniers are less deep so that you could find items quickly, but because you are using the front-loading mechanism, it is allowed to be longer."
- Aesthetics: "Make it fit on several brands of speed pedelecs and e-bikes?"
- Front carrier: "Maybe it would be a nice feature to have an extra see-through plastic sleeve where you can put a map or your iPhone?"
- Security: "Yes, this is a significant advantage: now I have to take my Vaude everywhere with me, and that would not be the case anymore with this container."
- Leave your laptop behind? "It depends a lot on the context: if I am quickly going to the Delhaize to get a water bottle, I would definitely trust that, partly because people do not expect there to be a laptop inside."
- Hardshell vs Softshell: "I think the hard shell is an advantage in terms of durability. I did an internship at Samsonite and discovered that many hard shells are very flexible these days, so I am not worried about losing much flexibility. If you were to make this ins CURV material, that would definitely be OK. If it is empty or not heavily loaded, it will not give, but when you have a lot with you, the shell can deform somewhat."
- Second container? "I Would definitely buy a second one because you can carry more."
- Trolley? " A trolley function presents no added value for me."
- Safety of contents: "This is an advantage: as long as your laptop or valuables stay safe."

Iteration

- "The hardshell looks better, smarter, fits speed pedelecs better."
- **"If you would want that kind of flexibility and expansion, then you would buy a Vaude or an Ortlieb. However, if you want something rigid, the hardshell would be the way to go."**
- "One possibility would be to add a soft pouch in front of the hardshell cargo container to allow some easy access, like keys or a biscuit."

- “The front is handy for stowing away a helmet, but I personally do not need this because I do not have a helmet.”

(6)

Gender: **Male**, Age: 21 years old
E-bike? **no**
Commuter? **Yes** (distance one way: 1,5 km)

Prototype

- “The expandability is good, but I would want to make sure that the durability is good enough.”
- Volume: “I would not want expandable storage. Instead, I would go for a fixed volume (explain a scenario where the user buys a bread, user understands).”
- Fixation of contents: “In a regular bicycle pannier, your contents are sort of fixed inside, here the items might not be tight, a bit loose.”
- “Hinges make the action a little more convenient.”
- Hardshell vs softshell: “I would prefer a combination of both: one part which is hard to protect the contents, and one part which is soft to allow flexibility.”
- Organisation, front-loading: “It is effortless to organise your stuff. Because the surface area is so large, you have a good overview of your items, and dI like that because I am an organised person. “
- **“I think loading vertically is impaired a little, and this is a problem. I would be tempted to go for regular bicycle panniers then.”**
- The user suggests a kind of packet delivery box system so that you can fill the container at an angle, and nothing will fall out (However, this would entail that the volume would have to be fixed, so it is not really a possibility).
- Laptop: “I would never leave my laptop behind, but rather take it with me in a backpack.”
- Security: “I think there are some limitations to how safe you can make this system because you could always steal the bicycle.”
- “Security is an advantage, but concerning leaving behind valuables, it does not add much value for me.”
- Safety: “The corners need to be rounded, but it does protect the contents better!”
- Weight: “The weight is okay. It is not a dealbreaker for me.”
- Volume: “A box in the front is something is that I have never seen before. Does this exist? However, it is hard to imagine very sporty speed pedelec users use this front container. One would really use this more for practical than for aesthetic reasons. I think the volumes are okay.”
- Second container? “It depends on the final use. I would start with one and maybe buy a second one in the future if I like it.”
- Trolley feature? “If you incorporate the trolley function, you are assuming that the user will always remove the cargo container from the bicycle. If you are doing grocery shopping, this might be useful, but otherwise, it is a bit of a redundant function.”

Iteration

- “I think this will be less durable. Also, tearing the fabric is a risk, and you might have to have a repair service, which will come with a cost…”
- “The lock would be better if it were incorporated to make sure that it is more secure than this padlock. However, on the other hand, because it is a softshell, very robust security may be too much.”
- “I think I prefer this system, maybe even convert it to a backpack?”

(7)
Gender: **Female**, Age: 22 years old
E-bike? no
Commuter? **Yes** (distance one way: 7,5 km)

Prototype:

- Expandability: “The expandability is good, sufficient.”
- Front-loading / top-loading and organisability: I think it is nice that you can organise your items better. However, on the other hand, it would really bother me when you have to add something to your cargo container when it is already on the bicycle.”
- Weight: “It is heavier than regular bike panniers, but it does not bother me.”
- Security: “This is a significant added value. Especially locking the contents is nice, but locking it to the bicycle is also needed. “
- Volume: ok
- Second cargo container? “I would buy one to start and maybe add a second one later on.”
- Trolley function: “It might be helpful, but it would have to be designed very well, so you do not look like a granny. I would prefer it as a backpack.”
- Safety: “I would never think about this aspect. It is neutral to me.”
- Aesthetics: “Because it is a hard shell, I have the connotation with the trolley, which I do not really like. On the other hand, because it is a hard shell, organisation inside is much easier.”

Iteration:

- “I would be more inclined to leave the hard shell on the bike, while the softshell is more like something you take with you.”
- “I’m not sure if it is a significant advantage that this is lockable. Because it is softshell, you will be more tempted to take it from the bicycle, while the hard shell is more likely to stay on the bicycle, it does not seem very transportable and more business-like.”

(8)
Gender: **Male** Age: **21** years old
E-bike? **no**
Commuter? **Yes** (distance one way: 1 km)

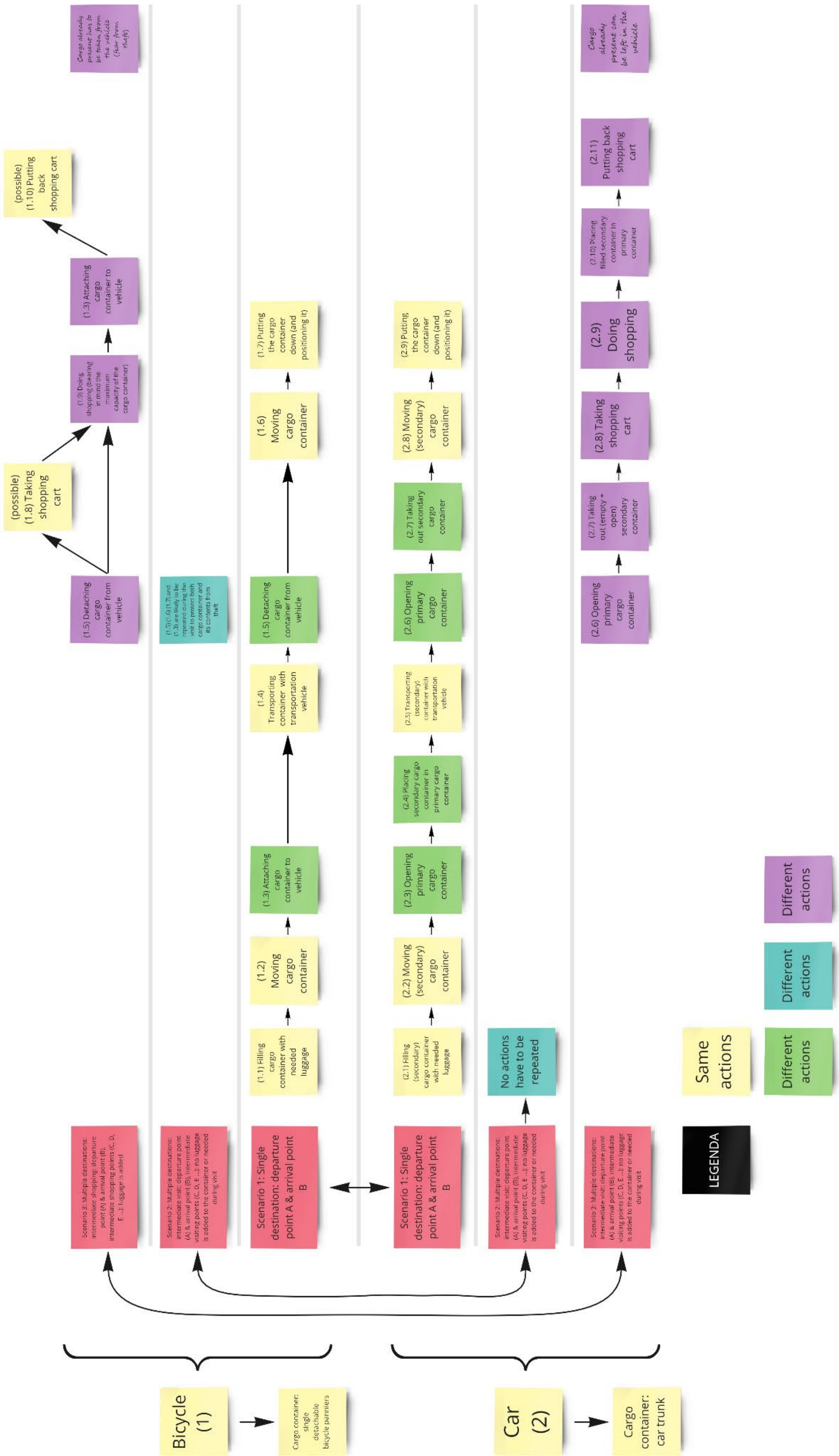
Prototype:

- Expandability: “This expandability is excellent, especially when you are doing some groceries.”
- Organisability: “Make sure that your items do not fall out when you are opening the cargo container (still attached to the bicycle).”
- “It reminds me of trekking backpacks which you can load at the top, but also in the front.”
- Safety: “No opinion.”
- Weight: “Oh, that is light. It does not weigh much, no problem at all, as long as it does not weigh 10 kgs.”
- Security: “It is good that you can leave it everywhere, without having to worry about it. However, I would not use it because I would put my laptop in my backpack. If it is for commuting, I think it is a significant advantage, but I really would not care for doing groceries.”
- Volume: “The rear container is already voluminous, but okay, you do not have to expand it all the way.”
- “I like the handle. It is always ergonomic.”
- “It feels sturdy when you are holding the rear container, which is nice.
- Front: “Ideal because you can fit your helmet. It does not need to be smaller or bigger.”
- Second rear container? “Yes, for stability’s sake.”
- Trolley: “No, I think this looks moronic.”

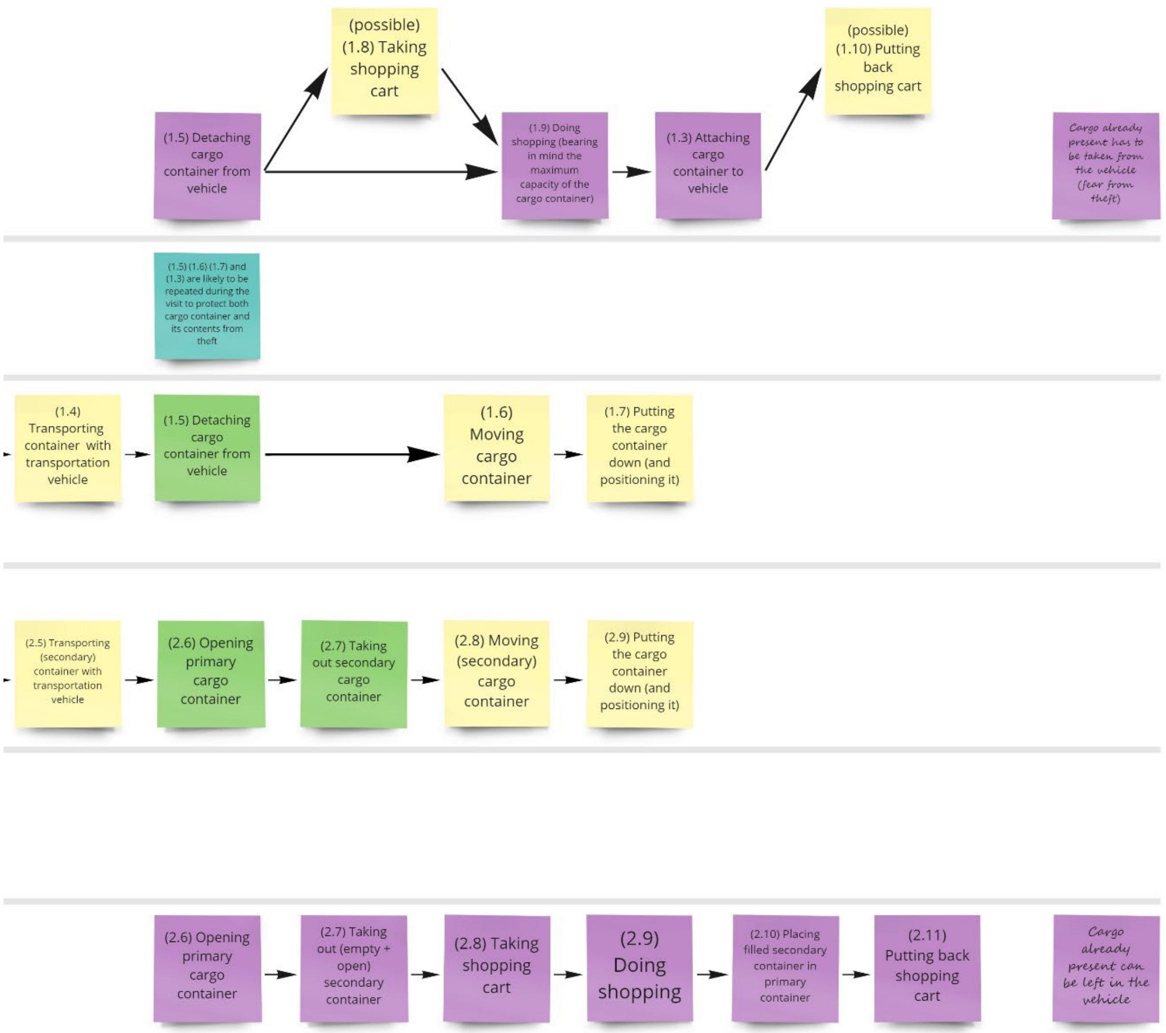
Iteration:

- “For going grocery shopping, I would take this. You have more flexibility than with the complete hardshell. Furthermore, you are less able to cram stuff into the hardshell container because of the front loading.
- “ The most significant advantage of this concept is that you can just throw stuff in from the top. So I prefer this concept.”
- “That you can lock these concepts is definitely an advantage for commuting, less for grocery shopping.”

9.2. User journey mapping



Bicycle (1)
Cargo container: single detachable bicycle panniers
Car (2)
Cargo container: car trunk
Scenario 3: Multiple destinations: intermediate shopping: departure point (A) & arrival point (B), intermediate shopping points (C, D, E ...): luggage is added
Scenario 2: Multiple destinations: intermediate visit: departure point (A) & arrival point (B), intermediate visiting points (C, D, E ...): no luggage is added to the container or needed during visit
Scenario 1: Single destination: departure point A & arrival point B
(1.1) Filling cargo container with needed luggage
(1.2) Moving cargo container
(1.3) Attaching cargo container to vehicle
Scenario 1: Single destination: departure point A & arrival point B
(2.1) Filling (secondary) cargo container with needed luggage
(2.2) Moving (secondary) cargo container
(2.3) Opening primary cargo container
(2.4) Placing secondary cargo container in primary cargo container
Scenario 2: Multiple destinations: intermediate visit: departure point (A) & arrival point (B), intermediate visiting points (C, D, E ...): no luggage is added to the container or needed during visit
No actions have to be repeated
Scenario 3: Multiple destinations: intermediate visit: departure point (A) & arrival point (B), intermediate visiting points (C, D, E ...): no luggage is added to the container or needed during visit
LEGENDA
Same actions
Different actions
Different actions
Different actions


(possible) (1.8) Taking shopping cart
(possible) (1.10) Putting back shopping cart
(1.5) Detaching cargo container from vehicle
(1.9) Doing shopping (bearing in mind the maximum capacity of the cargo container)
(1.3) Attaching cargo container to vehicle
Cargo already present has to be taken from the vehicle (fear from theft)
(1.5) (1.6) (1.7) and (1.3) are likely to be repeated during the visit to protect both cargo container and its contents from theft
(1.4) Transporting container with transportation vehicle
(1.5) Detaching cargo container from vehicle
(1.6) Moving cargo container
(1.7) Putting the cargo container down (and positioning it)
(2.5) Transporting (secondary) container with transportation vehicle
(2.6) Opening primary cargo container
(2.7) Taking out secondary cargo container
(2.8) Moving (secondary) cargo container
(2.9) Putting the cargo container down (and positioning it)
(2.6) Opening primary cargo container
(2.7) Taking out (empty + open) secondary container
(2.8) Taking shopping cart
(2.9) Doing shopping
(2.10) Placing filled secondary container in primary container
(2.11) Putting back shopping cart
Cargo already present can be left in the vehicle