Development of a next-generation parking brake for heavy-duty cargo bikes

Master's thesis in Product Development

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Development Of A Next-Generation Parking Brake For Heavy-Duty Cargo Bikes

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Cover: Cargo bike visualization constructed in Solidworks showing the final concept implemented on the bike.

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Abstract

The thesis presents the design and development of a parking brake system for a heavy-duty cargo bike in collaboration with Velove Bikes AB. Velove bikes AB is a start-up located in Gothenburg, Sweden, developing and producing Armadillo Cargo bikes. Moreover, the company uses these bikes for last-mile delivery operations to various delivery companies such as Budbee and Airmee with the help of trained riders in order to execute a fast delivery operation.

Initially, a requirement specification was tabulated during the product development process to identify the customer's needs. This was followed by functional decomposition to map out various procedures during the parking brake operation. Then, multiple ideas were generated and combined to form various concepts in the concept generation phase. The best concept was then selected based on the methodologies of concept evaluation. The chosen concept was finally prototyped using tools and materials available at the company's R&D facility. This was then tested to check the fulfilment of the initial requirements in a real-world environment. Furthermore, an additional commercial assessment, recommendation and concluding action plan are provided to get the solution closer to realisation and aid potential future work.

The final product consists of two commercially available mechanical disc brake callipers mounted on the bike's rear wheels. The two brake cables from these callipers are then coupled into a single cable using a junction mechanism. A single cable is then pulled in tension with the help of a mechanical lever placed adjacent to the rider's seat, which provides easy and fast access to activate or deactivate the brake and works similarly to the old car hand brakes. Additionally, provisions can be made on the hand lever to alter and remind the riders to disengage the brake system when necessary. This works in tandem as an anti joy side system to prevent outsiders from using the bike for short rides while the rider is away from the bike and delivering the packages.

Keywords: cargo bikes, parking brake, handbrake, brake.

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Yasin Demirci & Chirag Aloysius Mascarenhas, Gothenburg, June 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

3D	3 Dimensional
CAD	Computer Aided Design
FFF	Fused Filament Fabrication
LMD	Last Mile Delivery
LCV	Light Cargo Vehicles
PLA	Polylactic Acid
R&D	Research & Development
STL	Standard Tessellation Language

Contents

1
Introduction

1.1 Background

Ever since the 1800's humans have been using bicycles to transport goods, groceries, or even people from one place to the other. Bicycles have been an integral part of the merchants and the craftsmen to carry out their business and logistics [1]. These unusual-looking bikes with a box-like structure in front of them are the reason for the birth of a new segment in bicycles known as cargo bikes. The invention of fossil fuels and their applications in transport declined the usage of these cargo bikes over the years until recently. As the earth's temperatures are getting warmer every year due to the increase in air pollution, many countries are running a race to lead a sustainable future [2]. The switch towards electric mobility with its numerous benefits has been a primary factor in the rebirth of modern-day cargo bikes. As more companies are exploring the different applications of cargo bikes, some companies have created new designs of the bikes that offer more promising advantages than ever before.

1.1.1 Background of Velove Bikes AB

Velove Bikes AB is a startup located in Gothenburg, Sweden, developing and producing electric armadillo cargo bikes. The company was initially co-founded in 2011 by Dennis Kanter, Linda Kanter and Johan Johansson with a vision to provide an alternative mode of transport to family cars and thus lower the CO2 emissions as a step towards a sustainable future. The armadillo electric bikes could also be used as a taxi to occupy two passengers on the back in a weather-proof cabin. As the years progressed, the developments on the bike saw a radical change in the company's business model than it was initially thought about. Velove changed its business to selling its bikes to delivery companies such as DHL and Pling to be used as an alternative to their current vans. In 2018, Velove's business model further evolved into starting its own last-mile delivery service by partnering with various package delivery companies such as Budbee and Airmee, the big players for package delivery in Sweden. Compared to the delivery vans, Velove's armadillo bikes are more efficient in the number of packages delivered per hour. They are wide enough to fit within the existing bicycle lanes and can be parked in small spaces to execute a quick delivery operation.

1.1.2 Last Mile Delivery

Last mile delivery is the last process of the delivery operation where the goods are delivered to the customer's front door or a common pickup point from the sorting warehouse. In a conventional last mile delivery process, the packages from the warehouse are loaded onto the vans and the driver delivers the goods directly to the customers (see figure 1.1 (a)). The vans not only impact the overall carbon footprint but also add to the traffic congestion. Upon comparison, Velove uses small containers, which are first leased to the partner delivery companies [3]. The containers are then loaded with the packages by the partner delivery companies and delivered to the Velove hub. These containers are then loaded into the armadillo bikes at the Velove hub for a specific delivery route (see figure 1.1 (b)). Trained riders ride the armadillo bikes and deliver the packages to the customers, efficiently fulfilling the last-mile delivery operation. Currently, Velove has operations in three cities: Gothenburg and Stockholm in Sweden, and Copenhagen in Denmark. The company plans to expand this model to various other cities across Europe in the upcoming years.

(a) Conventional process of last mile delivery operation

(b) Velove's process of last mile delivery operation

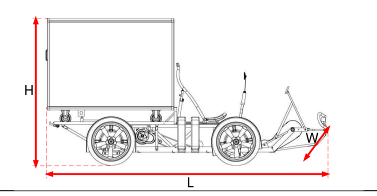
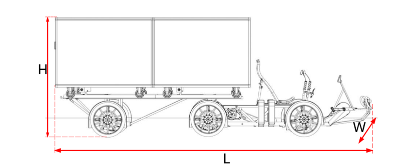
Figure 1.1: Comparison of conventional and Velove's process of LMD operation

1.1.3 The Armadillo Cargo Bike

The electrically assisted pedal bike developed at Velove Bikes AB consists of a wide quadricycle to fit into most bike lanes with a maximum 25 km/h speed. The rider can comfortably sit on the front seat of the bike to pedal and manoeuvre using the two handlebars. The addition of double wishbone suspensions on the front and rear wheel axles and a low centre of gravity provide greater stability and control of the bike to the rider. The bike is equipped with a 14 gear speed hub that connects to a 250W motor on the rear axle for additional assistance while peddling. The primary brakes of the bike use hydraulic disc brakes, connected to all four wheels.

The rear side of the bike includes a platform on which containers are loaded. These containers are built using lightweight composite materials along with waterproofing. Four wheels are attached to the bottom of the container to provide ease of handling while loading them onto the bikes. Two doors on the left side of the container are fitted with electronic and key enabled locks to secure the contents inside the containers.

The armadillo bike comes in two variants, one with a single container on the back and the other is a semi-trailer type that can occupy two containers. The technical specifications of the bikes are shown in the table 1.1 [4].

		
Length* (L) (cm)	312	462
Width* (W) (cm)	86	86
Height* (H) (cm)	162	170
Weight with one battery* (kg)	114	193
Container max total weight** (kg)	200	350
Maximum allowed weight of the vehicle (kg)	350	500
Total cargo volume (m^3)	1	2
Steering radius (cm)	58	
Suspension	Double wishbone with steel spring shocks absorbers	
Primary brakes	Hydraulic brakes in front and rear	
Frame	Aluminium 6060 & 6082	
Gears	Rohloff Speedub 14 gears	
Electric motor	Befang Max 250 watt	

* With the container loaded
** Incuding the max cargo load

Table 1.1: Comparison of two different armadillo bikes

1.2 Aim

Parking brakes on commuter bikes are not as critical as compared to cargo bikes. In cargo bikes, parking brakes are crucial especially in hilly regions. The Velove armadillo bikes are mainly used for package delivery operations, with heavy cargo loaded in a container behind them. When the riders of the bikes are away while delivering the packages, the cargo bikes have to be parked safely, restricting their movement since the bikes are mainly used in urban areas with cars and pedestrians in close vicinity. On certain occasions, pedestrians tend to ride the bikes without authorization of the rider, especially for quick joy rides. In order to find an optimal solution, the aim of the thesis can be formulated as follows:

- To find the best possible solution for immobilising the bike movement when the bike is left unattended.
- To provide additional features into the solution, such as preventing the access to the cargo bike by unauthorised people, especially for quick joy rides.
- To prototype and test the final solution and give proposals for a detailed design for future implementation.

This project is carried out by two students studying for master's in product development as a part of their thesis work at the Chalmers University of Technology on behalf of Velove Bikes AB.

1.3 Delimitations

The thesis work is completed within 20 weeks with certain delimitations set by the project team and Velove Bikes AB.

1. No significant modifications to the bike's frame or critical components are carried out.
2. Any movement of the bike caused due to slippage of wheels while it is in contact with the ground surface is out of this project's scope.
3. The prototype of the parking brake is not to be tested on a live delivery shift.

1.4 Research Questions

The specification of the issues includes research questions to be verified or rejected over the course of the thesis work.

- What is the currently implemented parking brake solution? And why is a new solution required?
- What are the potential concepts available to address the underlying issues and meet the customer's needs?
- What are the strengths and weaknesses of the new parking brake compared to the current solution in terms of effectiveness, cost, implementation, maintenance, and usage?

2
Theory

The theory section of the report covers brief information about the cargo bikes and the different types of brakes that is important for the reader to understand.

2.1 Cargo Bikes

A cargo bike, also known by different names such as a freight bicycle, or a cycle truck, is a human-powered vehicle with or without electric assistance used mainly to transport goods within a short distance. Cargo bikes come in various sizes, depending on the payload requirement. Currently, cargo bikes are widely used for mail delivery, transporting children, warehouse inventory transport, as an efficient taxi, and similar use cases involving the transportation of heavy goods [5] (see figure 2.1 (a))

(a) Image of a commonly used cargo bike [6]

(b) A modern cargo bike used to delivery packages [7]

Figure 2.1: Examples of use cases on cargo bikes

The conventionally used light cargo vehicles (LCV's) such as vans used for last-mile delivery operations come with various climate emissions, noise, and traffic congestion problems. The focus on "achieving a CO2-free city logistics in major urban centres by 2030", as formulated by the European Commission Whitepaper [8] has led to finding alternatives to these operations.

One major alternative that has been widely discussed and is currently being implemented is modern-day cargo bikes for last-mile delivery operations (see figure 2.1 (b)). These bikes offer a plethora of advantages such as the low operating cost, use of bicycle lanes to counter the traffic and parking issues which directly increases the productivity rate (the number of packages delivered within an hour) and, most importantly, lower emissions of CO2, thus focusing towards a sustainable future.

2.2 Brakes

Brakes are used to slow down the speed of a machine element and/or to hold a machine element stationary. Generally, the braking is done by compressing a moving member with a stationary one, resulting in kinetic energy being converted to heat [9]

Brakes are classified into three main types:
1. Mechanical brakes
2. Hydraulic brakes
3. Electric brakes

A brief description and working of the above mentioned brake types is explained in the subsequent section below.

2.2.1 Mechanical Brakes

In the working of a mechanical brake system, the mechanical force is applied to a pedal or a lever. This force is then transmitted to the brake shoe pads using mechanical linkages such as a rod, wire, or spring. The brake shoe pushes against the moving part to generate friction and thus stops the movement. Mechanical brake systems come in various types. However, in this report, only 3 types are explained that are more relevant to the scope of the work.

Drum Brake
In drum brakes, the brake pads are attached to the external surface of a curved bracket, which is called a shoe. There are different configurations of drum brakes, but the most common include two shoes installed on a drum on a plate. The cylinder pushes the shoe inside the drum to start decelerating.

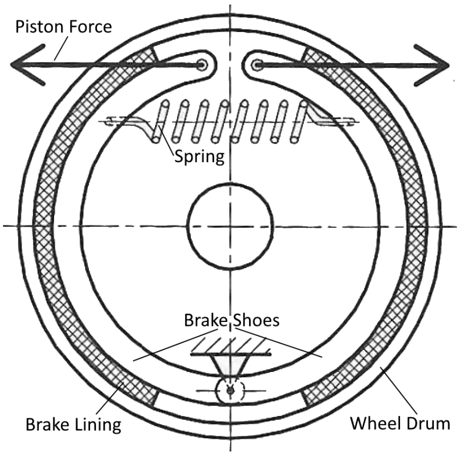


Figure 2.2: A simple figure of a drum brake [9]

Band Brake
Band brakes consist of a band made of friction material aligned concentrically around a moving part. A lever is used to tighten the band in order to slow or stop the moving part completely. Band brakes are generally used in industrial machines due to their compact and rugged mechanism. They also serve as an emergency brake during the failure of a primary braking system as the design is simpler.

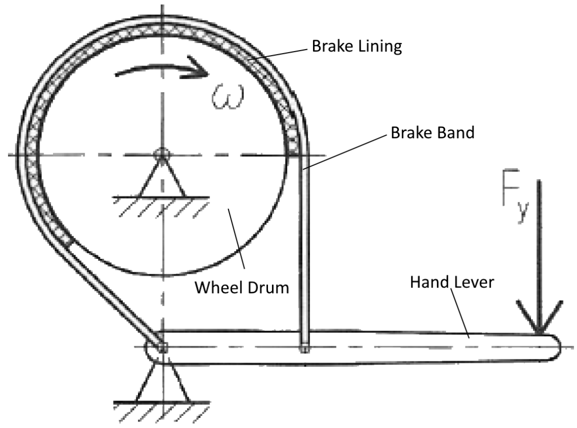


Figure 2.3: A simple figure of a band brake [9]

Disc Brake
Disc brakes use metal discs, known as rotors, connected to the axle and spin between the brake callipers. To decelerate, the pads inside the callipers press against the rotor surface. The pressing action causes friction between the two surfaces and thus can be used to slow down the spinning part or hold it stationary. The disc component of the brake is made of cast iron or carbon materials as per the cost and use case.

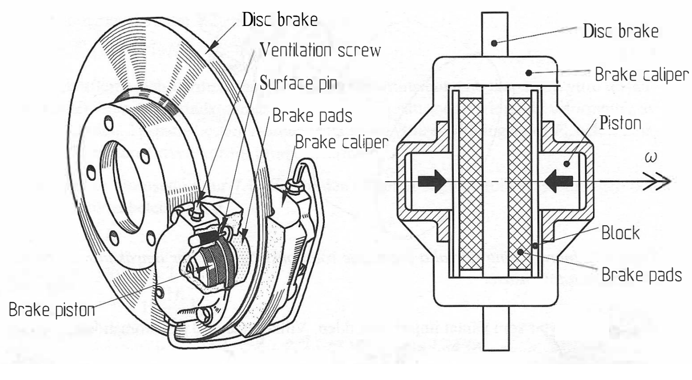


Figure 2.4: A simple figure of a disc brake [9]

2.2.2 Hydraulic Brakes

Hydraulic brakes have similar brake types, such as drum brake, band brake and disc brake, but the main difference is that the hydraulic brakes use incompressible fluids to actuate the braking mechanisms. All hydraulic brake systems will have a closed hydraulic system consisting of a master cylinder that is used to move the incompressible fluid in the hydraulic lines to actuate the braking device.

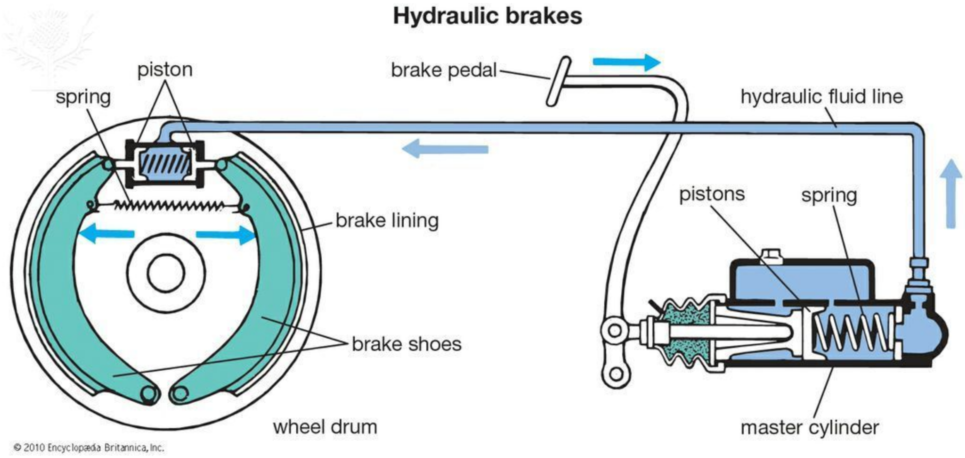


Figure 2.5: A simple figure of a hydraulic brake [10]

2.2.3 Electric Brakes

Electric brakes use electric current or magnetic force to slow down or stop the motion of a machine element. The main types of electric brakes are friction and magnetic. The Electric Brakes can be further sub-divided into different types. however, the other types of electric brakes are outside the scope of this report.

3
Methods

The method chapter describes the various product development methodologies used while carrying out the project. The process is inspired from the product development methodology outlined in 'Product Design and Development' by Ulrich and Eppinger [11] and few methodologies from 'Produktutveckling - Effektiva metoder för konstruktion och design' by Johannesson, Persson and Petersson [12]. Additional inputs have been taken into consideration from the R&D team at Velove Bikes while developing the solution. The development process followed through the course of this project is shown in figure 3.1.

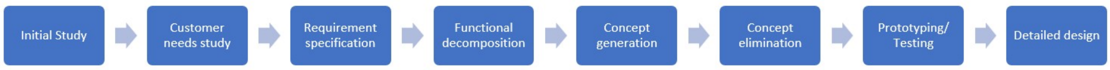


Figure 3.1: Product development process

3.1 Initial Study

The initial study on the project involved understanding the existing solution's problems. Furthermore, the investigation was conducted to understand a broader perspective of the project and how the shortcomings of the previous solution could be taken as a learning during the course of the current project. Additionally, literature survey, patent search and the possible solutions that the company investigated internally were also studied.

3.2 Customer Needs Study

One of the many primary steps in any product development process includes identifying the customer's needs and gathering raw data. Parallelly, the people involved in the project, also known as stakeholders, are identified, and the needs from their perspective are considered. The stakeholders were classified based on their role in the company and the experience on using the product. Next, interviews were conducted with the various stakeholders to gather as much data as possible. This raw data gathering was then interpreted as customer needs.

3.3 Requirement Specification

The requirement specification is a list of requirements that the product must comply with to meet the customer's needs. Here, the customer's latent needs are transformed into technical terms with target values, verification methods, and references to whom the requirements were aimed [11].

After the customers' needs study and the interviews, the project team created an initial requirement specification document. The requirements were separated into various categories based on their functions. Furthermore, some of the requirements were categorised into wishes and a rating was given to define their importance. The initial requirement specification was continuously updated as the project progressed. Once the final product prototype was developed and tested, it was verified on the fulfilment of these requirements.

3.4 Functional Decomposition

Functional decomposition was used to decompose a system in terms of its purpose, such as "what it does" and "what it should do" [13]. Possible applications of this method includes:

- to describe a complex system and its components,
- to support to design and synthesise a system under development,
- to analyse or improve an existing system [13]

The functional decomposition method was used since the first and last points mentioned above were applicable for this product development process. Two different models were used to answer the questions: "what it does do?" and "what it should do?".

A black box model has been used to answer the first question, "what it does?", by dividing the complex functions of the old parking brake system into simpler subfunctions. This model provided information about input and output and the flow of the function.

A function tree was used for the possible solution to answer the second question, "what it should do?". A function tree is used when its difficult to identify the flows or actual transformations of operands [13].

3.5 Concept Generation

After understanding the various functions of the parking brake system, the project team began with developing various solution principles/combinations in this phase. This segment was divided into two phases: Brainstorming, morphological matrix and concept combination.

3.5.1 Brainstorming

Brainstorming is the process of utilising the knowledge gained from previous studies to generate ideas by all means without taking into account their feasibility. Brainstorming is usually carried together as a group or done individually [11].

During the brainstorming process, the project team recorded solution principles based on the functions identified from the functional decomposition and came up with various ideas that could be implemented. All the brainstormed ideas were written down in text format.

3.5.2 Morphological Matrix

Morphological matrix is a method of idea generation where the concepts from the individual functions are taken into focus while developing various concepts [14]. The results from the brainstorming session were combined in a way such that they form the whole concept. Furthermore, care was taken that the combination of the concepts enabled feasibility of various functions.

3.5.3 Concept Combination

Concept combination is a process of combining the different elements of the individual concepts to form a single complete concept. When combining the different elements, care is taken that the individual requirements are fulfilled.

While undertaking the concept combination, the individual elements from the morphological matrix were used per function of the parking brake. Although some concepts were deemed to be infeasible from the team's point of view, they were still considered in order to gather more information. Finally, the project team came up with eight different concepts.

3.6 Concept Evaluation

Various generated concepts were reduced to a handful of numbers during the product development process without actually testing the product in real life. To eliminate the inferior concepts that were not fulfilling the requirements and the customer's needs, the generated concepts were scrutinised using various scoring methods and compared. The three methods that were used in this project are described below:

3.6.1 Elimination Matrix

The first step of the evaluation process is the elimination of concepts that failed to fulfil the demands established in the requirement specification. In this step, these points are clarified for all the concepts:

- Solves the main problem
- Compatible / realistic

- Reasonable cost
- Safe and ergonomic
- Fits portfolio
- Enough information exists

Table 3.1: Blank elimination matrix

Concepts	Solves main problem	Compatible / Realistic	Reasonable cost	Safe and ergonomic	Fits portfolio	Enough information exists	Criteria fulfilment: (+) Yes (-) No (?) More info needed **Comments**	Decision: (+) Continue (-) Remove (?) More info needed **Decision**
C1								
C2								
C3								
C4								
C5								
C6								
C7								
C8								

Table 3.1 above shows a blank elimination matrix. The first column on the left lists different concepts. All concepts are evaluated in terms of points, as mentioned earlier. If the concept fulfils the criteria, it gets a plus (+). Else it gets a minus (-). Some concepts require more information to be understood before scoring, and it gets a question mark (?) in the respective column. When a concept gets its first minus (-), it is directly eliminated without considering the other criteria. If the concept gets a question mark (?) in any criteria, it will go to the next stage [11]. However, some more information about its working needs to be understood. The remaining concepts will continue to the next stage of the evaluation process.

3.6.2 Pugh Matrix

Pugh matrix reduces the concepts by eliminating them compared with a reference concept. In the matrix, criteria are taken from the requirement specifications. The criteria combine all wishes plus some of the essential requirements. The evaluation was made using the following matrix as shown in table 3.2. The project team decided to carry out this process in two iterations whilst taking two different reference concepts. The second iteration was carried out to ensure that no good concept was eliminated due to errors and ensure accurate comparisons. The blank layout of a Pugh's matrix is shown in table 3.2 below.

Table 3.2: Blank Pugh's matrix

Velove Bikes	PUGH MATRIX					
Concepts →						
Criteria ↓		C1	C2	C4	C5	C6
	D A T U M					
∑+						
∑-						
∑S						
Ranking						

The criteria, as mentioned earlier, are placed in the criteria column in the matrix. The Pugh matrix method compares the remaining concepts from the elimination matrix with a reference. The reference can be an existing solution or a competitor solution. It can also be one of the concepts the project group has comprehensive knowledge and information about.

When the reference is chosen, the next step will be to compare concepts with the reference, one by one, using the criteria. If the concept fulfils the criteria better than the reference, it gets a plus (+); if the concept is worse than the reference, it gets a minus (-), and if both of them are on the same level, it gets a zero (0). After the comparison is completed, the next step is to sum all pluses and minuses, and the net value is calculated. This is done to facilitate the decision making of the project group by ranking the concepts by the net values.

3.6.3 Kesselring Matrix

The last stage in concept evaluation is the Kesselring matrix. The remaining concepts from the previous stage were examined further in this matrix. Although the criteria chosen in the Kesselring matrix are the wishes from the requirement specification, a weightage score is given to each wish as per their importance.

Table 3.3: Blank Kesselring matrix

VELOVE BIKES		KESSELRING MATRIX									
Variant →		Ideal		C1		C2		C5		C6	
Criteria ↓	w	v	t	v	t	v	t	v	t	v	t
Decision:											
Date:		**Issued by:** Velove Bikes Project Group									

This matrix (see table 3.3) shows the importance of the criteria, also known as wishes, inserted in the w column. Each concept has a v column and a t column. In the v column, grades of how well the concept fulfils that criteria are written, the grades are often between 1 and 5. The t column describes the multiplication of v and the weightage w.

The ideal column in this matrix presents the perfect solution which gets the highest scores in the v column, and the sum of them will be used as V_{max}. The multiplication of w and v in this column results in the highest t values, and the sum of all t values in this column will be used as T_{max}.

Concepts are graded as described above, and the sum of V and T is written in the respective column and cell. Then the V/V_{max} and T/T_{max} values are calculated. Finally, to compare the results and rank the concepts, the V, V/V_{max}, T and T/T_{max} values are used.

3.7 Prototyping and Testing

Prototyping and testing is a phase in the product development cycles where an approximation of the chosen concept is made either physically or analytically. Furthermore, prototypes are used to understand the working mechanism within a product and how well it translates to the customer's needs. The methods used for prototyping and testing during this project is outlined below.

3.7.1 3D Modelling and Rapid Prototyping

This stage involved building a scale model of the chosen concept in a CAD platform and then creating a physical model using an additive manufacturing technology

(3D printing). The prototyping was mainly carried out for the basis of testing the concepts in real life before getting into a more detailed design, thus ensuring the feasibility of the various functions.

While undertaking the prototyping, the project team discussed with the R&D engineer at Velove Bikes to get a thorough understanding of the design space on the armadillo bike. Furthermore, CAD models of the bike were obtained from the R&D engineer to produce the virtual prototypes. Simultaneously, certain standard parts that could be used to conduct the tests were selected. The project team could create physical prototypes parallelly to run assessments with access to an in-house 3D printer, and various manufacturing tools and standard parts.

3.7.2 Testing & Validation

Testing and validation involve studying the product's performance using a physical prototype and receiving a response from the customers or users. Testing also involves understanding the solution's effectiveness for the requirements set.

During the project, the testing was done parallelly with prototyping. The prototype was tested physically for the effectiveness of the brake in holding the bike in place. Additionally, areas of concern that could cause the part's potential failure were documented. Although the testing could not be conducted in a live delivery shift, a similar scenario was simulated on the road to document the results.

3.8 Detailed Design Proposal

The project's final phase includes a detailed design of components that could be beneficial for the company to develop the solution on a larger scale. The learnings from the prototyping and testing phase are accounted for, and detailed manufacturable drawings are provided for further work on the project. Along with the drawings, a preliminary cost calculation is carried out with the supplied bill of materials. However, due to the time frame of the project, the detailed design needs refinement from the company before proceeding with the implementation.

4
Results

This chapter will include the results of methods that have been used during the project.

4.1 Initial Study

The initial study on the project involved understanding the currently implemented parking brake solution. In order to park the bikes on flat or elevated roads, the bikes were previously equipped with a Mechanical disk brake caliper on the front left wheel. The brakes were activated using a plastic hand brake lever vertically mounted on the front of the bike (see figure 4.1). However, this solution was relatively ineffective because most of the cargo load is concentrated on the rear wheels. Additionally, the quality of the parts, mainly the brake lever, required frequent adjustment to stay effective. Velove decided to obliterate these brakes from all their bike models.

Figure 4.1: An image of the current parking brake system

Currently, the riders use the locking switch located on the primary hydraulic brakes of the bike as an alternative solution (see figure 4.2). Although locking the primary brakes as a parking brake solution works quite effectively, it has its disadvantages. The reasons are:

(i) hydraulic brakes are not meant to be kept locked and can cause pressure loss in the cylinder due to prolonged use.

(ii) The locking switch is highly prone to damage or gets stuck as this feature is not designed for a high number of usage cycles (average of 50 times locking and unlocking per shift)
(iii) The laws for cargo bikes require a mechanical parking brake system to be installed.

(a) Hydraulic brakes turned on as parking brake

(b) Hydraulic brakes released

Figure 4.2: Alternative solution on parking brake using hydraulic brakes with locking switch

After understanding the currently implemented solution, the project group conducted a literature survey to understand concepts of various braking systems and information related to cargo bikes. One of the findings revealed the cargo bike laws in Switzerland that stated the use of a mechanical parking brake as a secondary means of braking on cargo bikes. Additionally, a preliminary patent search for the brake on cargo bikes did not yield great results. Most of the patents were related to automotive brakes, that were set as an inspiration while developing the solutions. Furthermore, The project group found an internal project undertaken by the company to solve the parking brake issue. The project used an electric motor to actuate the existing parking brake solution. However, the project was not taken further, which is not discussed due to confidentiality reasons.

4.2 Customer Needs Study

As the primary step was gathering information, a customer needs study was performed. The first step during the phase was to identify the stakeholders of this project. The following people were identified as stakeholders of the project:

- **Management team:** The people involved in the day-to-day functioning of the business and decision making. Additionally, they acquire complaints and feedback from the users and work on these areas for improvement.
- **R&D engineer:** The engineer involved in the design and development of the bike and solving various issues that arise from the technical point of view.
- **Maintenance & assembly technician:** The technician is responsible for fixing the temporary issues due to the failure of certain parts. Additionally, the person is also assembling the bike and its components.

- **Bike riders:** These are the end-users of the product or solution to be developed.

After identifying the stakeholders, the project team wanted to gather qualitative data by conducting interviews with the stakeholders mentioned above.

First, a group discussion with three people from the management team was held to understand more about the company and the features they would like in the solution. Additionally, the cost aspects of the solution were also asked. After this, a face-to-face interview with the R&D engineer and the Maintenance & assembly technician was carried out to understand the technical aspects of the bike. The questions ranged from the basic functioning of the bike to the issues faced in the old parking brake solution.

Lastly, individual interviews with the end-users: the riders, were performed at the hub in Gothenburg. As a user-centric design approach where the suggestions from the riders is of much importance, the data from the interviews were helpful in understanding the problems faced by the riders during their work shifts and the different work environments they were subjected to. The interviews were conducted with ten riders in the hub, including some veteran riders and some new recruits. The questions asked during this process are documented in table 4.1.

Table 4.1: A questionnaire table with questions, average and range

Questions	Average/ Statements	Range/ Intepretation
How long have you been a rider at Velove?	5 months	1 - 12 months
Do you cycle frequently?	40 % yes	Binary
Do you enjoy riding the riding the armadillo bike?	90% yes	Binary
What do you like about the Armadillo bikes?	cool, great workout, something new	Keywords
How many shifts do you usually work in a month?	7	4 - 15
Do you like riding for Airmee (without trailer) or Budbee (trailer attached) and why?	70% Airmee: Compact and less weight	Statement
How do you find the normal brakes on the bikes? Are they easy to use and effective?	80% Satisfied	Binary
Do you find it difficult to park the bike on slopes? (does it roll back or front)	60% No	Binary
Have you found yourself in a dangerous situation while parking?	70% No	Binary
Did you have any injuries caused by the parking?	85% No	Binary
Any suggestions to make your riding experience better or something you want to be added to the bike?	Recorded as customer statement	Statement

Certain data from the interview was recorded as a customer statement and further translated into customer needs as shown in table 4.2. The needs were used as a reference while creating the requirement specification and generating the concepts.

Table 4.2: Table of customer statements converted into needs

Customer statements	Interpreted needs
Even though the parking brake was activated, the bike used to slide down on a slope	The parking brake is effective all the time
The old brake needed frequent adjustments	The parking brake requires less maintenance
The parking brake failed when the container was very heavy	The parking brake holds its braking force when the container is loaded to the maximum limits
The parking brake cable used to freeze during the winters	The parking brake functions during different weather conditions
Sometimes I forget to deactivate the parking brake until I started peddling and felt some resistance	The solution can alert users about its status
The brake handle felt it will breakdown quickly	Use higher quality parts
It was uncomfortable to activate the brake handle by bending forward	The parking brake can be activate is a good ergonomic position

4.3 Requirement Specifications

Table 4.3 shows the initial requirement specification tabulated. The specifications are divided into nine categories primarily identified from the study of customer needs. The interviews and information gathering from the R&D team at Velove were the primary input source. The requirements specifications are divided into requirements (R) and wishes (W). Furthermore, the wishes are given a score between 1 (least important) to 5 (most important). An additional scaling table for 'easy to implement' criterion was created as reference. (see table 4.4)

Table 4.3: Initial requirement specification

	Document type	**Requirement specification**	Velove Bikes AB Chalmers University of Technology			
	Project	Develop parking brake for heavy-duty cargo bike				
Issuer:	Chirag Aloysius Mascarenhas	***Created:*** *2022-02-11*				
	Yasin Demirci	***Modified:***				
Critierias		***Target Value***	***R/W***	***Imp.***	***Verification method***	***Reference/*** *(who is conducting verification)*
Function(s)						
1. Performance						
1.1	Brake the bike with full load at flat surface	0% slope	R		Engineering assessment	Product development team
1.2	Brake the bike with full load on slope surface	5% slope	R		Engineering assessment	Product development team
1.3	Time to activation of parking brake	<5 seconds	R		Engineering assessment	Product development team
2. Usability						
2.1	User adoptation time	< 8 hours	R		Feedback	User
2.2	Training time	< 2 hours	R		Feedback	Hub & Fleet Manager
2.3	Position of parking brake activation from user	<45 cm from the rider	W	3	Engineering assessment	Product development team
3. Lifetime						
3.1	Lifetime of parking brake	<5 years	R		Engineering assessment	Product development team
4. Economics						
4.1	Cost of entire parking brake system	< 200 euros	W	5	Cost analysis	Product development team R&D team
5. Implementability						
5.1	Easy to implement on current bikes	=>2 (see scaling)	R		Engineering assessment	Product development team R&D team
5.2	Easy to gather required parts	< 1 month	W	4	Engineering assessment	Product development team
5.3	System integration	Seperate system	R		Engineering assessment	Product development team
6. Maintenance						
6.1	Main maintenance	Approx. 50 shifts	R		Feedback	Maintenance team
6.2	Weekly maintenance	7 days or approx. 5 shifts	R		Feedback	Maintenance team
7. Functionality/Features						
7.1	Non-freezing or freeze resistant system	Up to -10 degrees Celcius	R		Engineering assessment	Product development team
7.2	Use as emergency brake	Main brake force < 0 N	W	2	Engineering assessment	Product development team
7.3	Prevent bike theft	Tamper proof	W	4	Engineering assessment	Product development team
7.4	Alert user about p-brake status	P-brake = on	W	3	Engineering assessment	Product development team
8. Environment / Legality						
8.1	Do not use hydraulic system	Switzerland requierement aSi-19-0097-TK001 (The company has these requirements as basis)	R		Engineering assessment	Product development team
9. Safety						
9.1	Prevent unauthorized deactivation	Authorized rider de-activation	R		Engineering assessment	Product development team

Table 4.4: Scale of easy to implement criterion from the requirement specification

Easy to implement	
1	Huge modifications on bike frame
2	Some modifications on bike
3	No additional modifications

The first requirement focuses on the performance of the overall system. Here, the brake activation time and the force from the bikes are considered. The ability of the brake to hold the bike in place on a flat surface is tested first, and subsequently similar tests will be performed on a sloped surface. The second category determines the usability of the parking brake. These include the time the rider will take to learn about using the new system and the time required to train the new approach.

Additionally, the ergonomic aspects of the brake actuator are included in this category.

The third category includes the overall lifetime of the brake. It is noted that the lifetime does not involve the wearing of certain parts, such as brake pads in any case. The economics of the system was mainly discussed with the R&D team to limit the cost of the overall system and can be deemed a critical criterion. The category on the implementability determines the complexity of the solution and the logistics involved in gathering the necessary parts. Since the solution was intended to be implemented into the existing bikes in use, the project group had to work on various trade-offs during the conceptualization stage. Additionally, the brakes tend to wear out during normal usage and require maintenance. Thus a maintenance requirement was counted.

The category on the functionality/ features includes the various additional features to be added onto the parking brake system, such as alerting the user, the efficiency of the brake under multiple weather conditions and anti-theft features. One of the primary constraints on the design of the parking brake was to use a mechanical system to abide by the law governing the design of the parking brake system of bikes. The constraint was set as a requirement under environment/ legality. The last category on the requirement includes the safety of the system.

4.4 Functional Decomposition

After the requirement specification was created, the project group decided to use two different methods for functional decomposition. A black box method was used for the current parking brake system, and a function tree method was used for the possible solution.

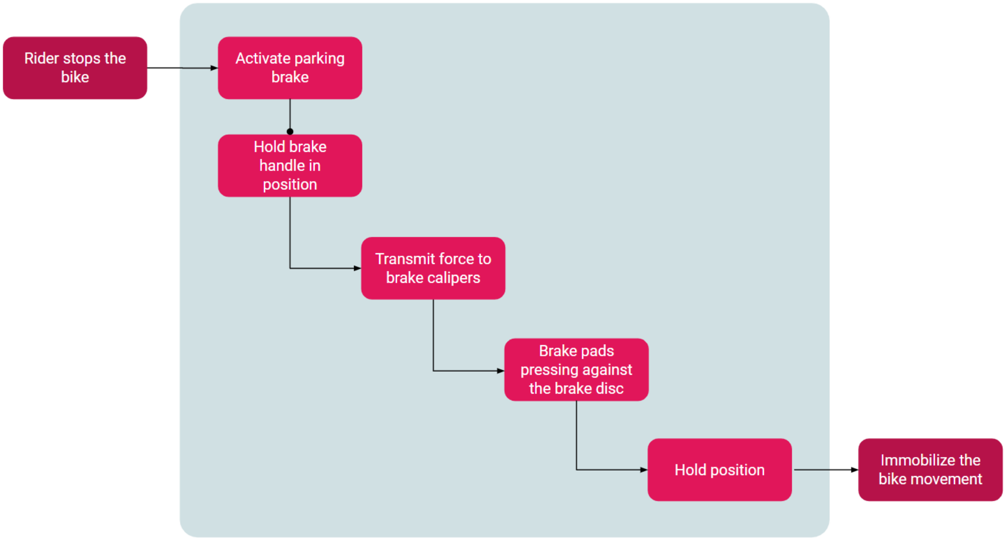


Figure 4.3: Black box model of the existing parking brake

In the figure 4.3 above, a detailed flow to activate the brakes on the current parking brake system is presented. The input of this black box model is “rider stops the bike” and the output is “immobilize the bike movement”. All other actions in between the input and output are placed within the box.

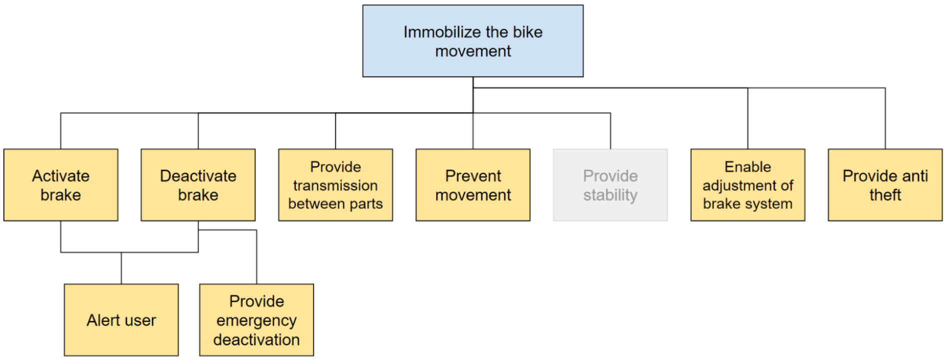


Figure 4.4: Function tree for the possible solution

The figure 4.4 above presents a function tree for the possible solution. The main function “immobilise the bike” is divided into five different subfunctions and two side functions. The subfunction “provide stability” is out of scope, which was decided after a meeting with the concerned R&D engineer.

4.5 Concept Generation

In this section, the results of concept generation methods, and created concepts are presented.

4.5.1 Brainstorming

The project group used the subfunctions of the function tree as different categories to generate some ideas in each category. The brainstorming session was performed in a quiet room and took about 3 hours to identify the different solutions for each function. The project group brainstormed ideas in each category and documented them, as shown in table 4.5.

Table 4.5: Brainstormed ideas divided into categories

Activate Brake	De-Activate brake	Alert User	Transmission	Prevent Movement	Adjustment	Anti - theft
Button	Manual	Lights	Wire	Brake calipers	Pulling wire	Tag/key for deactivation
Hand-Lever	Auto deactivation	Sounds	Wireless	Lock axle	Thumb screw	Sirens (sound alarm)
Rope/ Wire	Force sensor on pedals	Vibration	Electric motor	Lock chain	Auto adjustment with sensors	Steering lock
App		Notification on mobile phone	Magnetic/ electromagnetic force	Inner disc calipers	Springs	Stickers/ Label to scare
Automatic w/ Sensors		Notification on odometer	Rod	Gears	Clamps	Pin-code for deactivation
Foot Pedal		Limit motor assist	Linear motion guide	Band brake	Valves	Keyless deactvation
Container integrated auto-brake			Pulley mechanism			
Integrated to main brake levers			Hydraulic			
RFID- activation						

As seen from the table 4.5 above, the ideas from the brainstorming session were based on solutions that could be possible without giving importance on their functional point or how it fits with the different parts of the bike. Few of the brainstorms such as force sensors on pedals, vibration method for alerting users or using axle to lock the movement were still considered to facilitate a broader solution however aberrant they may seem from the readers point of view.

4.5.2 Morphological Matrix

After the brainstorming sessions, the project group created a morphological matrix. The project group created sketches as per their imagination for each solution and put them in a matrix (see table 4.6). The subfunctions from the function tree are the rows of the morphological matrix. Each cell has presented and documented the brainstormed ideas/solutions in a pictorial form. However, the adjustment part from the brainstorming was omitted from the morphological matrix since it relates to how a part functions.

Table 4.6: Morphological matrix without concept combinations

		1	2	3	4	5	6	7	8
Activate brake	**A**	Button	Hand lever	Rope/Wire	App	Foot pedal	RFID-tag	Integrated to the handles	RFID-button
Deactivate brake	**B**	Deactivate same way as activation	Auto-deactivation Force sensor	Auto-deactivation Seat sensor					
Alert user	**C**	Light	Sound	Vibration	Notification on app	Notification on app	Limit motor assist		
Transmission	**D**	Wire	Wireless	Electric motor	Electromagnetic	Wire & Rod	Linear motion guide	Pulley system	Hydraulic
Prevent movement	**E**	Disc brake	Band brake on axle	Chain lock	Inner disc brake	Gear lock			
Tamper-proof (Anti-theft)	**F**	RFID-tag	Siren	Steering lock	Keyless	Sprocket lock			

The next step of the morphological matrix method was to synthesise the various solutions for each function to arrive at a complete concept in the later steps. As seen in table 4.7 below, the concept synthesis was done by drawing dots and lines which connect each other. Each coloured line represents a whole concept. The concepts were arrived at by choosing one solution from the first column and moving to the right columns individually by ensuring compatibility between each solution. A total of 8 concepts were derived from the table. Although many more concepts could be generated, the chosen eight concepts are coherent from one another in terms of their functionality and the way they are implemented. Additionally, the requirement specification is taken as a reference to develop a concise version of each concept. Table 4.8 shows the concept combinations without their pictorial counterpart.

Table 4.7: Morphological matrix with possible concept combinations

		1	2	3	4	5	6	7	8
Activate brake	**A**	Button	Hand lever	Rope/Wire	App	Foot pedal	RFID-tag	Integrated to the handles	RFID-button
Deactivate brake	**B**	Deactivate same way as activation	Auto-deactivation Force sensor	Auto-deactivation Seat sensor					
Alert user	**C**	Light	Sound	Vibration	Notification on app	Notification on app	Limit motor assist		
Transmission	**D**	Wire	Wireless	Electric motor	Electromagnetic	Wire & Rod	Linear motion guide	Pulley system	Hydraulic
Prevent movement	**E**	Disc brake	Band brake on axle	Chain lock	Inner disc brake	Gear lock			
Tamper-proof (Anti-theft)	**F**	RFID-tag	Siren	Steering lock	Keyless	Sprocket lock			

Table 4.8: Concept combinations obtained from morphological matrix

CONCEPTS	POSSIBLE SOLUTIONS					
Concept 1	A1	B2	C1	D3	E1	F3
Concept 2	A2	B1	C2	D1	E1	F2
Concept 3	A5	B3	C1	D5	E5	F3
Concept 4	A8	B1	C3	D4	E2	F1
Concept 5	A7	B1	C2	D5	E2	F2
Concept 6	A6	B1	C1	D3	E1	F1
Concept 7	A3	B1	C6	D7	E1	F5
Concept 8	A4	B3	C4	D6	E5	F4

4.5.3 Concepts

The concepts derived from various combinations from the morphological matrix resulted in 8 full-fledged concepts. To make it easier for the reader to distinguish between the various concepts, the various concepts are named concept 1 and concept 2 until concept 8. The figures and a short description of all the concepts are shown below.

4.5.3.1 Concept 1

Concept 1 (see figure 4.5) consists of a system where the rider presses a button near the handlebar to lock and unlock the parking brake. Initially, the rider presses the parking brake button, which activates the motor consisting of a screw mechanism and pulls the caliper wire in tension to engage the brake. Simultaneously, the user is alerted about the parking brake engagement with a light in front of him near the odometer. The disengagement process works similarly in reverse. The button is pressed again and the motor turns in the reverse direction to release the tension in the wires and disengage the brake.

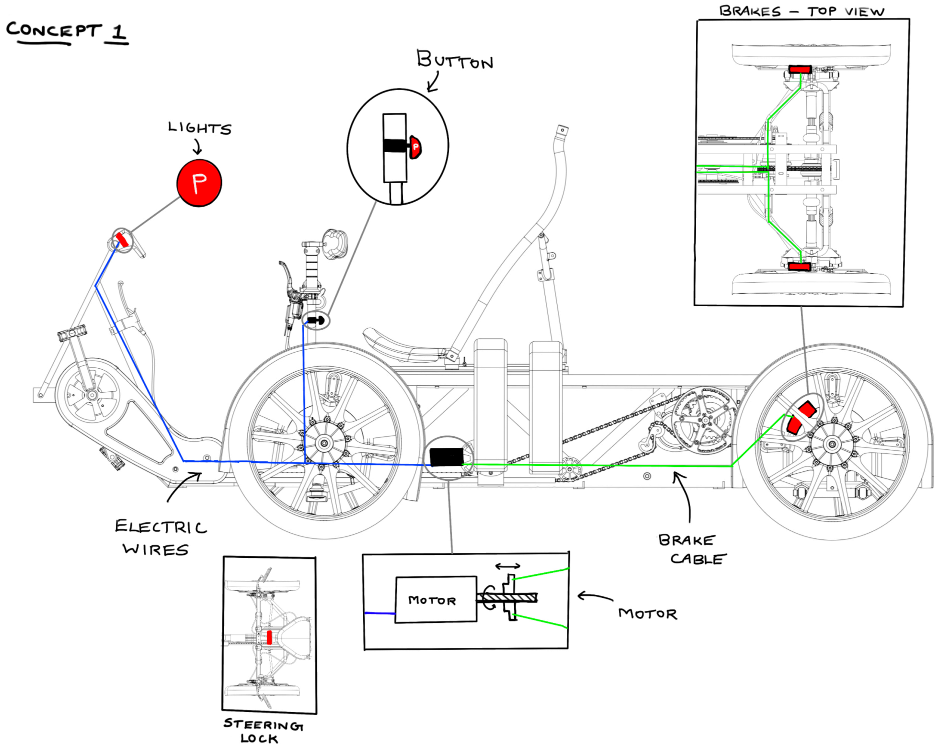


Figure 4.5: Sketch for Concept 1

4.5.3.2 Concept 2

Concept 2 (see figure 4.6) works similarly to how the parking brakes work on a car. Two mechanical disc brake calipers are installed on the rear wheels. The brakes are then engaged using a wire pulled using a lever installed beside the rider's seat for quick and easy activation. Additionally, sound systems alert the rider that the parking brake is engaged. The brake can be disengaged by pushing a button on the brake lever and lowering the lever.

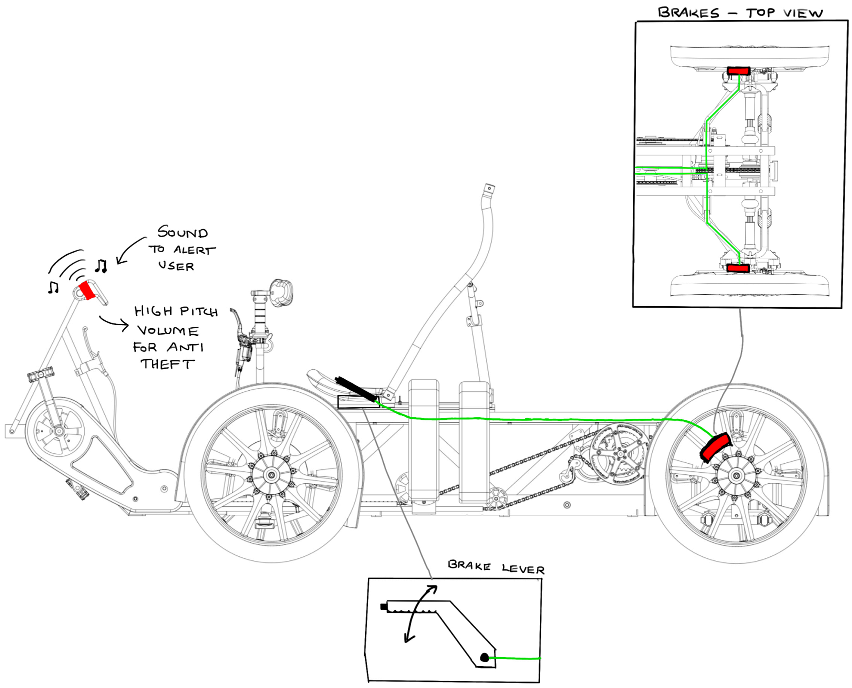


Figure 4.6: Sketch for Concept 2

4.5.3.3 Concept 3

Concept 3 (see figure 4.7) uses a lock mechanism to latch the gear on the motor from spinning. The rider needs to press the foot pedal to activate the parking brake. The brake pedal is connected to the gear locking mechanism through a wire cable. When the riders sit back on the seat, force sensors placed underneath the seat deactivate the parking brake via a release mechanism.

For added features, a light indicator alerts the rider when the parking brake is either on or off. A steering lock has been developed to prevent riding of the bike by unauthorised people. To lock the steering, it is enough to turn it to the right or left entirely.

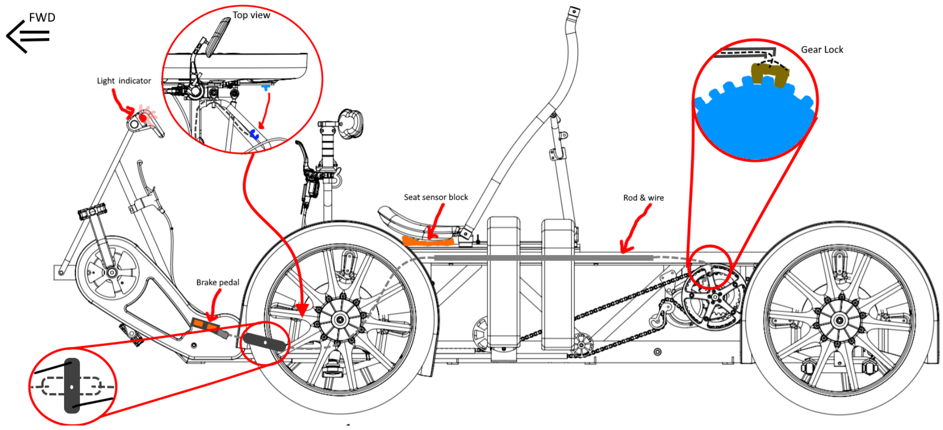


Figure 4.7: Sketch for Concept 3

4.5.3.4 Concept 4

Concept 4 (see figure 4.8) is built on RFID activation and deactivation of parking brakes. The rider holds an RFID tag to the reader, which activates the electro-magnet. The magnetic force fastens the particular type of brake, and presses the friction material against the axle. The rider is alerted about the status of the brake by haptic feedback (vibration), installed inside the handlebar.

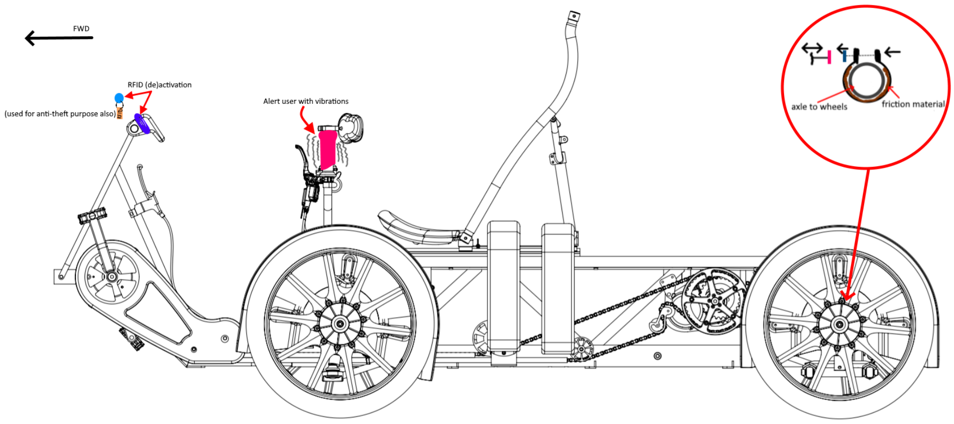


Figure 4.8: Sketch for Concept 4

4.5.3.5 Concept 5

Concept 5 (see figure 4.9) uses the exact brake mechanism to lock the axle as Concept 4. The brake is activated by pressing the small switch near the handle and creating tension in the brake cable. However, a rod is used for most of the force transmission in the significant portion. When the brake is activated, the rider is alerted by a sound from the speaker. Furthermore, moving the bike without releasing the parking brakes activates an alarm coming from the same speaker.

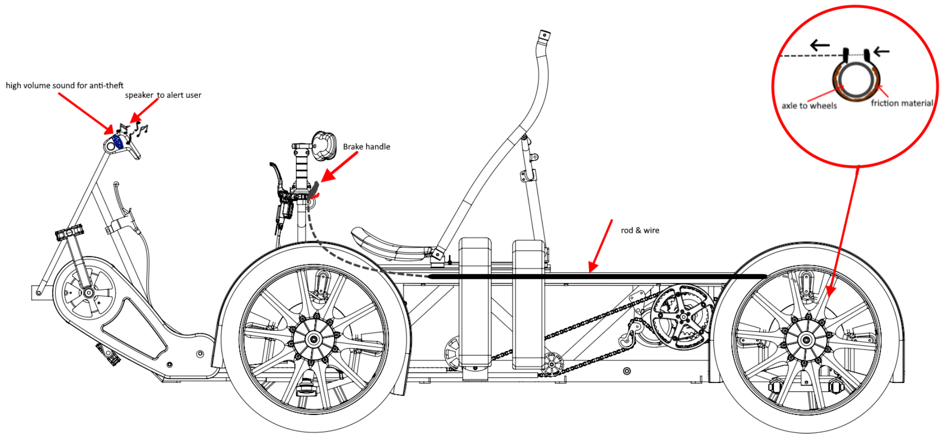


Figure 4.9: Sketch for Concept 5

4.5.3.6 Concept 6

Concept 6 (see figure 4.10) is built on a tag-activated brake system. An RFID tag is used to activate the electric motor to actuate the rear disc caliper wires. To alert riders about the brake status, a light system is used. The RFID system by itself also works as an anti-theft feature.

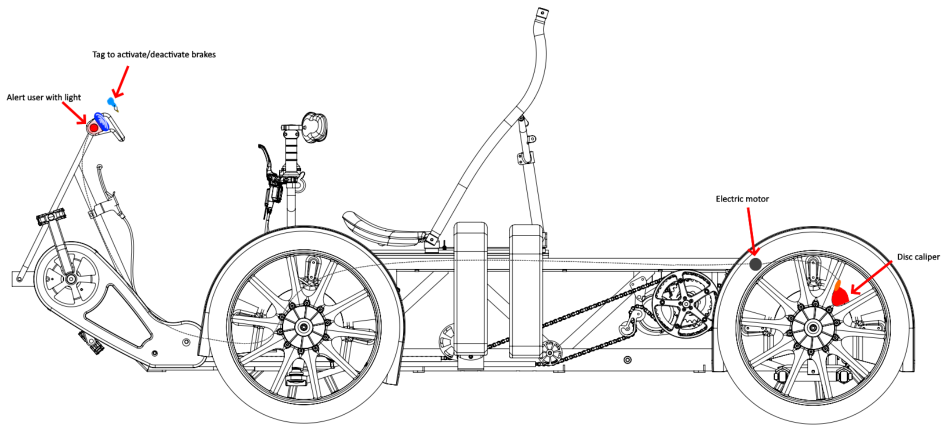


Figure 4.10: Sketch for Concept 6

4.5.3.7 Concept 7

Concept 7 (see figure 4.11) uses a pull and twist key to actuate the rear disc brake caliper wires. To reduce the pulling force of the actuator, a pulley mechanism is used. Simultaneously, a system will limit the motor-assist of the bike, so the rider knows the parking brake is on when or if he forgets to disable it. A locking bar is inserted into the chain sprocket for anti-theft features to prevent the bike access by intruders. The same actuator is twisted and pulled back by a spring to disable the parking brake.

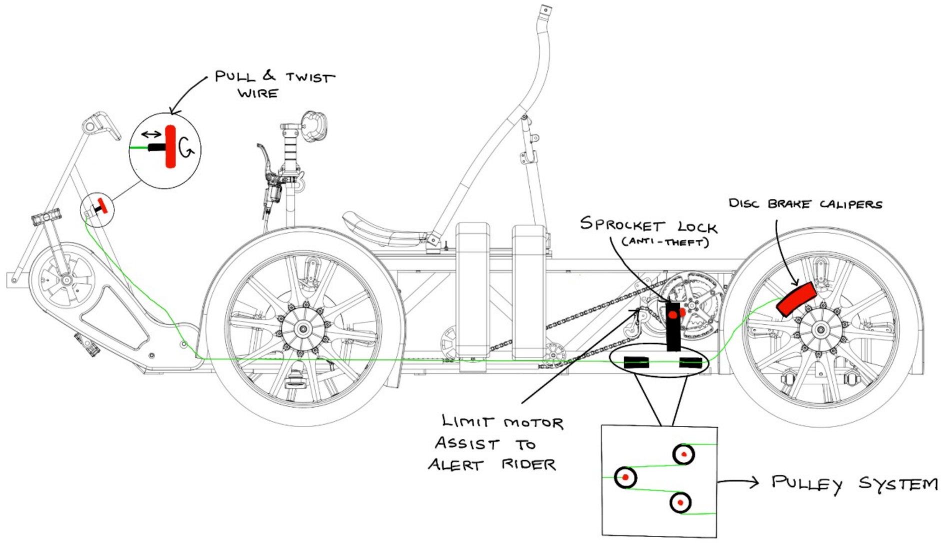


Figure 4.11: Sketch for Concept 7

4.5.3.8 Concept 8

Concept 8 (see figure 4.12) is mainly based on a mobile app where the rider can activate the parking brakes. Parking brakes are deactivated by sitting on the bike's bike's seat. The control module can automatically deactivate the brakes using sensors in the seat. Additionally, the app can deactivate the parking brake in case of a sensor malfunction.

The proximity of the phone's connection with the bike ensures that no outsiders can deactivate the brake system, which acts as an anti-theft/ anti joyride feature.

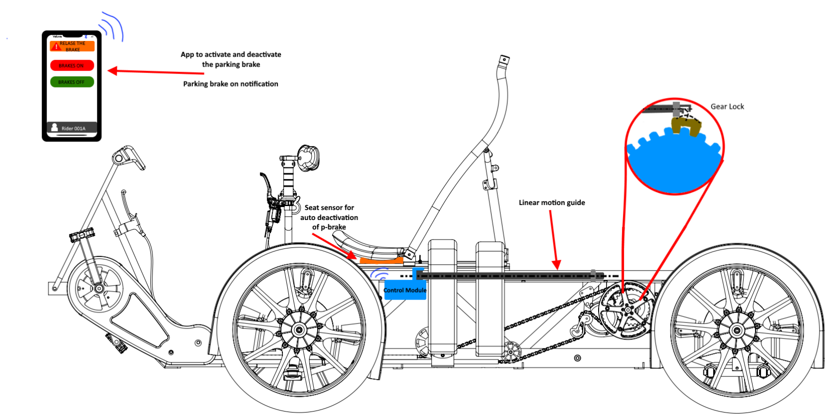


Figure 4.12: Sketch for Concept 8

4.6 Concept Evaluation

This chapter presents the results of choosing the best out of the eight concepts described above using the different methods.

4.6.1 Elimination Matrix

An elimination matrix is used for the first round of eliminating the matrix. The eight concepts developed in the concept generation phase are listed in the first column of the elimination matrix, as shown in table 4.9. Starting from the first concept, an assessment is done by checking how well the concept meets the requirements listed. A plus (+) is added to the corresponding column of the requirement for that particular concept when it meets the requirement. Similarly, The concept that failed to meet any requirement was marked with a minus (-) and eliminated. The reason for elimination is explained in the comments column of the matrix. However, some concepts require further investigation of their requirements due to uncertainties. These concepts are marked as (?) and considered for the subsequent elimination stage after resolving these uncertainties.

Table 4.9: Elimination matrix with 8 concepts

Concepts ↓	Solves main problem	Compatible / Realistic	Reasonable cost	Safe and ergonomic	Fits portfolio	Enough information exists	Criteria fulfilment: (+) Yes (-) No (?) More info needed Comments	Decision: (+) Continue (-) Remove (?) More info needed Decision
C1	+	+	?	+	+	+		+/ ?
C2	+	+	+	+	+	+		+
C3	+	?	?	?	-		Existing gears are not strong enough and requires major modifications on the bike.	-
C4	+	?	+	?	+	?	Unsure of the electoromagnet when power cuts off.	+/ ?
C5	+	+	+	+	+	+		+
C6	+	+	?	+	+	+		+/ ?
C7	+	-					Space constaints with the bike seems infeasible. The pulley system is not a necessary addition.	-
C8	+	+	-				App costs (development & maintenance) are not fitting in the cost constraints.	-

In this stage, concepts C3, C7 and C8 are eliminated. Concept C3 was eliminated for not fitting into the portfolio since the concept requires significant modifications on the bike. Similarly, C7 was eliminated due to space constraints, and C8 was eliminated as it failed to meet the cost constraints.

4.6.2 Pugh Matrix

The Pugh matrix was followed to eliminate the remaining concepts further. The method used eight criteria derived by the wishes from the requirement specification as shown in table X. However, the project group decided to count an additional requirement, "prevent unauthorised usage", because the criterion was accessed as an essential for implementing into the solution.

Table 4.10: Pugh matrix with old parking brake system as reference

Velove Bikes	PUGH MATRIX					
Concepts → / Criteria ↓	Current parking brake system	C1	C2	C4	C5	C6
Position of parking brake activation from user	D A T U M	+	+	+	+	+
Cost of entire parking brake system		-	-	-	-	-
Easy to gather required parts		-	0	-	-	-
Use as emergency brake		+	+	0	+	0
Easy to implement on current bikes		-	0	-	0	-
Prevent unauthorized usage		+	0	+	0	+
Alert user about p-brake status		+	+	+	+	+
∑+		4	3	3	3	3
∑-		3	1	3	2	3
∑S		1	2	0	1	0
Ranking		2	1	3	2	3

In table 4.10 above, the current brake system, with a mechanical disc brake on the front left wheel (explained in the initial study), was used as a reference. First, the concept C1 was compared with the datum or reference for a particular criterion and denoted by a (+) if it performed better. Moreover, a (-) if it did not meet the criterion. Similarly, a (0) was assigned if the performance of the concept matched equally with the reference for that corresponding criterion.

From the economic point of view, all the concepts were higher cost than the old solution, resulting in a (-) for all of them. However, all concepts performed better in their position to activate the brake and the alerting feature that the old solution did not possess. Similarly, the other comparisons followed the group's assessment as seen in table 4.10. The negative scores can also be looked at as an area for improvement when developing the final solution of the selected concept. Upon the end of the evaluation, concepts with a score of 0 or lower were decided for elimination, which were C4 and C6. Concept C2 performed the best with a score of 2.

Another iteration of the Pugh matrix was carried out to further verify the accuracy of the results. The best performing concept from the first iteration, C2, was chosen as a reference as it already performed well from the old parking brake solution. The second iteration led to a decision to compare the scores with the first iteration and eliminate concepts that performed lower in both.

Table 4.11: Pugh matrix with concept 2 as reference

Velove Bikes	PUGH MATRIX				
Concepts →					
Criteria ↓	C2	C1	C4	C5	C6
Position of parking brake activation from user	DATUM	0	0	0	0
Cost of entire parking brake system		-	-	0	-
Easy to gather required parts		-	-	-	-
Use as emergency brake		0	-	0	-
Easy to implement on current bikes		-	-	-	-
Prevent unauthorized usage		+	+	0	+
Alert user about p-brake status		0	-	0	0
∑+		1	1	0	1
∑-		3	5	2	4
∑S		−2	−4	−2	−3
Ranking		1	3	2	2
Decision	Concept C4 is eliminated.				

Table 4.11 above shows the iteration of the Pugh matrix with concept C2 as reference. The results showed that acquiring the parts and implementing the solution were better than the others. Concept C4 and C6 scored the same values in the first iteration and were considered for elimination but the results in the second iteration show that concept C6 performed better than C4. Hence, concept C4 with the lowest score in both the iterations was eliminated.

4.6.3 Kesselring Matrix

The last stage in the concept evaluation phase is the Kesselring matrix. The remaining concepts from the Pugh matrix were listed in the Kesselring matrix, as shown in table 4.12. Unlike the Pugh matrix, where the concepts are compared with a reference, the Kesselring matrix assigns weighted scores to the wishes from the requirement specification. This provides a better precision in the assessment. The project group decided on the weighting factor as per their importance level. As the cost of the product was a primary criterion for the solution, it was assigned a weight of 5. The ease of gathering the parts and preventing unauthorised usage features were given a score of four, followed by the rest, as shown in table 4.12. An ideal solution column is created to see how much the concept score varies from an ideal solution. Similarly, a scale with values was created for each criterion to make the scoring easier.

Table 4.12: Kesselring matrix with scaling criteria

VELOVE BIKES		KESSELRING MATRIX									
Variant →		Ideal		C1		C2		C5		C6	
Criteria ↓	w	v	t	v	t	v	t	v	t	v	t
Position of parking brake activation from user	3	5	15	5	15	5	15	5	15	4	12
Cost of entire parking brake system	5	5	25	2	10	4	20	3	15	2	10
Easy to gather required parts	4	5	20	3	12	4	16	3	12	3	12
Use as emergency brake	2	5	10	3	6	5	10	4	8	2	4
Prevent unauthorised usage	4	5	20	4	16	3	12	3	12	5	20
Alert user about p-brake status	3	5	15	5	15	5	15	5	15	5	15
$V = \sum v_i$		30		22		26		23		21	
V/V_{max}		1		0,733		0,867		0,767		0,700	
$T = \sum t_i$		105		74		88		77		73	
T/T_{max}		1		0,705		0,838		0,733		0,695	
Ranking				3		1		2		4	
Decision:											
Date: 2022-03-09		**Issued by:** Velove Bikes Project Group									

	SCALE (1-worst and 5-best)				
	1	**2**	**3**	**4**	**5**
Position of parking brake activation from user	>45 cm	45-35 cm	45-25 cm	24-15 cm	14-0 cm
Cost of entire parking brake system	>200 €	200-161 €	160-121 €	120-81 €	<80 €
Easy to gather required parts	> 1 month	21-28 days	14-21 days	7-14 days	<7 days
Use as emergency brake	Subjective Evaluation				
Prevent unauthorised usage	Easily prone to joy rides	-	Deterrent system	-	Tamper-proof
Alert user about p-brake status	Subjective Evaluation				

Upon assessing the Kesselring matrix, an ideal solution would have a score of 1. The other concepts were then subjected to the scoring for their respective criteria. The results show that concept C2 performed better than the other concepts with a score of 0.838, followed by concept C5 as shown in table 4.12. The two other concepts, C1 and C6, were deviational by a close margin with low scores. These both were subjected to elimination.

To further verify the accuracy of the results, a sensitivity analysis of the Kesselring matrix was created (see table 4.13). The sensitivity analysis shows that upon changing the values of the weighted scores (marked in red in the table), the results from the Kesselring matrix do not change and can be deemed trustworthy.

Table 4.13: Kesselring matrix with changed values for sensitivity analysis

VELOVE BIKES		KESSELRING MATRIX									
Variant →		Ideal		C1		C2		C5		C6	
Criteria ↓	w	v	t	v	t	v	t	v	t	v	t
Position of parking brake activation from user	3	5	15	5	15	5	15	5	15	4	12
Cost of entire parking brake system	4	5	20	2	8	4	16	3	12	2	8
Easy to gather required parts	4	5	20	3	12	4	16	3	12	3	12
Use as emergency brake	4	5	20	3	12	5	20	4	16	2	8
Prevent unauthorised usage	4	5	20	4	16	3	12	3	12	5	20
Alert user about p-brake status	2	5	10	5	10	5	10	5	10	5	10
$V = \sum v_i$		30		22		26		23		21	
V/V_{max}		1		0,733		0,867		0,767		0,700	
$T = \sum t_i$		105		73		89		77		70	
T/T_{max}		1		0,695		0,848		0,733		0,667	
Ranking				3		1		2		4	
Decision:											
Date: 2022-03-09		**Issued by:** Velove Bikes Project Group									

As seen in table 4.13, slight change in weighted values of three criteria do not change the overall ranking of the concepts. Although there is slight variation in the total scores, Concept C2 and C5 still remain as the top scoring concepts.

4.6.4 Final Chosen Concept

The results from the concept elimination reduced the eight concepts down to two concepts C2 and C5. After a meeting with the stakeholders, the concept C2 was considered very simple and economical to prototype and test in a short time frame. Furthermore, concept C2 did not require any significant modifications to the bike. Hence a final decision was made to eliminate concept C5 and proceed with prototyping concept C2.

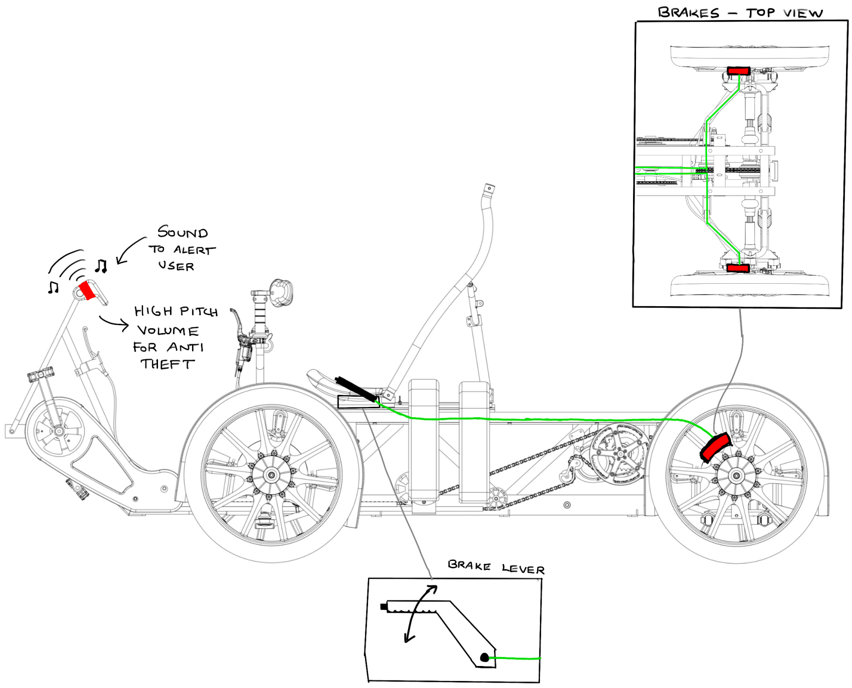


Figure 4.13: Chosen concept 2 for further development

4.7 Prototyping & Testing

This section includes the prototyping and test steps and their results.

4.7.1 Initial Set Up

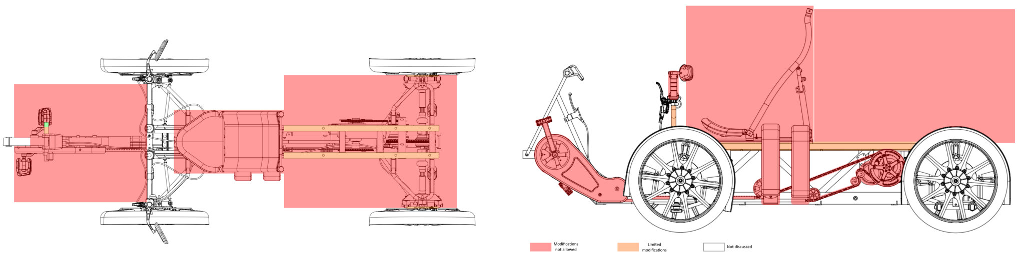
After discussing with the R&D engineer, a decision to undertake rapid prototyping was taken since it would be highly beneficial to quickly prototype the concept & undertake tests, thus saving time and costs. Before the prototyping, the project group was handed over a single container armadillo bike to try the concept and undertake the testing on it. Parallelly the project group also acquired the CAD files for the entire bike from the R&D engineer, as shown in figure 4.14. The CAD software used here was Solidworks 2019.

The R&D facility at Velove had a lot of spare parts for its bike components. Additionally, there were raw materials, fasteners and tools available at the disposal for most of the prototyping.

(a) R&D bike model (b) CAD model

Figure 4.14: Prototype set up including an armadillo bike & the CAD model

The next step involved identifying the critical parts on the bike that were out of reach for any modifications. After a discussion with the maintenance & assembly technician, it was concluded that most parts located on the rear part of the bike were to be left unmodified. These mainly include the transmission parts of the bike, such as the motor and the gearbox. Other parts such as the seat, suspension system, and handlebars are already mounted and cannot be altered. Upon close inspection, the project group found that the right centre portion of the bike's frame had some room to mount any mechanisms and the brake lever. This was not possible on the centre-right portion of the brake since that side is used to mount the batteries. Figure 4.15 shows the available areas/spaces from the top and the side views.



(a) Top view of model (b) Side view of model

Figure 4.15: Simple visualization of available and non-available spaces on the bike

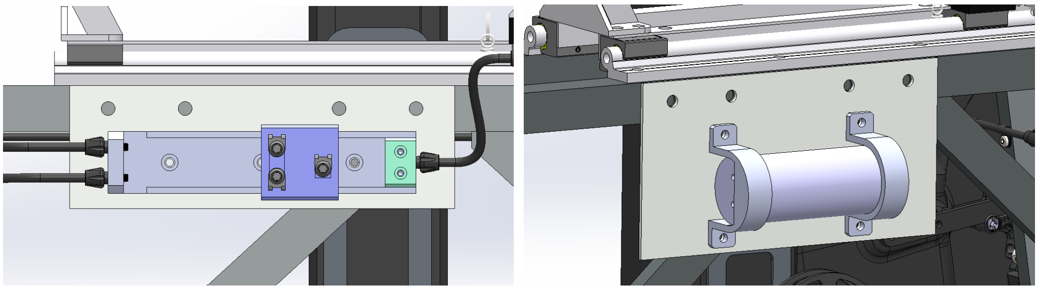
4.7.2 Prototyping

As concept 2 consisted of two mechanical brake calipers on the bike's rear wheels, a decision to use the existing parking brake caliper from the front left wheel of the old solution and mount it on the rear brake disc of the primary braking system. The bike's frame consisted of mounting holes for brake pads due to its symmetric design. Hence, no modification was required to install the calipers on the frame, as shown in figure 4.16. Two brake cables were then attached to these calipers and were run down over the bike's frame towards the middle section.

Figure 4.16: Brake calipers mounted on the bike

4.7.2.1 CAD Model

The front end of the brake cables had to be pulled in tension to activate the brake calipers. A hand lever mechanism was to be designed to pull the brake wires. However, the two wires had to be converted into a single wire to be installed onto the hand lever. For this purpose, two mechanisms were developed on CAD, namely, Connector A and Connector B, as shown in figure 4.17.



(a) Connector A **(b)** Connector B

Figure 4.17: Mechanisms developed on CAD to combine the brake wires

In Connector A, the two wires from the brake caliper are bought in tension from the rear using a cable housing and installed into a stationary rail block, as shown in figure 4.17(a). The extended wires from the cable housing are tightened using Socket head cap screws that rests on a slider block. The slider block can slide freely on the stationary rail block. Furthermore, a single cable is derived from the slider block to connect it to a hand lever. The whole unit is mounted on a 3mm thick steel base plate that can be installed on the midsection of the bike frame using fasteners.

Connector B works similarly to the previous mechanism. However, instead of a sliding block, a circular slab slides in a hollow cylindrical housing with the help of internal guides (see figure 4.17(b)). The cables from the rear brake calipers are installed on the cylindrical housing, and the wires are held together in the internal circular slab with the help of end stoppers. Similarly, a single wire with cable housing is installed on the other end of the hollow cylindrical housing. The internal circular slab slides inside the hollow cylinder, pulling a single wire. The whole unit is secured on the same base plate as mechanism A with the help of mounting clips and end clamps.

4.7.2.2 Handbrake Lever

As mentioned earlier, a system was required to actuate one of the mechanisms. The most secure and stable way to actuate is to use a hand lever, used in old model cars. By using this, the rider can easily activate and deactivate the brake system without wait time. This is very practical for riders, too, as they can easily access the handle located to the side of the seat and quickly activate it.

Initially, research was carried out to find the different types of hand levers available in the market and learn the different types of mechanisms they implement. Most hand brake levers used in cars are obsolete due to advancements in technology leading toward electrical actuation systems. Before designing and prototyping an in house hand brake lever, the project group decided to test the concept for the effectiveness of the brake calipers and the connector mechanisms. This was done by acquiring a handbrake lever from a discontinued Volvo V70 car model found from a local scrap yard (see figure 4.18). The handbrake lever was mounted on a steel plate and to be fitted into the bike's frame.

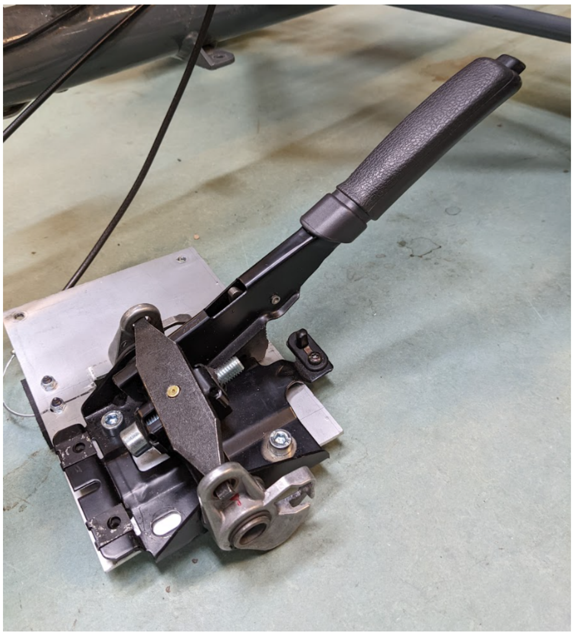
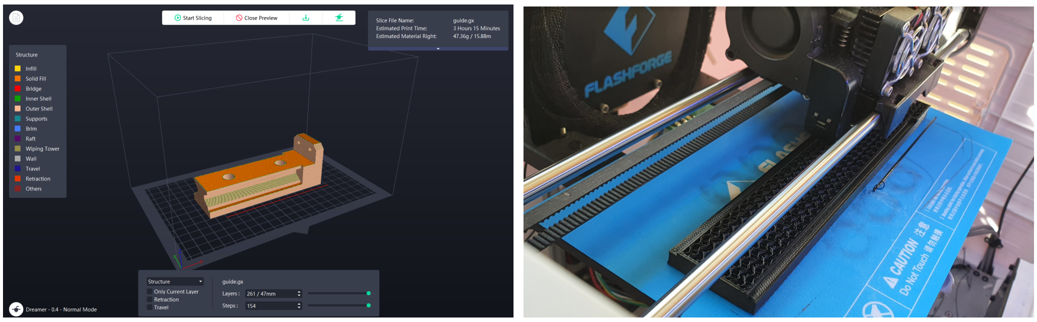


Figure 4.18: Acquired Volvo V70 handbrake lever

4.7.2.3 Rapid Prototyping & Assembly

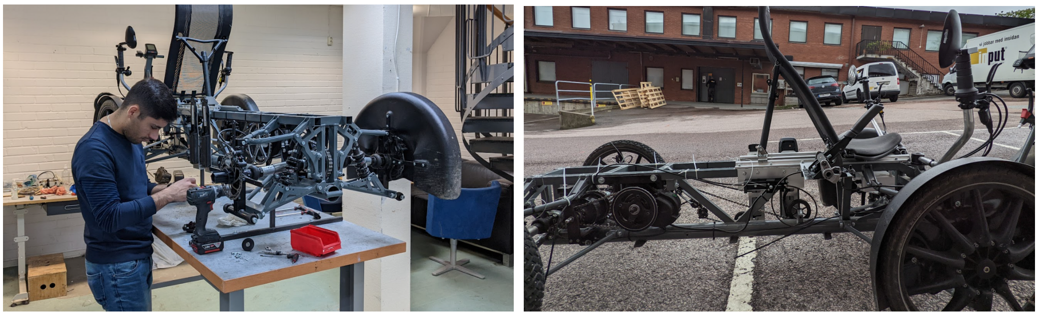
In order to reduce the cost and time, some of the complex parts from the CAD models were built using a Fused Filament Fabrication (FFF) 3D printer available at the Velove R&D facility. The flash forge printer uses PLA (polylactide acid) filament with two extruders that can print dimensions 200 x 148 x 150 mm models. This approach was beneficial in building complex parts such as the connector mechanism that require suitable tolerances. The CAD models were exported from Solidworks in STL file format and imported into the 3D printing software, Flash print 5 (see figure 4.19(a)). Once imported, the software automatically prepares the model to be sent to the 3D printer upon giving optimal parameters such as the model's orientation and the temperature of the base plate on which the model rests. These files are then printed by the 3D printer taking from 30 minutes to 2 hours, depending on the size and complexity of the part (see figure 4.19(b)).



(a) 3D printing software (FlashPrint) **(b)** 3D printing of the model

Figure 4.19: 3D printing software & hardware

However, certain parts, such as the cable end blocks subjected to very high tension forces, are prone to breaking with the 3D printed materials. Most of the prototyping raw materials like plates, tubes, fasteners, and the various cutting tools were available at the R&D facility for quick prototyping as shown in figure 4.20(a). The raw materials, standard parts, coupled with the 3D printed parts, made it easier for us to translate from CAD to the actual model for testing purposes. As shown in figure 4.20(b), all the concept components were assembled and mounted onto the bike.



(a) Prototyping activity (b) Final assembly of the parts

Figure 4.20: Prototype assembling stage

4.7.2.4 Testing & Validation

Test 1: Car Handbrake Lever With No Container Loaded
Following the assembly of the components, initial tests were conducted using the hand brake lever from the car. The test was carried out in a flat surface environment where the bike was stationary without loading on the carriage platform. The main aim of this test was to determine the effectiveness of the brake and pinpoint the places for adjustments. First, the bike was mounted on a work table. The handbrake lever was gradually pulled to increase the tension on the cable up to a point where the brakes were slightly activated and to check that no parts were undergoing an excess stress point of deformation. Simultaneously, the wheels were subjected to a generous amount of torque by turning them manually with hand force. At one point of applying the torque, the wheels started turning. However, the hand lever could be pulled even further to tighten the tension on the brake cables. Upon this, the brakes were fully engaged, and the wheel movement was mobilised, showing the parking brake was fully effective. However, certain parts, such as the sliding block on the connector mechanism, were subjected to play upon visual inspection due to lower tolerances. Additionally, the mounting plate for the hand brake lever was also undergoing bending upon pulling the handbrake lever. These parts were especially noted for optimization for the final design.

Test 2: Car Handbrake Lever With Container Loaded
To carry out the test to check the effectiveness of the brake with the cargo load, the bike was first loaded with an empty container on the back. To simulate the weight of the packages, the project group used different weights that were kept for this purpose in the R&D facility. The weights included multiple water cans, dumbbells and other general weights used in the gym. The total weight measured was up to 200 kgs without the weight of the container included (see figure 4.21).

Figure 4.21: Bike container loaded with 200kgs

The tests were conducted outside the R&D facility on an elevated asphalt road with the container loaded. One of the requirements set by the R&D team at Velove was to immobilize the movement of the bike at an elevated slope of 5% encountered on extraordinary routes. A safety factor of 2.5 was added on top of this to accommodate unexpected routes. The elevation of the road was determined using a photo as a reference as shown in figure 4.22.

Figure 4.22: Bike on an elevated asphalt road

The windows in the photo were taken as a reference for the flat surface. The hypotenuse was placed right under the wheels, and the length of rise and run was gathered from the photo.

$$SLOPE\% = \frac{rise}{run} \cdot 100 \tag{4.1}$$

Equation 4.1 above was used to calculate the slope percentage. The result was as follows.

$$SLOPE\% = \frac{rise}{run} \cdot 100 = \frac{1.4cm}{10.33cm} \cdot 100 \approx 13.6\% \tag{4.2}$$

The safety factor then was $\frac{13.6}{5} = 2.72$ which was > 2.5 2.5 and indicated that this hill could be used to perform our tests.

The first test included setting the bike stationary on the elevated road and gradually pulling the brake lever until the brakes were activated to the maximum. Once the brakes activated, the bike was checked to see if it moved backwards with the rider sitting on the seat. The test passed well without any problems undergone. Similarly, another test was performed to simulate the actions performed by a rider during the test as shown in figure 4.23.

Figure 4.23: Rider sits on the bike on an elevated asphalt road

Here, the bike was gradually stopped while in motion using the primary brakes and the parking brake lever was pulled instantly with the rider getting off the bike. The parking brake was kept engaged for around 5 minutes on the elevated slope to create a package delivery scenario. This was repeated multiple times to check if the brakes lost their effectiveness over a few iterations.The tests showed promising results in terms of their overall effectiveness. However, there were specific issues with the brake lever from the ergonomic point of view that were documented. Additionally, the connector mechanism concept could also be optimised in size. These are discussed in the next section.

4.8 Detailed Design Proposal

This section includes the design of the handbrake lever, design optimization of the connector mechanism, and cost estimation.

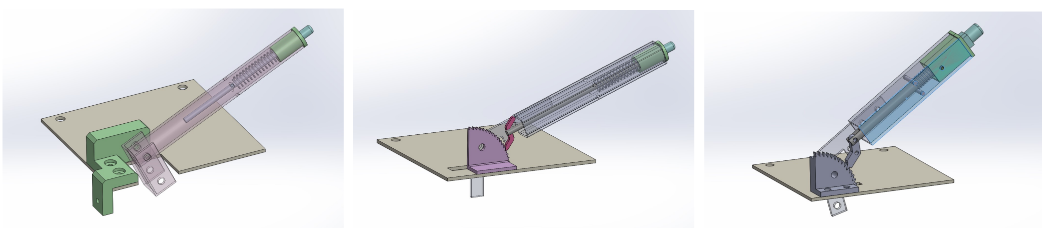
4.8.1 Handbrake Lever Design

After the tests, a detailed design for the brake parts was created in CAD. The main parts include the creation of a new hand brake lever and modification to the concept of the connector mechanism. During the concept testing, a hand brake lever from the car was used. Although the test results were promising, a new hand brake lever was required to be designed so it could be manufactured and mass-produced to be installed into many bikes as a working parking brake solution. During the testing phase, the following points were documented and considered while designing it on CAD.

1. The hand brake lever had to be placed at the proper distance from the rider's seat. Since, the rider's adjust the seat forward or backward as per their height, the hand brake lever was out of reach and created an uncomfortable position for activation.
2. The hand brake lever could create a minor collision when the bike's handlebars are turned rightwards towards the maximum position.
3. The plate on which the car hand brake lever was mounted was undergoing bending while activating the brake. Additionally, the weight of the whole lever unit was suspended in the form of a cantilever.

The issues 1 & 2 pertaining to ergonomics could be fixed by choosing the correct length of the parking brake lever or creating a lever that could be adjusted forward or backwards. The issue 3 could be fixed by mounting the whole hand brake lever unit on a rigid beam weldment.

Taking the hand brake lever from the car as an inspiration, The hand brake lever was done in three concept iterations and one final design. The first three concept iterations are shown in figure 4.24.



(a) Handbrake concept 1 **(b)** Handbrake concept 2 **(c)** Handbrake concept 3

Figure 4.24: Three different concepts of handbrake design

These designs were first created on CAD and then taken for prototyping. But the project group found various flows mid way such as parts being too small to manufacture or requiring precision in manufacturing. Hence these three models. Starting from iteration 1 the designs evolved along the way and a final design was created (see figure 4.25).

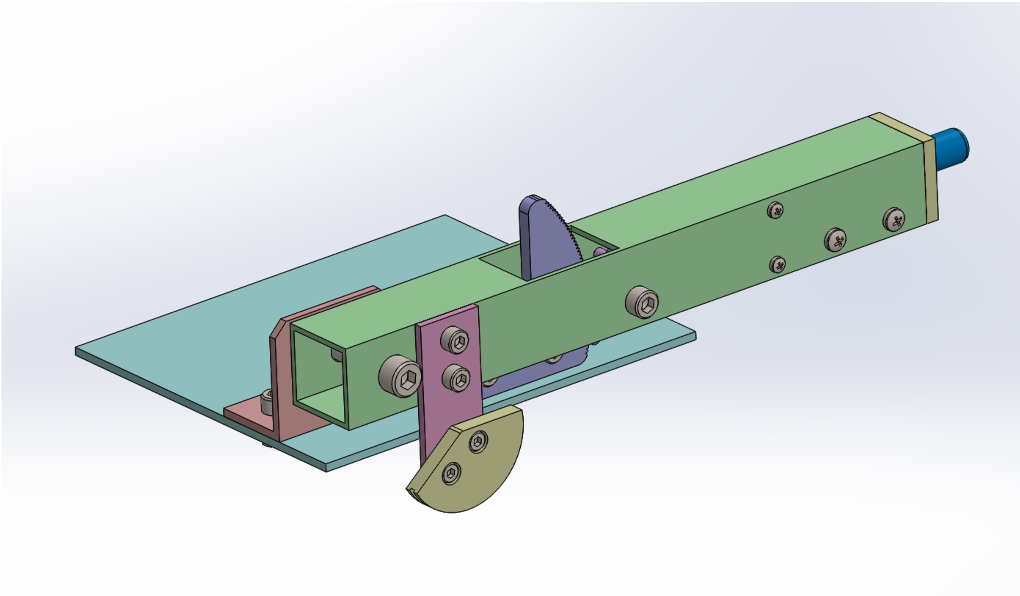


Figure 4.25: Final CAD design of handbrake lever

The model of the hand brake lever uses a rectangular tube with cutouts at its centre and is mounted on the edge of a rectangular plate using an L channel and fasteners at the bottom end. The top end of the hand brake lever consists of a button system that retracts back and forth with the help of spring when it is pressed. The bottom end of the button has a provision for inserting a steel road. The rod functions as a connecting point to actuate a small elliptical-shaped plate called a pawl located inside the rectangular tube and is mounted at its centre. Similarly, a ratchet profiled gear is mounted near the centre of the rectangular tube on the plate. When the button on the rectangular tube is pressed, the pawl is disengaged from the ratchet gear, and the rectangular tube can be pulled upwards. On releasing the button at this position, the pawl gear locks to the gear teeth of the ratchet, thus keeping the rectangular tube in its position. The rectangular tube can be lowered by pressing the button and lowering it. The other end of the rectangular tube consists of a provision to connect the brake cable wire. Similarly, the parking brake alerting system can be installed using a normally open switch on the rectangular plate (see figure 4.26).

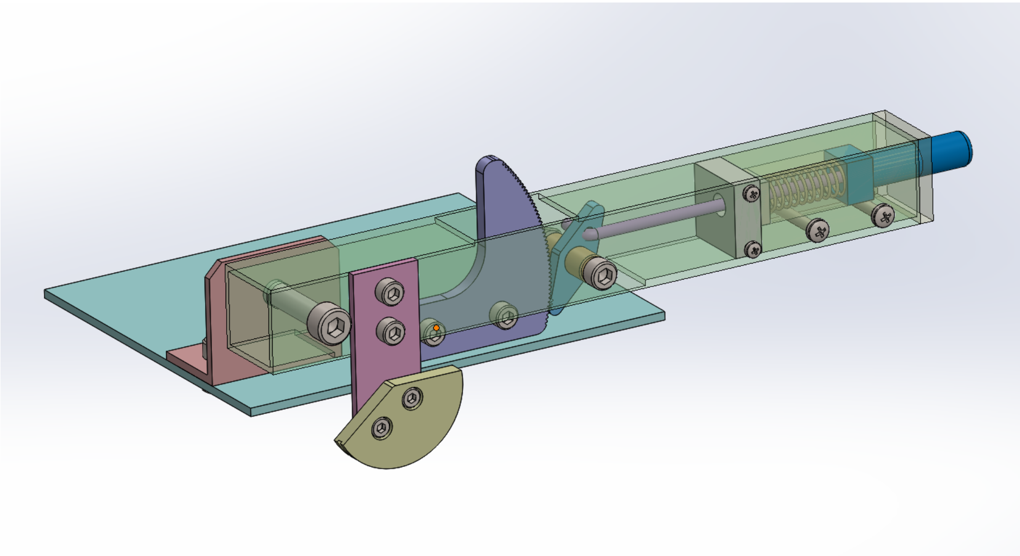


Figure 4.26: CAD model of the handbrake lever with internal parts

4.8.2 Optimization Of The Connector Mechanism

The optimization of the connector mechanism mainly includes a reduction of its size and better placement of the brake wires with knobs for a minor adjustment for wire tension. When the concept CAD for the connector mechanism was created, its size was quite large as the project group was unaware of the distance the sliding block had to travel to engage the brake fully. For the optimization of the connector mechanism, the following points were considered.

1. During the test, the project group noticed that the block slides back and forth by around 80-120mm. Hence the rail on which the block slides would be reduced in length and be more contact in design.
2. The method of clamping the brake wires from the caliper end and the brake hand lever was done using fasteners and washers. This was highly prone to cause sliding in the brake wires during high tension force. Thus a new method of clamping the wires to the block was designed.
3. There were no points of quick adjustment included in the connector mechanism. By using adjustable knobs on both ends of the mechanism, slight cable tension adjustment could be made.

The optimized CAD model of the connecting mechanism is shown in figure 4.27 below.

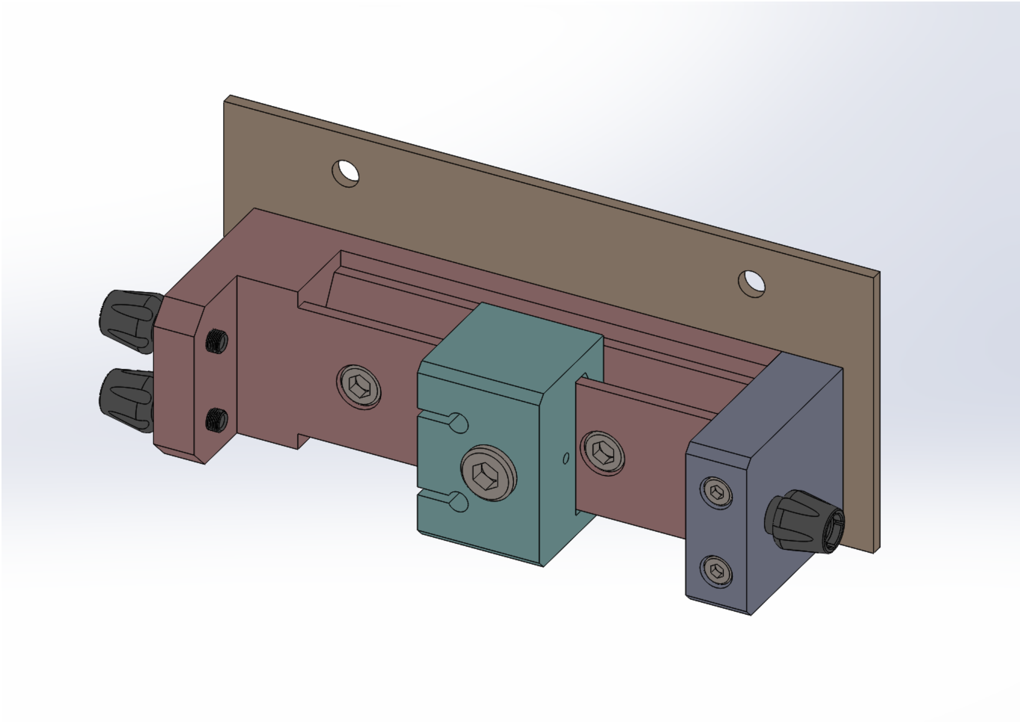


Figure 4.27: CAD model of the connecting mechanism

The optimised model of the connector mechanism has three holes drilled along the horizontal direction of the sliding block. The wire ends of the brake caliper side are inserted directly into the top and bottom holes and use cable stoppers to hold the wire in place. Thus the main adjustments for these wires are made only on the brake calipers. The brake wire from the hand lever end is inserted into the centre hole and held in place using an M4 socket head screw. This makes all the wires stay in place. At both ends of the connector mechanism, adjustment knobs are provided for slight adjustments in the wire tension.

After assembly of all the above components, the complete model of the bikes with the parking brake lever is shown in figure 4.28.

Figure 4.28: Complete CAD model of the bike with the detailed design.

4.8.3 Cost Estimation

During the initial stages of the project, one of the primary requirements of the customer was a cost-effective solution within the range of 2000 SEK. The cost of the previous solution implemented by the company was meagre, but it was a tradeoff between the cost and the performance. The unit consisted of a simple off-the-shelf brake lever and a single mechanical disc brake caliper with a single brake cable. The cost of the previous solution was approximately 250 SEK.

Using the detailed design of the new solution as a starting point and acquiring costs of standard parts from the R&D engineer o, the project group could approximate the cost of the new solution. However, these estimated costs do not include accurate dimensions and processing, as the additional costs must be calculated after the detailed design. The following are the subsystems within the solution:

1. The brake calipers and the cables.
2. The connector mechanism sub assembly.
3. The hand lever sub assembly.

The cost breakdown of the three subsystems is shown in table 4.14

Table 4.14: Bill of materials and cost estimation

Part Name	Part Type	Material	Quantity (Nos)	Unit cost	Material cost / kg	Mass (kg)	Total cost (SEK)
Brake system							
Brake calliper unit	Standard	-	2	227	-	-	454
Brake cable housing	Standard	-	1	7	-	-	7
Brake wires	Standard	-	1	11	-	-	11
						Total cost of brake system	**472**
Connector mechanism							
Sliding block	Manufactured	Low Carbon Steel	1	-	7	0.213	1.491
Sliding rail	Manufactured	Low Carbon Steel	1	-	7	0.878	6.146
End block	Manufactured	Low Carbon Steel	1	-	7	0.194	1.358
Base plate	Manufactured	Low Carbon Steel	1	-	7	0.258	1.806
						Total cost of connector mechanism	**10.801**
Hand lever mechanism							
Mounting plate	Manufactured	Low Carbon Steel	1	-	7	0.218	1.526
Square tube	Manufactured	Low Carbon Steel	1	-	7	0.366	2.562
Connecting plate	Manufactured	Low Carbon Steel	1	-	7	0.078	0.546
Gear plate	Manufactured	High Carbon Steel	1	-	7	0.082	0.574
Cam	Manufactured	High Carbon Steel	1	-	7	0.012	0.084
Holding structure	Manufactured	Low Carbon Steel	1	-	7	0.483	3.381
Gear mounting plate	Manufactured	Low Carbon Steel	1	-	7	0.044	0.308
Wire holder plate	Manufactured	Low Carbon Steel	1	-	7	0.033	0.231
Wire holder	Manufactured	Low Carbon Steel	1	-	7	0.037	0.259
Knob plate	Manufactured	Low Carbon Steel	1	-	7	0.033	0.231
Sleeve	Manufactured	Low Carbon Steel	2	-	7	0.003	0.042
Button holder plate	Manufactured	Low Carbon Steel	1	-	7	0.048	0.336
Connecting rod	Manufactured	Low Carbon Steel	1	-	7	0.12	0.84
Button holder	Manufactured	Plastic (ABS)	1	-	18	0.034	0.612
Button	Manufactured	Plastic (ABS)	1	-	18	0.006	0.108
Spring	Standard	-	1	20	-	-	20
						Total cost of hand lever mechanism	**31.64**
						TOTAL COST (SEK)	514.441

The total cost of all the subsystems can be estimated at around 514 SEK. The cost of manufacturing, tooling, fasteners and supply chain-related costs must be included on top of these estimates. A detailed estimation can be completed by adding the overhead costs after a final quotation from the components supplier during the final stages of development. Lastly, the costs also vary depending on the quantity to be manufactured.

5
Discussion

The chapter reflects on the project results and how the product development methodologies helped find a possible solution for an easy and effective paring brake on the Velove cargo bike. Additionally, the fulfilment of the customer's requirements and future development work that could be carried out is also discussed.

The initial stages of the project involved understanding the problem in detail and knowing the customer's needs. Most of the theoretical parts were carried out as a combination of methods from the 'Product Design and Development' by Ulrich and Eppinger [11] and 'Produktutveckling - Effektiva metoder för konstruktion och design' by Johannesson, Persson and Petersson [12], whichever the group found as most suitable. Although most of the solutions generated during the brainstorming and concept generation phase were deemed suitable to be implemented, trade-offs had to be made due to time constraints. There were also knowledge areas that the project group lacked, such as understanding the electrical systems.

One of the most challenging parts of the project involved prototyping the various concepts from its digital counterparts. The translation of the CAD model to a manufactured part requires precision and understanding of design from various perspectives. By undergoing iterations of design, building and testing, the project group could find flaws in the initial design to create a better model and arrive at a final solution.

5.1 Fulfilling The Customer's Requirement

During the first stages of the project, various needs from the stakeholders were documented as customer requirements. The project group created the concepts revolving around these requirements. The final proposed solution is traced back to these requirements to check for its fulfillment as shown in table 5.1.

Table 5.1: Validation of the requirements against the proposed solution

			Document type	**Test & Validation**		
			Project	Develop parking brake for heavy-duty cargo bike		
Issuer:	Chirag Aloysius Mascarenhas Yasin Demirci	***Created:*** *2022-05-25*				
Critierias/ Function(s)		***Target Value***	***Verification method***	***Reference***	**Test/validation**	**Justification**
1.	**Performance**					
1.1	Brake the bike with full load at flat surface	0% slope	Engineering assessment	Product development team	Pass	Physical tests performed
1.2	Brake the bike with full load on slope surface	5% slope	Engineering assessment	Product development team	Pass	Physical tests performed
1.3	Time to activation of parking brake	<5 seconds	Engineering assessment	Product development team	Pass	Physical tests performed
2.	**Usability**					
2.1	User adoptation time	< 8 hours	Feedback	User	Pass	Simple mechanical system
2.2	Training time	< 2 hours	Feedback	Hub & Fleet Manager	Pass	Simple mechanical system
2.3	Position of parking brake activation from user	<45 cm from the rider	Engineering assessment	Product development team	Pass	Detailed Desing Proposal
3.	**Lifetime**					
3.1	Lifetime of parking brake	<5 years	Engineering assessment	Product development team	Unknown	Requires usage data over the course of time
4.	**Economics**					
4.1	Cost of entire parking brake system	< 200 euros	Cost analysis	Product development team R&D team	Partially fullfilled	Passes the preliminary cost estimation
5.	**Implementability**					
5.1	Easy to implement on current bikes	=>2 (see scaling)	Engineering assessment	Product development team R&D team	Pass	No major modifications Results needed to present in the report
5.2	Easy to gather required parts	< 1 month	Engineering assessment	Product development team	Partially fullfilled	The desing proposal does not use many standard parts
5.3	System integration	Seperate system	Engineering assessment	Product development team	Pass	Seperate system than
6.	**Maintenance**					
6.1	Main maintenance	Approx. 50 shifts	Feedback	Maintenance team	Unknown	Requires implementation of the soluton
6.2	Weekly maintenance	7 days or approx. 5 shifts	Feedback	Maintenance team	Unknown	Requires implementation of the soluton
7.	**Functionality/Features**					
7.1	Non-freezing or freeze resistant system	Up to -10 degrees Celcius	Engineering assessment	Product development team	Fail	Needs further improvement in design
7.2	Use as emergency brake	Main brake force < 0 N	Engineering assessment	Product development team	Pass	Physical tests performed - can be used in case of emergency
7.3	Prevent joy rides	Tamper proof	Engineering assessment	Product development team	Fail	Needs further improvement in design
7.4	Alert user about p-brake status	P-brake = on	Engineering assessment	Product development team	Partially fullfilled	Suggested in the detailed desing proposal
8.	**Environment / Legality**					
8.1	Do not use hydraulic system	Switzerland requierement aSi-19-0097-TK001 (The company has these requirements as basis)	Engineering assessment	Product development team	Pass	Mechanical system
9.	**Safety**					
9.1	Prevent unauthorized deactivation	Authorized rider de-activation	Engineering assessment	Product development team	Fail	This requirment was deemed not necessary

As seen from the table, the proposed solution could fulfill most of the customer's requirements. The requirements subjected to pass in the validation column were either verified during the concept testing phase or suggested in the detailed design proposal on how they could be fulfilled. Specific requirements could not be verified due to insufficient data available at the perusal. These are marked either by unknown or partially fulfilled. Lastly, there are a few requirements that the project group failed, which are explained in the subsequent sections.

From the performance and usability point of view, the tests confirmed that the solution could meet the needed requirements. The lifetime of the brake and the maintenance depends on how the solution can handle over time and could be verified through a pilot implementation of the solution on a few bikes. The economic criteria require a complete detailed design and supplier information to deduce the exact cost of the system since the cost varies depending on a lot of factors, such as batch size, tooling and machining costs and other overhead costs.

There were a few requirements in the functionality that the project group failed to fulfill, such as working of the brake system in extreme cold weather conditions and how the system could function as a means to prevent joy rides or unauthorized deactivation of the parking brake.

5.2 Specifications Of The Issues Under Investigation.

During the start of the project, there research questions were framed. The results obtained answers the following questions.

1. **What is the currently implemented parking brake solution? And why is a new solution required?**

   During the project's initial study, the project group investigated the currently implemented parking brake consisting of a simple hand lever and a single mechanical disc brake caliper mounted on the front left wheel. On further testing, the solution could not mobilise the bike's movement under the heavy loading of the cargo in the rear. The parking brake lever was made of substantially lower quality material and required frequent adjustment, making it highly unreliable. A new solution was needed to solve the issues mentioned above.

2. **What are the potential concepts available to address the underlying issues and meet the customer's needs?**

   During the project work, the project group could create multiple concepts that could solve the issues of the old parking brake solution. The concepts were further evaluated depending on fulfilling the customer's requirements. Although two concepts were highly potential in solving the underlying issues, the project group decided to undertake prototyping and testing of one of the best-performing concepts.

3. **What are the strengths and weaknesses of the new solution compared to the current solution in terms of effectiveness, cost, implementation, maintenance and usage?**

   Even though the detailed design could not be prototyped and tested within the stipulated thesis time, a general comparison of the current solution with the new solution using the Volvo V70 handbrake lever is documented. Table 5.2 below presents the strengths and weaknesses of the current solution, alternative solution and the new solution.

Table 5.2: Comparison of prototype, current brake system and the alternative solution in terms of strengths and weaknesses

	Current solution	Alternative solution	New solution (prototype)
Strengths	+ Low-cost solution. + Easy to impelement on all bikes. + Easy to gather the required parts.	+ Stable positioning of the brake handles. + Highly effective. + Easy to implement to all bikes.	+ Effective brakes on slopes up to 13%. + Easily activated and deactivated. + Can be used as an emergency brake. + Easy to implement on all bikes. +Any damaged parts can be replaced, saving costs.
Weaknesses	- Ineffective during heavy cargo loads - Placement of the lever is unergonomic. - Low quality brake handle. - Cannot be used as an emergency brake since the wheel is locked only on a single wheel. - Requires frequent adjustments.	. Non-mechanical solution. - Higher cost for replacement. - Risk for hydraulic failure. - Relies on the locking switch, which is prone to damage. - Cannot be used as emergency brakes.	- Position of the hand brake lever can hinder other movements. - Has more parts than the other solutions. - No weatherproofing. - Expensive than the current solution.

5.3 Future Development

At the time of discussion, the final solution is still under development and not fully ready to be implemented on the cargo bike. The complete development of the solution spans over a more extended period and could not be completed due to time constraints. Upon using the final design proposal as a reference and refining it, along with further testing, the solution could come close to realization.

Some recommendations that the project group puts forwards for future developments are:

- The mechanical brake calipers used from the old parking brake solution could be changed to a new model in terms of the better build quality of parts and thus further increase the efficiency of the braking in the longer run.
- The 3D printed connector mechanism concept developed requires better tolerancing and finishing on the final product for a smoother sliding and to prevent unnecessary movement. An addition of a cover bracket would prevent it from rain and dust.
- The hand brake lever mechanism needs prototyping and testing to check if it functions as intended, mainly in the area where the rack and pawl mechanism is proposed.
- Design a locking mechanism into the hand brake lever to prevent the bike from unauthorized usage.
- Further research and analysis on the materials and stresses on the parts would be highly beneficial.

6 Conclusion

The solution to finding an effective parking brake that could be implemented into the Velove bike's armadillo cargo bikes was addressed in this project work. Upon understanding the shortcomings of the existing solution for the parking brake implemented on the bike and deducing the requirement specifications and final solution was designed. The solution has been achieved following the various methodologies of product development to enable the right trade-offs.

The final concept solution consists of mounting two mechanical brake calipers on the rear discs of the bike and actuating it with a simple parking brake hand lever placed on the side of the rider's seat. This concept was prototyped using various manufacturing tools available coupled with 3D printed parts to enable rapid construction. The concept of testing was able to hold the bike by mobilizing its movement on the desired slope with the maximum cargo load. Most of the customer's requirements were fulfilled, and some needed more refinement in the design and further testing to validate their results.

Although a detailed design was proposed to the customer, the project group failed to prototype it due to time and resource constraints. The detailed design proposed could be beneficial as a starting point to make necessary reworks mainly to meet the failed requirements. Additionally, some recommendations laid out for future work would bring the solution close to realization.

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