The Development of an Electric Cargo Vehicle

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DIVISION OF INNOVATION | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
2026

MASTER THESIS

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DELIVERY

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The Development of an Electric Cargo Vehicle

Applying Systematic Product Development to the Bolivian Context for Sustainable Urban Deliveries

Published by
Department of Design Sciences
Faculty of Engineering LTH, Lund University
P.O. Box 118, SE-221 00 Lund, Sweden

Subject: Product Development (MMKM05), Technical Design (MMKM10)
Division: Innovation
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Examiner: Elin Olander

Abstract

This master's thesis presents the development of an electric cargo vehicle adapted to the urban, infrastructural and socioeconomic conditions of Cochabamba, Bolivia. The project was conducted in collaboration with Eco Delivery, a Bolivian last mile logistics company seeking a sustainable and locally manufacturable transport solution capable of supporting urban delivery operations under demanding conditions.

The work followed an adapted Double Diamond design process combined with human centred design principles. Initial stages included benchmarking of existing cargo bikes and electric utility vehicles, field observations, stakeholder interviews and operational analysis of Eco Delivery's current fleet. The collected insights revealed the importance of stability, rider comfort, manoeuvrability, durability and serviceability within the Bolivian context, leading to the selection of a narrow four wheel vehicle architecture.

The Develop phase focused on the systematic design and integration of subsystems including the frame, suspension, steering, drivetrain, braking system, cargo module, seating and electric powertrain. Emphasis was placed on the use of locally available materials and simple manufacturing methods to improve maintainability and feasibility for local production.

The outcome of the project is the digital prototype Tunari 1.0, an electric cargo vehicle designed to transport payloads of up to 200 kg while remaining compact and manoeuvrable in rough urban environments. The project demonstrates how engineering design can be adapted to local constraints to support more sustainable and accessible urban logistics solutions.

Keywords: Electric cargo vehicle, last-mile delivery, double diamond method, low-resource engineering contexts.

Sammanfattning

Detta examensarbete presenterar utvecklingen av ett elektriskt lastfordon anpassat för de urbana, infrastrukturella och socioekonomiska förhållandena i Cochabamba, Bolivia. Projektet genomfördes i samarbete med Eco Delivery, ett bolivianskt företag inom sista milens logistik som efterfrågade en hållbar och lokalt producerbar transportlösning för stadsdistribution under krävande förhållanden.

Arbetet genomfördes med en anpassad Double Diamond-designprocess i kombination med människocentrerade designprinciper. De inledande faserna omfattade benchmarking av befintliga lösningar, fältobservationer, intervjuer med intressenter samt analys av Eco Deliverys nuvarande fordonsflotta. Resultaten visade att stabilitet, förarkomfort, manövreringsförmåga och hållbarhet var särskilt viktiga inom den bolivianska kontexten.

Utvecklingsfasen fokuserade på systematisk konstruktion och integration av delsystem såsom ram, fjädring, styrning, drivlina, bromssystem, lastmodul, sittposition och elektrisk drivlina. Stor vikt lades vid användning av lokalt tillgängliga material, enkla tillverkningsmetoder och simpel konstruktion för att förbättra underhållsmöjligheter och genomförbarhet för lokal produktion.

Projektets slutresultat är den digitala prototypen Tunari 1.0, ett elektriskt lastfordon konstruerat för att transportera laster upp till 200 kg samtidigt som det förblir kompakt och manövrerbart i tät stadsmiljö. Projektet visar hur ingenjörsdesign kan anpassas till lokala förutsättningar för att bidra till mer hållbara och tillgängliga urbana logistiklösningar.

Nyckelord: Elektriskt lastfordon, sistamilen-leveranser, Double Diamond-modellen, Ingenjörsutveckling i resursbegränsade kontexter.

Acknowledgments

We would like to thank our supervisor Axel Nordin at Lund University for the support and guidance throughout the project, despite the geographical distance during our time abroad.

We would also like to thank Jazmin and Franco at the Technology Cluster at UMSS in Cochabamba for welcoming us, guiding us and helping us navigate both the project and daily life in a completely new environment. We are especially grateful for their work in facilitating the collaboration between Sweden and Bolivia and in connecting us with local opportunities throughout the project.

Finally, we would like to express our gratitude to Miguel and Eco Delivery for the collaboration and for allowing us to contribute to the development of more sustainable urban transportation solutions in Bolivia. We are thankful for the opportunity to be part of a project striving for innovation and positive change within a context characterised by significant challenges and uncertainty.

Lund, May 2026

Felix Langenius and Zoë Birgersson

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Introduction

This chapter introduces the background and context of the master's thesis, through the lens of the geographical location in which the work is conducted. It outlines the background and defines the purpose, objectives, scope and constraints of the project.

1.1 Background

Urban logistics systems are changing as demand for convenience and sustainability increases. Fast, reliable and cost effective deliveries have become essential for business competitiveness, leading to a growing number of daily urban deliveries. At the same time, fossil fuel based transport contributes to traffic congestion, air pollution and greenhouse gas emissions, increasing the need for logistics solutions that reduce environmental impact and support more sustainable urban transportation systems (World Health Organization, 2021). In response, electric vehicles have become an increasingly common alternative for urban transport.

In Cochabamba, Bolivia, geographical and socioeconomic conditions strongly influence the implementation of such solutions. The city is in a valley where pollution tends to accumulate. Furthermore, limited financial resources, reduced fuel subsidies (Reuters, 2025) and restricted access to advanced materials and technologies limit the adoption and development of expensive and technologically complex solutions. Additionally, poor road conditions, high altitude terrain, limited cycling infrastructure and a large population of young people seeking employment opportunities contribute to the number of challenges faced in Bolivia.

Within this context, electric cargo vehicles represent a viable alternative for last mile logistics. Most existing cargo bike solutions are developed for European urban environments and are not directly adapted to the conditions found in Bolivia. Developing a reliable and sustainable cargo transport solution therefore requires consideration of local operating conditions, manufacturing methods, maintenance culture and component availability. For such solutions to function effectively within the Bolivian context, they must not only reduce environmental impact but also remain reliable, serviceable and economically feasible under demanding operating conditions. Addressing these challenges forms the foundation of this master's thesis.

1.2 About Eco Delivery

Eco Delivery is a last mile logistics startup in Cochabamba, Bolivia. The company was founded in 2016 after the team's victory in the first solar vehicle competition in Latin America, the *Carrera Solar Atacama 2016* (Innovación Sostenible, n.d.). Founded by Miguel Fernández and collaborators, Eco Delivery delivers B2B and selected B2C services with a primary focus on supporting small and medium sized enterprises that lack access to affordable and sustainable logistics. The startup responds to rising urban delivery demands, increasing operational costs and the environmental and traffic related challenges in Bolivian cities (Bolivia Emprende, 2022).

The company operates a fleet of conventional bicycles, electric bicycles and custom cargo bicycles designed for transporting heavier loads. These vehicles are developed and assembled locally, adapting bicycles and components in workshops. Eco Delivery employs approximately 30 active cyclists, primarily young people and university students, offering flexible part time employment. The company prioritises reliability, service quality and cost effectiveness while integrating environmental considerations and social objectives within their operations (Bolivia Emprende, 2022).

1.3 Project Description

The aim of this master's thesis is to develop an electric cargo vehicle adapted to the urban and socioeconomic conditions of Cochabamba, Bolivia. The project addresses the growing demand for reliable and cost effective last mile logistics while responding to environmental challenges related to air pollution and fossil fuel based transportation. The focus is on developing a solution that is robust and serviceable while remaining suitable for local production and long term operation within the constraints of the Bolivian context.

The design is adapted to local manufacturing methods and seeks to utilise existing material inventories, workshop tools and readily available standard components. Emphasis is placed on mechanical simplicity, durability and ease of maintenance to support continued operation in an environment with limited resources.

A central aspect of the project is the development of a cargo transport solution capable of enabling efficient and safe transportation of goods under demanding urban conditions. The cargo system includes a covered cargo box designed to improve ease of loading, cargo protection and operational flexibility for different types of deliveries. The vehicle is intended to carry large payloads while maintaining stability and manoeuvrability. The electric system ought to assist the cyclist whilst the vehicle remains functional without it. The design must also be safe to use and be cost effective.

The development process is iterative, involving continuous concept evaluation and refinement based on user needs, benchmarking, subsystem integration and manufacturing considerations. The project ultimately aims to deliver a cargo vehicle concept that can support the continued development of sustainable urban logistics solutions within Bolivia.

1.4 Delimitations

The scope of this master's thesis is limited by the duration of the onsite project period, which is restricted to 84 days. Due to the limited timeframe and the complexity of the product, the project primarily focuses on concept development, CAD modelling and overall system design rather than complete manufacturing and validation of a final product. The developed vehicle is regarded as a first conceptual prototype. Full scale production, long term testing, detailed simulations and performance validation are outside the scope of the thesis. The work therefore focuses primarily on design feasibility, manufacturability and applicability within the Bolivian context rather than final product certification or commercial deployment.

2 Method

This chapter presents the methodological framework used in the project. It outlines the design process, including the Double Diamond model, human centred design principles and how the method was adapted to the specific context and constraints of the project.

2.1 Design Process

2.1.1 Generative AI Disclaimer

ChatGPT was used throughout the project as a supporting tool. More advanced AI tools were not available during the project period in Bolivia. ChatGPT was used to help structure the report, explore research approaches and discuss ideas and engineering concepts. It served as a search engine to supplement theoretical understanding and speed up the gathering of information. It also functioned as a language assistant for grammar, clarity and the generation of selected figures. All engineering decisions, calculations, design work, evaluations and conclusions were performed and verified by the authors.

2.1.2 Double Diamond

In this project the design process follows the Double Diamond model, which consists of four distinct phases: Discover, Define, Develop and Deliver. This structured design framework was introduced by the UK Design Council and is used to help designers understand problems more thoroughly before developing solutions (Design Council, 2019). The first diamond focuses on understanding and defining the problem, while the second diamond focuses on developing and delivering the solution. The process is illustrated in Figure 2-1.

The process begins with an initial brief or requirement specification. However, the Double Diamond highlights that design should not be treated as a strictly linear process. Instead, it encourages designers to step back and question whether the right problem is being solved. The first diamond includes the Discover and Define phases. During the Discover phase, research is carried out to better understand the users, the context and the challenges connected to the problem. This can include observations, interviews, benchmarking and early testing. The goal is to gather insights and move closer to the real needs of the users. In the Define phase, the collected information is analysed and structured to then create a clearer and improved design brief. This revised brief forms the foundation for the second diamond.

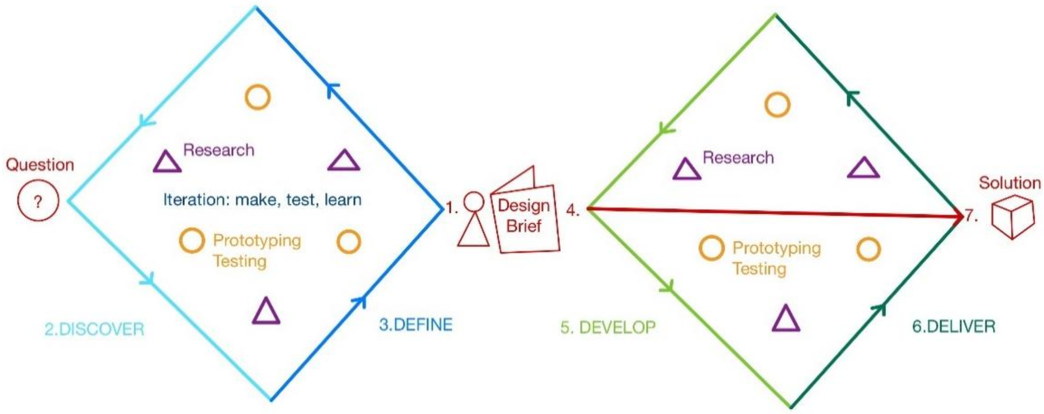

Figure 2-1. Illustration of the Double Diamond process (Source: Author).

The second diamond consists of the Develop and Deliver phases. In the Develop phase, potential solutions are generated, tested and refined. Prototyping, technical development and user feedback play an important role at this stage. The process remains iterative, meaning that solutions are continuously evaluated and improved. The Deliver phase focuses on finalising and validating the solution. This includes testing and ensuring that the design meets the specifications. (Design Council, 2019).

The Double Diamond structure allows the design process to be adapted to the specific context of Cochabamba, Bolivia. The framework supports conducting local research, field observations and hands on testing to better understand the issues at hand. It also makes it possible to adjust the development process to the short timeframe and limited resource availability. By generating concepts early, building prototypes and incorporating continuous feedback, the project increases the likelihood of delivering a functional and context appropriate cargo bicycle within the given constraints.

2.1.3 Human Centred Design

Human centred design is a development approach that places the user and their real context at the centre of the design process. Rather than beginning with technical solutions, the process starts by understanding user behaviour, needs, limitations and working conditions through observation, dialogue and testing. Design decisions are continuously reviewed based on feedback and iteration, ensuring that the solution is usable and safe. As described by Norman (2013), effective design requires a deep understanding of the people who interact with a system, since products must adapt to human capabilities rather than expect humans to adapt to the product.

2.1.4 Product Design and Development

As previously stated, the Double Diamond model was used as the overall framework for the project. Within the Discover, Define, Develop and Deliver phases, selected methods from Ulrich and Eppinger's *Product Design and Development* (2016) were applied to accelerate and structure the development process. These methods were not used as separate processes, but as tools within the Double Diamond model. Examples include identifying customer needs, developing requirements and specifications, and evaluating concepts using concept screening and concept scoring. This approach takes advantage of the flexibility of the Double Diamond model as an overarching guide while incorporating established product development methods from Ulrich and Eppinger within the different phases.

2.1.5 The Design Process at Eco Delivery

Eco Delivery operates with a “hands on” and opportunity driven development approach. As a small and ambitious company, their focus is on rapid innovation and fast delivery of solutions that respond directly to emerging market needs. Development is practical and fluid rather than strictly systematic. Concepts are often inspired by existing solutions from other parts of the world. These are then modified to be applied locally. Components, technologies and mechanisms from different technical areas are combined and repurposed to meet needs, often within tight budget constraints. The process is strongly oriented toward delivering a functioning result, with immediate problem solving having priority over long term development. Manufacturing is viewed as an accessible and manageable part of development, enabling iterations and continuous adaptation of existing products.

2.1.6 Adaptation of the Double Diamond to the Project Context

Although the Double Diamond model presents a structured progression from problem investigation to solution development, the process in this project required a more flexible approach. Due to the practical constraints of the project, including limited time onsite and the ambition to reach a manufacturable outcome, some activities overlapped between phases. Research, early concept development and stakeholder feedback were carried out in parallel rather than sequentially. This meant that early concepts were used not only to explore solutions, but also to better understand the problem and refine the design brief. This change incorporates iterative concept development, early visualisation and feedback to support our understanding of the problem and the rapid creation of an innovative solution.

3 Discover

This chapter presents the Discover phase of the project, focusing on understanding the existing conditions, operational challenges and user context within Eco Delivery's ecosystem. It outlines the activities that form the foundation for defining and refining the design brief.

3.1 Benchmarking

Benchmarking involves analysing competing or relevant products to better understand the market, user needs and technical constraints (Ulrich and Eppinger, 2016). This product development tool can be implemented by physically examining products and or by analysing available technical specifications.

The benchmarking study included four cargo bike solutions: Original Bullitt, Laplandar Urban Box, Fulpra Quatro and eCarla as depicted in Figure 3-1. The selected products represented different approaches to urban cargo transportation with differing levels of complexity, payload capacity and stability. The products were chosen to provide insight into relevant system configurations, cargo solutions, materials and manufacturing methods.

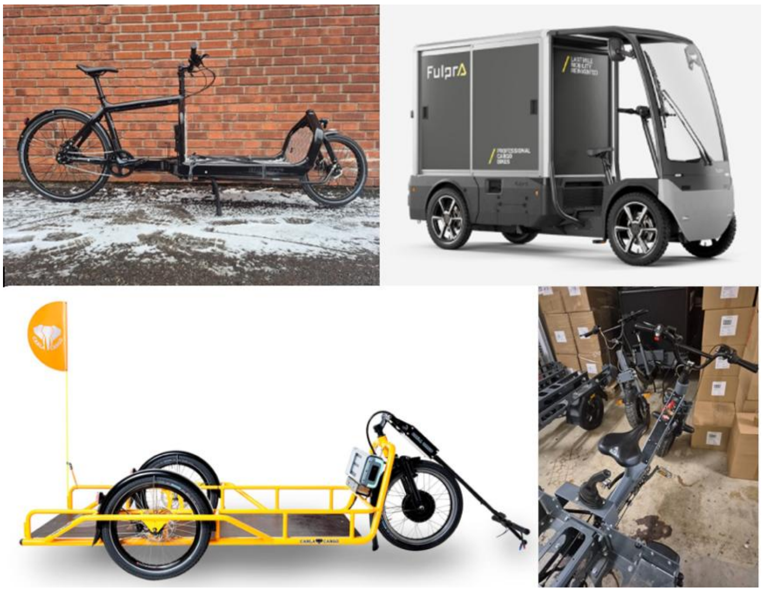

Figure 3-1. Benchmarked products – Bullitt Bike (top left, source: Author), Fulpra Quatro (top right, source: Fulpra (n.d.)), Carla Cargo (bottom left, source: Carla Cargo Engineering GmbH (2025)) and Laplandar (bottom right, source: Author).

The Bullitt and Laplandar bikes were physically inspected and tested, while Fulpra and eCarla were analysed based on available technical specifications. The evaluation of Laplandar was conducted in collaboration with the product designers, allowing for more detailed insights and data.

Key aspects considered during benchmarking included dimensions, handling, price, safety, sustainability and ergonomics. The most relevant metrics are summarised in Table 3-1. Detailed benchmarking documents are provided in Appendix B.

Table 3-1 Benchmarking of 4 cargo bicycles.

Data	*Laplander Urban Box*[a]	*Fulpra Quatro*[b]	*Original Bullitt*[c]	*eCarla*[d]
Weight (kg)	170	325	22	43
Frame Material	Steel, zinc	Steel	Aluminium	Steel
Dimensions (W;L;H)	n.a	1.0;3.25;1.57	0.46;2.43;n.a	0.952;3.0;0.795
Range (km)	45	40-60	n.a	30-50
Max payload (kg)	250	325	180	200
Cargo space (m^2)	1.2	1.8	0.32	1.5
Motor power (W)	250-1000	250	n.a	250
Motor torque (Nm)	135	320	n.a	45
Battery capacity (Wh)	480	3600	n.a	720
Seating	Adjustable saddle	Adjustable saddle	Adjustable saddle & handlebars	n.a
Unit cost (USD)	8333	19992	5550	9000
Brake type	Front/rear; disc	Front/rear; disc	Front/rear; disc	Front/rear; hydraulic disc
Stability at stop	Good; parking brake	Good; parking brake	Medium; double kickstand	Good; parking brake
Stability in motion	Good; 3 wheels; pivot	Good; 4 wheels	Medium; 2 wheels	Good; 3 wheels

Note:
Metrics marked n.a. indicate that the information was not available or relevant in the examined sources Observations were recorded during physical inspection conducted by the authors.

[a] Data obtained from Laplandar datasheet (Laplandar, 2026).

[b] Data obtained from Fulpra datasheet (Fulpra, n.d.).

[c] Data obtained from Bullitt datasheet (Splendid cycles, n.d.).

[d] Data obtained from Carla Cargo datasheet (CARLA CARGO Engineering GmbH, 2025).

The benchmarking study revealed several trade offs between stability, payload capacity, manoeuvrability and system complexity. Simpler two wheel solutions offered lower weight and improved manoeuvrability but reduced stability under heavy loads. Larger multi wheel vehicles improved cargo capacity and standstill stability at the cost of increased weight and mechanical complexity. These observations became important during later concept development and influenced several design decisions regarding vehicle architecture, cargo placement and subsystem design.

3.2 Testing of Eco Delivery Cargo Bikes

3.2.1 Field Observation

An observation was conducted during an early morning delivery round in the city of central Cochabamba. This was done to analyse real world operating conditions and bicycle performance. The study was performed during a morning shift with an electric cargo bike courier. The session began at approximately 06:15 with parcel collection from a food outlet. A cargo box containing ten parcels was loaded and deliveries were carried out sequentially. At each location, a loaded parcel was exchanged for an empty one. If a customer did not respond within seven minutes, the parcel was returned to the cargo box and the courier proceeded to the next stop. The route covered approximately 20 kilometres and took slightly more than two hours.

The route included a combination of major roads, uneven side streets, cycle lanes, sidewalks and large roundabouts. Roundabouts were particularly challenging due to traffic rules that do not prioritise bicycles. While most drivers maintained reasonable distance, rush hour at conditions after 7:30 significantly increased risk levels. Communal minibuses frequently stopped unexpectedly, forcing the cyclist into faster moving lanes. Additional hazards included aggressive homeless dogs, frequent speed bumps and potholes capable of trapping wheels and increasing mechanical wear.

The road surface was notably uneven, contributing to vibration, structural stress and rider fatigue. Speed bumps were difficult to navigate, especially under load. The route was not optimized to minimise the distance cycled because of a specific delivery schedule, resulting in travelling back and forth across the same streets multiple times.

From this observation, the following operational requirements can be identified:

- Increased structural robustness for uneven roads and potholes
- Stability under load at low speeds
- Improved performance over speed bumps
- Durable drivetrain components resistant to high wear
- Safety considerations for mixed traffic environments
- Design capable of handling repeated vibration and dynamic loading

These findings contributed to decisions during concept development regarding suspension systems, wheel selection, drivetrain robustness, frame dimensions and cargo stability.

3.2.2 Technical and Operational Evaluation

In collaboration with the chief engineer and an experienced courier, the existing cargo bike solution was assessed and tested in the form of a bike ride and closer observation. This was done to incorporate both technical and operational perspectives when evaluating the performance and characteristics of the bicycle.

Figure 3-2. The current cargo bike solution at Eco Delivery (Source: Author).

The cycling test revealed that the bike exhibited a relatively large turning radius, which negatively affected manoeuvrability, particularly in confined urban environments. In addition, low speed handling was found to be challenging, requiring increased rider control and attention. Stability at standstill was also assessed as inadequate, lacking kickstands, parking brakes, or similar solutions.

Cargo handling was evaluated positively. Loading and unloading procedures were straightforward with few handling steps and the cargo compartment design was easy to understand. A summary of the main strengths and weaknesses identified during the evaluation is presented in Table 3-2.

Table 3-2 Positive and Negative Aspects of Current Product.

	Positive Aspects	*Negative Aspects*
Cargo Bicycle	+ Low cost + Narrow width good for city traffic + Simple cargo loading process + Short braking distance + Steel frame easy to repair	- High maintenance due to failures - Frame and axle experience high stress - Low stability - Cargo less stable with heavy loads - Motorcycle brakes too aggressive - Bicycle brakes wear out quickly - Short lifespan (< 6months) - Batteries not waterproof -Charging cable easily damaged - Not suitable for different rider sizes - Mixed bike/electric parts difficult to service - Limited foot clearance

The evaluation showed that many of the drawbacks of the current solution were related to durability, stability and long term operational reliability under demanding urban conditions. On the other hand, several positive aspects such as low cost, narrow vehicle width and repairability were considered important to keep in mind during further development. These observations highlighted the need to balance robustness and stability improvements with manufacturability, simplicity and operational functionality.

3.3 User Research Methods

3.3.1 Expertise Insights

Several informal discussions were conducted with knowledgeable individuals to gain practical insights into operational challenges, technical limitations and business constraints associated with cargo bicycles used for last mile deliveries. The collected insights form a foundational basis for defining the technical, economic and functional requirements of the proposed cargo bicycle concept and are presented below.

3.3.1.1 CEO at Eco Delivery

Operational continuity was emphasised as critical. The bicycles must remain in working condition, as downtime directly affects the company's ability to reach its financial targets. Increased payload capacity is a priority, with a desired range between 100 kg and 200 kg to expand the company's services. The vehicle width should remain between 0.8 m and 1.0 m to ensure compatibility with urban traffic conditions and existing bicycle paths.

The cargo solution must include a covered, lockable and easily removable cargo box suitable for food industry use. As Eco Delivery operates through contractual partnerships with companies, there is interest in a modular system in which each partner could own a dedicated cargo box that can be quickly mounted onto a stock delivery vehicle. If the cargo box isn't fully enclosed, the goods risk exposure to the environment. A system similar in concept to the DHL Cubicycle, is seen as a desirable benchmark.

From a regulatory perspective, it is important that the vehicle legally qualifies as a bicycle. It must therefore be capable of functioning without electric assistance in case of legislative checks or battery failure. The bicycle should retain full pedal functionality and not rely exclusively on motor power. The throttle function is viewed negatively, as it tends to break and encourages overuse. Preserving battery life and encouraging riders to pedal are considered important operational principles.

The vehicle must handle diverse delivery contents, ranging from crates of beverages and dairy products to personal meals and packaged food. This requires flexibility in cargo configuration while maintaining hygiene and safety standards. Target unit cost is under 4000 USD and the design should prioritise affordability. The desired operational lifespan is at least six months as a minimum baseline, but preferably up to six years under sustained use. The average operational speed is approximately 30 km/h.

Robustness and safety are central concerns. The vehicle should be more durable than the current fleet and capable of withstanding daily use in poor road conditions. Three or four wheels are preferred to improve stability. Consideration should also be given to crash scenarios, as riders may be thrown into the handlebars during collisions. The use of existing carbon steel tubing from previous prototypes is encouraged to reduce cost and utilise available inventory. Steel is preferred due to ease of welding and repair. Chinese made bicycle components are readily available and inexpensive, making them a viable option.

Based on these insights, the following key design requirements can be identified:

- Payload capacity between 100 kg and 200 kg
- Vehicle width between 0.8 m and 1.0 m
- Covered, lockable and food safe modular cargo box system
- Swappable cargo boxes for different contractual partners
- Ability to function fully without electric assistance
- Reduction of throttle based operation
- Robust structural design with extended service life
- Target unit cost below 4000 USD
- Compatibility with locally available components
- Use of steel for manufacturability and repairability
- Improved rider safety and crash consideration
- Three- or four wheel configuration for increased stability

These requirements established the overall project direction by emphasising robustness, payload capacity, manufacturability and low operational cost while maintaining legal classification as a bicycle.

3.3.1.2 Chief Engineer at Eco Delivery

The current two wheeled cargo bicycles present significant stability challenges during operation. The bikes lack handbrakes and kickstands, which reduces stability during loading and at standstill. Ground clearance is considered too high, contributing to a raised centre of gravity and reduced stability. A lower frame would likely improve handling. The front fork angle is described as too slack, making the bicycle unstable and twitchy, particularly at low speeds. Steering becomes more difficult when pedal assist engages and the activation of the throttle can feel unpredictable. Couriers are initially trained using a throttle-only version of the bike to familiarise themselves with steering behaviour before transitioning to pedal assist. The bicycles mainly operate at low speeds and routes are planned to avoid the steepest areas of the city.

Battery management is an important operational factor. Swappable batteries are considered essential, as electricity consumption varies between riders and the bicycles must be ready for multiple two hour shifts per day. Riders are instructed to use pedal assist level two out of five during normal operation and reserve maximum assistance for steep hills.

Maintenance and durability challenges are recurring and critical. Chains are typically replaced every six to eight months. The rear hub motor complicates basic repairs such as fixing punctures, which discourages conventional bike mechanics from servicing the bicycles, making Eco Delivery responsible for all repairs. Motor cables and charging cables frequently become damaged. The rear axle integrated in the hub motor often breaks due to rough roads and heavy daily use, sometimes resulting in complete motor failure. It is common for at least one of eight cargo bicycles to be in the workshop awaiting repair. The need to separate mechanical bicycle components from electronic components was emphasised, along with improved cable protection, stronger axles and potentially a suspension system that can handle for example potholes.

The desired outcome is a cargo bicycle that is more robust, capable of carrying high loads and able to withstand rough roads daily, while still behaving and being perceived as a bicycle rather than a motor vehicle. Motorcycle components were identified as potentially advantageous due to their lower cost and higher durability compared to standard bicycle components. A trailer solution has previously been tested but was not successful, as it interfered with rider leg movement.

Based on these insights, the following key design requirements can be identified:

- Improved frame geometry to enhance low speed stability
- Lower centre of gravity and reduced ground clearance
- Predictable and controllable electric assist engagement
- Swappable and modular battery system
- Reinforced rear axle and drivetrain components
- Clear separation between mechanical and electronic systems
- Protected and durable cable routing
- Increased structural robustness to withstand rough roads and high loads

- High serviceability using locally available components
- Use of motorcycle grade components where appropriate

These requirements emphasised the importance of robustness, stability and serviceability while highlighting the need for drivetrain and suspension solutions capable of withstanding demanding daily operations.

3.3.1.3 Courier at Eco delivery

The courier expressed a clear preference for two wheeled bicycles due to familiarity and perceived manoeuvrability. Larger cargo bikes were considered intimidating by some riders and both new and experienced couriers sometimes preferred their own regular bicycles equipped with backpacks and panniers instead of the company provided cargo bikes.

Battery performance was considered insufficient and riders are restricted to using lower assist levels on flat terrain to conserve energy. The bicycles are not well adapted to different rider sizes and the standover height is perceived as too high. Motorcycle style brakes were described as overly aggressive for some riders, requiring careful braking.

From a loading perspective, it would be beneficial to increase cargo capacity. The handlebar layout currently limits vertical stacking of boxes, reducing usable cargo volume. A more aerodynamic and sportier riding position was suggested to improve efficiency. Ease of repair was emphasised as critical, as breakdowns during delivery routes must be resolved quickly to avoid operational disruption.

Based on this discussion, the following key user requirements can be identified:

- Improved ergonomic adaptability for different rider sizes
- Lower standover height
- Increased cargo capacity and stacking flexibility
- Handlebar layout that does not obstruct cargo volume
- Balanced and controllable braking system
- More aerodynamic riding position
- Reliable battery performance with predictable assist behaviour
- Easy roadside repair and maintenance

The courier perspective highlighted the importance of rider confidence, ergonomics and ease of use, emphasising the need to balance robustness and payload capacity with manoeuvrability and rider familiarity.

3.4 Exploratory Concept Development

As part of the ongoing investigation, three rough concepts were sketched during the initial stages of the project. These concepts were developed as tools to support discussion with the company and to visualise different structural layouts and cargo loading solutions. The intention was not to define a final solution, but to use early concepts to explore different ideas and get feedback from stakeholders. The concepts were used to explore possible solutions and to help refine the project direction. The insights gathered from this exchange were used to further refine user needs and guide the continued development of the design brief.

3.4.1 Concept 1 – The Delta Tricycle

The first exploratory concept is a delta tricycle configuration with two wheels in the rear combined with a conventional bicycle structure in the front (Figure 3-3). Standard bicycle geometry is used for steering and rider positioning in the front, while the rear structure uses robust square steel profiles to support the cargo. The cargo is positioned centrally over the rear axle to improve weight distribution and stability under load. A differential is required on the rear axle to ensure proper traction and predictable handling during cornering. The drivetrain is divided into two cranksets: the right side crankset functions as a conventional pedal driven system connected via chain to a sprocket on the rear axle, while the left side crankset is connected to the electric motor. The concept is designed to carry high payloads while maintaining good forward visibility and a familiar bicycle like steering feel.

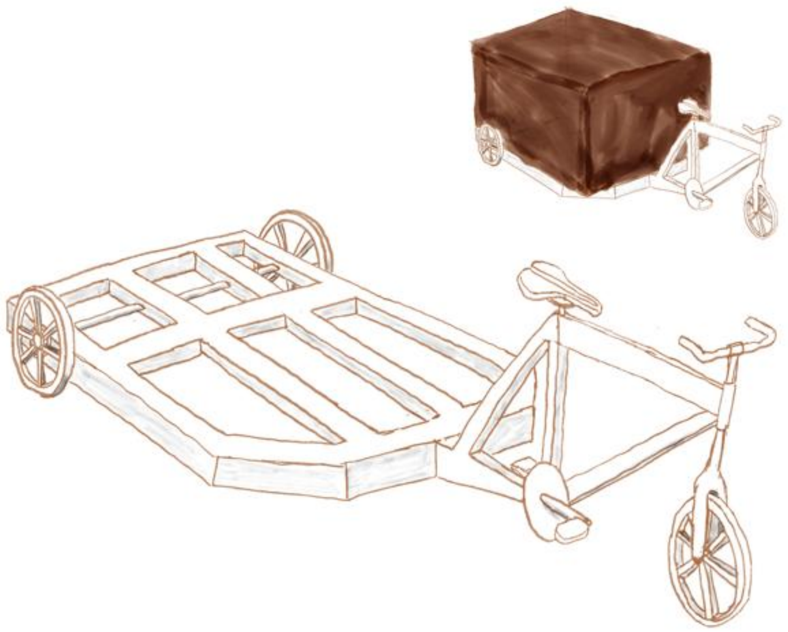

Figure 3-3. Sketch of Concept 1: The Delta tricycle (Source: Author).

Manufacturing is considered relatively straightforward due to the use of a standard bicycle front frame and simple welded rear structure. However, the differential increases mechanical complexity. The cargo system consists of two foldable loading ramps that allow a wheeled cargo box to be rolled into position and secured. Integrated frame mounts enable vertical poles to be attached to further stabilise the cargo. A potential weakness of this concept is rider vulnerability in frontal collisions, as there is limited structural protection in front of the rider.

3.4.2 Concept 2 – The Trailer

The second concept is based on a simple steel trailer construction with two wheels positioned at the rear and a single freely rotating front wheel mounted in a fork, forming a three wheel trailer system (Figure 3-4). The two rear wheels are independent and mounted in the trailer frame. The construction is designed with a low deck height, lowering the centre of gravity thus improving stability and the ease of loading. The system is very manoeuvrable and pivots naturally behind the bicycle. The idea is to integrate an electric hub motor in the front trailer wheel to provide propulsion assistance.

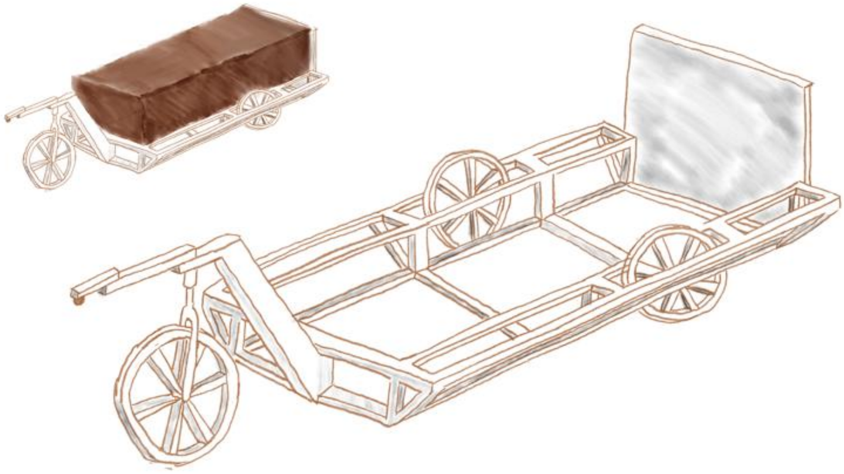

Figure 3-4. Sketch of Concept 2: The trailer (Source: Author).

The cargo is loaded from the rear using a fold down ramp that also functions as a rear wall once closed, preventing the cargo box from sliding off. The trailer frame surrounds the cargo area and secures the box laterally. A central technical challenge in this concept concerns safety, particularly the development of a reliable braking and propulsion interface between the trailer and the bicycle. The coupling must ensure stable load transfer and predictable braking behaviour under heavy loads. An advantage of this configuration is its compatibility with standard bicycles, allowing flexibility in fleet use. The construction is relatively simple, robust and based on an already established geometry, which reduces technical risk compared to more integrated vehicle solutions.

3.4.3 Concept 3 - The Tadpole Tricycle

The third concept is a tadpole tricycle configuration with two wheels positioned at the front and a conventional bicycle frame at the rear (Figure 3-5). The drivetrain follows a similar dual crankset principle as Concept 1, with one chainring connected to the electric motor and the other connected to the pedal driven drivetrain. However, the rear drivetrain remains closer to a standard bicycle setup, resulting in a shorter chain and reduced mechanical complexity compared to the delta configuration. The need for a differential is avoided.

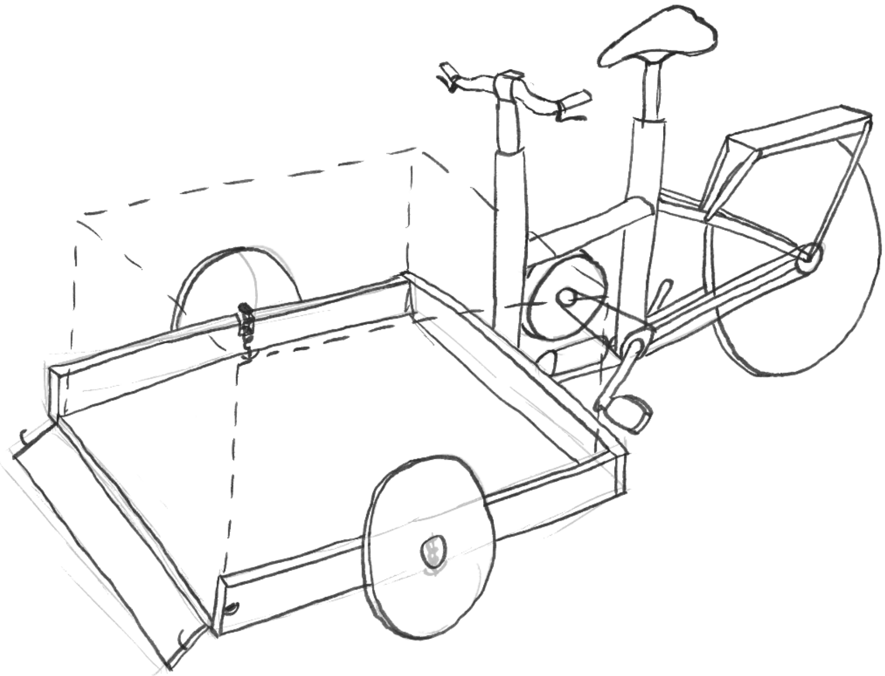

Figure 3-5. Sketch of Concept 3: The Tadpole Tricycle (Source: Author).

The cargo box is positioned at the front between the two wheels and loaded via a fold down front ramp. The front wheels are mounted independently within the frame, like Concept 2, allowing for relatively simple suspension integration if required. Additional cargo capacity can be provided through a rear pannier system mounted to the bicycle frame. Overall loading capacity is somewhat reduced, but the construction remains relatively simple to manufacture due to the use of standard bicycle components. A key challenge of this configuration is steering behaviour, as the cargo mass is located above the steering assembly.

3.4.4 Initial Stakeholder Feedback on Early Concepts

The three concepts were presented during a brief meeting with the company CEO to gather initial reactions and identify strategic priorities. The trailer concept raised the most concern regarding safety, particularly the integration of braking and motor control between the bicycle and the trailer. It was emphasised that braking failure would be catastrophic in the chaotic traffic environment and that riders must retain as much direct manual control over propulsion and braking systems as possible. Safety was therefore identified as critical. The tadpole configuration was perceived as too similar to the company's current bicycles and did not offer a significant increase in payload capacity or cargo volume. More generally, it was expressed that the new vehicle should represent a clear change from the existing fleet, both in robustness and visual differentiation. Increasing cargo volume through a larger enclosed box was highlighted as important, especially considering potential company growth and new contracts. A four wheel configuration was suggested as an idea to be further explored with the intention of improved stability and safety. Across all concepts, emphasis was placed on durability, the use of serviceable and affordable components and improved safety for riders operating in demanding traffic conditions. The feedback gathered during this stage contributed significantly to the later shift towards larger and more stable multi wheel vehicle configurations with large cargo volume and more rider protection.

The early concept exploration also served a strategic purpose beyond concept generation. Due to the limited project duration and the ambition to progress towards a manufacturable solution, it was important to establish a shared understanding of the project direction as early as possible. The concepts were therefore used as communication tools to align the expectations of the project team, Eco Delivery and potential customers. This approach deviated somewhat from a more sequential product development process but helped reduce uncertainty in a project where requirements and ambitions evolved continuously throughout development.

3.5 Review of Solar Vehicles

The company’s existing solar vehicles were investigated to get a better idea of what design elements have proved successful and implementable. The vehicles are based on a three wheel tadpole configuration, with two wheels in the front and one in the rear (Figure 3-6). The structure was manufactured in stainless steel (INOX) and produced within a three week timeframe with a total budget of approximately 3500 USD. The frame bending and welding were carried out by a professional workshop, while electrical integration was performed in-house. The vehicles have front and rear suspension systems, which were developed in two iterations after an initial structural failure, but functioned effectively in the final version. A rear hub motor was used for propulsion, simplifying assembly but increasing component cost and complicating serviceability. The system also included a dynamo intended to recharge the battery, but testing showed that the rider’s pedalling power was not enough to recover energy, resulting in net losses.

Figure 3-6. Images of the solar car: front suspension and the rear wheel motor (Source: Author).

The steering system was of a recumbent type with lever based control, contributing to rider protection and improved ergonomic safety. The vehicle included a roll cage and seatbelt, offering protection in the event of a collision. Conventional bicycle components were used for the drivetrain, including pedals, gears, chains and sprockets. Disc brakes were mounted on each wheel, with moped style brake levers. The wheels were mounted with a single bolt, making them easy to remove for service. While handling characteristics were described as responsive, the tadpole configuration was instable during cornering and downhill braking, with high risk of tipping. Although the vehicle was not designed for cargo applications, it was reportedly capable of carrying approximately 200 kg in steep terrain such as La Paz.

These observations provided practical insight into the advantages and disadvantages of a three wheel configuration applied in Bolivia.

3.6 Evolving Strategic Direction

Approximately five weeks into the design phase, the direction of the project evolved following additional discussions with the CEO. Emerging contract opportunities with larger industrial clients led to increased expectations regarding safety, reliability, documentation and perceived build quality. As a result, the focus shifted from relatively conventional cargo bike configurations towards exploring a larger four wheeled vehicle concept. This concept ought to incorporate recumbent seating, an non-centred steering system with improved rider protection, stability, handling and cargo capacity. The project should now pivot towards innovative solutions like the DHL Cubicycle that place greater emphasis on performance. Ambitions were expanded to include higher operational speeds of up to 45 km/h, increased motor power and the ability to transport payloads of 200 kg in steeper terrain conditions found in cities such as La Paz.

Overall, the aim is to better meet higher industrial standards and communicate a more professional product identity. The collaboration with two universities accompanied with structured technical documentation and simulations, was also viewed as a bonus for strengthening the commercial credibility of the project.

This shift significantly increased the technical complexity of the project compared to the earlier concept exploration phase. The new direction required consideration of more advanced mechanical systems, additional specialised components and less conventional vehicle architectures. It also required reinterpretation and prioritisation of previously identified user requirements and technical specifications. The broadened scope increased design uncertainty and impacted the project timeline, as changing requirements required continuous adaptation of development priorities throughout the project. After the changed project directions, it was unlikely to have enough time for physical production, digital validation or testing.

3.7 Vehicle Architecture Exploration: Three vs Four Wheels

Following the stakeholder discussions and review of the company's solar vehicles, three- and four wheel vehicle architectures were evaluated. While three wheel cargo vehicles are widely used in urban logistics, four wheel solutions such as the DHL Cubicycle are increasingly associated with improved stability and industrial credibility. In the context of this project, the selected architecture of the vehicle must balance rider safety, high payload capacity, regulatory compliance, manufacturability and operational robustness. A comparison of the key characteristics of three- and four wheel configurations is presented in Table 3-3.

Table 3-3 Architectural Comparison: Three vs Four Wheels.

Aspect	***Three Wheel (Trike)***	***Four Wheel (Quad)***
Stability	Lower lateral stability under cornering and downhill braking; increased tipping risk if CoG is high.	Higher lateral stability due to four contact points and rectangular support base.
Tripping Behaviour	Sensitive to load distribution and track width; prone to rollover in aggressive manoeuvres.	Reduced rollover tendency; improved stability at standstill and under heavy load.
Manoeuvrability	More agile in narrow streets and bike lanes.	Larger turning radius; less agile in tight urban environments.
Payload Capacity	Typically up to ~300 kg depending on configuration.	Comparable or slightly higher payload; better load stability under full weight.
Centre of Gravity Influence	Highly sensitive to load height and lateral shift.	More tolerant to higher centre of gravity.
Energy Efficiency	Lighter frame; lower rolling resistance; greater ranger per battery.	Heavier; higher energy consumption.
Regulatory Simplicity	More commonly classified as bicycle.	Regulatory grey zone.
Manufacturing Complexity	Simpler drivetrain and steering; fewer components, more conventional bicycle components.	Increased mechanical complexity (more moving parts, suspension, steering linkage).
Maintenance	Easier to service; fewer parts.	More components, higher maintenance demand.

Note: Table informed by Jeudy (2025) and project observations.

Three- and four wheel architectures present distinct trade-offs in terms of stability, manufacturability, regulatory classification and operational suitability. Three wheeled vehicles generally allow for easier integration of conventional bicycle geometry and components, resulting in lower weight, simpler steering and suspension systems and easier maintenance. This makes them advantageous in urban environments where manoeuvrability and minimised downtime are important. However, their lateral stability is more sensitive to track width, centre of gravity height and load distribution which increases the risk of rollover. Four wheel configurations provide improved static and dynamic stability due to a rectangular support base and four contact points, which improves safety under high loads and during standstill. This increased stability comes at the cost of greater mechanical complexity, additional components, higher energy consumption and potential regulatory issues in terms of vehicle classification. In the context of this project, the demanding road conditions, increased payload requirements and greater emphasis on rider safety contributed to continued exploration of four wheel vehicle architectures despite the increased technical complexity associated with such a system.

3.8 Additional Concept Exploration – Four Wheel Configuration

To ensure that the project has shifted in the right direction a four wheel concept was developed. The fourth exploratory concept has two wheels in the front and two in the rear, forming a narrow quad layout with a total width below one metre (Figure 3-7). The rider sits in a recumbent seating position at the front of the vehicle, ensuring good visibility. The steering consists of a lever based system directly linked to the front wheels, while both the front and rear wheels are equipped with suspension to improve stability and comfort under load. The cargo box is positioned on a rear platform and centred over the rear axle to improve weight distribution. The vehicle uses a pedal based drivetrain supported by a central electric motor, with power transmitted to the rear axle through a differential mechanism. The frame consists primarily of welded square and round steel profiles.

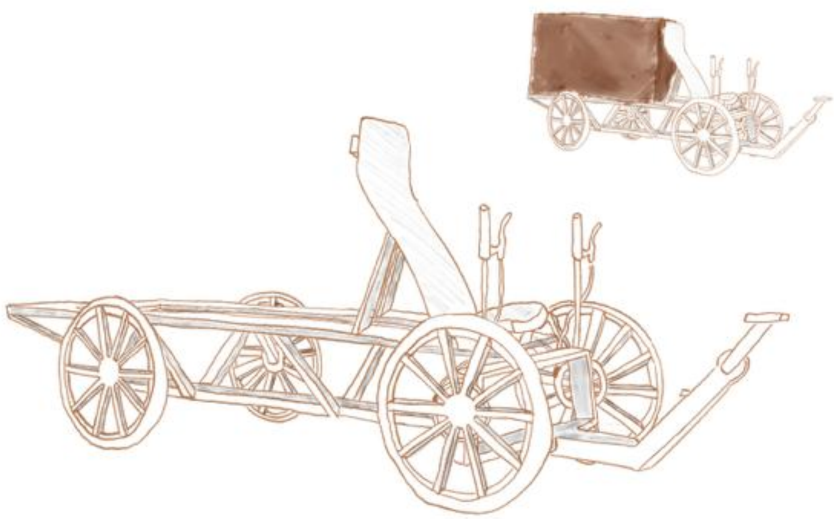

Figure 3-7. Concept Sketch of quadricycle (Source: Author).

Compared to the earlier tricycle concepts, the four wheel configuration introduces significantly greater mechanical and manufacturing complexity due to additional steering linkages, suspension systems, drivetrain components and the requirement for a rear differential type function. While the layout improves both perceived and actual stability under heavy loads and enables payloads of up to 200 kg, the narrow geometry presents challenges related to rollover behaviour, packaging constraints and subsystem integration. The increased number of moving components also reduces the reliance on conventional bicycle architecture and introduces additional maintenance and manufacturing challenges.

The development of the four wheel concept represented an increase in project scope and technical complexity compared to the earlier project direction. At the same time, it became increasingly important that the project progressed quickly. The greatest value for Eco Delivery would come from producing a prototype or at least initiating the manufacturing phase. The concept needed to align with both the ambitions of Eco Delivery and the wants of potential future customers. This created a need for a more rapid development process to progress as far as possible towards the overall project goal within the limited timeframe.

4 Define

This chapter presents the Define phase of the project, where the findings from the Discover phase are translated into user needs, design requirements and technical specifications. These outcomes form the foundation for concept selection and continued development of the cargo vehicle.

4.1 Identifying User Needs

Extracting user statements is a critical step in structured product development because it separates raw qualitative data from interpretation. Ulrich and Eppinger (2016) state that identifying customer needs begins with gathering raw data before translating it into structured need statements. This helps prevent premature technical interpretation and ensures that the development process is based on real user input. Documenting user statements preserves the opinions of stakeholders and ensures traceability between research findings and subsequent design decisions. It also supports systematic analysis, comparison and prioritisation in later development stages.

From interviews with stakeholders, user need statements were extracted as subjective statements and opinions and then translated into interpreted needs, as shown in Table 4-1.

Table 4-1 User Need Statements and Interpreted needs.

Category	*User Statement / Observation*	*Interpreted Need/Requirement*
Stability & Handling	The bike should be able to travel safely at 45 km/h. The bike must be stable when braking in hills and not tip over.	The vehicle must provide high lateral stability during operation under full load.
	It is difficult to control the bicycle at low speeds. It is difficult to turn in narrow streets. Conventional bicycle steering is not good. The steering system must be robust and easy to repair.	The vehicle must offer predictable and controllable handling and both low and higher operating speeds.
	The suspension system should be simple and effective. Speed bump challenges Rough road vibration and potholes.	The vehicle must manage road irregularities while maintaining mechanical simplicity.
	Frequency stop-and-go delivery. Need for handbrake and stand.	The vehicle must remain stable when stationary during loading and unloading.
	Too high ground clearance. Solar vehicles susceptible to tipping. Instability under load.	The vehicle must maintain a low centre of gravity to reduce rollover risk.
Durability & Maintenance	The rear axle keeps breaking because of rough roads. The bike should survive continuous daily use and abuse by cyclists. Bolivian roads and traffic are harsh. Use safety factors to ensure rider safety.	The structure and drivetrain must withstand dynamic loads from rough urban environments.
	We cannot afford to have bikes out of operation. Repairs during a delivery route must be quick and simple. Charging cables and motor cables get damaged easily. Wheels should be fastened with one bolt.	The system must achieve high reliability and minimise downtime.
	IP65 water leaks Electrical cables get damaged.	Electrical and mechanical systems must resist water, dust and vibration exposure.

Cargo & Modularity	We need to carry heavier loads to expand our services. 100-200 kg payload or more is preferred. Industrial delivery ambitions.	The vehicle must support increased payload capacity and enable business growth.
	The cargo box should be covered and lockable. It should be easy to swap cargo boxes between partners. Must be suitable for large scale industry deliveries. Big companies require secure transport.	The cargo system must allow secure and modular transport of goods.
	Beer crates. Insulated food boxes. 60x40 cardboard boxes.	The cargo system must accommodate standardise commercial box dimensions.
Powertrain & Energy	A 3 kW motor is good for the steep hills. The bike should work in cities like La Paz. Steep hill performance is important.	The propulsion system must provide adequate torque and performance for steep gradients and high-altitude operation.
	The battery does not always last for a full shift. Range 40-60 km or more.	The energy system must provide sufficient range for a full day of operation.
	The bike should still function if the battery runs out. It must still be a bicycle.	The vehicle must remain fully functional without electrical assistance.
	40 deliveries per day during 4 shifts 20 km route in 2 hour shifts Non-optimised routes.	The vehicle must support continuous high-frequency daily operation.

Safety & compliance	Don’t want any scratches on the employees. Steering must not be in the way in the event of a crash. The bicycle must be safe for the rider. Some riders have asked for seat belts.	The design must minimise rider injury risk in normal operation and collision scenarios.
	Cyclist must have as much control over braking and propulsion manually as possible. No throttle. Current braking systems are unreliable and either too aggressive or weak.	The rider must retain direct and predictable manual control over braking and propulsion systems.
	Must have documentation and simulations. Must give a professional and safe impression. Large companies require industrial credibility.	The product must communicate professional quality and be supported by technical documentation and validation.
	It should still have bicycle parts. The bicycle must have pedals.	The vehicle must comply with bicycle regulations.
	Must fit bicycle path. Must remain narrow.	The vehicle must integrate safely into mixed urban traffic environments.
Ergonomics	The bicycle does not fit riders of different heights very well. The driver should sit comfortably. High stand over height issues.	The vehicle must accommodate riders of different body sizes and provide ergonomic comfort.
Manufacturing & Scalability	Use steel frame Weldable materials Simple construction Workshop repair capability	The vehicle must be manufacturable using locally available materials and workshop capabilities.
	2000-4000 USD. As cheap as possible.	The vehicle must remain economically viable for fleet-scale deployment.

4.2 Consolidated User Needs

The collected user statements were translated into a consolidated set of core user needs. This was done to structure the main design considerations and support decision making. The statements gathered during interviews and observations were rewritten into clear and neutral needs, focusing on what the design must fulfil rather than how it should be solved. It was important at this stage to avoid jumping to technical solutions too early and instead remain objective.

Overlapping needs were merged, resulting in a reduced list of 14 core needs. Each need was assigned an importance rating from 1 to 5, where 5 represents the highest priority. The final set of consolidated user needs and their associated importance ratings are presented in Table .

Table 4-2 Consolidated User Needs.

User Needs	*Importance*	*Comment*
High dynamic and lateral stability under load	5	Critical for safety, braking on hills and higher speed operation.
Predictable and controllable handling	5	Necessary for both low-speed manoeuvring and higher-speed stability.
High structural robustness	5	Rough urban roads, potholes, heavy loading.
High operational reliability and functioning time	5	Minimal downtime allowed.
High payload capacity	5	Required for business expansion.
Modular, secure and weather protected cargo system	5	Delivery requirements.
Adequate hill-climbing performance	4	Required for steep terrain.
Sufficient operational range	4	Must support full delivery rounds.
Pedal operability without electric assist	4	Reliability and regulations.
Direct and predictable manual braking and propulsion control	5	Avoid throttle misuse, rider safety.
Rider safety and injury risk minimisation	5	Central strategic shift in project direction.
Regulatory compliance and dimensional constraints	5	Project focus shift.

Manufacturability using locally available materials and parts	5	Limited resources.
Economic viability	5	Company resource constraint.

4.3 Design Requirements and Target Specifications

The consolidated user needs were further translated into design requirements and measurable target specifications. While the user needs describe what the system must achieve, this section defines how these needs can be evaluated in a more concrete and technical way. Wherever possible, qualitative needs were converted into quantifiable targets to support validation through testing, simulation, or calculation. These requirements form the practical foundation for concept evaluation and continued development. The resulting system requirements and associated target specifications are presented in Table 4.3.

Table 4-3 System Requirements and Target Specifications

	Requirement	*Target Metric*
Stability & Handling	Vehicle must remain stable under full load.	No wheel lift or rollover at 30 km/h with 200 kg payload.
	Vehicle must remain stable during downhill braking.	No tipping during emergency braking on 10 % incline at 200 kg payload.
	Vehicle must be controllable at low speed.	Stable steering at ≤5 km/h without oscillation.
	Vehicle must remain stable at standstill.	Self-stable without rider support for ≥60 seconds.
	Low centre of gravity.	Cargo floor height ≤ 350 mm from ground.
Structural Robustness & Durability	Frame must withstand rough roads.	Safety factor ≥1.5 under maximum static load.
	Drivetrain must withstand dynamic loading.	Rear axle rated ≥1.5× expected torque load.
	High operational reliability.	Service interval ≥1000 km.
	Fast repairability.	Wheel removal ≤5 minutes using standard tools.
	Electrical protection.	Min IP65 rating battery enclosure.
Payload & Cargo	High payload capacity.	Target payload 200 kg.
	Cargo must be enclosed.	Fully covered box with lock.
	Modular cargo compatibility.	Compatible with 600x400 mm crates.
	Fast box exchange.	Box swap ≤5 minutes by one operator.
Powertrain & Energy	Hill-climbing capability.	Maintain ≥15 km/h on 10% incline with 200 kg payload.
	Maximum assisted speed.	30 km/h
	Operational range.	≥50 km under mixed urban conditions.
	Pedal operability without motor.	Vehicle can be pedalled ≥5 km without assist.
	No throttle propulsion.	Assist active only when pedalling.

Safety & Compliance	Injury risk reduction.	No rigid steering column directly in front of torso.
	Controlled braking.	Equipped with progressive braking.
	Bicycle classification.	Equipped with functional pedals.
	Width constraint.	Maximum overall width ≤1000 mm.
Manufacturing & Cost	Local manufacturability.	Frame made from locally available materials.
	Local serviceability.	≥80 % components available locally.
	Cost constraint.	Unit manufacturing cost ≤4000 USD.

4.4 Refined Design Brief

During the concept exploration phase, feedback was gathered from potential transport service customers of Eco Delivery through discussions with the company CEO. This information provided additional insight into the expectations of larger commercial clients that Eco Delivery aims to work with. The discussions and evaluations of the early concepts helped refine the design brief and clarify several of the project priorities and requirements.

The feedback indicated that stability and rider comfort are considered the most important characteristics of a future delivery vehicle in combination with the functionality of the modular cargo box system. Several clients expressed concerns regarding the stability of three wheel configurations, particularly under heavy loads and showed a preference for a four wheeled vehicle. At the same time, manoeuvrability in dense urban environments remains important, as delivery routes often pass through crowded markets and narrow streets. Rider safety was not considered as critical as previously anticipated by the CEO, but it remains an important aspect of the design.

It was emphasised that the most important outcome for potential customers and Eco Delivery is a functioning prototype that demonstrates the concept in practice. If the vehicle performs well and meets operational expectations, the clients expressed interest in potentially purchasing Eco Delivery's services. Technical documentation, simulations and engineering validation are therefore considered secondary at this stage but may become important later to support credibility and further development.

The feedback also confirmed that the previously developed technical requirements document was aligned with the expectations of the company and its potential clients. Minor adjustments were discussed, including a target operational speed of 30 km per hour and the acceptance of a structural safety factor of 1.5 for the prototype. The requirements document therefore serves as the primary reference for the development phase and is included in the Appendix D.

This resulted in the project direction shifting towards the development of a four wheel vehicle concept that prioritises stability, rider comfort, modular cargo handling and manoeuvrability in urban environments while remaining compatible with the defined technical requirements.

Revised design brief:
A narrow four wheel electric vehicle with a cargo box system capable of transporting a 200 kg payload in urban delivery operations while prioritising stability, rider comfort and manoeuvrability within the technical and manufacturing constraints defined in collaboration with Eco Delivery.

5 Develop

This chapter presents the Develop phase of the project, where the refined design brief and technical requirements are translated into the development of a concept. The work focuses on brainstorming, subsystem development, detailed design of key mechanical systems and systematic evaluation.

5.1 Brainstorming

At the beginning of the Develop phase, a brainstorming stage was carried out to explore different overall vehicle. The goal was to quickly generate and visualise multiple possible configurations to use as reference in subsequent development stages.

5.1.1 Crazy Eights

The Crazy Eights method was used to quickly generate several concept ideas within a limited time. Generally, in this exercise, eight different sketches are produced in eight minutes, encouraging rapid thinking and preventing the over analysis of early ideas. The method forces designers to explore multiple variations rather than focusing on a single concept too early. This approach is commonly used in design sprint processes to stimulate rapid ideation and visual exploration of concepts (Google Design Sprint Kit, n.d.).

During the session, both separate parts and complete vehicles were ideated to form new concepts. The session was structured into eight sprints according to the method, but the time in each sprint was doubled to two minutes because of the time it took to sketch the complex products. After the session was completed individually, all new concepts were reviewed and discussed in collaboration. Illustrations of the different concepts are shown in Figure 5-1.

Concepts ideated include:

1. Double fork design
2. Rectangular cage for rider safety
3. Rectangular truss frame
4. Triangular T-frame

5. Simple bumper
6. Direct lever steering
7. Triple telescopic suspension
8. Parallel runners under cargo
9. Bobsled geometry
10. Crane cargo system
11. Trailer clasps on cargo
12. Low complexity flat frame
13. Unicycle with trailer
14. Tracked 6-wheel
15. Wind powered propulsion
16. Roof rack

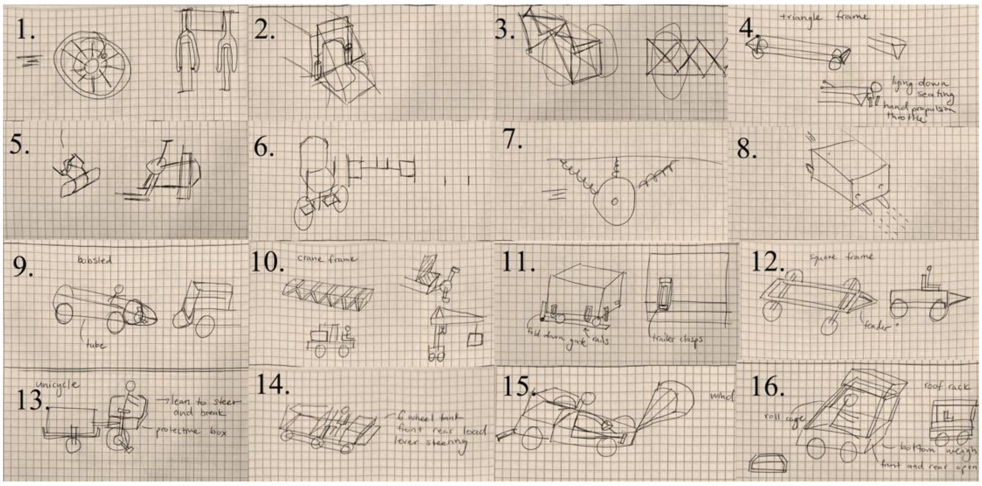

Figure 5-1. Concepts from Crazy Eight session (Source: Author).

5.1.2 Scamper

The SCAMPER method was used as a structured brainstorming technique to modify and expand existing ideas. The acronym encourages designers to consider how a concept can be Substituted, Combined, Adapted, Modified, Put to another use, Eliminated, or Rearranged (Dam & Siang, n.d.). By applying these prompts to existing cargo bike solutions gathered through research and earlier concept explorations, new variations and improvements were identified. This helped challenge initial assumptions and reveal alternative mechanical configurations.

Substitute

- Aluminium and stainless steel replaced with carbon steel for easier welding and lower cost
- Gearbox replaced with external sprocket drivetrain
- Differential replaced with two chains or freewheel system
- Advanced wishbone suspension replaced with simpler suspension mechanisms
- Automatic cargo box securing replaced with manual locking
- Mesh seat replaced with woven seatbelt or automotive seat
- Standard pedals replaced with pedals with straps
- Triangular frame cross section replaced with square cross section
- Custom wheels replaced with stock bicycle wheels
- Round profile beams replaced with square profile beams
- Bumper integrated with pedal structure
- Bumper integrated with frame
- Handle integrated with gear shifter
- Roll cage integrated with cargo locking structure
- Lighting integrated with pedalling system (dynamo concepts)
- Steering system combined with braking levers
- Cargo securing mechanism integrated with loading system
- Gear system combined with differential
- Seat combined with seatbelt and weather protection

Adapt

- Motorcycle components such as chains, sprockets and brakes adapted to fit with bicycle systems
- Suspension solutions from solar vehicles adapted for higher payload capacity and more narrow build
- Moped mirrors and indicators adapted for improved road visibility
- Adjustable seating concepts adapted from other vehicles

Adaptations to Bolivian operating conditions:

- Stronger frame and axle components
- Locking mechanisms for security
- Lower cost materials
- Reduced system complexity
- Standardised components
- Protected vulnerable components like mirrors and lights

Adaptations to regulatory constraints:

- Minimum operating speed of approximately 30 km/h
- Pedal drivetrain maintained to preserve bicycle classification

Modify

- Derailleur used as chain tensioner
- Suspension springs sourced from other vehicles
- Electric bicycle conversion kits modified to fit vehicle architecture
- Modified wheel hubs and axle solutions
- Modified battery mounts
- Increased vehicle width
- Cargo box volume adjusted according to client needs
- Larger cargo volume combined with lower operational speed

Put to another use

- Cargo boxes used as transport containers for air travel
- Vehicle used for moving services
- Vehicle used for street vending such as water or food sales
- Cargo bicycles used as rental vehicles
- Cargo box integrated with battery housing
- Cardboard waste reused as packaging material
- Insulated cargo boxes used as refrigerators powered by the battery
- Vehicle adapted as low emission taxi concept

Eliminate

- Fenders
- Multiple hand brakes
- Chain guard
- Automatic cargo box locking mechanisms
- Differential and gearbox
- Expensive materials
- Electronic display systems
- Complex frame geometries
- Number of employed riders

Rearrange

- Loading direction changed to side, front or top loading
- Driver seating repositioned above, below or between cargo
- Front wheel drive configurations
- Rear wheel steering configurations
- Steering levers positioned parallel to the ground

- Pedal position moved below rider centre of gravity for improved biomechanics
- Cargo positioned between wheels instead of above the frame
- Cargo box remains fixed while only contents are exchanged

The SCAMPER exercise helped identify several mechanical simplifications, component substitutions and configuration changes that were later considered during subsystem development.

5.2 Subsystem Development and Selection

5.2.1 Identifying subsystems

Mechanical products are often made up of several subsystems that together allow the product to perform its intended function. By separating the product into smaller functional parts, each subsystem can be analysed and developed individually before being integrated into the overall design. This provides a structured framework for developing complex products and supports more systematic concept generation and evaluation. According to Ulrich and Eppinger, dividing a product into subsystems helps manage complexity and supports the development of integrated product architectures. The subsystems were separated based on their functions and based on common subsystems used in vehicle development. The following subsystems were identified:

Table 5-1 - Identified product subsystems.

Subsystem	*Function*
Frame	Enables protected storage and handling of parcels.
Steering	Controls vehicle direction and manoeuvrability.
Suspension	Reduces vibrations and shocks.
Hubs and Wheels	Supports vehicle load and transfers propulsion and braking forces to the ground.
Braking	Enables controlled deceleration and stopping.
Drivetrain	Transforms biomechanical power into torque.
Powertrain and Energy Storage	Stores and converts electrical energy into propulsion torque.
Cargo	Enables protected storage and handling of parcels.
Seating	Assists the rider to ride for long intervals.
Safety	Protects the rider during operation and potential collisions.

5.2.2 Subsystem Interference

The subsystems of the cargo bicycle are interdependent. Design decisions in one subsystem influence and are influenced by the design and function of others, making it necessary to consider subsystem interference throughout the development process and to structure it based on which systems are most dependent on one another.

Frame
The frame provides the structural foundation of the vehicle and determines the mounting points and spatial layout for most other subsystems, including the steering, suspension, drivetrain, powertrain, cargo system and seating.

Steering System
The steering system interacts primarily with the front wheels, front suspension and frame. Steering geometry affects wheel placement, turning behaviour and stability and must be compatible with the suspension layout and frame structure.

Suspension System
The suspension connects the wheels to the frame and influences ride stability and structural load transfer. Front suspension geometry must work together with the steering system, while rear suspension must be compatible with rear drive axle.

Hubs, Wheels and Braking
The hubs and wheels serve as the interface between the suspension, braking system, drivetrain in the rear and steering system in the front. They support the

vehicle load while transmitting propulsion and braking forces to the ground. The hub connects the wheel to the axle and transfers torque from the drivetrain to the wheel. Wheel size and placement influence ground clearance, braking performance and overall vehicle grip and control.

Drivetrain

The drivetrain transfers power from the powertrain to the driven wheels. Its layout is constrained by the frame structure. The drivetrain must be arranged so that it does not interfere with suspension movement, wheel position or braking components and must remain compatible with their mounting points.

Powertrain and Energy Storage

The powertrain includes the motor and electric components that provide energy from the battery to the vehicle. The motor, battery and controllers must be securely mounted within the frame and connected to drivetrain for power transmission to the wheels. The placement of the powertrain and energy storage affects weight distribution and be packaged close together along with other components in the frame whilst maintaining accessibility.

Cargo System

The cargo system directly affects load distribution and therefore influences vehicle stability, braking performance and structural loads on the frame.

Seating

The seating position interacts with the steering system and frame geometry to ensure proper rider ergonomics, safety and control of the vehicle.

Safety

Safety features can be developed by adapting the design of other concepts to protect the rider, goods and vehicle when in use. Additional components can also be added to increase the safety of the overall design with potential for interference with all the other subsystems.

Due to these interdependencies, subsystem development was carried out consecutively, subsystem by subsystem, starting with the most foundational subsystem, the frame and concluding with safety features to ensure cross compatibility and a coherent design.

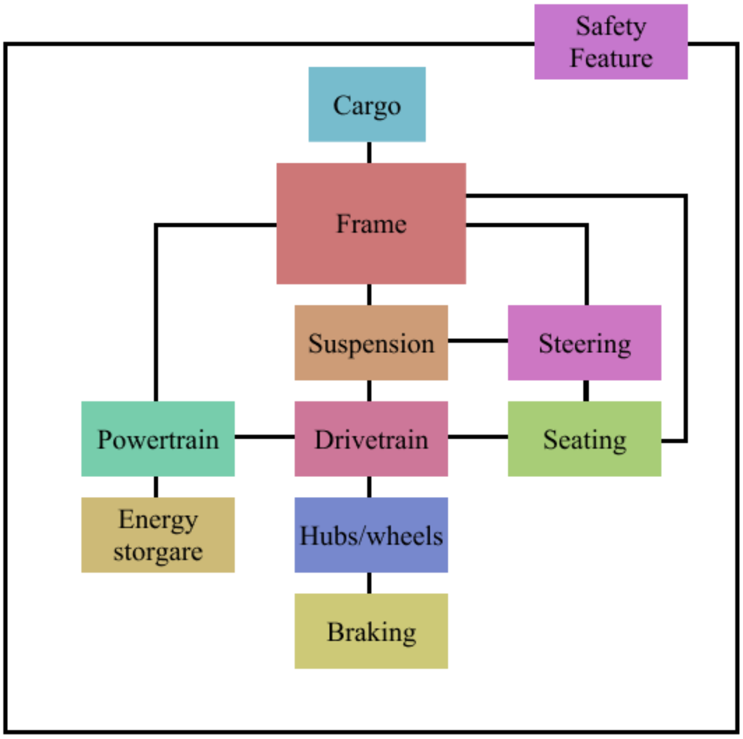

Figure 5-2. Subsystem interference (Source: Author).

5.2.3 The concept generation and evaluation process

Due to the complexity of the vehicle and the limited project duration, the development process was streamlined through a common template that was followed for most subsystems. A cargo vehicle is a large and complex product with many parts that need to become a functioning whole. A lot of time can be spent developing a single subsystem, but considering the project aim and the limited timeframe, it was important that development continued to move forward. The same development template was therefore used throughout the concept development phase, allowing several solutions to be explored while maintaining progress towards the creation of a complete vehicle concept.

The process began by defining subsystem specific requirements based on the overall system requirements presented in Table 4-3. Several concepts were then developed based on benchmarked products, online sources and existing solutions used by Eco Delivery.

After conceptualisation, the concepts were evaluated using scoring matrices based on the selected subsystem requirements. The weights were based on the priorities identified during the Define phase, while the scores were based on benchmarking, stakeholder feedback, previous findings, online sources and engineering guidelines. In most cases, the highest scoring concept was selected, although expert feedback or integration constraints sometimes led to another alternative being chosen.

5.2.4 Frame

Function and requirements

The frame forms the primary structure of the bicycle. It supports the rider, cargo and all major components while maintaining structural integrity under dynamic loads. The frame design influences overall stiffness, weight, durability and stability, particularly when transporting heavy cargo. The subsystem must satisfy several key criteria as defined in Table 4-3, including:

1. Payload capacity (200 kg)
2. Safety factor ≥1.5
3. Withstand rough roads
4. Vehicle stability under load
5. Low centre of gravity / cargo floor ≤350 mm
6. Manufacturable from locally available materials
7. Maximum vehicle width ≤1000 mm
8. High operational reliability

These requirements formed the basis for the development and evaluation of concepts in this subsystem.

Concept Generation and Exploration

To develop potential solutions for the frame, several concepts were generated through a combination of digital research and benchmarking of existing vehicles. Three feasible subsystem concepts were developed for evaluation.

Concept 1 – Triangular T-frame

The *Triangular T-frame* structure consists of one square beam forming the bottom member with two parallel square beams on the top. The top beams are connected by horizontal bars. and a system of vertical and diagonal bars link the top beams to the bottom beam to create a triangulated frame.

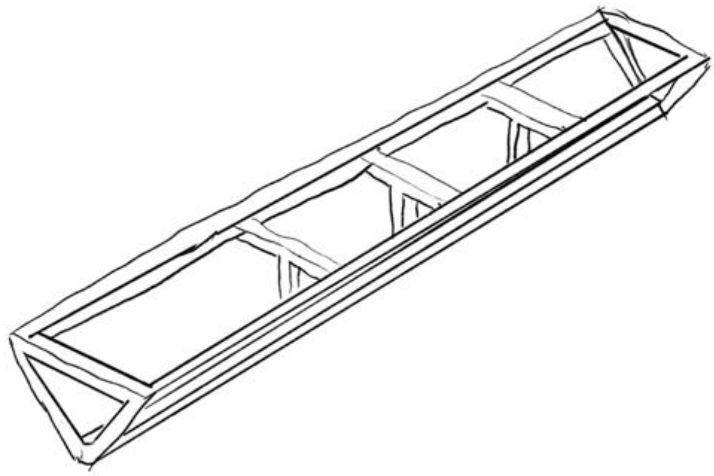

Figure 5-3. Sketch of frame Concept 1: Triangular T-frame (Source: Author).

Concept 2 – Rectangular Truss

Trusses are a type of structure that are stable and have high load bearing capacity (Shi et al., 2023). There are different kinds of trusses, but all share the diagonal beam design shown in Figure 5-4. The *Rectangular Truss* structure consists of four square beams forming a rectangular frame, with diagonal bars installed on each side between the beams to create triangulated sections. The beams themselves are also square.

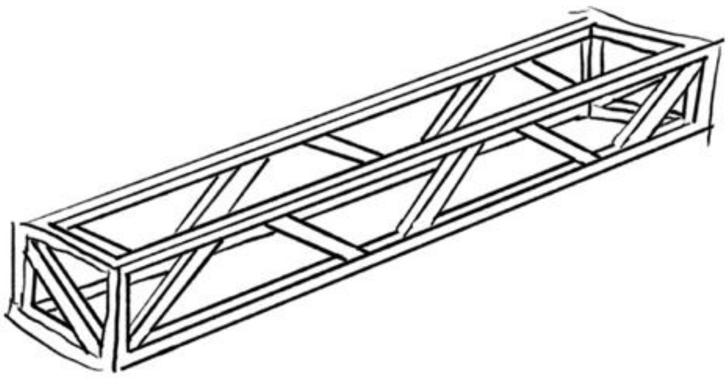

Figure 5-4. Sketch of frame Concept 2: Rectangular Truss (Source: Author).

Concept 3 – Ladder Chassis

The *Ladder Chassis* is a flat frame consisting of two parallel square beams connected by several horizontal cross members between them, forming a ladder type structure (Hizuno, 2025).

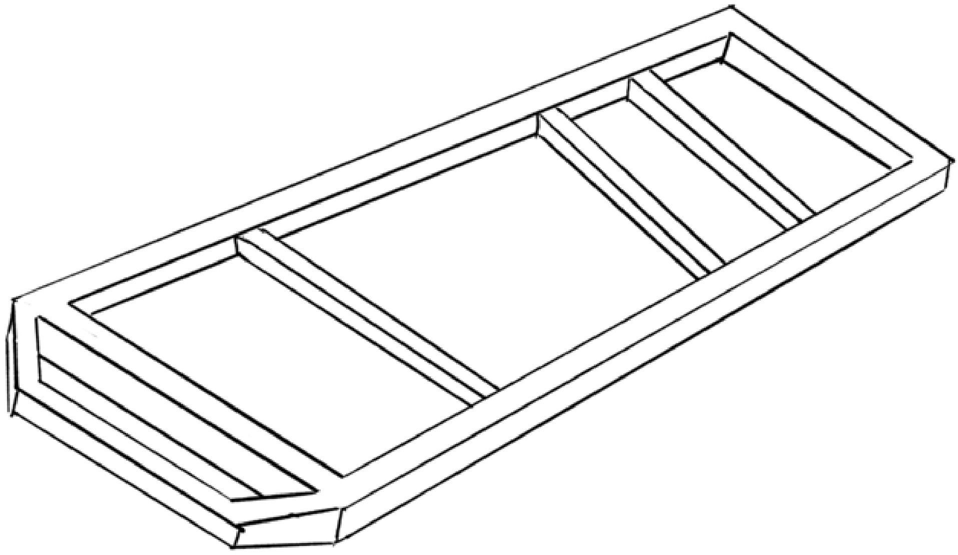

Figure 5-5. Sketch of frame Concept 3: Ladder Chassis (Source: Author).

Concept Evaluation

To select the most viable concept, the alternatives were evaluated using a weighted scoring matrix. The evaluation criteria were derived from the subsystem requirements and project constraints. Each concept was scored on a scale from 1 (poor) to 5 (excellent) for each criterion. The score was multiplied by the criterion weight to obtain a weighted score.

Scoring Matrix - Frame							
	Triangular T-frame		**Rectangular truss**		**Ladder chassi**		**Comment**
Criteria/Score(1-5)	Score	Weighted	Score	Weighted	Score	Weighted	
Load bearing capacity - 4	3	12	4	16	3	12	Truss structure is optimal
Stability - 5	3	15	4	20	5	25	Ladder chassi - low c. of grav.
Durability - 4	4	16	4	16	3	12	Durability - resistance to dynamic loads
Manufacturability - 4	3	12	4	16	5	20	Ladder chassi - low complexity
Servicability - 3	3	9	4	12	5	15	Ladder chassi - low complexity
Weighted total	64		80		84		Ladder chassi

Figure 5-6. Scoring matrix of Frame subsystem (Source: Author).

Selected Frame Concept

Based on the scoring matrix evaluation, Concept 3: *Ladder Chassis* achieved the highest overall score and was therefore selected as the preferred design for the frame.

5.2.5 Suspension

Function and Requirements

The suspension absorbs shocks and vibrations from uneven roads. Suspension improves rider comfort, cargo stability and overall handling performance whilst also prolonging the lifespan of the vehicle.

The subsystem must satisfy several key criteria defined in Table 4-3, including:

1. Ability to withstand rough road conditions
2. Vehicle stability under full payload
3. No tipping during emergency braking on a 10 % incline with 200 kg payload
4. No wheel lift or rollover at 30 km/h with 200 kg payload
5. High operational reliability
6. Service interval ≥ 1000 km
7. Manufacturability using locally available materials

These requirements formed the basis for the development and evaluation of suspension concepts. The front and rear suspension were developed separately, since they fulfil different functions within the vehicle. The front suspension must be compatible with the steering system and primarily support handling and directional control, while the rear suspension carries most of the payload and must integrate with the rear drivetrain.

Front Suspension Concept Generation and Evaluation

Concept 1 – Upper mounted coilover

The *Upper mounted coilover* suspension is a variation of the double wishbone suspension in which the coilover is mounted above the upper wishbone using an arched mounting beam welded to the chassis (Figure 5-7).

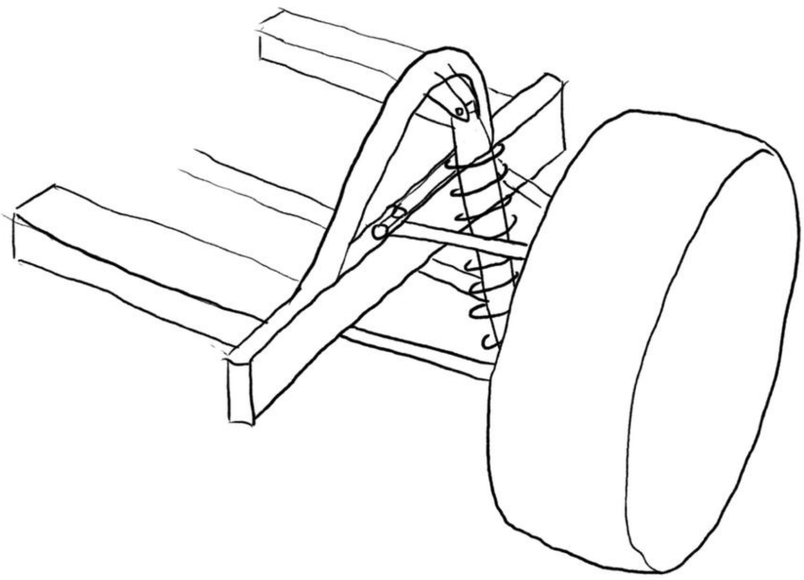

Figure 5-7. Sketch of front suspension Concept 1: Upper mounted coilover (Source: Author).

Concept 2 – Frame mounted coilover

The *Frame mounted coilover* concept is a variation of the double wishbone suspension in which the upper wishbone and coilover are mounted to the upper section of the box frame, while the lower wishbone is mounted to the lower section of the frame (Figure 5-8).

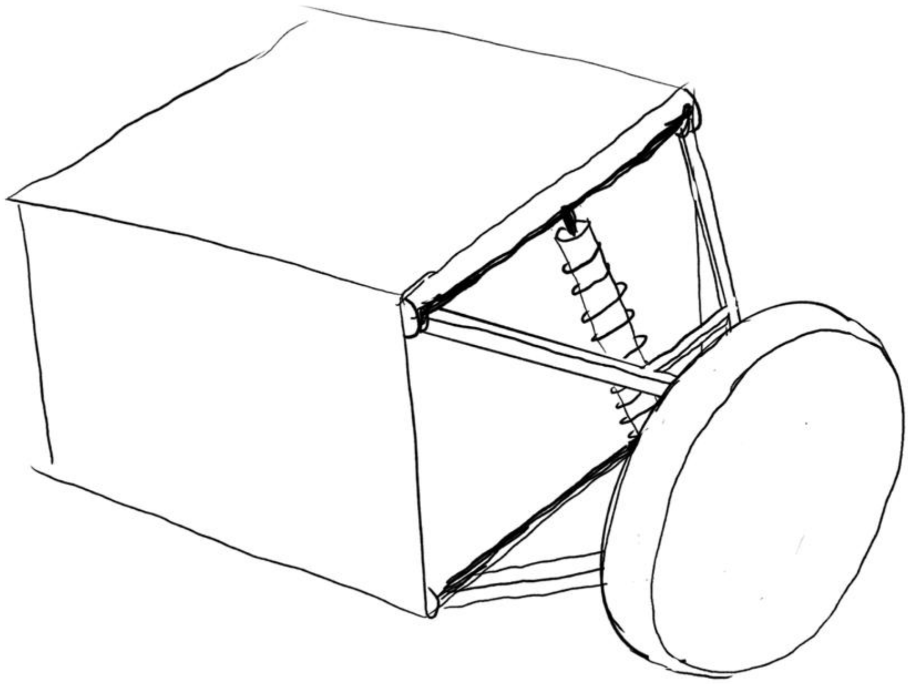

Figure 5-8. Sketch of front suspension Concept 2: Frame mounted coilover (Source: Author).

Concept 3 – Mounting tower

The *Mounting tower* concept is a variation of the double wishbone suspension in which a vertical tower is welded to the frame to support the upper wishbone and coilover (Figure 5-9).

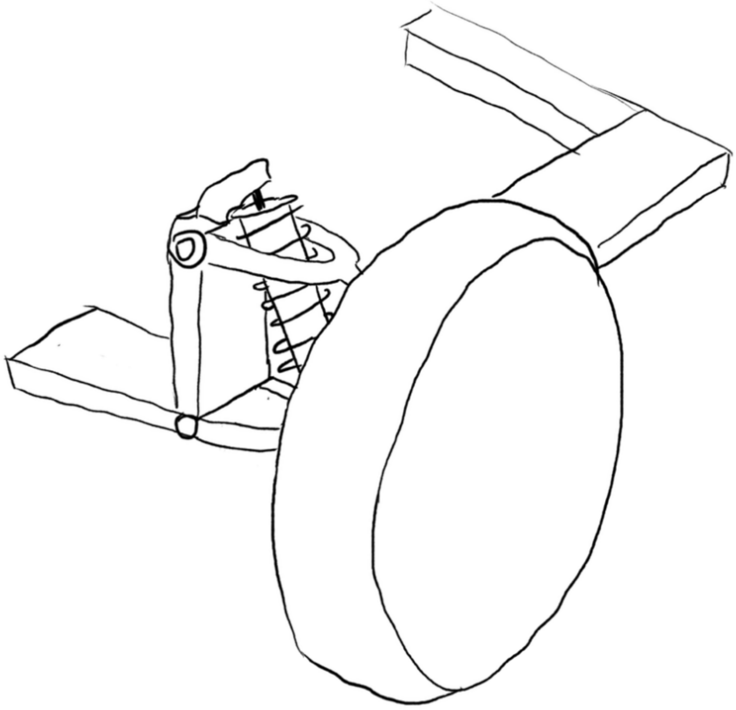

Figure 5-9. Sketch of front suspensions Concept 3: Mounting tower (Source: Author).

Scoring Matrix - Front suspension							
	Upper mount coilover		Frame mounted coilover		Mounting tower		Comment
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Stability - 5	4	20	5	25	4	20	Main function of suspension
Manufacturability - 4	3	12	4	16	4	16	Difficult to bend upper mount
Durability - 4	4	16	5	20	3	12	Estimated time before service
Servicability - 5	4	20	4	20	5	25	Level of difficulty to repair
Cost - 3	3	9	4	12	3	9	Material usage and manufactuing time
Weighted total	77		93		82		Winner: Frame mounted coilover

Figure 5-10. Scoring matrix of front suspension subsystem (Source: Author).

Selected Front Suspension Concept

Based on the scoring matrix evaluation (Figure 5-10), the *Frame mounted coilover* received the highest score and was therefore selected as the preferred front suspension solution.

Rear Suspension Concept Generation and Evaluation

In a similar manner as for the front suspension, three rear suspension concepts were developed for evaluation.

Concept 1 – Leaf spring

The *Leaf spring* suspension concept uses a rigid rear axle supported by leaf springs mounted between the axle and the frame (Figure 5-11).

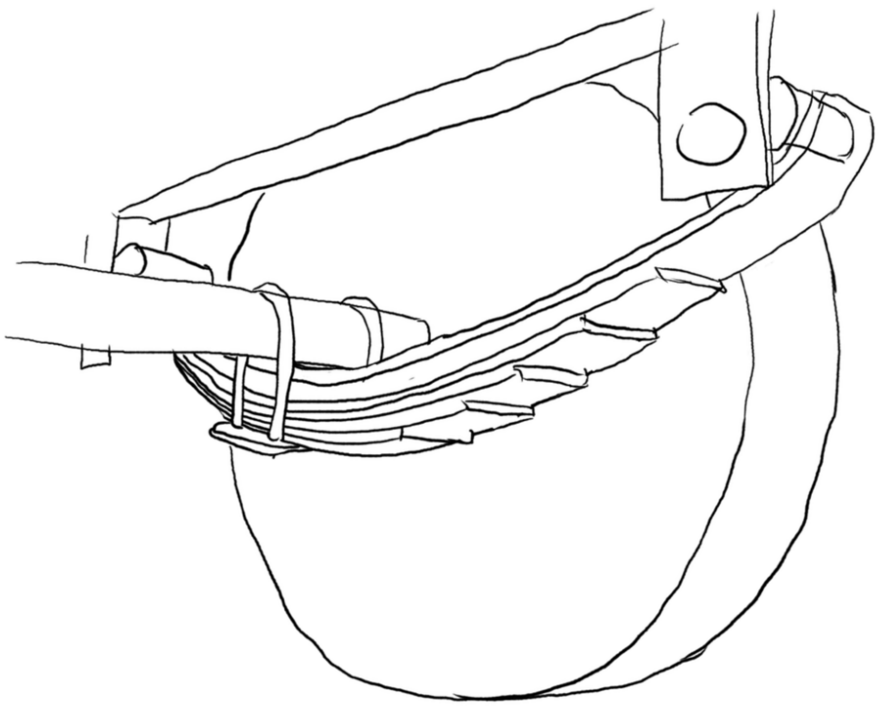

Figure 5-11. Sketch of rear suspensions Concept 1: Leaf Spring (Source: Author).

Concept 2 – Trailing swing arm

The *Trailing swingarm* suspension concept uses a rigid rear axle connected to the frame by two arms that guide the vertical motion of the axle (Figure 5-12). Separate coil springs and dampers are mounted between the swing arms and the frame.

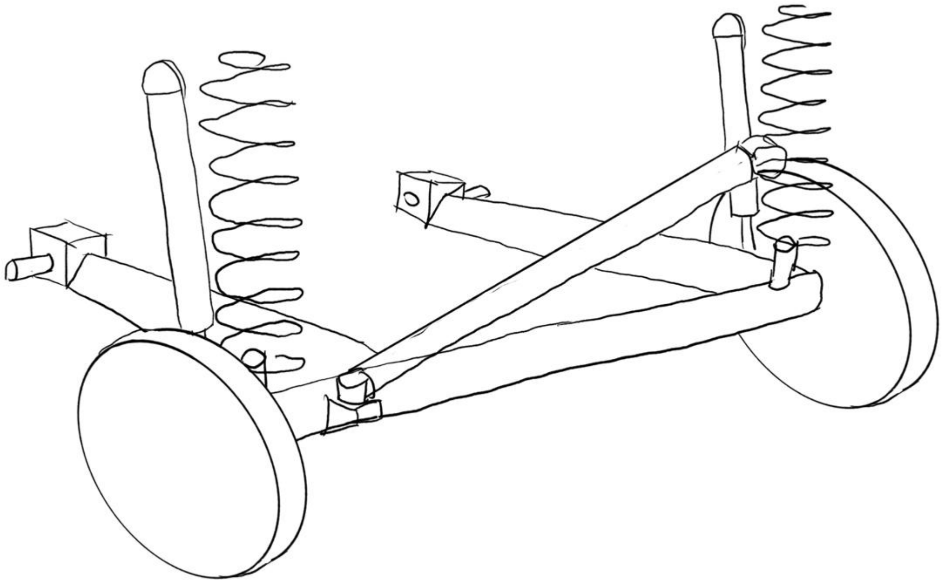

Figure 5-12. Sketch of rear suspensions Concept 2: Trailing swingarm (Source: Author).

Concept 3 – Four-link

The *Four-link* suspension concept consists of a rigid rear axle connected to the frame through four control arms, with two upper and two lower links mounted between the axle housing and the chassis. Separate coil springs and dampers are mounted between the axle and the frame (Figure 5-13).

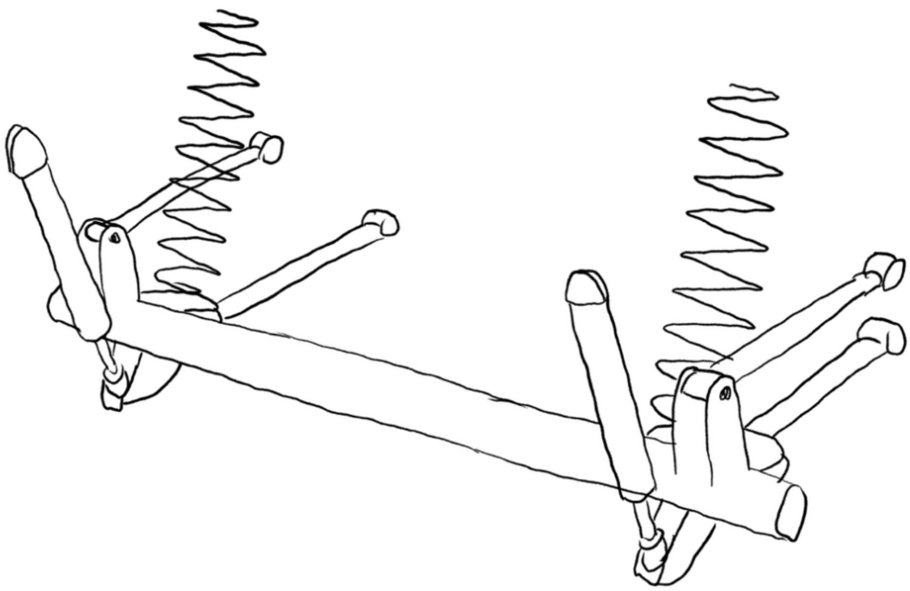

Figure 5-13. A sketch of rear suspensions Concept 2: Four-link (Source: Author)

Scoring Matrix - Rear suspension							
	Leaf spring		Trailing swing arm		Four-link		Comment
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Stability - 5	4	20	4	20	5	25	Stability of rear susp. less important
Manufacturability - 4	4	16	4	16	2	8	Four link high complexity
Durability - 4	5	20	4	16	3	12	Estimated time before service
Servicability - 4	3	12	4	16	3	12	Level of difficulty to repair
Load bearing capacity - 5	5	25	4	20	4	20	Load located above rear suspension
Weighted total	93		88		77		Winner: Leaf spring

Figure 5-14. Scoring matrix of the rear suspension subsystem (Source: Author).

Selected Rear Suspension Concept

Based on the scoring matrix evaluation (Figure 5-14), the *Leaf spring* suspension achieved the highest overall score due to its simplicity, durability and strong load carrying capability. However, during discussions with an external expert in vehicle suspension design, it was suggested that a more modern trailing swing arm suspension could be a more suitable solution for this application. The expert highlighted that a trailing swing arm combined with coil springs and dampers may provide improved shock absorption on rough roads, better control of axle motion and greater adjustment options in terms of the suspension characteristics. These factors can contribute to improved ride comfort, reduced impact loads transmitted to the frame and better overall performance when riding on uneven roads.

5.2.6 Steering

Function and Requirements

The steering subsystem enables the rider to control the direction of the cargo bicycle. Functioning steering mechanisms are critical for maintaining manoeuvrability and stability under heavy load as well as vehicle control in traffic.

1. Turning radius ≤ 5 m
2. Vehicle stability under full payload (200 kg)
3. No wheel lift or rollover at 30 km/h with 200 kg payload
4. High operational reliability
5. Service interval ≥ 1000 km
6. Manufacturability using locally available materials
7. Maximum vehicle width ≤ 1000 mm

These requirements formed the basis for the development and evaluation of steering subsystem concepts.

Concept Generation and Evaluation

Three potential solutions for the steering subsystem were generated and subsequently evaluated.

Concept 1 – Three-piece lever

The *Three-piece lever* steering system consists of two vertical steering levers positioned on each side of the rider (Figure 5-15). The levers actuate tie rods parallel to the riding direction, which connect to a three piece steering linkage that distributes the steering motion to the front wheel steering arms.

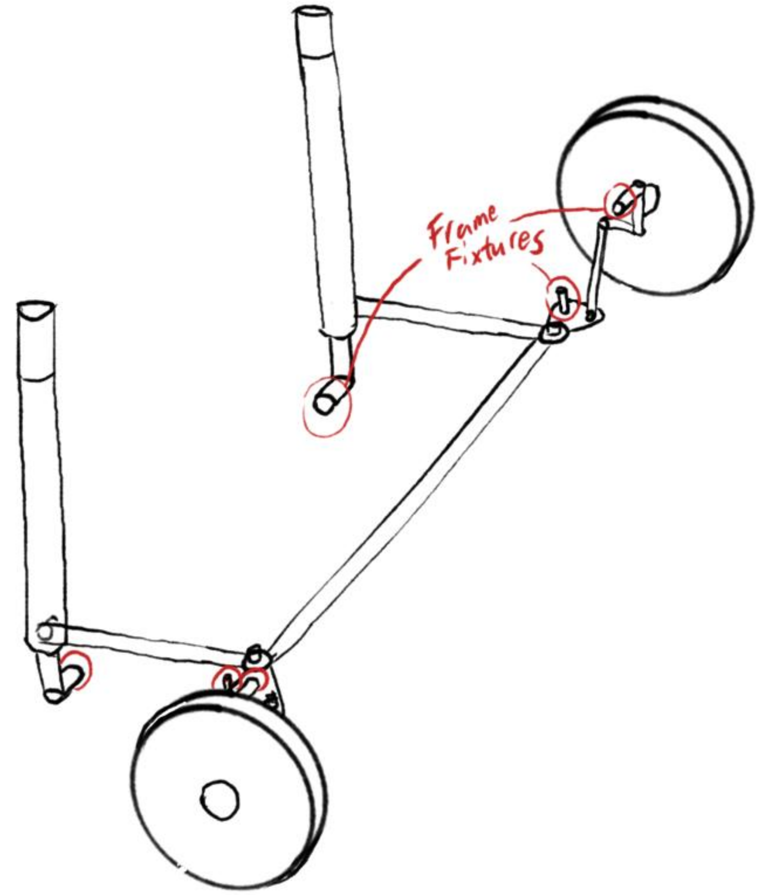

Figure 5-15. Sketch of steering system Concept 1: Three-piece lever steering (Source: Author).

Concept 2 – Handlebar with steering column

The *Handlebar with steering column* system uses a central steering column that passes through a mounting bracket and actuates a bell crank (Figure 5-16). The bell crank transfers the steering motion through two tie rods to the front wheel steering arms.

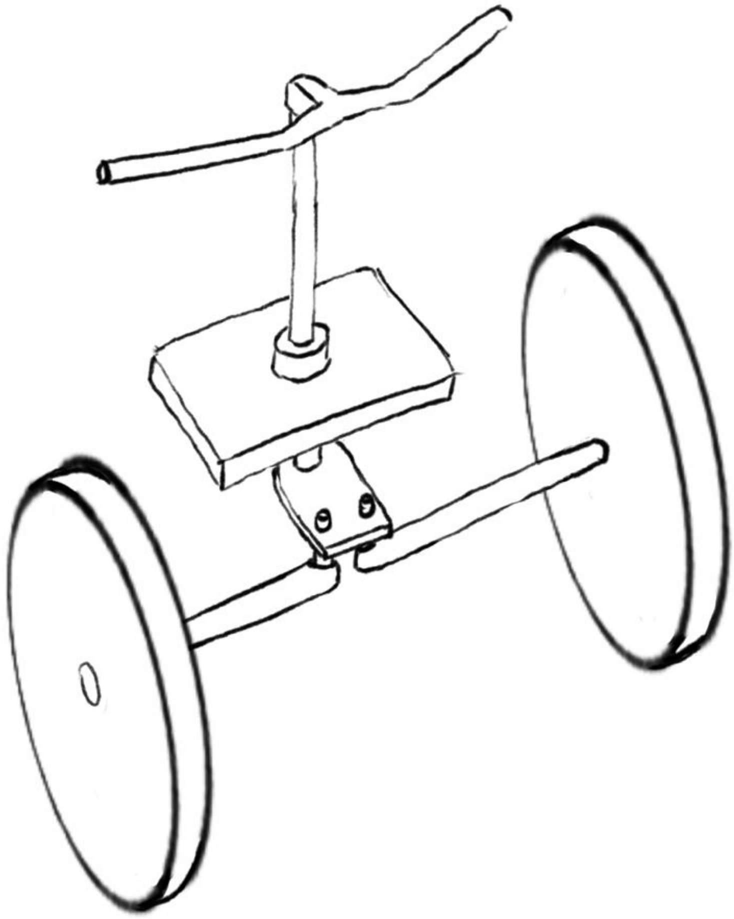

Figure 5-16. Sketch of steering system Concept 2: Handlebar with steering column (Source: Author).

Concept 3 – Handlebar with tie rods

The *Handlebar with tie rods* steering system (Figure 5-17) uses a rigid handlebar mounted beneath the rider that pivots about a central mount. A plate positioned behind the handlebar mount connects to the tie rods and transmits the steering motion by pushing and pulling the rods.

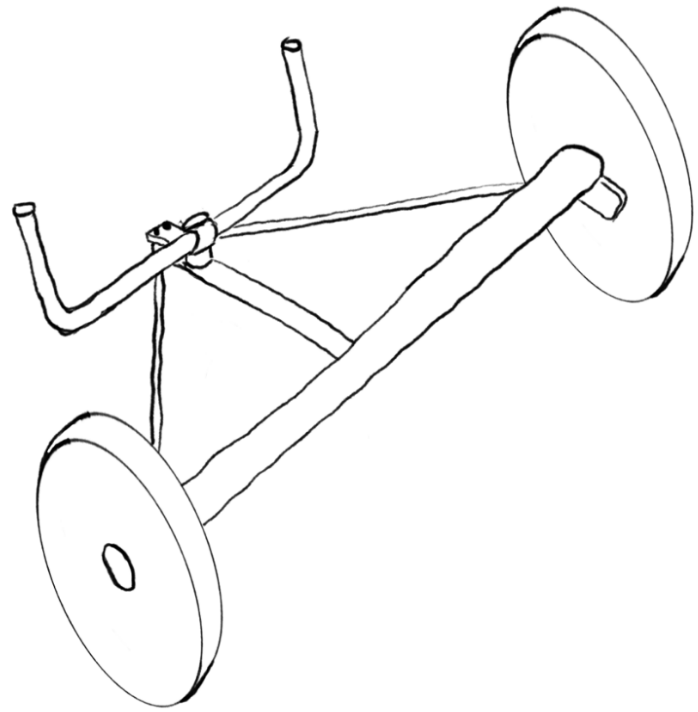

Figure 5-17. A sketch of steering system Concept 3: Handlebar with tie rods (Source: Author).

Scoring Matrix - Steering							
	Three-piece lever		**andlebar w. steering colum**		**Handlebar with tie rod**		**Comment**
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Maneuvrability - 4	4	16	5	20	5	20	Turning radius and ease of steering
Stability - 5	4	20	5	25	4	20	Stable behaviour under load
Manufacturability - 4	3	12	4	16	5	20	Complex components
Serviceability - 3	4	12	3	9	5	15	Ease of repair
Integration - 5	5	25	2	10	4	20	Must fit with the other parts of the vehicle
Weighted total	85		80		95		Winner: Handlebar with tie rod

Figure 5-18. Scoring matrix of the steering subsystem (Source: Author).

Selected Steering Concept

The steering concepts were mainly evaluated based on simplicity, serviceability, manufacturability and compatibility with the front suspension and vehicle layout. Based on the scoring matrix evaluation (Figure 5-18), the *Handlebar with tie rods* concept achieved the highest overall score. This system is deemed to be very simple in terms of manufacturability, serviceability and integration with the rest of the vehicle whilst providing adequate steering functionality.

5.2.7 Hubs and Wheels

Function and Requirements

The hubs and wheels subsystem includes the rims, spokes, tires and wheel mounts. The wheel is mounted on the hub which is then connected to the vehicle through the suspension and axle. The front hubs also need to integrate with the steering system. Wheel selection affects the performance, control, durability and load carrying capability of the vehicle. Commercially available parts will be used where possible in combination with custom solutions to integrate the wheels with the other subsystems of the vehicle.

The following requirements are the most relevant for the wheel subsystem:

1. Ability to support the maximum payload of 200 kg
2. Stable operation at 30 km/h under full load
3. Structural robustness for operation on rough urban roads
4. Serviceability, including wheel removal in less than 5 minutes
5. Use of locally available components where possible

Wheel Evaluation and Selection

Wheel types commonly used in bicycles, mopeds and small motorcycles were considered as candidate solutions. Typical rim sizes and axle diameters for these wheel types are summarized in Table 5-2.

Table 5-2: Comparison of common wheel types.

Wheel type	*Rim size*	*Axle Diameter*	*Intended use*
Bicycle [a]	26″ - 29″	9 - 12mm	Human powered transport, light loads.
Moped [b]	16″ - 17″	12 - 15mm	Small motorised urban vehicles.
Motorcycle [c]	17″ - 19″	15 - 20mm	Motorized high speed vehicles.

[a] Typical bicycle wheel sizes and axle standards (Sheldon Brown, n.d.).

[b] Typical specifications of small commuter mopeds (Honda Motor Co., 2024).

[c] Typical specifications of small commuter motorcycles (Bajaj Auto, 2024).

The identified wheel concepts were evaluated using criteria derived from the subsystem requirements, as presented in Table 5-3.

Table 5-3 Evaluation of candidate wheel concepts.

Criteria	*Bicycle wheel*	*Moped wheel*	*Motorcycle wheel*
Structural robustness	Low	Medium	High
Axle Strength	Low	Medium	High
Brake compatibility	Medium	High	High
Local availability	High	Medium	High
Weight	Low	Medium	High
Integration with vehicle	Medium	Medium	Medium

As shown in Table 5-3, motorcycle wheels provide the highest structural robustness and axle strength. While heavier than bicycle wheels, they offer improved durability and compatibility with robust disc braking systems. Considering the expected payload and rough operating conditions, the motorcycle wheels provide the most suitable solution for the vehicle. Additionally, it is relevant that motorcycle parts are inexpensive and readily available in Bolivia.

Hub Concept Generation

The hub ensures that the wheel integrates with the vehicle suspension, drivetrain and braking system. Several hub concepts were therefore generated and evaluated.

Concept 1- Coffin

The first concept, referred to as the *Coffin* design (Figure 5-19), consists of an elongated hexagonal housing with a through-hole for the wheel hub axle. Mounting points for the suspension links are located on the top and bottom faces of the component. A separate welded bracket is used to attach the steering tie rod.

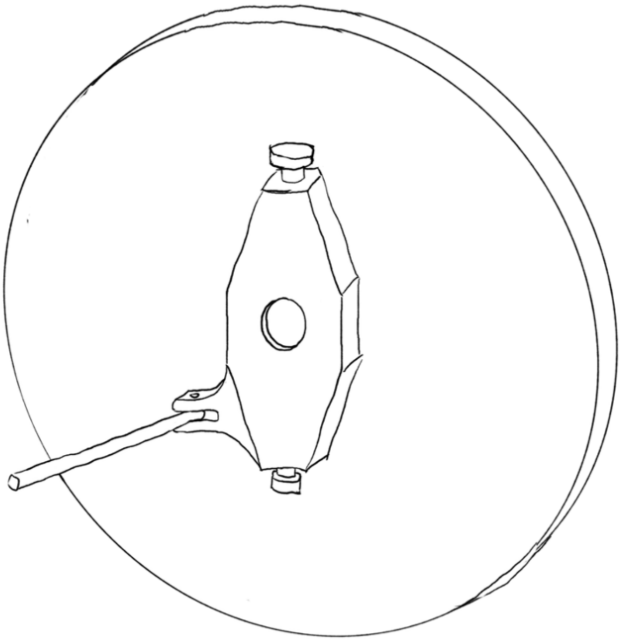

Figure 5-19. Sketch of hub-system Concept 1: Coffin (Source: Author).

Concept 2- T-axle

The second concept, referred to as the *T-axle*, consists of a vertical axle with a horizontal stub axle onto which the wheel hub is mounted (Figure 5-20). The suspension arms are attached to the upper and lower ends of the vertical axle. A separate bracket is welded to the vertical axle to provide an attachment point for the steering tie rod.

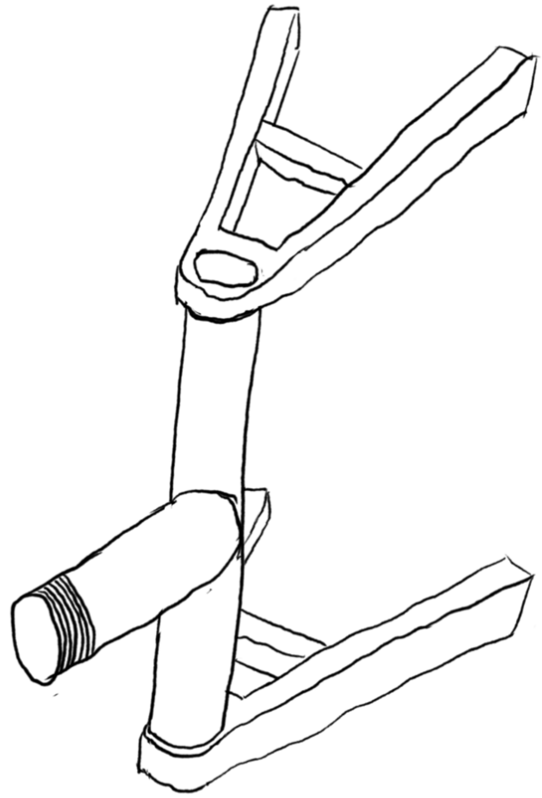

Figure 5-20. Sketch of hub-system Concept 2: T-axle (Source: Author).

Concept 3- Stub axle

The third concept, referred to as the *Stub axle* design, consists of a square mounting plate with a stub axle welded to its centre, onto which the wheel hub is mounted (Figure 5-21). Separate brackets extend from the plate to provide attachment points for the steering tie rod and suspension arms.

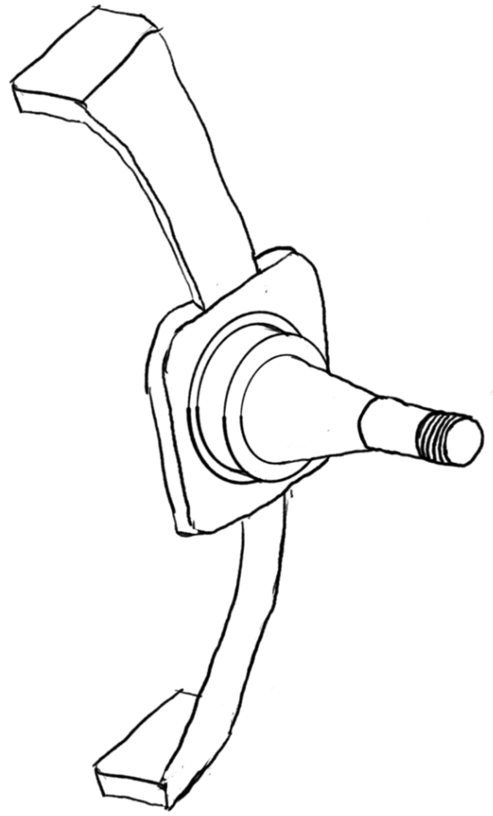

Figure 5-21. Sketch of hub-system Concept 3: Stub axle (Source: Author).

Hubs concept evaluation

The hub concepts were evaluated using a weighted scoring matrix (Figure 5-22) based on the selected criteria. The criteria were assessed based on expected structural robustness, ease of manufacturing, serviceability and integration with the suspension, steering and wheel assembly.

Scoring Matrix - Hubs and wheels							
	Coffin		T-axle		Stub axle		Comment
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Robustness - 5	5	25	3	15	4	20	Withstand loads under harsh conditions
Manufacturability - 4	3	12	4	16	3	12	
Integration - 5	5	25	4	20	3	15	Steering, suspension and braking
Servicability - 3	4	12	4	12	4	12	
Cost - 3	3	9	4	12	4	12	
Weighted total	83		75		71		Winner: Coffin

Figure 5-22. Scoring matrix of the hub subsystem (Source: Author).

Selected Wheel-Hub Concept

The final solution consists of *motorcycle wheels* combined with the *Coffin hub* concept. The *Coffin hub* design will be used for the front hubs, where it integrates with the suspension and steering system. The rear hubs will use a modified version of this concept to interface with the solid driven axle and transmit torque from the drivetrain.

5.2.8 Braking

Function and Requirements

Brakes enable controlled deceleration and stopping of the cargo bicycle. The braking subsystem must provide reliable stopping performance under full load while remaining compatible with the selected wheels and hub configuration. Commercially available components will be used where possible.

The following requirements are the most relevant for the braking subsystem:

1. Ability to safely decelerate and stop the vehicle under maximum payload (200 kg)
2. Safe and stable braking at the maximum operating speed of 30 km/h
3. Reliable operation on rough urban roads
4. Serviceability, including simple maintenance and repair
5. Use of locally available components where possible

Brake Concept Generation and Evaluation

Based on the subsystem requirements, three concepts for the braking system were selected. These concepts used standard commercially available components and are briefly described below.

Concept 1 – Drum Brake

The first concept uses a *Drum Brake* integrated into the wheel hub. In this design, brake shoes press against the inner surface of the drum to generate braking force.

Concept 2 – Mechanical Disc Brake

The second concept uses a *Mechanical Disc Brake*. A brake disc is mounted to the wheel hub and a calliper applies braking force to the disc through a cable mechanism.

Concept 3 – Hydraulic Disc Brake

The third concept uses a *Hydraulic Disc Brake*. A brake disc is mounted to the wheel hub and a hydraulic caliper applies braking force to the disc using brake fluid pressure.

The braking concepts were evaluated using criteria derived from the subsystem requirements, see Table 5-4.

Table 5-4 Evaluation of candidate braking concepts

Criteria	*Drum brake*	*Mechanical disc*	*Hydraulic disc*
Braking performance	Medium	Medium	High
Reliability	High	Medium	High
Serviceability	Medium	High	Medium
Local availability	High	Medium	High
Integration with vehicle	Medium	High	High

Selected Braking Concept

The final solution consists of *Hydraulic Disc Brakes* mounted on the motorcycle wheels. Hydraulic disc brakes provide higher braking performance and better heat dissipation than drum brakes while remaining widely available due to their common use on motorcycles. They also integrate well with the selected motorcycle wheels.

5.2.9 Drivetrain

Function and Requirements

The drivetrain transfers mechanical power from the rider's pedalling to the wheels. Design choices include the selection of gear ratios and gearing through a sprocket and chain drive. The drivetrain must efficiently transfer the power generated by the rider whilst integrating with the powertrain and the wheel hub system. The design of the drivetrain affects riding performance in terms of grip, power transfer and rider comfort.

The following requirements are the most relevant for the drivetrain subsystem:

1. Ability to transmit rider and motor power under the maximum payload of 200 kg
2. Provide suitable gear ratios for efficient operation up to 30 km/h
3. Structural robustness for operation on rough urban roads
4. Serviceability, including simple maintenance and repair
5. Use of locally available and inexpensive components

Concept Generation and Evaluation

Three drivetrain concepts describing the layout of the system and its components were developed and subsequently evaluated.

Concept 1 – Jackshaft Dual Freewheel Drive

The first concept uses a jackshaft to distribute power to the rear wheels (Figure 5-23). A cassette mounted on the jackshaft provides multiple gear ratios, while two freewheel sprockets drive the left and right rear wheels through separate chains. The freewheels allow the wheels to rotate at different speeds during cornering, avoiding the need for a differential.

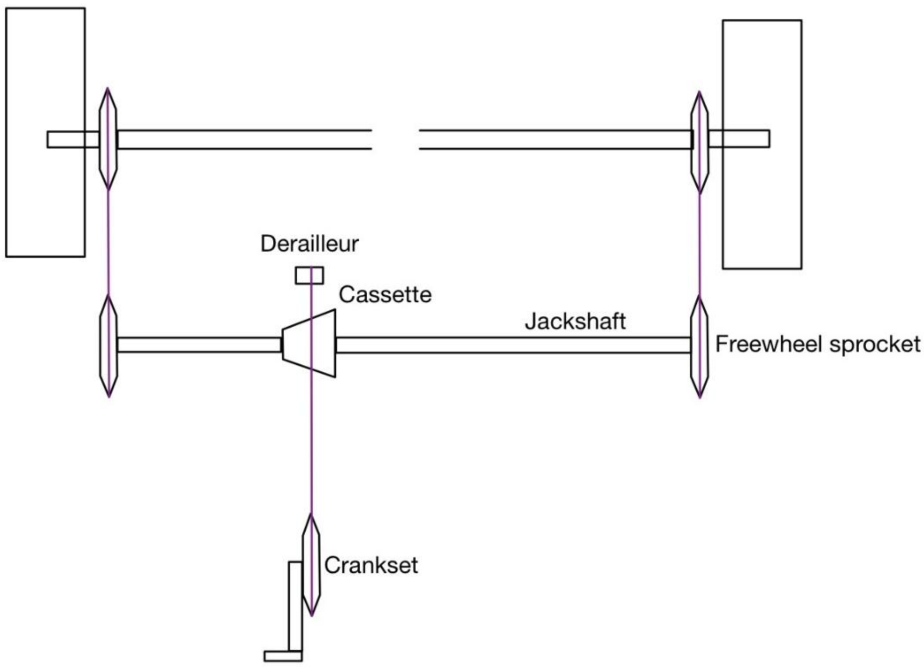

Figure 5-23. Sketch of the drivetrain layout for Concept 1: Jackshaft Dual Freewheel Drive (Source: Author).

Concept 2 – *Front Derailleur Jackshaft Drive*

The second concept uses a front derailleur to provide gearing at the crankset (Figure 5-24). Power is transmitted through a chain to a jackshaft with a single sprocket. From the jackshaft, two freewheel sprockets transfer power to the left and right rear wheels through separate chains. The freewheels allow the wheels to rotate at different speeds during cornering.

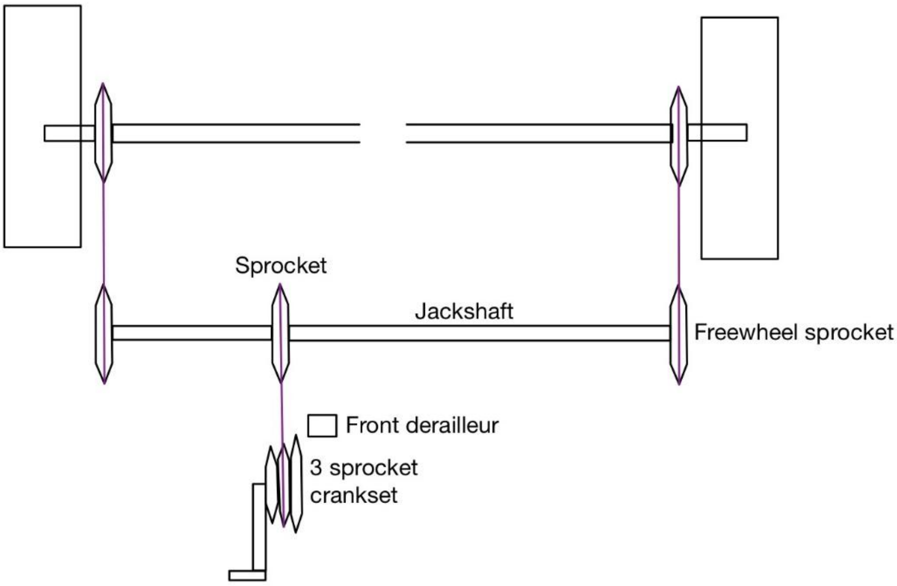

Figure 5-24. Sketch of the drivetrain layout for Concept 2: Front Derailleur Jackshaft Drive (Source: Author).

Concept 3 – *Differential Rear Axle Drive*

The third concept uses a crankset with a single sprocket to transmit power through a chain to the rear axle (Figure 5-25). A cassette and a differential are mounted on the rear axle, allowing the rear wheels to rotate at different speeds during cornering while transmitting power to both wheels.

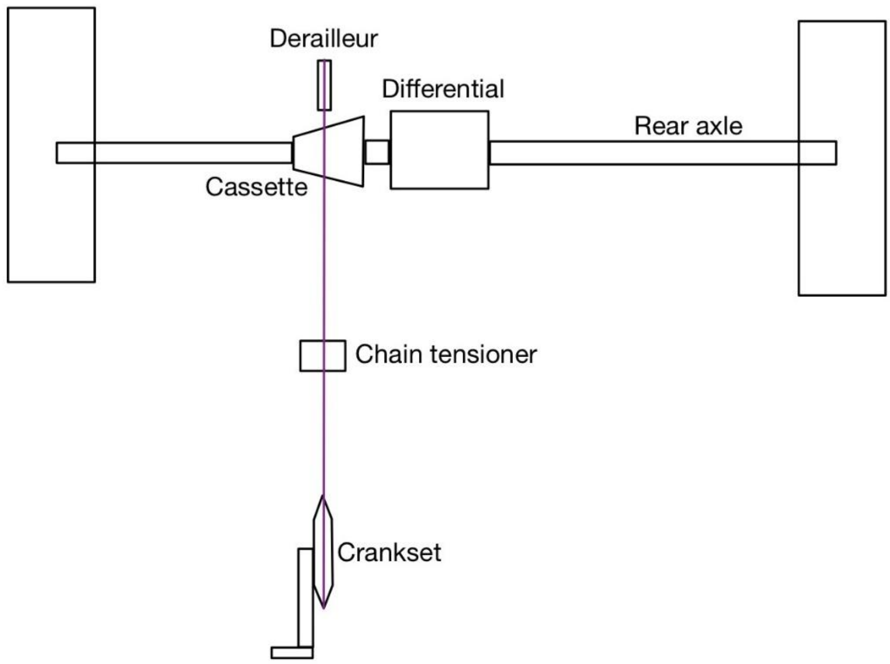

Figure 5-25. Sketch of the drivetrain layout for Concept 3: Differential Rear Axle Drive (Source: Author).

The drivetrain concepts were evaluated using criteria derived from the subsystem requirements, as presented in Figure 5-26.

Scoring Matrix - Drivetrain							
	J Dual freewheel		Front deraileur JD		Differentail RAD		Comment
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Performance - 4	4	16	5	20	4	16	Efficiency of power transfer
Integration - 5	4	20	3	15	3	15	Compatibility w. other components
Robustness - 5	4	20	5	25	4	20	Reliability, durability and strength
Manufacturability - 4	4	16	5	20	3	12	Simplicity of design
Cost - 3	4	12	5	15	3	9	Third party components and material
Weighted total	84		95		72		

Figure 5-26. Scoring matrix of the drivetrain subsystem (Source: Author).

Selected Drivetrain Concept

Based on the scoring matrix evaluation, Concept 2: *Front Derailleur Jackshaft Drive* achieved the highest overall score. The concept provides some gearing while maintaining a simple. robust and inexpensive layout. It also offers good manufacturability and integrates well with the vehicle architecture.

5.2.10 Powertrain and Energy Storage

Function and Requirements

The powertrain provides electric assistance to the rider. It includes the electric motor, motor controller, sensors and other necessary electronics. This subsystem determines the level of assistance, efficiency and responsiveness of the electric cargo bicycle. Important design choices include the motor size, mounting position and integration with the drivetrain. The powertrain must provide sufficient assistance while maintaining predictable and natural vehicle behaviour.

The powertrain goes hand in hand with the energy storage system which consists of the battery pack and the battery management system. In practice, these components are often supplied and purchased as a complete system or kit.

The following requirements are the most relevant for the powertrain subsystem:

1. Provide sufficient power assistance under the maximum payload of 200 kg
2. Maintain at least 15 km/h on a 10% incline with 200 kg payload
3. Support operation up to 30 km/h
4. Integrate with the drivetrain and rear axle configuration
5. Integrate with the battery and electrical storage subsystem
6. Provide pedal-assist functionality through a suitable sensor system
7. Ensure predictable interaction between rider input and electric assistance
8. Use simple, robust and locally serviceable components where possible
9. Provide sufficient energy capacity to support the required operating conditions

Determining required power output

To determine what power input is required, calculations were made. According to Nyberg (2014) and the sought variable was P expressed in watts. The required force F is expressed in Newtons and velocity v in meters per second. The constant $g \approx 9.81\ \frac{m}{s^2}$ and assuming the rider weights approximately 80 kg and bike 100 kg, $m \approx 200 + 100 + 80 = 380$ kg. The assumption was made that the power transfer efficiency is 95% based Liew et al. (2025). Theta θ is angle in degrees between the gravitational direction and normal plane of the vehicle, often meaning the incline of the road.

$$P = \frac{dW}{dt} = F \cdot v \tag{5.1}$$

$$F = m \cdot g \cdot \sin\theta \tag{5.2}$$

$$\theta = \tan^{-1} 0.10 \tag{5.3}$$

$$P = m \cdot g \cdot \sin\tan^{-1} 0.10 \cdot v \tag{5.4}$$

$$P_{real} = P \cdot 0.95 \tag{5.5}$$

Nominal power output $P \approx 2.37$ kW and real power transfer $P_{real} \approx 2.49$ kW. To guarantee required specifications, the ideal motor power output was chosen to be 3 kW.

Motor Type Evaluation and Selection

Based on the required nominal motor output, different motor types were considered. Important aspects in this evaluation were integration with the drivetrain, pedal assist functionality, packaging, serviceability and compatibility with locally available components. The motor types were compared in Table 5-5 and evaluated based on selected criteria in Table 5-6.

Table 5-5 Motor type characteristics.

Motor type	*Main characteristics*	*Advantages*	*Disadvantages*
Brushed DC Motor	Simple DC motor with brushes	Low cost	More maintenance
Brushless DC Motor	Electronically commutated	High efficiency, low maintenance	Requires controller
Hub Motor	Motor integrated into wheel hub	Simple packaging	Complex wheel maintenance

Table 5-6 Evaluation of candidate motor concepts.

Criteria	*Brushed DC Motor*	*Brushless DC Motor*	*Hub Motor*
Power capacity	Medium	High	Medium
Lifespan	Low	High	High
Integration with drivetrain	Medium	High	Low
Cost efficiency and availability	High	Medium	Medium
Serviceability	Medium	High	Low

The brushless motor was chosen as the best alternative due to its high power capacity, long lifespan and good serviceability.

Battery Capacity Estimation

To ensure that the selected powertrain can support the required operating conditions, an estimation of the required battery capacity was performed. The calculation is based on the required motor power and expected operating duration under load.

Based on the required motor output estimated at 3 kW and the intended use of the vehicle, the battery capacity must be sufficient to provide adequate range while maintaining reliable operation. The exact battery specification will be selected as part of the final powertrain solution.

$$E = P_{avg} \cdot t \tag{5.6}$$

$$P_{avg} = \frac{1}{t}\int_0^t F(t) \cdot v(t)\, dt \tag{5.7}$$

$$t = \frac{d}{v_{avg}} \tag{5.8}$$

$$v = \frac{d}{v_{avg}} \tag{5.9}$$

Assuming the rider will not be travelling at peak power or velocity always, but around half of this value, the average power output $P_{avg} = 0.5 \cdot P_{real} \approx 1.25\text{kW}$ and average velocity $v_{avg} = 0.5 \cdot v_{top}$. The required top speed and distance per charge is 40 km/h and 50 km, which means that $v_{avg} = 20$ km/h, $t = \frac{50}{20} = 2.5\ h$ and $E = 3.125$ kWh. This value is relatively high compared to the market average for cargo bike energy storage solutions according to United Mobility (2026).

Powertrain Concept Generation

Three concepts that describe the layout of the powertrain and its integration with the drivetrain were developed and subsequently evaluated using a weighted scoring matrix.

Concept 1 – Mid Motor Crank Drive

The first concept uses a mid-mounted brushless DC motor to provide pedal assistance (Figure 5-27). The motor drives a sprocket mounted on the left crank arm through a chain. On the right side of the crankshaft, a second crank arm with a sprocket transmits power to the drivetrain. In this configuration, motor power and rider input are combined at the crankset before being transferred to the remainder of the drivetrain.

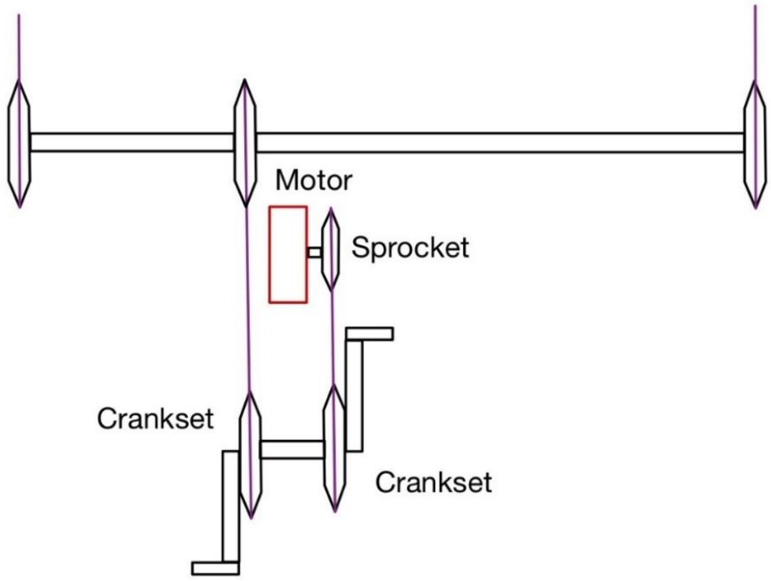

Figure 5-27. Sketch of the powertrain layout for Concept 1: Mid Motor Crank Drive (Source: Author).

Concept 2 – Mid Motor Jackshaft Drive

The second concept uses a mid-mounted brushless DC motor to provide pedal assistance (Figure 5-28). In this configuration, the motor drives the drivetrain through a chain connected to an additional sprocket on the jackshaft. Rider power is transmitted through the crankset to the drivetrain, while the motor assists by delivering power directly to the jackshaft before it is distributed to the rear wheels.

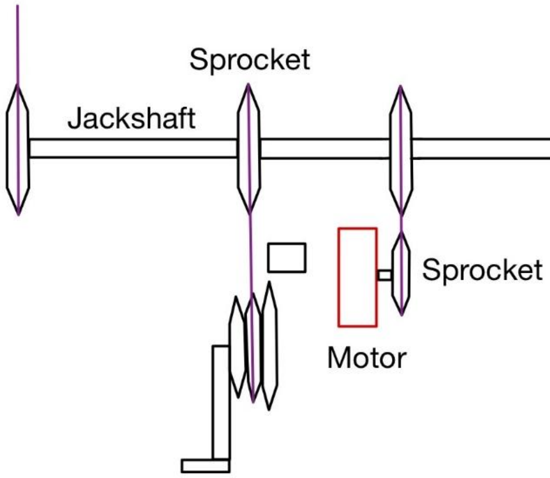

Figure 5-28. Sketch of the powertrain layout for Concept 2: Mid Motor Jackshaft (Source: Author).

Concept 3 – Rear Motor Jackshaft Drive

The third concept uses a brushless DC motor mounted near the rear axle to provide pedal assistance (Figure 5-29). Power from the motor is transmitted through a chain to a sprocket on the jackshaft. Rider power is transferred through the crankset to the drivetrain, while the motor assists by delivering power to the jackshaft from the rear of the vehicle.

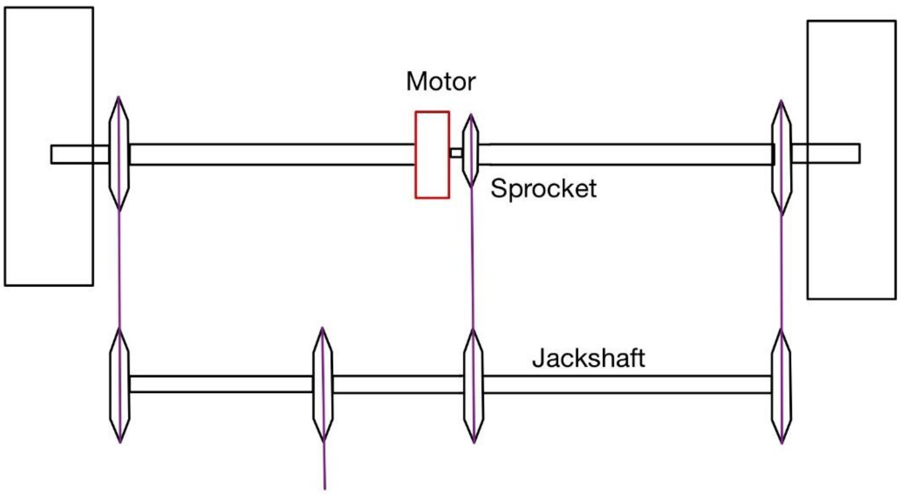

Figure 5-29. Sketch of the powertrain layout for Concept 3: Rear Motor Jackshaft Drive (Source: Author).

Powertrain Concept Evaluation

The powertrain concepts were evaluated based on criteria derived from the subsystem requirements (Figure 5-30).

Scoring Matrix - Powertrain							
	Mid Motor Crank Drive		Mid Motor Jackshaft Drive		Rear Motor Jackshaft Drive		Comment
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Power transfer efficiency - 3	3	9	4	12	4	12	Power output of motor trasfered to wheel
Lifespan - 4	3	12	4	16	4	16	Time before needed service
Integration drivetrain - 5	5	25	4	20	3	15	compatibility with chosen drivetrain
Manufacturability - 4	5	20	4	16	3	12	Availability very different from Sweden
Servicability - 4	5	20	4	16	3	12	Simplicity of service
Weighted total	86		80		67		Mid Motor Crank Drive

Figure 5-30. Scoring matrix of the powertrain subsystem (Source: Author).

Selected Powertrain Concept

Concept 2 the *Mid Motor Crank Drive* received the highest score. This concept provides good integration with the drivetrain while offering easy access and serviceability compared to the other concepts.

It is planned to use a commercially available powertrain and energy storage kit, including motor, controller, batteries, sensors and associated electronics. The selected kit will be checked to ensure sufficient battery capacity and appropriate environmental protection, including waterproofing. The exact mounting position of the components will be defined in the detailed design phase once the overall vehicle architecture is starting to get finalised.

5.2.11 Cargo

Function and Requirements

The cargo subsystem includes the structures and interfaces used to transport goods. This includes how the cargo is loaded, secured and removed. Its design determines load capacity, cargo stability, ease of use and compatibility with third-party systems. The subsystem must integrate with the frame while allowing flexible and efficient handling of different types of cargo.

1. Support the maximum payload of 200 kg
2. Ensure stable and secure transport of cargo during operation
3. Allow easy loading and unloading of cargo
4. Integrate with the vehicle frame and overall architecture
5. Provide compatibility with different cargo types and third-party solutions

6. Use simple, robust and locally manufacturable components

Cargo Concept Generation

Three concepts for the cargo system were developed. The sketches and brief description of each system are presented below.

Concept 1 – Rail Cargo Box

The first concept consists of a rectangular cargo box with four wheels on the underside, allowing it to be rolled onto the cargo bike (Figure 5-31). The cargo bike is equipped with two parallel rails aligned with the riding direction, which guide the box into position. A front "stop" with an integrated locking mechanism secures the box using two locking pins. The rear of the box is secured by a folding ramp, which is used for loading and unloading and, when raised, prevents the box from rolling off the back.

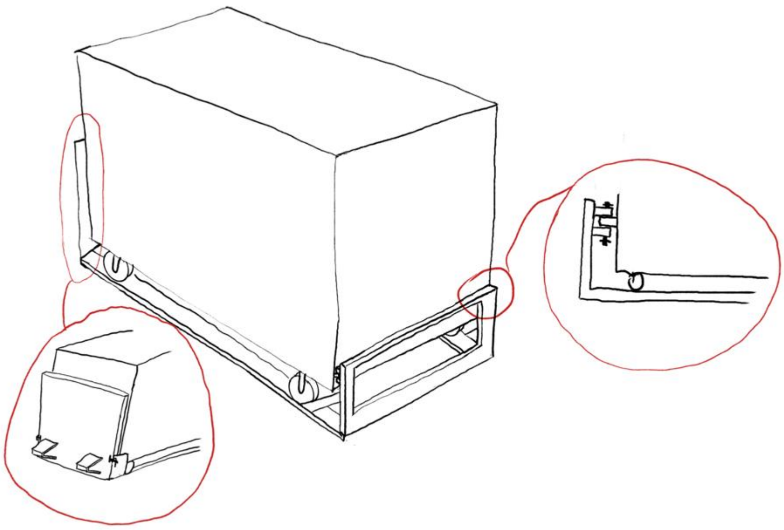

Figure 5-31. Sketch of the cargo layout for Concept 1: Rail Cargo Box (Source: Author).

Concept 2- Lift in Cargo Box

The second concept consists of a rectangular cargo box supported by four wheels, which is manually lifted into position on the vehicle (Figure 5-32). The cargo vehicle incorporates a box frame with low walls and four holes in the floor that align with the wheels to position and secure the box. The box is secured to the frame using four mechanical latches located at the front and rear, preventing movement during operation.

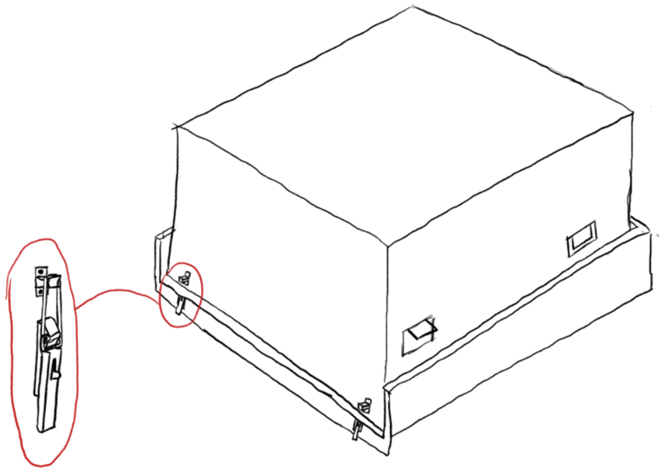

Figure 5-32. Sketch of the cargo layout for Concept 2: Lift in Cargo Box (Source: Author).

Concept 3 - Forklift Cargo Box

The third concept consists of a rectangular cargo box with a base profile similar to a standard pallet, allowing it to be handled using a forklift (Figure 5-33). The cargo bike features a flat loading platform with a low front wall that acts as a stop to prevent forward movement. The box is secured using two straps that are hooked into loops on the sides of the platform to hold the box in place.

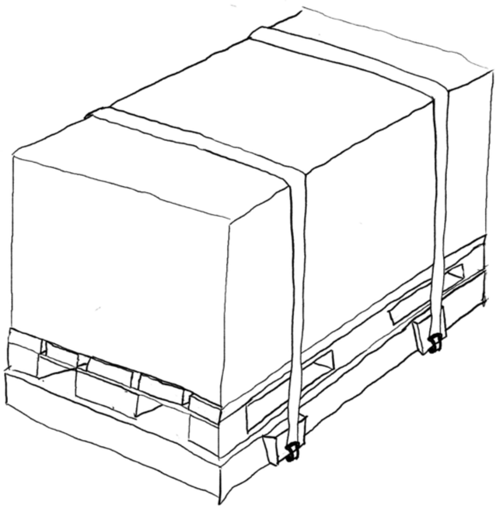

Figure 5-33. Sketch of the cargo layout for Concept 3: Forklift Cargo Box (Source: Author).

Cargo Concept Evaluation

The Cargo concepts were evaluated based on criteria derived from the subsystem requirements (Figure 5-34).

Scoring Matrix - Cargo							
	Rail		Lift In		Forklift		Comment
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Cost - 3	3	9	3	9	4	12	Materials and labour
Integration - 4	4	16	4	16	5	20	Fixture to frame
Ease of use - 5	5	25	3	15	3	15	Maximum 2 persons
Stability - 5	5	25	5	25	3	15	Height of centre of gravity and balance
Manufacturability - 4	4	16	4	16	5	20	complexity of construction
Weighted total	91		81		82		Winner: Rail Cargo Box

Figure 5-34. Scoring matrix of the cargo subsystem (Source: Author).

Selected Cargo Concept

Concept 1 the *Rail Cargo Box* received the highest score. This concept provides good stability in motion and ease of use for one to two persons compared to the other concepts.

5.2.12 Seating

Function and Requirements

Seating provides ergonomic support for the rider. Proper seating design influences rider posture, safety and comfort.

The following requirements are the most relevant for the seating subsystem:

1. Provide ergonomic support for the rider during operation
2. Ensure rider comfort during extended use
3. Ensure rider safety during operation
4. Allow the rider to effectively steer the vehicle and generate propulsion force
5. Integrate with the frame and vehicle geometry
6. Use simple, robust and locally available components

Concept Generation

Three seating concepts describing the rider position and seat configuration were developed and subsequently evaluated using a scoring matrix.

Concept 1 – Composite bucket seat

The composite bucket seat (Figure 5-35) is designed as one whole component produced through a single part moulding process. This approach integrates all structural and functional features into one continuous geometry, reducing the need for joints, fasteners and secondary assembly operations.

Figure 5-35. Sketch of Seating for Concept 1: Composite bucket seat (Source: Author).

Concept 2 –Fabric seat with frame

The second seat concept is designed as an assembly consisting of a structural frame and a woven seating surface (Figure 5-36). The load bearing frame provides overall stiffness and geometry, while the woven material forms the seating surface, allowing for flexibility, ventilation and ergonomic conformity. This approach separates structural and comfort functions, enabling repair or replacement of individual components and materials.

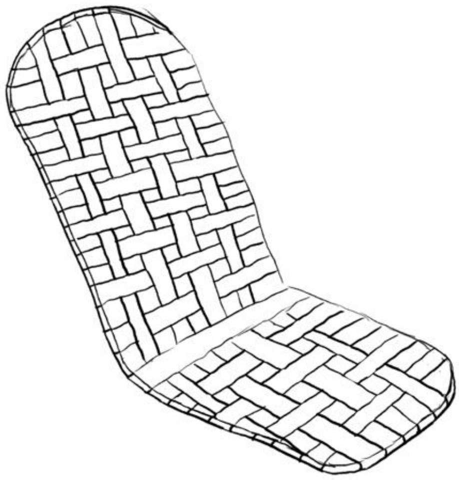

Figure 5-36. Sketch of Seating for Concept 2: Fabric seat with frame (Source: Author).

Concept 3 – Three-piece seat

This seat is a three part system consisting of a headrest, backrest and seat, connected with rods (Figure 5-37). Each component serves a distinct functional role, providing support to different regions of the body. The seat distributes the rider's weight, the backrest supports the torso during acceleration and braking and the headrest offers additional support for the neck.

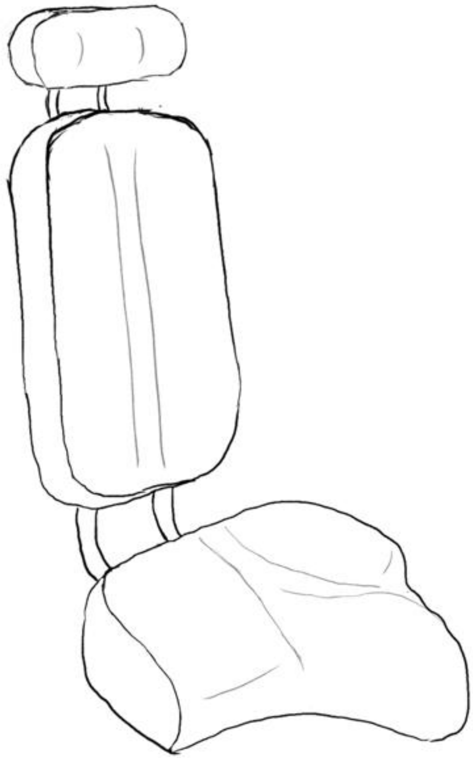

Figure 5-37. Sketch of seating for Concept 3: Three-piece seat (Source: Author).

Concept Evaluation

The seating concepts were evaluated using criteria derived from the subsystem requirements (Figure 5-38).

Scoring Matrix - Seating							
	Composite bucket seat		**Fabric seat with frame**		**Three-piece seat**		**Comment**
Criteria/Score	Score	Weighted	Score	Weighted	Score	Weighted	
Comfort - 4	3	12	4	16	5	20	Ergonomics
Integration - 5	5	25	3	15	4	20	Interaction with steering, drivetrain, etc
Cost - 3	4	12	5	15	4	12	Assuming in-house production
Safety - 5	4	20	3	15	5	25	In case of crash
Manufacturability - 4	2	8	4	16	2	8	Assuming in-house production
Weighted total	77		77		85		Winner: Three-piece seat

Figure 5-38 Scoring matrix of the seating subsystem (Source: Author).

Selected Seating Concept

The solution with the highest score was the *Three-piece seat* (Concept 3). This concept provides improved comfort and rider support while maintaining a simple and ergonomic design.

5.2.13 Safety Features

The safety features subsystem includes components designed to increase rider and cargo safety. These features primarily reduce the risk in the event of accidents and in urban environments. The subsystem focuses on increasing visibility, protecting the rider and ensuring safe cargo transport. Bolivia does not have safety regulations regarding bicycles, but the city of Cochabamba, where the project was conducted, has rules implemented in 2025 (Asamblea Legislativa Departamental de Cochabamba, 2025). These rules are generally not followed by the population, but act as a reference for the development of safety features.

The following requirements are the most relevant for the safety features subsystem:

1. Increase visibility of the vehicle in urban traffic
2. Protect the rider during operation
3. Ensure safe transport of cargo under dynamic conditions
4. Reduce the risk of accidents and damage
5. Integrate with the existing vehicle design
6. Use simple, robust and locally available components

Safety Feature Category Identification and Development

The developed safety features were grouped into three different categories and are listed below. Features from the different categories were then combined and implemented as one safety feature set.

Passive Safety Features

Passive safety features improve visibility and reduce risk without requiring rider action.

- Front light
- Rear light
- Reflectors
- High-visibility painted frame
- Chain guard
- Battery firewall

Structural Safety Features

Structural safety features provide physical protection to the rider and cargo during operation and in the event of minor collisions.

- Front bumper: protects in case of frontal collision
- Rear bumper: protects in case of rear collision
- Side bumper: protects rider legs in collision
- Hand brake

Operational Safety Features

Operational safety features improve safe interaction with traffic during use.

- Turn indicators
- Horn/bell
- Mirrors
- Brake light
- Engine cutoff at breaking

Selected Safety Features

The following safety features were selected to be incorporated into the design based on the system requirements and the available resources:

- Front light
- Rear light
- Reflectors
- High-visibility painted frame
- Chain guard
- Front and side bumpers
- Hand brake
- Bell
- Mirrors

5.3 System Integration

5.3.1 Integration Strategy

The integration of the subsystems into a unified vehicle concept was carried out using an iterative approach. The process began with the definition of an initial frame layout, which served as the primary structural reference and established the overall vehicle architecture. The remaining subsystems, including suspension, steering and drivetrain, were then progressively integrated into this layout, with adjustments made to ensure geometric compatibility, functionality and manufacturability. The integration was supported by successive refinement of sketches, starting from rough layouts to more detailed designs, allowing for continuous improvement. Packaging conflicts and alignment issues were remedied continuously, ultimately resulting in a coherent system level design.

5.3.2 Design Decisions during System Integration

The integration of the subsystems revealed several design challenges that required adjustments of the initially selected concepts.

The front suspension was relatively straightforward to integrate, as mounting points could be introduced by adding square structural elements to the front of the ladder frame. These elements provide a simple and robust interface for attaching the double wishbone suspension without significantly altering the overall frame concept.

In contrast, the rear suspension presented greater challenges. During integration, it became clear that the initial assumption of a rigid rear axle when selecting the rear suspension was incorrect and does not function with the selected drivetrain concept. In avoiding the use of a differential, separate rear wheel axles were selected. This required a redesign of the rear suspension.

Two alternative solutions were developed based on the rest of the vehicle's subsystems and component availability. The first solution consists of an independent rear swing arm suspension with a centrally mounted jackshaft, where each rear wheel is mounted on a separate pivot fork equipped with two spring dampers. Power is transmitted from the jackshaft to each wheel via individual chain drives. This concept is inspired by motorcycle rear suspension systems and enables independent wheel movement while maintaining compatibility with the other subsystems. The design of the frame was modified to accommodate this rear suspension and the design complexity increased moderately.

The second solution utilises a conventional axle with an integrated differential and axle, combined with a standard leaf spring suspension. This configuration simplifies the drivetrain and suspension design, but it introduces packaging and integration challenges in terms of wheels, motor and powertrain. Additionally, the availability of such a small differential with axle is uncertain, the dimensions and costs unknown.

Based on these considerations, the independent rear suspension with jackshaft drive was selected as the preliminary solution since this is feasible to design and manufacture. The possibility of integrating an existing differential and axle is put on standby.

The remaining subsystems were integrated with few adjustments, mainly to the geometry of the frame. The steering system was positioned below the seat, while the seat itself was placed slightly behind the front axle to reduce steering load and improve handling. The motor was positioned above or slightly in front of the front axle to improve weight distribution and minimise the distance to the front crankset, allowing for simpler wiring and shorter chain routing. It remains to be seen whether the planned packaging is functional, but there is room for changes in placement of for example powertrain components.

The cargo system integrates well with the overall frame structure, as it is mounted on a dedicated rear platform. However, potential challenges related to ramp size and the incline of the ramp were identified and will be further evaluated during the dimensioning phase. Furthermore, the height of the centre of gravity of the entire vehicle may need to be determined to check that the construction is stable.

5.3.3 System Level Trade-offs

System compatibility versus structural complexity:

Achieving compatibility between the rear suspension and drivetrain required a more complex structural solution, resulting in increased frame complexity. This also makes chain alignment, tensioning and packaging more critical.

Packaging versus stability:

Rear suspension and drivetrain integration influence the height of the cargo platform, creating a trade-off between packaging constraints and maintaining a low centre of gravity.

Geometric consistency versus available space:

Maintaining consistent track width between front and rear required a narrower front frame, reducing available space for subsystem integration in the front section.

Performance versus feasibility of component placement:

The front mounted motor improves weight distribution and drivetrain efficiency, but may be constrained by limited available space, requiring potential design adjustments.

5.3.4 Overall Vehicle Concept

The final vehicle concept integrates all subsystems into a unified four wheel configuration, as shown in Figure 5-39 and Figure 5-40. The layout consists of a narrow front section with a double wishbone suspension and a wider rear section supporting the cargo platform. The rider is positioned slightly behind the front axle with an under seat steering system. The crankset it positioned in front of the rider and the rider has a slightly upright position. Front and side bumpers are integrated into the main frame structure to protect the rider in the event of a collision.

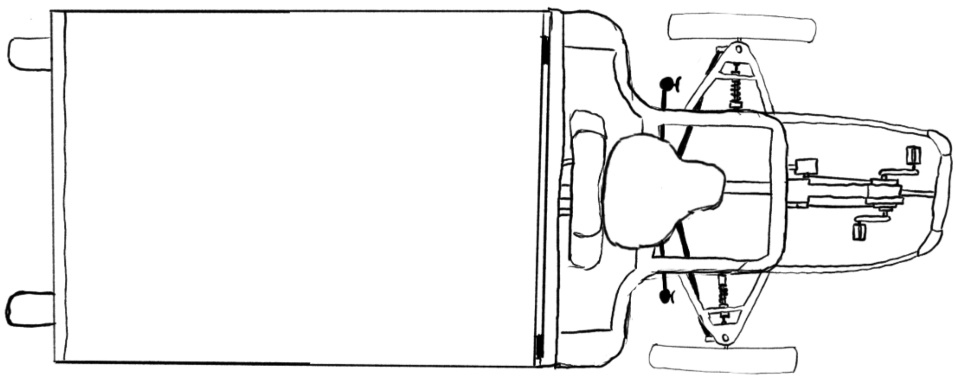

Figure 5-39. Top view of the integrated vehicle concept (Source: Author).

The drivetrain is arranged along the central axis of the vehicle, with power transmitted from the front mounted motor and crankset to the jackshaft from which it is then further distributed to each rear wheel via individual chain drives see, figure 5-41. The rear suspension consists of independent swing arms, allowing each wheel to pivot separately. The cargo system is mounted on a dedicated rear platform that has an integrated ramp. The square tubular frame beam profile was chosen because of availability, manufacturability and robustness.

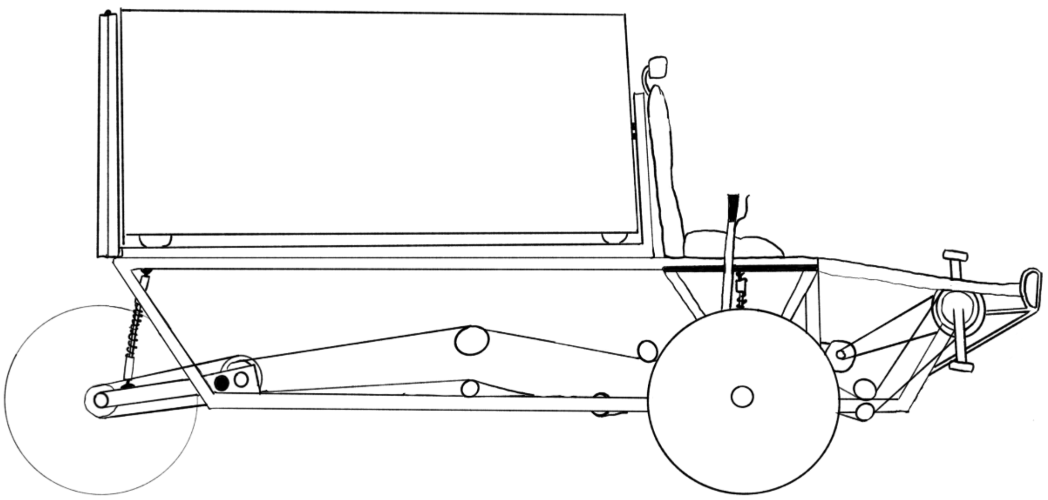

Figure 5-40. Side view of the integrated vehicle concept (Source: Author).

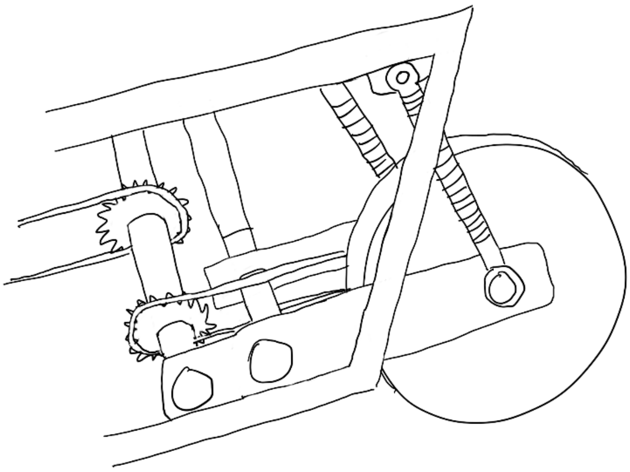

Figure 5-41. Revised rear suspension concept with independent swing arms and jackshaft drive (Source: Author).

5.4 Stakeholder Evaluation

A stakeholder meeting was conducted with the CEO of Eco delivery, the head of the production facility PDTF and academic supervisors from the technology cluster at UMSS. Overall, the feedback was highly positive. The CEO approved the proposed design and emphasized the importance of progressing rapidly to the next development stages. From a production perspective, the head of PDTF highlighted the necessity of producing detailed technical drawings, as these are essential for manufacturing. It was agreed on that the performed calculations can be reviewed and validated by the production engineer to ensure structural reliability. It was also recommended to perform finite element analysis (FEA) of the frame to further verify structural strength.

The academic supervisors responded positively to the applied methodology, particularly the structured approach based on Ulrich and Eppinger, where the cargo bike was decomposed into subsystems and developed individually.

Based on this feedback, the next steps involve defining frame dimensions based on benchmarking data and technical requirements, followed by selecting appropriate dimensions for structural beam elements. Development will then proceed with a parametric CAD model while dividing tasks efficiently: one individual focuses on numerical analysis of complex systems using engineering calculations and best practices and the other on initial CAD modelling. Subsequently, responsibilities will shift toward the CAD assembly and the creation of technical drawings to support manufacturing in accordance with the project timeline.

5.5 System Dimensioning and Structural Validation

5.5.1 Preliminary System Dimensions

The overall dimensions of the cargo vehicle were defined based on benchmarking data, stakeholder input and system requirements. These dimensions were used as a basis so that design work of subsystems could continue in parallel. The preliminary system dimensions are listed in Table 5-7 and illustrated in Figure 5-42.

Table 5-7 Preliminary system dimensions.

Parameter	*Value (mm)*	*Comment*
Total Length	3000	Slightly shorter than benchmarked reference.
Total Width	960	Under max. allowed width of 1000mm.
Total Height	1500	Low profile below typical traffic sightlines.
Wheelbase	1350	Approx. 45% of total vehicle length.
Track width	900	Close to maximum allowable width.
Main beam profile	40x40	Square tubular (available in Cochabamba)
Secondary beam profile	30x30	Cross members/support main structure
Wall thickness of profiles	2	Will later be validated using FEA
Material	Carbon steel	Cheap and readily available

Note: Dimensions defined as outer extents; wheelbase measured axle to axle and track width wheel to wheel (centre to centre).

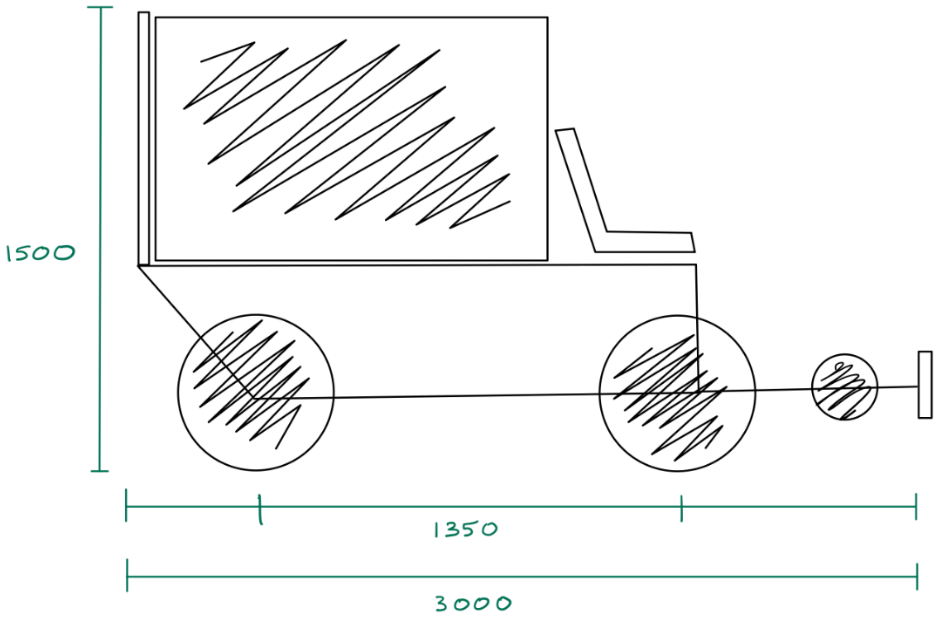

Figure 5-42. Annotated sketch containing the overall dimensions of the cargo bike (Source:Author).

To gain an overview of the critical loads that the system is expected to withstand, three load cases were defined based on the preliminary system dimensions. These load cases can then be used in the event of further structural simulations. The load cases represent vertical loading under maximum payload, braking on an incline and cornering conditions.

5.5.2 Load case 1: Static Vertical Loading at standstill

Load case 1 represents the vehicle standing still on level ground under maximum payload. The purpose of this load case is to determine vertical reaction forces acting at the wheels.

Free Body Diagram

The free body diagram for load case 1 is shown in Figure 5-43. The total load consists of the vehicle weight W_v, rider weight W_R and payload weight W_P. These forces act at each objects centre of gravity. The reaction forces are labeled R_F and R_R for the front and rear axles.

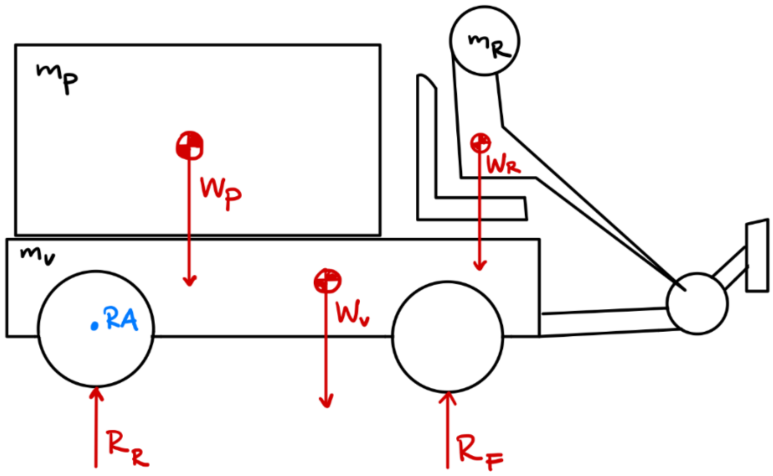

Figure 5-43. Free body diagram for load case 1: static vertical loading of the whole vehicle on level ground(Source: Author).

Equilibrium Calculations and Result

The equilibrium equations shown in Figure 5-43. Free body diagram for load case 1: static vertical loading of the whole vehicle on level ground(Source: Author). are used to determine the vertical reaction forces at the front and rear axles. The equations are formulated using static force and moment equilibrium. The moment equilibrium is taken about the rear axle. The distances x_v, x_r and x_p are the longitudinal positions of the vehicle, rider and payload centres of gravity relative to the rear axle.

Force equilibrium

$$\Sigma F_y = 0$$

$$\uparrow: \quad R_F + R_R - W_v - W_R - W_P = 0$$

Moment equilibrium

$$\Sigma M_{RA} = 0$$

$$\circlearrowleft RA: \quad R_F \cdot L - W_R \cdot x_R - W_v \cdot x_v - W_P \cdot x_P = 0$$

Reaction forces

$$\Rightarrow R_R = W_v + W_R + W_P - R_F$$

$$\Rightarrow R_F = \frac{W_R \cdot x_R + W_v \cdot x_v + W_P \cdot x_P}{L}$$

Figure 5-44. Equilibrium equations for load case 1 (Source: Author).

The equations show that the load distribution between the front and rear axles depends mainly on the longitudinal positions of the vehicle, rider and payload. The position of the payload has the greatest influence on the reaction forces because it has the largest relative mass. The equations provide a clear overview of the force distribution and can later be used to calculate the actual loads once the design is finalised.

5.5.3 Load case 2: Braking on a downward incline

Load case 2 represents braking on an incline with maximum payload. The purpose of this load case is to evaluate the longitudinal load transfer in the vehicle and to identify the risk of rear wheel lift during braking.

Free Body Diagram

The free body diagram for load case 2 is shown in Figure 5-45. The vehicle is modelled as a rigid body on an incline with slope α. The total weight W is the sum of the weights of all 3 objects. The front and rear axle normal forces are labelled N_F and N_R. The braking forces are represented by F_{BF} and F_{BR}. The direction of travel is indicated by the velocity v.

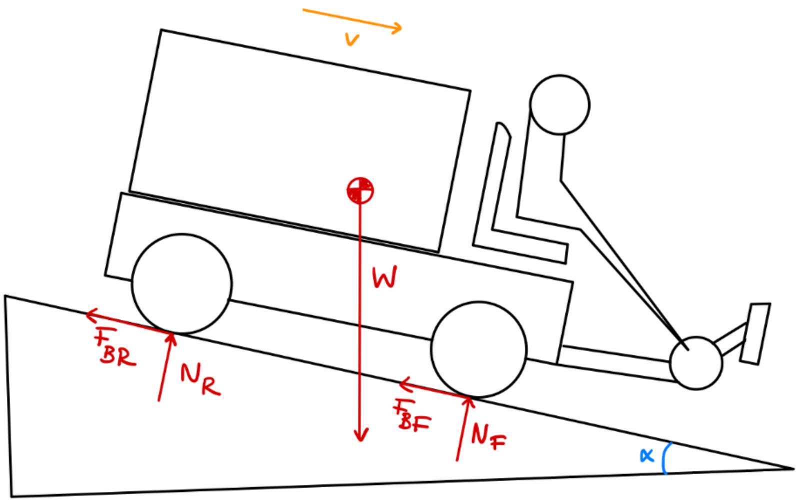

Figure 5-45. Free body diagram for load case 2: braking on an incline (Source: Author).

Equilibrium Calculations and Result

The equilibrium equations are shown in Figure 5-46. The moment equilibrium is taken about the rear axle. The positive horizontal direction is defined in the downhill direction. The longitudinal acceleration is negative because the vehicle decelerates while moving in the positive direction.

The centre of gravity is defined by its longitudinal position x_{cg}, measured from the rear axle and its height above the ground h_{cg}. The braking force $F_B$acts along the slope, opposite to the direction of travel.

<u>Force equilibrium</u>

$$\Sigma F_x = m a_x \;,\; a_x < 0 \;,\; \Sigma F_y = 0$$

$$F_B = F_{BF} + F_{BR}$$

$$\rightarrow : (N_F + N_R)\sin\alpha - F_B \cos\alpha = m a_x$$

$$\uparrow : (N_F + N_R)\cos\alpha + F_B \sin\alpha - W = 0$$

<u>Moment equilibrium</u>

$$\Sigma M_{RA} = 0$$

$$\circlearrowleft RA : N_F \cdot L - W \cdot x_{cg}\cos\alpha - W \cdot h_{cg}\sin\alpha - F_B \cdot h_{cg} = 0$$

<u>Solution</u>

$$\Rightarrow N_F = \frac{W \cdot x_{cg}\cos\alpha + W \cdot h_{cg}\sin\alpha + F_B \cdot h_{cg}}{L}$$

$$\Rightarrow N_R = \frac{W - F_B \sin\alpha}{\cos\alpha} - N_F$$

$$\Rightarrow F_B = W \cdot \sin\alpha + m a$$

Figure 5-46. Equilibrium equations for load case 2 (Source: Author).

The resulting equations for the front and rear axle reaction forces show that a lower centre of gravity and a longer wheelbase reduce the risk of tipping during braking. The critical point occurs when the rear axle normal force becomes zero:

$$N_R = 0$$

At this point the rear wheel has lifted and tipping occurs. This condition can be used to evaluate the stability of the vehicle during braking.

5.5.4 Load case 3: Cornering and lateral stability

Load case 3 represents the vehicle cornering under maximum payload. The purpose of this load case is to evaluate the lateral load transfer in the vehicle and to identify the risk of wheel lift and rollover during turning. This load case is important due to the narrow vehicle width and high payload.

Free Body Diagram

The free body diagram for load case 3 is shown in Figure 5-47 and includes both a rear view and a top view of the vehicle during cornering. The rear view shows the weight W, the vertical wheel reactions $N_L$and N_R, the track width t and the centre of gravity height h_{cg}. The lateral tire forces are also shown and supply the centripetal force. The top view illustrates this force together with the vehicle velocity v.

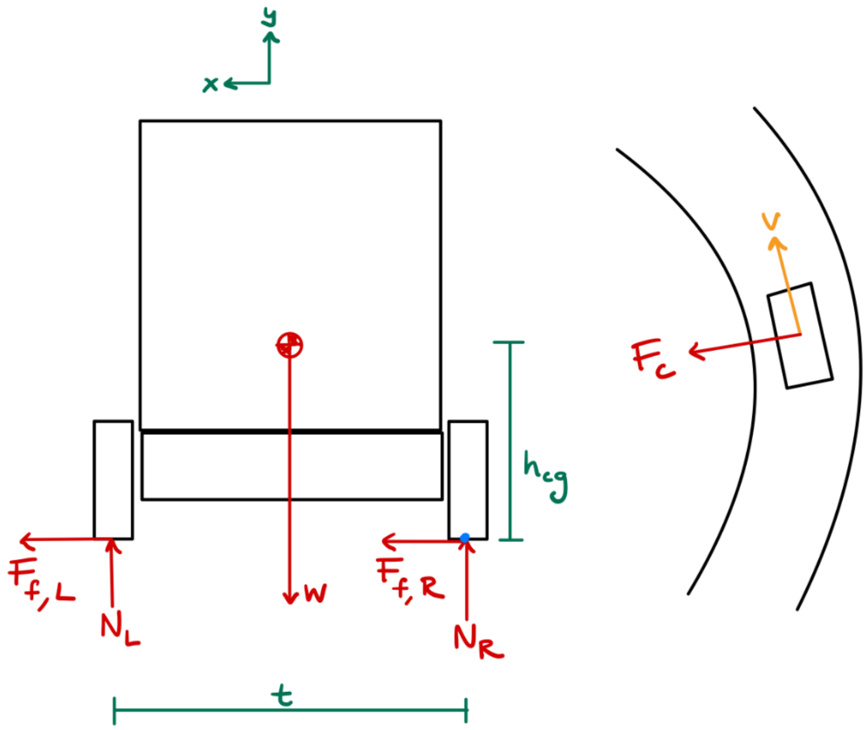

Figure 5-47. Free body diagram for load case 3: cornering and lateral stability (Source: Author).

Equilibrium Calculations and Result

The force and moment equilibrium equations are shown in Figure 5-48. The limiting condition for rollover occurs when the reaction force at the inner wheel becomes zero. Thus, the moment is taken about the outer wheel as the vehicle will rotate about this point when it starts to roll.

Force equilibrium

$$\sum F_x = F_c = m a_x \,, \sum F_y = 0$$

$$\leftarrow : \quad F_{f,L} + F_{f,R} = m a_x$$

$$\uparrow : \quad N_L + N_R - W = 0$$

Moment equilibrium

$$\sum M_R = 0 \,, \quad \text{Rollover} : N_{inner} = 0$$

$$\circlearrowleft M_R : \quad -W \cdot \frac{t}{2} + m a_x \cdot h_{cg} = 0$$

Solution

$$\Rightarrow \quad a_x = g \cdot \frac{t}{2h_{cg}} \quad \Rightarrow \quad F_{tip} = \frac{W_t}{2h_{cg}}$$

Figure 5-48. Equilibrium equations for load case 3 (Source: Author).

Solving the equilibrium equations gives the critical lateral acceleration a_x and the corresponding lateral force required to tip the vehicle. The results show that the track width and the centre of gravity height affect the risk of rollover. A larger track width and lower centre of gravity improves stability.

5.5.5 Rear Suspension Geometry

This section defines the rear suspension design loads and the initial suspension geometry used for dimensioning the swingarms, dampers and mounting points. The suspension was first dimensioned according to general rules of thumb and then iteratively adjusted to suit the required needs whilst remaining functional.

Design Inputs and Assumptions

The key design inputs used for dimensioning the rear suspension are summarized in Table 5-8 and are based on the preliminary system dimensions.

Table 5-8. Design Inputs for the Rear Suspension.

Parameter	*Symbol*	*Value*
Rider mass	m_r	90 kg
Payload mass	m_p	200 kg
Frame mass	m_f	70 kg
Other components	m_c	70 kg
Total vehicle mass	m_{tot}	430 kg
Gravitational acceleration	g	9.81 m/s^2
Total weight	$W = m_{tot}\, g$	4218 N
Rear axle load	W_{rear}	2953 N
Static rear wheel load	$W_{wheel}=W_{rear} / 2$	1476 N
Wheel stiffness	$k_w= W_{rear} / s_w$	59 N/ mm
Wheel size		17 inches
Estimated outer wheel diameter	D_w	570 mm
Estimated outer wheel radius	R_w	285 mm
Speed bump max. height	h_s	120 mm
Target safety factor	SF	1.5

Target values

Based on these inputs, a set of target values were defined to guide the initial suspension dimensioning. The target values were selected based on the vehicle layout and expected operating conditions. A rear load fraction of 70% was assumed due to the payload being positioned above the rear axle. The wheel travel of 100 mm was chosen to accommodate road irregularities such as speed bumps up to 120 mm in height, while a static sag of 25% of the total travel was selected.

- Rear load distribution at full payload: $\lambda_{rear} = 0.70$
- Total wheel travel: $T_w = 100mm$
- Static sag: $s_w = 25$mm
- Upward wheel travel: $T_b = T_w - s_w = 75\ mm$
- Ride Height: $H_r = 220mm$
- Rear Axle at Ride Height: $H_{axle,ride} = 285mm$
- Axle height at full bump: $H_{axle,bump} = H_{axle,ride} + T_b = \ 360\ mm$
- Swingarm length: $L = 400mm$
- Damper angle from vertical: $\theta = 30°$

A loaded ride height of 220 mm was selected as it maintains the necessary ground clearance and keeps the centre of gravity low. The rear axle height at ride height was defined from the estimated wheel radius of the 17-inch wheel and tire combination, resulting in an axle height of 285 mm. From the selected wheel travel and sag, the upward wheel travel from ride height is 75 mm, resulting in a maximum axle height of 360 mm. A pivot position of approximately 400 mm ahead of the axle and 300 mm above ground resulted in a swingarm length of approximately 400 mm.

Coilover Length and Stiffness

The coilover length was determined geometrically from the selected suspension layout, seen in Figure 5-49. The image shows the rear suspension swingarm at ride height and follows the movement of the swingarm along its radius when the coilover is compressed at the "bump" condition. The model is used as a type of motion study of the rear suspension system.

Based on the preliminary suspension geometry, the coilover length at ride height was 260 mm and the corresponding length at full bump was 238 mm. This resulted in a required coilover stroke of 22 mm. To provide sufficient design margin and avoid bottoming, a coilover stroke of at least 35 mm is required, while a 40–50 mm stroke is considered preferable.

- Required coilover stroke: $S_{req} = L_{c,ride} - L_{c,bump} = 22mm$
- Recommended minimum coilover stroke: $S_c \geq 35mm$

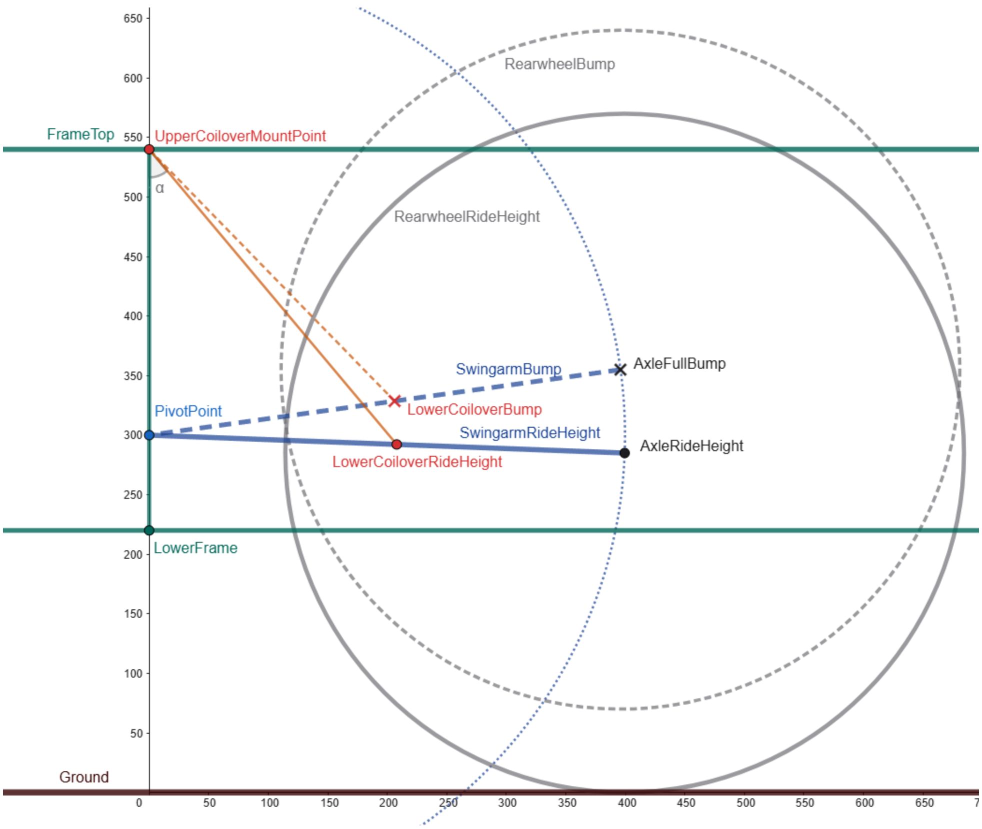

Figure 5-49. Model of rear suspension made in GeoGebra used for iterative development of the design (Source: Author).

The initial suspension geometry resulted in an unrealistically high required spring stiffness due to a low motion ratio. This would require spring stiffness values significantly higher than those available in standard motorcycle or ATV coilover units. Therefore, the geometry was iteratively adjusted. The upper coilover mounting point was raised by 20 mm and the coilover inclination was increased to 40° from vertical. In addition, the static sag was increased from 25 mm to 30 mm. The ride height was also lowered to 180mm to make the vehicle more stable. These modifications resulted in a more effective suspension geometry that aligns with commercially available coilover components.

- Lower mount position: $L_{mount} = 208$ mm
- Upper mount position: $H_{Umount} = 320$ mm
- Coilover length: $L_{c,ride} = 347$ mm
- Coilover stroke: $S_c \geq 33mm$
- Spring stiffness: $k_c = \frac{W_{wheel}}{2\, s_w\, MR^2} = 121\ N/mm$

5.5.6 Front Suspension Geometry

Design Inputs and Assumptions

The key design inputs used for dimensioning the front suspension are summarized in Table 5-9.

Table 5-9 Design Inputs for the Front Suspension.

Parameter	***Symbol***	***Value***
Rider mass	m_r	90 kg
Payload mass	m_p	200 kg
Frame mass	m_f	70 kg
Other components	m_c	70 kg
Total vehicle mass	m_{tot}	430 kg
Gravitational acceleration	g	9.81 m/s^2
Total weight	$W = m_{tot}\, g$	4218 N
Front load fraction	λ_{front}	0.30
Front axle load	W_{front}	1265 N
Static wheel load	$W_{wheel} = W_{front}/ 2$	632 N
Wheel size		17 inches
Estimated outer wheel diameter	D_w	570 mm
Estimated outer wheel radius	R_w	285 mm
Track width (front)	t_f	900 mm
Wheelbase	L	1350mm
Speed bump max. height	h_s	120 mm
Target safety factor	SF	1.5

Target values

Based on these inputs, a set of target values was defined to guide the initial front suspension sizing. The target values were selected based on the vehicle layout and expected operating conditions. A front load distribution of 30% was assumed due to the payload being primarily positioned towards the rear of the vehicle. The wheel travel of 100 mm was chosen to accommodate road irregularities such as speed bumps, while a static sag of 25% of total travel was selected to ensure balanced suspension operation. The ride height and axle height remained the same as for the rear.

- Front load distribution at full payload: $\lambda_{front} = 0.30$
- Total wheel travel: $T_w = 100mm$
- Static sag: $s_w = 25$mm
- Upward wheel travel: $T_b = T_w - s_w = 75\ mm$
- Downward wheel travel: $T_d = s_w = 25\ mm$
- Ride Height: $H_r = 180mm$
- Front Axle at Ride Height: $H_{axle,ride} = 285mm$
- Axle height at full bump: $H_{axle,bump} = H_{axle,ride} + T_b = 360\ mm$

For the initial double wishbone geometry, dimensions were selected based on the available frame packaging and system requirements such as track width. The selection of wheel angles such as camber and toe was determined to not be within the scope of this project and can be adjusted for during testing.

An initial configuration of the coilover position and suspension geometry was modelled in GeoGebra as shown in Figure 5-50. The model shows a front view of the two suspension arms connected to the hub/upright that the wheel is mounted to. The coilover spring is compressed as the arms move upwards along their respective arcs, simulating the wheel moving over a speed bump for example. This model can be used to determine values such as the length of the coilover, required spring stiffness and the motion of the system once the geometry has been set in the CAD model. The goal is for the spring stiffness to be withing the 60–65 N/mm range according to available coilovers on the market.

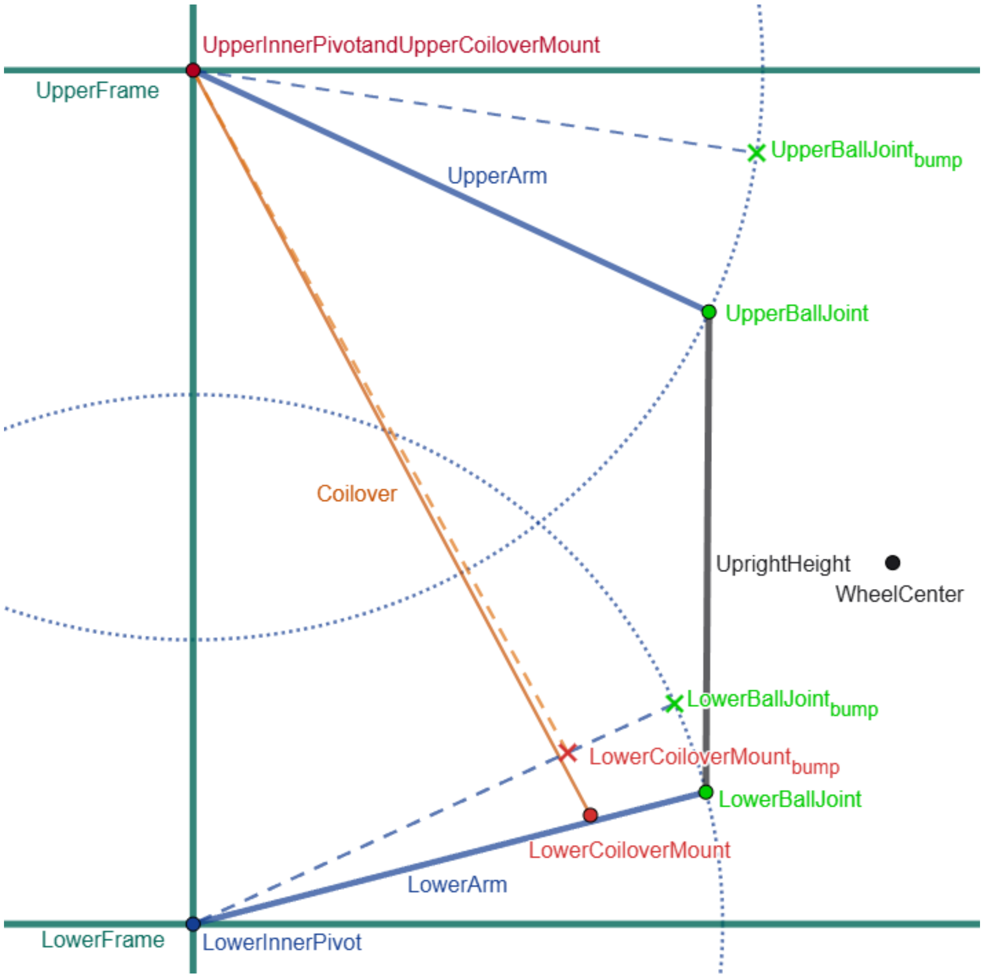

Figure 5-50. Model of front suspension made in GeoGebra used for iterative development of the design, front view (Source: Author).

5.5.7 Seating Dimensioning

A study was conducted on the recumbent position of the rider compared to the drivetrain crankset using the report from Garnet (2004). The goal of the specific study was to determine the distance between hip joint and bottom bracket of crank set. The study also included questions regarding seating angles, height and seat geometry. The study from Garnet (2004) found that the optimal distance between hip pivot to bottom bracket was 841 mm, which was deemed relevant in physical tests. In the report, the most ergonomic, safe and effective seating angle was approximately 53 degrees from upright but depends on various variables and can be inappropriate in some cases.

5.5.8 Drivetrain Dimensioning

The drivetrain was preliminarily dimensioned to meet the target 30 km/h cruising speed while maintaining pedal operability without motor assist, as defined in the requirement specifications.

The wheel diameter with tyre was estimated to *D*, giving a circumference *C*. At a velocity of 30 km/h, the required wheel rotational speed becomes

$$n_{wheel} = \frac{v}{C}$$

A relatively low cadence of 70 rpm was selected to prioritise control and stability under high load and in unpredictable traffic conditions. The required total transmission ratio is therefore given by

$$i_{tot} = \frac{n_{wheel}}{n_{crank}}$$

This ratio is then used to size the middle chainring as the primary operating gear, while the smaller chainring allows for easy hill starts and the larger chainring enables the target speed of 30km/h. The drivetrain consists of a two stage transmission, crankset to jackshaft and then jackshaft to the rear wheels. The total ratio is therefore defined as:

$$i_{tot} = \frac{T_{front}}{T_{jack,in}} \cdot \frac{T_{jack,out}}{T_{wheel}}$$

The number of teeth on each sprocket in the drivetrain are selected based on this ratio whilst considering part availability.

5.6 Prototyping

5.6.1 CAD Modelling Strategy

A top-down CAD modelling strategy was used. The CAD was constructed to be parametric, allowing changes to the geometry to be easily made. Dimensions such as the width, length and height of the frame were parameterised. The frame geometry was continuously altered to fit each new subsystem. Key subsystems were designed as subassemblies and then integrated into the frame. The design was iteratively refined throughout the CAD process based on packaging constraints, manufacturability considerations and engineering design guidelines.

5.6.2 Iterative Design Changes

Several design changes were made during the CAD process to ensure proper subsystem integration, part availability and manufacturability.

Frame and Packaging

The ride height was reduced to approximately 180 mm to lower the centre of gravity and improve stability. The frame height was therefore increased to accommodate the coilover. The rear section of the frame was reduced to 800 mm in width to match the cargo box width, reducing material use and unnecessary structural width. The overall vehicle width was kept below the 1000 mm requirement to maintain compatibility with narrow roads and bicycle infrastructure in Cochabamba. Several secondary support beams were reduced in size to save weight and improve component packaging.

Wheels, Suspension and Hubs

The wheels were changed from larger motorcycle wheels to 20 inch BMX wheels. This change improved compatibility with bicycle components. It also reduced packaging complexity around the rear axle and made the drivetrain easier to integrate. However, the change required revised suspension geometry and hub design.

The rear suspension was redesigned so that the wheels were positioned outside the frame while the two dampers were placed inside the chassis. This improved packaging and allowed the suspension to be integrated within the available frame width. The front and rear suspension mounting points were adjusted several times to reduce interference between the wheels, wishbones, steering links, brake discs and frame.

The front suspension was revised to use standard rod end bearings and straight circular tubes. This improved manufacturability and maintained structural simplicity. The hub geometry was also simplified after several iterations to reduce manufacturing cost and improve compatibility with the wishbones, wheel mounts and steering linkage.

Steering

The steering system was redesigned from the initially selected direct steering concept to a headset based system with tie rods and a central link. During CAD integration, the original steering layout was found to interfere with the suspension and wheel packaging. The revised solution allowed the use of standard bicycle components such as headset bearings while improving serviceability and availability.

The introduction of tie rods and a central link increased mechanical leverage, reducing steering effort under heavy load. However, the required steering linkage geometry also increased the wheelbase. This slightly reduces turning performance but improves longitudinal stability and creates more packaging space for the rider, cargo and drivetrain.

Cargo System

The cargo box door placement was revised to improve access to the full cargo volume. The locking mechanism between the cargo box and frame was also updated to make fast cargo exchange possible while keeping the mechanism reachable and simple to operate.

The ramp concept was simplified by removing unnecessary components. This improved manufacturability, reduced weight and made the loading system more robust.

Braking and Safety

The rear braking system was changed to motorcycle brake discs because the rear axle carries a large part of the payload and therefore requires higher braking capacity. This is also consistent with Eco Delivery's existing experience, where motorcycle braking components have already been used to improve robustness and braking performance. Bicycle disc brakes were retained at the front to reduce complexity and weight.

The rear brake disc diameter was later increased to 180 mm to resolve interference between the driven sprocket and braking system. A bicycle brake lever with integrated locking function was selected for the front brakes, while an additional locking clip was designed for the rear brake lever to improve parking safety on inclines. Front lights, rear lights and reflectors were also added for traffic safety.

Drivetrain and Powertrain Packaging

The drivetrain sprockets were changed to use more common tooth counts and to better accommodate the high rpm motor. The jackshaft was selected as a solid shaft to withstand the expected torque transfer from both the motor and pedal drivetrain. The motor was repositioned to the rear section and connected directly to the jackshaft. This avoided routing high motor torque through the front crank area and reduced the risk of excessive loading in the pedal drivetrain. A freewheel was integrated on the pedal side of the jackshaft to prevent the motor from back driving the crankset during operation.

The battery placement was also revised so that the batteries were mounted low and centrally between the axles, symmetrically around the vehicle centreline. This was done to improve weight distribution and lower the centre of gravity.

Fasteners and Manufacturing

Hex socket head cap screws were selected for the main bolted joints. This reduces tool variation during assembly and maintenance and supports a more standardised manufacturing process.

6 Deliver

This chapter presents the Deliver phase of the project, where the developed concept is finalised. The work focuses on presenting the final CAD model and specifying the subsystems and their respective components.

6.1 The Digital Prototype - Tunari 1.0

The main subsystems that make up the first prototype, Tunari 1.0, are presented below:

Frame

The Frame is made of lightweight aluminium square beams with dimensions 30x30x2 with support beams being 25x25x2. It is a solid welded structure with drilled holes for mounting of subsystems. The frame is shown in Figure 6-1.

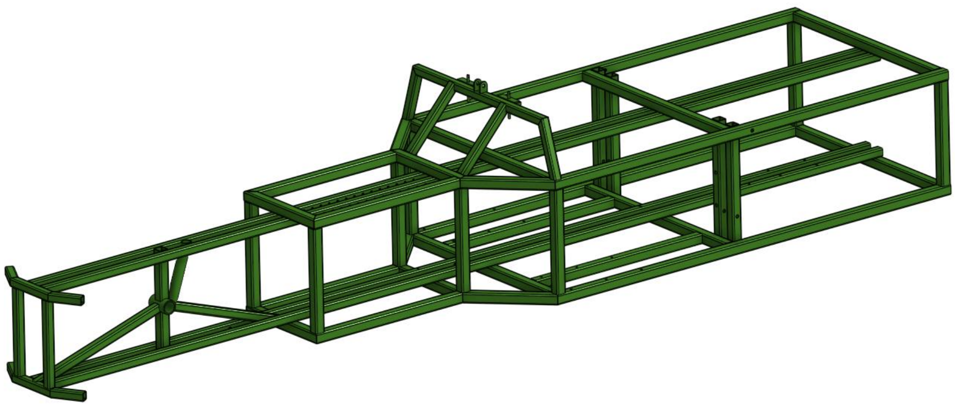

Figure 6-1. Digital prototype of frame (Source: Author).

Steering

The steering system repurposes two standard bicycle steering systems as seen in Figure 6-2. The headtube from a bicycle is to be mounted to the frame. The steering tube is cut off from the fork and used in conjunction with the headset and stem. A custom handlebar is mounted in the stem. The two steering columns are connected via a centre link. Each steering column is connected to the hub via a tie rod.

Figure 6-2. Digital prototype of steering (Source: Author).

Front Suspension

Each front suspension configuration consists of two wishbone arms connected to the wheel upright and frame brackets via fisheye rods. On each upright, a 20-inch BMX wheel is mounted with a 10 mm axle. The upright also includes a mounting plate for disc brake callipers, which interacts with brake discs on the wheel. The left and right front suspension units operate independently from each other but are connected via the steering centre link. The digital prototype of the front suspension is shown in Figure 6-3.

Figure 6-3. Digital prototype of front suspension (Source: Author).

Rear Suspension

The rear suspension consists of two coilovers per side with a swingarm connected to the frame. A 20-inch BMX wheel with a disc brake compatible hub is connected to the swingarm as seen in Figure 6-4. A custom sprocket carrier allows for brake disc and sprocket to be mount on the same side of the wheel. A fixed bolt on BMX style sprocket with 34T is used in conjunction with a motorcycle brake disk and a corresponding brake caliper.

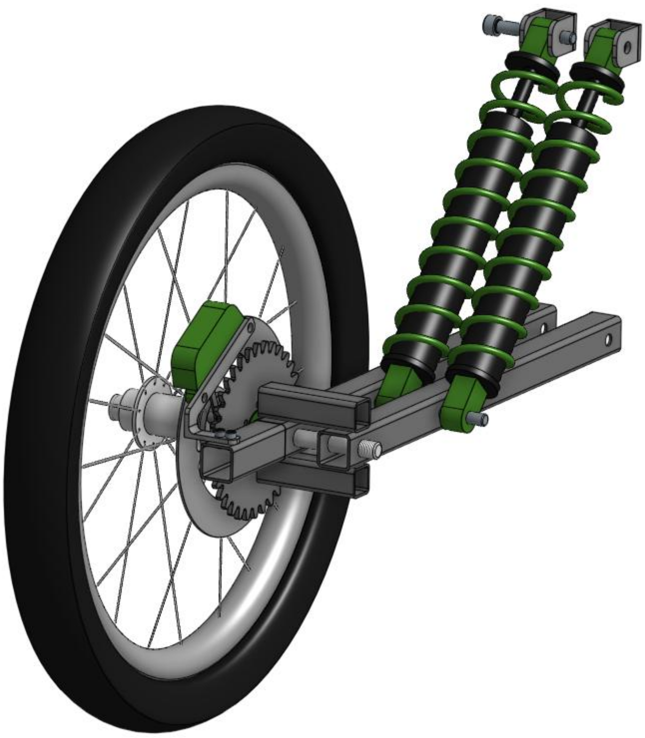

Figure 6-4. Digital prototype of rear suspension (Source: Author).

Drivetrain

The drivetrain consists of a 3 speed crankset with a front derailleur. Plastic chain rollers guide and tension the 6 speed chain to the 20T freewheel on the jackshaft. The freewheel is mounted to the jackshaft using a custom freewheel adapter. A 16T BMX freewheel with a corresponding adapter transmits the torque to each rear wheel via BMX chain. The jackshaft is mounted to the frame using two pillow block bearings. The drivetrain is shown in Figure 6-5.

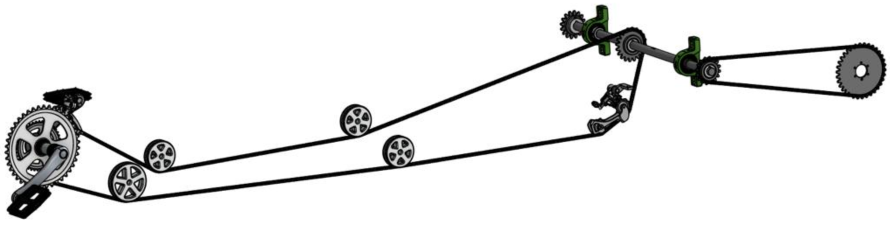

Figure 6-5. Digital prototype of drivetrain (Source: Author).

Powertrain

The powertrain system, as shown in Figure 6-6, includes a 48 V brushless DC motor. The energy storage consists of two 48 V 30 Ah batteries connected in parallel. An 11T to 60T sprocket pair using a 428 motorcycle chain connect the motor to the jackshaft. Motor output is regulated by a 48 V BLDC motor controller, while a pedal assist sensor (PAS) controls the level of motor assistance and a Cycle Analyst unit functions as the rider interface. The system also includes a DC circuit breaker for safety and a DC-DC converter for the front and rear lights.

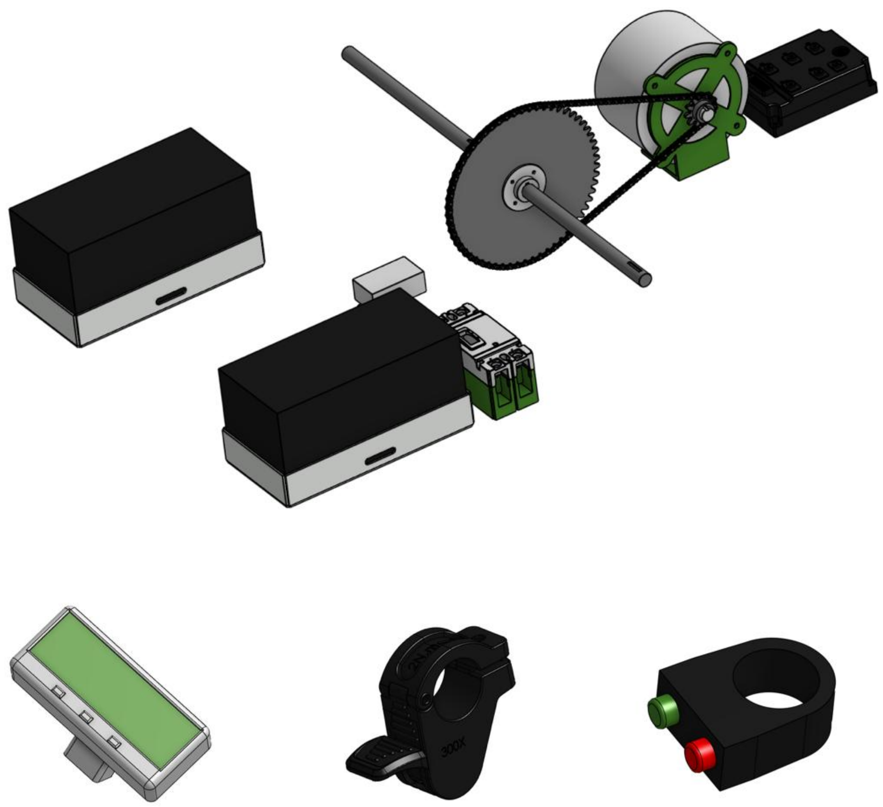

Figure 6-6. Digital prototype of powertrain (Source: Author).

Cargo

The cargo box rests on rails placed on top of the frame and can wheeled on and of the rear ramp. The structure of the box consists of welded beams with insulated sandwich panels as walls, ceiling and floor. The box can be opened from the side for quick access but can also be opened from the rear when the ramp is folded down.

The doors on the box are locked with clasps and hinges. The cargo box and ramp can be seen in Figure 6-7.

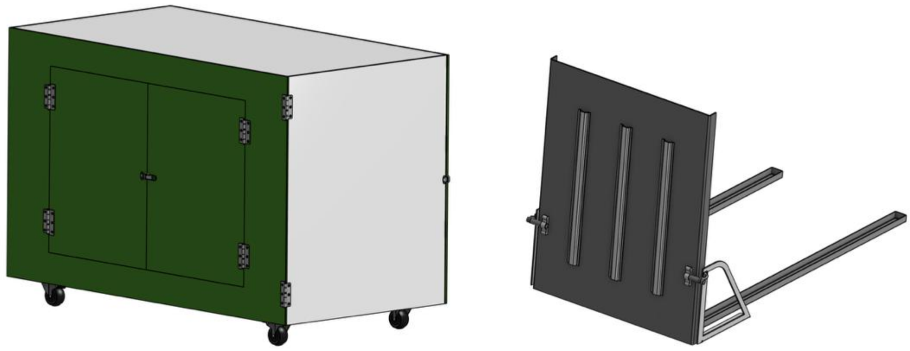

Figure 6-7. Digital prototype of cargo (Source: Author).

Seating

The rider sits on an adjustable recumbent seat on top of the frame. The seat is manufactured with a skeleton structure of beams and later dressed in fabric. It consists of a bottom part, backrest and headrest which together improve ergonomic aspects of the seat and reduce risk of whiplash injury in case of a crash. The seat is adjustable through a slide mechanism on the frame to ensure the correct distance between rider and pedals. The subsystem is shown in Figure 6-8.

Figure 6-8. Digital prototype of seating (Source: Author).

Safety Features

This subsystem is not a connected set of parts, but several components that individually improve the safety of the rider and surrounding traffic, as shown in Figure 6-9. Taillights, headlights and reflectors improve visibility. The lights are connected to the main battery via a converter. The side mirrors enable the rider to see behind the cargo box and the horn is especially important in Bolivian traffic conditions as many riders and drivers use their horn to signal right of way in intersections. The front bumper is an additional physical protective measure that is integrated into the frame as seen in Figure 6-1.

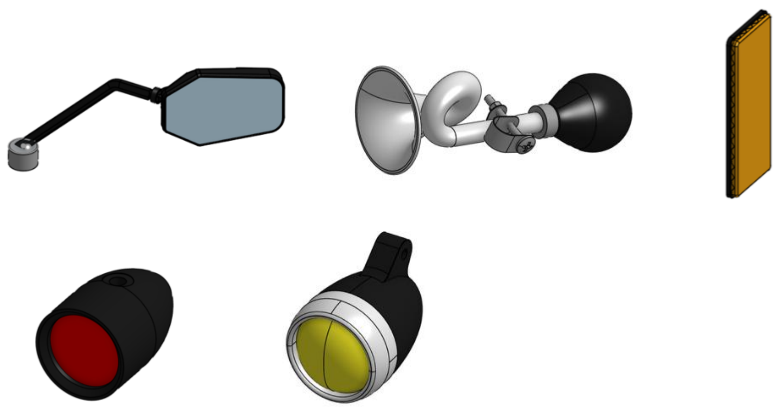

Figure 6-9. Digital prototype of safety features (Source: Author).

Assembled system

When combined, these subsystems create the final product. This assembled system of components was created to function with different configurations of bought components, because access to specific parts is not guaranteed. The delivered digital prototype consists of the above mentioned subsystems and can be used as a basis for creating manufacturing documentation and doing numerical analysis. The model was created to evaluate packaging compatibility, load distribution and overall function and simplicity. Attention was given to ensuring that subsystem interfaces did not conflict, especially in relation to suspension travel, steering linkages and drivetrain alignment.

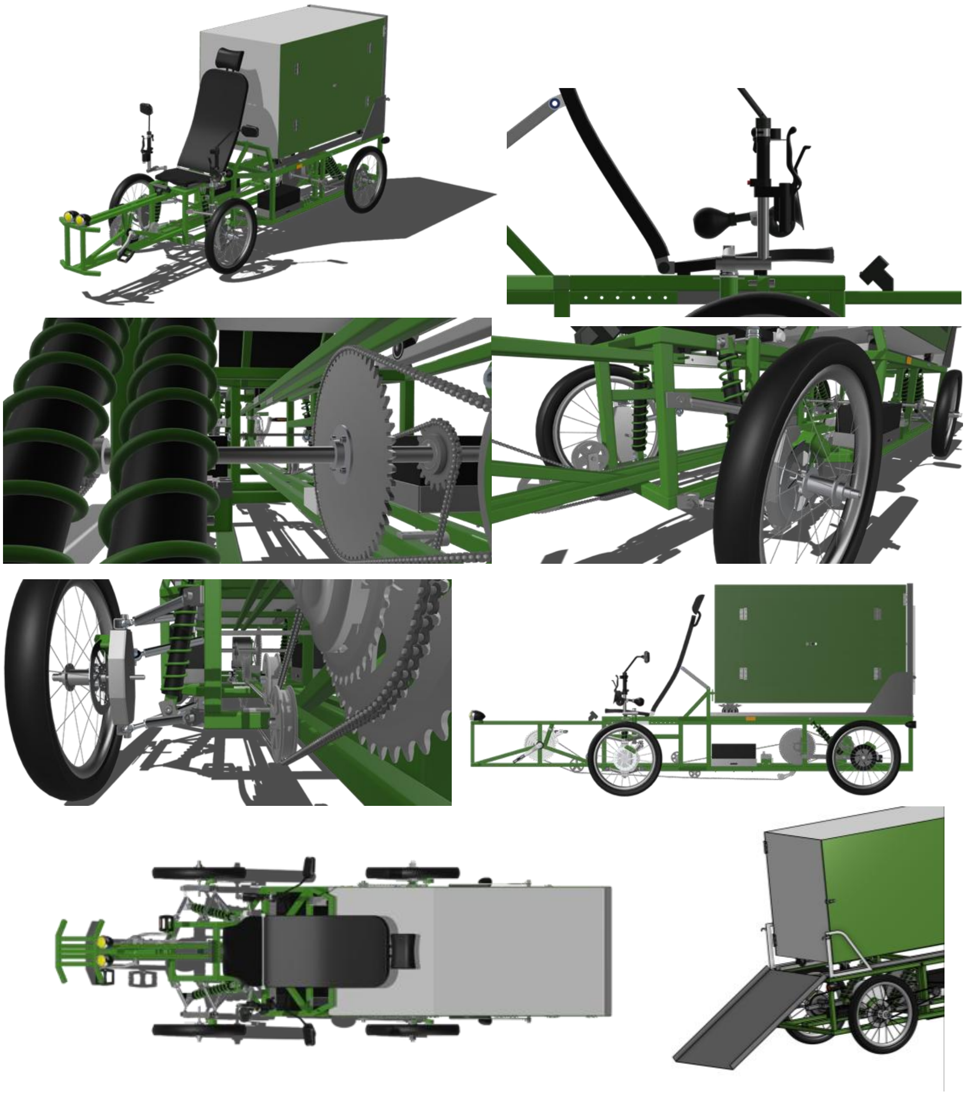

Figure 6-10. Digital prototype of assembled product (Source: Author).

6.2 Product Specifications and Manufacturing

Master Parts List

A list of all the parts was made to aid in manufacturing and assembly of the Tunari 1.0 concept cargo bicycle. The parts list contains the part name, description, quantity, material, whether it should be bought or made and how it is to be manufactured. The master parts list is included in Appendix C.

The master parts list in combination with the outsourced technical drawings and the digital prototype will be enought for a workshop in Cochabamba to be able to manufacture the physical prototype. The following manufacturing methods are to be used:

- Welding
- Turning
- Milling
- Drilling
- Cutting
- Bending
- 3D printing
- Painting

Dimensions

A summary of the overall dimensions of the vehicle is presented in Table 6-1Table 6-1.

Table 6-1 Dimensions of Tunari 1.0.

Dimension	***Value***
Total mass	150 kg
Total Length	3000 mm
Total Width	980mm
Total Height	1400mm
Cargo Volume	600L

7 Discussion

This chapter includes an evaluation of the final concept in relation to the defined technical requirements and project objectives. It also contains a discussion of the development process, methodological choices, engineering trade-offs and the challenges associated with designing within the Bolivian context.

7.1 Evaluation of the Development Process and Methodology

Throughout the project, the double diamond methodology was used. This included methods for data gathering, stakeholder understanding and product design. This section evaluates how well the applied methods benefitted the goal of the project and what changes could have been made to improve the results.

Benchmarking

Benchmarking sessions were conducted in Europe before work in Bolivia had begun. This part of the discover phase was especially important for collecting data on existing solutions for subsystems such as suspension, drivetrain and motor. The results were satisfactory and useful later in development.

The most insightful benchmarking session was at Laplandar, where quantitative data could be measured from the physical products and qualitative data could be collected from a company representative. The amount of detailed data gathered from Laplandar would ideally have be gathered for all benchmarked products, but due to time constraints, it was decided to work in depth with the Laplandar and Bullitt bikes, while quantitative data was gathered from a broader range of products. This method was beneficial and improved the design process.

When at a later stage in the project the direction changed, the benchmarking data became less relevant. The two products that were benchmarked qualitatively in-depth had two and three wheels respectively, but the CEO expressed a need for four wheels. If this was known before benchmarking had begun, four wheeled vehicles would have been more relevant to closely examine. The data was still used, but further research needed to be done on 4 wheeled vehicles specifically which was not planned for in the original timeline.

Interviews

Informal interviews, labelled as expertise insights, were conducted to collect user needs. Interviews are a straightforward method for gathering both quantitative and qualitative data. It is a time efficient method of discovery in combination with testing. The interviews led to easy collection of important stakeholder feedback. Stakeholder interviews were unstructured, enabling a freer exchange of opinions and perceived requirements than the structured benchmarking interviews had. The structured benchmarking interviews had a focus on data rather than opinions, which is the reason structured interviews were used. This had the wanted effect of nuanced, high quality data.

Iterative design,

An important aspect of design thinking is iterative design. In this project, that meant conceptualizing subsystems several times, making the concept more detailed with each iteration. Each iteration also included more than one concept. This method was chosen to explore the maximum number of solutions while effectively managing time. Although this iterative process delivered many ideas and was on schedule according to the project timeline, it was still time consuming and took more time than Eco Delivery had hoped. For observers, this method seemed ineffective and sometimes unnecessary but was in fact significant to ensure the final design is tested against other alternatives concepts.

Concept evaluation

During the evaluation process of the develop phase, the scoring method could have been done more thoroughly. Scoring was done with available information and experiences, but ideally the decisions would have been based on studies created specifically for the project, such as Finite Element Analysis or physical prototyping. The time required for this was however too long compared to what was available. In addition, many of the scores were based on engineering judgement, stakeholder feedback and available information rather than project specific testing. This introduces a degree of subjectivity into the concept selection process. Different evaluators, requirements or priorities may therefore have resulted in different concept selections.

Construction

The last three weeks of the project were dedicated to the 3D modelling of the Tunari 1.0. Because of the lack of experience using the construction software named Onshape, modelling was difficult. The software was chosen because of its simplicity in document sharing because of its cloud based infrastructure, and because it was free to use for the intended purpose in contrast to other alternatives such as SolidWorks. A downside to using Onshape was the increasing lag throughout the project. Because of the cloud connection, the slow internet connection in Bolivia caused the increasingly bigger file sizes to strain the programme.

Prototyping

The initial plan was to end the project with a physical prototype, but after the late stage direction change, that became difficult to deliver. If possible, the physical prototype would have been a useful tool for further development. Eco Delivery, in collaboration with the local university, will continue with the project and aim to create a physical prototype. A next step in the process could be to create the frame in a smaller scale. Another option is to create the entire or parts of the model using additive manufacturing, commonly known as 3D printing. However, this does have some inherent challenges due to the many parts in the model and the complex geometries.

User observations

Though user observations were few, they were an important part of the discover phase. During these observation sessions, many insights regarding real operating conditions were made. For example, while riding with a courier, it was possible to note usual routes, customer and producer interactions and oral feedback from actual users of cargo bikes. It would have been relevant to continue user observations and test rides but was limited due to time restriction and safety risks in current working conditions.

Double Diamond and Design Thinking

Generally, the design thinking methodology by Ulrich and Eppinger and the double diamond approach have been effective structures to develop the product while ensuring stakeholder needs are met. The methods described throughout the report have been relatively slow, meaning that ideation and development could have been faster with other methods. The slow speed of development is not without benefit, because possible errors are easier to prevent and address. This product development method has also been a tool to prevent expensive and time consuming mistakes in production. Comprehensive discover and define phases have simplified decision making during construction. It became apparent that Bolivian product development culture usually meant not using such methods in order to save time in the development process, but ultimately often ended with longer production time and costs with many errors. Therefore, it was especially important to challenge this norm.

At the same time, the limited project duration and changing project requirements meant that some development activities were sped up compared to a more traditional product development process. This introduced a degree of bias into the development process, as some design decisions and concept selections were based on the project team's own assessments, experiences and opinions together with stakeholder feedback rather than extensive research, testing and validation. Different designers or stakeholders may have arrived at different solutions under the same conditions.

7.2 Adaptation to the Bolivian Context

The product development process in Sweden and Bolivia differs in several ways. Manufacturing methods, material availability and product requirements must be adapted to the regional context. In the case of this project, the Bolivian context significantly influenced both the development process and the resulting concept.

One major difference compared to Sweden was the need for increased durability and reliability due to rough road conditions and dense urban traffic. Poor infrastructure and uneven road surfaces place greater stress on vehicles and increase the importance of safety and robustness during daily operation. Traffic conditions and road safety also differ considerably, requiring the product to function reliably in more unpredictable urban environments.

Manufacturing and sourcing conditions in Bolivia also influenced the project significantly. Local manufacturing capacity is relatively high for simple fabrication methods such as welding and metalworking, while more advanced manufacturing processes and specialised components are less accessible. Because Bolivia lacks direct access to naval ports and has limited railway infrastructure, imported products and components are often expensive and difficult to source. In addition, many components are sourced through informal markets, local workshops and small stores with limited digital presence rather than through standardised suppliers or online catalogues. Availability, dimensions, specifications and prices can vary significantly depending on supplier, location and timing, while information regarding available products is often communicated through word of mouth rather than formal documentation.

This created challenges during the development process because it was difficult to predict which components would ultimately be available during manufacturing. As a result, the project could not rely on fixed subsystem specifications or a strictly predetermined production cost. Previous local projects also lacked detailed cost documentation due to the variability of component sourcing and informal pricing. Consequently, the concept development process relied heavily on observations of commonly available vehicles, materials and components found in local workshops and markets. Examples included mountain bike and BMX components, steel fabrication methods and motorcycle components from commonly available Chinese motorcycles.

The project was also influenced by broader economic and infrastructural uncertainty within Bolivia. Factors such as fuel prices, public transportation availability and government investment in infrastructure can fluctuate significantly over time depending on economic and political conditions. In addition, opportunities such as international grants, investments and development programs may appear or disappear rapidly, requiring companies such as Eco Delivery to continuously adapt their operations and priorities. This uncertainty affected the development process by causing project requirements, available resources and long term goals to change throughout the project. At the same time, the ambitions and expectations of the project remained high, creating challenges when attempting to define fixed specifications and development targets early in the process.

The maintenance culture in Bolivia also differs from that in Sweden. Spare parts are not always readily available and product replacement is often economically unrealistic. Instead, repair and modification are common practices due to lower labour costs and limited access to imported products. This creates a greater emphasis on repairability, manufacturability and long product lifespan compared to many European products and systems. This repair oriented maintenance culture may also contribute positively from a sustainability perspective by extending product lifespan and reducing material consumption over time.

Economic conditions further influenced the project requirements. During benchmarking it became clear that many European cargo bike solutions were financially inaccessible within the Bolivian market. Although Eco Delivery did not specify a strict target production cost, affordability was consistently identified as an important factor throughout the project. Consequently, subsystem costs and manufacturing feasibility became important considerations during the development process.

7.3 Evaluation against requirements

Product specifications were assessed based on stated product requirements and needs. The requirements are specified further in 4.3 Design Requirements and Target Specifications.

The product was designed based on these requirements, but some were not met and some were not tested. This was because of limited time, budget and overly ambitious goals. Because of time limitations, physical prototyping and testing was deferred which hindered the ability to evaluate. The design therefore became strictly digital. The planned finite element analysis was also not completed. This prevented assessment of loading requirements such as safety factors regarding cargo forces and torque. The construction was however deemed slightly overdimensioned by engineers at Eco Delivery to increase safety for the rider in case of accident.

Of the requirements that could be evaluated digitally, most were met. For example, the construction is self-stable because of the four-wheel construction, the cargo box is fully covered and compatible with relevant loaded goods. Rider safety around seat is equipped with necessary safety features and the risk of collision between rider and steering or drivetrain components are low. The materials are all available in the local market.

However, requirements that were not met include maximum cargo floor height, which should be 350 mm maximum, but because of the choice of cargo-to-frame mounting method, the floor height needed to be heightened to around 600 mm. This choice enabled a bigger cargo box, which was important to the stakeholders. According to mass and battery calculations, the product should have capacity to achieve the targeted speed and range within normal conditions but fail on steep sections due to heavier components than anticipated. Another requirement was that the rider should have to pedal to activate motor assist. This decision was changed because the motors on the market generally include this throttle and would make usage safer because of improved manoeuvrability.

Ultimately, most requirements were met or were considered accomplished, but some needed to be compromised. The most notable reason some untested conditions might not be met was because of increased weight in comparison to expected results,

7.4 Engineering and Design Trade-Offs

Several engineering trade-offs were made throughout the development process to balance manufacturability, durability, serviceability and vehicle performance within the Bolivian context.

One of the most important trade-offs concerned the drivetrain design. The final concept does not include a differential or gearbox because these components are difficult to source locally and significantly increase cost and complexity. Instead, the drivetrain was designed around readily available bicycle components that are familiar to local bicycle mechanics and easy to maintain. While this solution improves accessibility and repairability, bicycle drivetrain components are generally less robust than motorcycle or automotive alternatives. Components such as freewheels and bicycle chains are expected to experience greater wear under heavy loading conditions. However, these parts are inexpensive, widely available and simple to replace when damaged.

To improve serviceability, certain machined adapter components such as the freewheel adapter and sprocket hub adapter were included in the design. Although these components increase manufacturing complexity and cost slightly, they enable drivetrain components to be removed and replaced easily without requiring major modifications to the vehicle.

The wheel selection also involved compromise. BMX wheels were selected because they are lightweight, relatively robust and commonly available while still being compatible with bicycle drivetrain systems. Compared to conventional bicycle wheels they include thicker axles and stronger construction, improving durability under heavy loading conditions. However, they are less rugged than motorcycle wheels or fully custom wheel solutions and may therefore have reduced durability in long term heavy duty use.

A major challenge throughout the project was balancing durability and structural strength with vehicle weight. The vehicle was intentionally designed with many structural reinforcements to improve robustness and reliability during operation on poor road surfaces and in dense urban traffic conditions. The original concept used a fully steel frame construction, but the estimated vehicle mass became excessively high. Aluminium frame members were therefore selected for parts of the structure to reduce weight and improve vehicle handling and braking performance. Reducing the vehicle mass also lowers battery consumption and decreases strain on drivetrain and braking components. In addition, a lighter vehicle allows the rider to continue pedalling more easily in situations where battery power is unavailable. However, the use of aluminium introduces additional manufacturing complexity and reduces ease of repair compared to steel construction.

Another compromise involved drivetrain simplicity versus gear range. A simple front derailleur system was selected to reduce drivetrain complexity and simplify maintenance. This reduced the number of available gear ratios but made the system easier to repair and adjust. In the event of a chain derailment, the chain can also be repositioned quickly without specialised tools.

The vehicle dimensions were also influenced by stability and serviceability requirements. The final vehicle is wider than several benchmarked cargo bikes, although it remains within the specified maximum width requirement of one metre. The increased width improves stability and allows easier access to internal components during servicing and maintenance. However, the larger dimensions reduce manoeuvrability in narrow environments compared to smaller cargo bike configurations.

Motor selection similarly required compromise between weight and performance. A relatively large and powerful motor was selected to ensure sufficient performance in steep terrain and during operation with heavy cargo loads. While this improves climbing ability and overall reliability, the motor adds considerable weight to the vehicle. The high rotational speed of the motor also required large sprocket reductions to achieve suitable pedalling cadence and drivetrain speeds. This resulted in a drivetrain layout with a less optimal chain line and slightly lower transmission efficiency. Despite this, the simpler drivetrain configuration was prioritised to minimise the number of moving parts and reduce maintenance requirements.

Finally, easy of maintenance was taken into consideration throughout the design process. Hex bolts were selected for most fasteners and standardised where possible in order to simplify assembly and service. This reduces the number of tools required during servicing and makes repairs easier to perform using commonly available workshop equipment.

7.5 Limitations

A limitation of this project was that the final concept was not physically manufactured or tested within the scope of the thesis. As a result, several aspects of the design could only be evaluated digitally or through estimations. Planned validation methods such as finite element analysis, braking tests and real world riding evaluations were not completed. This limited the ability to fully verify structural durability, vehicle handling and long term reliability under realistic operating conditions.

The project also involved the development of a highly complex product within a limited timeframe by a team of two engineering students with limited prior experience in cargo vehicle development. The original project scope and time plan did not account for the development of a four wheel vehicle with advanced suspension systems and a high level of subsystem integration. In addition, the original planning did not include manufacturing preparation and validation to the extent eventually required by the final concept. As the project developed and ambitions increased, greater emphasis was placed on aspects such as suspension performance, structural robustness and safety considerations. Because the primary objective remained to deliver a complete and feasible vehicle concept adapted to the Bolivian context, less time could be dedicated to detailed subsystem optimisation and validation. The development process therefore prioritised overall system integration and concept feasibility over refinement of individual subsystems.

Another limitation was the uncertainty regarding locally available components, materials and manufacturing methods during the development process. Because component availability and sourcing conditions can vary significantly, several parts were modelled generically and may require adaptation during manufacturing. This uncertainty also reduced the reliability of detailed simulations and cost estimations, since final material selections, manufacturing methods, labour requirements and component specifications were not fully defined during the project. Manufacturing costs were also difficult to estimate accurately because labour time, workshop capabilities and component prices can vary considerably depending on supplier and availability.

In addition, product development in this context was highly iterative and adaptive in nature. Project requirements, priorities and safety considerations evolved throughout the development process as new information and constraints emerged. Early project phases focused primarily on achieving a feasible and manufacturable concept, while more detailed validation and safety considerations became increasingly important during later stages of development. Due to time and resource limitations, physical mock ups and prototype based testing were not conducted within the scope of the thesis. However, such iterative prototyping and testing would likely be necessary in future development stages to further validate and refine the concept.

7.6 Sustainability

From a sustainability perspective, the Tunari 1.0 concept has the potential to reduce dependence on fossil fuel powered urban deliveries by enabling larger deliveries to be carried out using an electrically assisted cargo bike. Within the Bolivian context, cargo bikes are currently limited in their carrying capacity and reliability, especially under demanding terrain and traffic conditions. The project therefore attempted to explore how a more robust and capable cargo bike platform could expand the practical use of electric cargo transportation for commercial deliveries.

The project also highlighted that sustainability within this context extends beyond operational emissions alone. Because imported products and replacement components are expensive and often difficult to source, repairability and long product lifespan become important sustainability factors. A product that can be repaired locally and remain in operation for many years can reduce material consumption and waste generation compared to products that are frequently replaced. This aligns with the existing maintenance culture in Bolivia, where repair and modification are often economically preferable to replacement.

Several design decisions throughout the project were therefore influenced by considerations regarding durability, repairability and local manufacturability. However the final concept is heavy and structurally overdimensioned to improve reliability and safety under harsh operating conditions. This increased material usage and reduced efficiency compared to more optimised commercial cargo bikes. Similarly, the use of batteries, aluminium components and manufactured subsystems still imply environmental impact through extraction, manufacturing and transportation processes.

Despite these limitations, the concept suggests that there is potential for electrically assisted cargo bikes to contribute to more sustainable urban logistics within Bolivia, particularly if reliability and carrying capacity can be improved sufficiently to replace a greater number of motorcycle and car based deliveries. Cargo bikes have strong potential to reduce emissions, congestion and environmental impact within urban freight transportation systems when adapted appropriately to local operating conditions (Kuzia, 2024).

7.7 Knowledge contribution

This thesis contributes knowledge regarding the development of electric cargo vehicles within the Bolivian context. Throughout the project, user requirements, technical requirements and design considerations specific to local operating conditions were identified and documented. The project highlights how factors such as repairability, uncertain component availability, local manufacturing capabilities and poor road conditions influence vehicle development and engineering decision making.

The thesis also demonstrates how systematic product development methods can be applied within a rapidly changing project environment where requirements, resources and project goals evolve throughout the development process. In addition to the final Tunari 1.0 concept, the project contributes design decisions, engineering analyses and lessons learned that can support future development of cargo vehicles and sustainable urban logistics solutions in Bolivia.

7.8 Future Work

Although the Tunari 1.0 concept has been developed to a detailed level, several steps remain before a fully functional and validated vehicle can be realised.

Further validation and testing of critical subsystems are required to ensure the reliability and safety of the design. Finite Element Analysis (FEA) should be conducted on structurally critical components, particularly the frame, suspension mounts and wheel hubs, to verify that the structure can withstand expected loading conditions without being unnecessarily overdimensioned. The cargo box, loading ramp and rail system should also undergo either structural simulations or physical testing to validate their functionality.

A critical element of the cargo bike is the loading procedure of the removable cargo box. The rail and ramp system should be tested to verify that two operators can safely and practically load and unload the approximately 200 kg cargo box under realistic working conditions. Depending on the results of these tests, further ergonomic improvements may be required, such as the integration of loading handles or a winch.

Before manufacturing, detailed technical drawings and manufacturing documentation must be produced for all custom components. A complete bill of materials should also be established to support sourcing and assembly. Following this, the custom components can be manufactured while standard components can be sourced and purchased.

The Tunari 1.0 should be regarded as a first generation prototype and must undergo extensive real world testing before implementation within Eco Delivery's operations. Several vehicle characteristics remain dependent on assumptions made during the development phase. For example, the estimated battery capacity is strongly influenced by the final vehicle mass, cargo weight, terrain conditions and rider behaviour. Real world testing should therefore be conducted to determine whether the proposed battery configuration is sufficient or requires changes.

Further development should also include suspension tuning and geometry refinement to improve vehicle handling, rider comfort and tire grip under varying road conditions. Brake testing, particularly on steep inclines, should be conducted to verify safe stopping performance under maximum loading conditions. In addition, cornering and stability tests should be carried out to evaluate rollover risk and overall vehicle safety.

Additional improvements to the drivetrain and rider experience could be explored in future iterations. For example, integrating a torque sensor into the powertrain could provide smoother and more responsive motor assistance for the rider.

Due to uncertainties regarding local component availability in Bolivia, several CAD components were modelled generically during the development process. This approach allows equivalent locally available components to be substituted during manufacturing. Consequently, certain design adaptations and dimensional modifications will be required depending on the components that are sourced locally.

8 Conclusion

This chapter presents the final conclusions of the project based on the development process, design outcomes and evaluation of the Tunari 1.0 concept.

This project explored the development of an electric cargo vehicle adapted to the Bolivian context. Through benchmarking, stakeholder discussions, user observations and iterative concept development, a final vehicle concept named Tunari 1.0 was developed. The project focused on creating a robust, serviceable and locally manufacturable solution capable of handling demanding urban delivery conditions while supporting more sustainable transport alternatives.

The development process highlighted the challenges of designing within a context characterised by uncertain component availability, changing requirements and limited resources. These conditions strongly influenced both the design process and the final concept. Several engineering trade-offs were necessary to balance stability, durability, manufacturability, weight, cost and serviceability.

Although the final concept was not physically manufactured or fully validated within the scope of the thesis, the project demonstrates the potential for larger electrically assisted cargo vehicles to support urban logistics within Bolivia. The Tunari 1.0 should therefore be regarded as a first conceptual prototype and a foundation for continued development, testing and refinement.

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Appendix A -Work distribution and time plan

A.1 Work distribution

The work distribution evolved throughout the project depending on subsystem complexity, CAD integration requirements and technical challenges. Both students participated continuously in concept development, stakeholder communication, subsystem evaluation and report work. The percentages shown represent the approximate primary contribution areas during the project.

Table 9-1. Work Distribution

Activity	*Zoë*	*Felix*
User research, stakeholder interviews, benchmarking and field studies	50%	50%
Concept Development		
Report writing, methodology and requirement specification	60%	40%
Brainstorming, concept generation and subsystem ideation	40%	60%
Sketching and visual concept development	25%	75%
Mechanical concept development and technical problem solving	70%	30%
Frame development and CAD strategy	30%	70%
Cargo box, ramp and seating subsystem development	20%	80%
Front suspension development and integration	35%	65%
Rear suspension development and geometry	85%	15%
Steering system development	75%	25%
CAD modelling and subsystem integration	45%	55%
Wheels and component selection	70%	30%
Drivetrain and powertrain development	70%	30%
Powertrain calculations and dimensioning	50%	50%
Load cases, dimensioning and engineering calculations	60%	40%
Presentation material and final deliverables	40%	60%

A.2 Project plan and outcome

Figure A.1 Project plan planned activities.

	Initiation & Planning	Comments
Mon 19/1	Initiation	
Tue 20/1	Project planning	Writing of this document
Wed 21/1	Project planning	
Thu 22/1	Logistical issues of field work	Meeting w. on-site supervisors
Fri 23/1	Benchmarking planning	
Mon 26/1	Supervisor meeting	Initiation of report writing, etc.
Tue 27/1		
Wed 28/1	Start up meeting	Supervisors and stakeholders
Thu 29/1		
Fri 30/1		
Mon 2/2		
Tue 3/2		
Wed 4/2	Arrival Cochabamba Bolivia	
Thu 5/2	Write interview questions	lunch
Fri 6/2	First visit to university	

Figure 9-1. Gant diagram of planned initiation phase

	Discover	Comments
Thu 22/1	Interview swedish bicycle courier - citymail	
Fri 23/1		
Mon 26/1	Benchmarking - VeLove	
Tue 27/1	Benchmarking - BullitBike	
Wed 28/1	Benchmarking - Nihola	
Thu 29/1	Benchmarking delivery bicycle	DHL cubicycle

Figure 9-2. Gant diagram of planned discover phase (Source: Author)

	Define	Comments
Mon 23/2	User persona creation	
Tue 24/2	User need statements	
Wed 25/2	User journey mapping	
Thu 26/2	Budgeting	Create budget to base decisions on
Fri 27/2		
Mon 2/3	Identification of key functional problem areas	
Tue 3/3	Translation of user needs into technical requirements	
Wed 4/3	Final problem statement/formulation	
Thu 5/3	Manufacturing methods	Take desision based on available resourses and budget
Fri 6/3	Supervisor review and refinement	With both on-site and academic supervisors

Figure 9-3. Gant diagram of planned define phase (Source: Author)

	Develop	Comments
Mon 9/3	Brainstorming	
Tue 10/3	Concept sketching	
Wed 11/3	Modular and cargo interface exploration	
Thu 12/3	Design for Environment	
Fri 13/3		
Mon 16/3	Concept screening and concept scoring	
Tue 17/3	Concept selection	physical mockups of concept/mechanical mechanisms
Wed 18/3	Concept development and definition	
Thu 19/3		
Fri 20/3		
Mon 23/3	CAD modelling	
Tue 24/3	Detailed CAD modeling	
Wed 25/3		
Thu 26/3		
Fri 27/3		
Mon 30/3	Definition of load cases	
Tue 31/3	Hand calculations	
Wed 1/4	Material selection	
Thu 2/4	FEA modelling	
Fri 3/4		
Mon 6/4	Preparation of drawings and BOM	drawings for each part

Figure 9-4. Gant diagram of planned develop phase (Source: Author)

	Deliver	Comments
Wed 8/4	First prototype assembly and review	physical proof of concept
Thu 9/4	Sustainability assessment	
Fri 10/4	Supervisor and stakeholder review	With both on-site and academic supervisors
Mon 13/4	Iterative improvement of design	
Tue 14/4		
Wed 15/4		
Thu 16/4		
Fri 17/4		
Mon 20/4	Final prototype	
Tue 21/4	Manufacturing documentation	
Wed 22/4		
Thu 23/4		
Fri 24/4		
Mon 27/4		
Tue 28/4		
Wed 29/4	Return to LTH	

Figure 9-5. Gant diagram of planned deliver phase (Source: Author)

	Reflect	Comments
Fri 23/1	Update thesis document	
Mon 26/1		
Tue 27/1		
Wed 28/1		
Thu 29/1		
Fri 30/1	Update thesis document	
Mon 2/2		
Tue 3/2		
Wed 4/2		
Thu 5/2		
Fri 6/2	Update thesis document	
Mon 9/2		
Tue 10/2		
Wed 11/2		
Thu 12/2		
Fri 13/2	Update thesis document	
Mon 16/2		
Tue 17/2		
Wed 18/2		
Thu 19/2		
Fri 20/2	Update thesis document	
Mon 23/2		
Tue 24/2		
Wed 25/2		
Thu 26/2		
Fri 27/2	Update thesis document	
Mon 2/3		
Tue 3/3		
Wed 4/3		
Thu 5/3		
Fri 6/3	Update Thesis document	
Mon 9/3		
Tue 10/3		
Wed 11/3		
Thu 12/3		
Fri 13/3	Update thesis document	
Mon 16/3		
Tue 17/3		
Wed 18/3		
Thu 19/3		
Fri 20/3	Update thesis document	
Mon 23/3		
Tue 24/3		
Wed 25/3		
Thu 26/3		
Fri 27/3	Update thesis document	
Mon 30/3		
Tue 31/3		
Wed 1/4		
Thu 2/4		
Fri 3/4	Update thesis document	
Mon 6/4		
Tue 7/4		
Wed 8/4		
Thu 9/4		
Fri 10/4	Update thesis document	
Mon 13/4		
Tue 14/4		
Wed 15/4		
Thu 16/4		
Fri 17/4	Update thesis document	
Mon 20/4		
Tue 21/4		
Wed 22/4		
Thu 23/4		
Fri 24/4	Update thesis document	
Mon 27/4		
Tue 28/4		
Wed 29/4		
Thu 30/4		
Fri 1/5		
Mon 4/5	Write report	
Tue 5/5		
Wed 6/5		
Thu 7/5		
Fri 8/5		
Mon 11/5		
Tue 12/5		
Wed 13/5		
Thu 14/5		
Fri 15/5		Finish report - send to supervisor
Mon 18/5	Create presentation	
Tue 19/5		
Wed 20/5		
Thu 21/5		
Fri 22/5		
Mon 25/5	Practice presentation	
Tue 26/5		
Wed 27/5		
Thu 28/5		
Fri 29/5		
Mon 1/6		
Tue 2/5		
Wed 3/5		
Thu 4/5		
Fri 5/5	Present thesis work!	

Figure 9-6. Gant diagram of planned reflect phase (Source: Author)

Figure A.2. Project plan performed activities.

Double Diamond phases		Initiation & Planning	Comments
Week 4	Mon 19/1	Initiation	
	Tue 20/1	Project planning	Writing of this document
	Wed 21/1	Project planning	
	Thu 22/1	Logistical issues of field work	Meeting w. on-site supervisors
	Fri 23/1	Benchmarking planning	
Week 5	Mon 26/1	Supervisor meeting	Initiation of report writing, etc.
	Tue 27/1		
	Wed 28/1	Start up meeting	Supervisors and stakeholders
	Thu 29/1		
	Fri 30/1		
Week 6	Mon 2/2		
	Tue 3/2		
	Wed 4/2	Arrival Cochabamba Bolivia	
	Thu 5/2	Write interview questions	lunch
	Fri 6/2	First visit to university	lunch

Figure 9-7. Gant diagram of executed initiation phase

Double Diamond phases		Discover	Comments
Week 4	Mon 19/1		
	Tue 20/1		
	Wed 21/1		
	Thu 22/1	Interview swedish bicycle courier - citymail	
	Fri 23/1		
Week 5	Mon 26/1	Benchmarking - VeLove	
	Tue 27/1	Benchmarking - BullitBike	
	Wed 28/1	Benchmarking - Nihola	
	Thu 29/1	Benchmarking delivery bicycle	DHL cubicycle
	Fri 30/1		
Week 6	Mon 2/2		
	Tue 3/2		
	Wed 4/2		
	Thu 5/2		
	Fri 6/2		
Week 7	Mon 9/2	Benchmarking, identify bottlenecks	introduction in report
	Tue 10/2	Benchmarking, stock parts list	method in report
	Wed 11/2	Onsite observations EcoDelivery	Follow cyclist, benchmark and test current design
	Thu 12/2	Visit workshop, inventory and tools inventory, manufacturing	pdtf, analysis of local materials/manufacturing methods
	Fri 13/2	User persona, user journey, summary of collected info	from stakeholders and discussions
Week 8	Mon 16/2	carneval	holiday
	Tue 17/2	Motor/drivetrain analysis, identification of key problem areas	placement, size, manufacturing, price
	Wed 18/2	Modular design - cargo	fixture, size, mounting, materials
	Thu 19/2	Concept sketching and mechanism solutions	available: 3kw motors and batteries
	Fri 20/2	Concept sketching and mechanism solutions	

Figure 9-8. Gant diagram of executed discover phase

Double Diamond phases		Define	Comments
Week 9	Mon 23/2	Concept sketching and updating report	Exploration
	Tue 24/2	Meeting axel nordin	
	Wed 25/2	Translation of user needs into technical requirements	User persona creation,user journey, user needs
	Thu 26/2	User statements and translation into needs	
	Fri 27/2	4th concept sketching and 4 vs. 3 wheel analysis	
Week 10	Mon 2/3	Report formalia, sourcing	waiting for response from CEO and company
	Tue 3/3	Preparation for develop phase and pptx. Start	waiting for response form CEO and company
	Wed 4/3		
	Thu 5/3	Meeting with Stakeholders	Define the brief, review customer feedback
	Fri 6/3		

Figure 9-9. Gant diagram of executed define phase

Double Diamond phases		Develop	Comments
Week 10	Mon 2/3		
	Tue 3/3		
	Wed 4/3		
	Thu 5/3		
	Fri 6/3	Brainstormning	SCAMPER and CrazyEight
Week 11	Mon 9/3	Subsystem design	3 concepts per system
	Tue 10/3	Subsystem design	
	Wed 11/3	Subsystem design	
	Thu 12/3	Subsystem design	
	Fri 13/3	Subsystem design	
Week 12	Mon 16/3	Subsystem design	
	Tue 17/3	Subsystem design	
	Wed 18/3	Subsystem design	
	Thu 19/3	Subsystem design - meeting with supervisor	discuss progress
	Fri 20/3	Subsystem design - Meeting with Lead Engineer	discuss technical details
Week 13	Mon 23/3	Combining subsystems	
	Tue 24/3	Combining subsystems	first iteration of design
	Wed 25/3	Combining subsystems	sketching, pptx.
	Thu 26/3	Design Thinking workshop	
	Fri 27/3	Concept presentation	meeting w. eco delivery
Week 14	Mon 30/3	Definition of load cases /CAD	Division of labour: Felix-CAD/Zoë F
	Tue 31/3	Hand calculations/ CAD	
	Wed 1/4	Dimensioning /CAD	
	Thu 2/4	FEA modelling /CAD	
	Fri 3/4	Dimensioning / CAD	
Week 15	Mon 6/4	CAD modelling	drawings for each part
	Tue 7/4	CAD modelling	
	Wed 8/4	CAD modelling	
	Thu 9/4	CAD modelling	
	Fri 10/4	CAD modelling	
Week 16	Mon 13/4	CAD/technical drawings	
	Tue 14/4	CAD/technical drawings	
	Wed 15/4	CAD/technical drawings	
	Thu 16/4	CAD Assembly/technical drawings	
	Fri 17/4	CAD Assembly/technical drawings	Digital prototype

Figure 9-10. Gant diagram of executed develop phase

Double Diamond phases		Deliver	Comments
Week 17	Mon 20/4	Finalize digital prototype and renderings	
	Tue 21/4	Master parts list	
	Wed 22/4	Master parts list	
	Thu 23/4	Prepare final stakeholder meeting and university presentation	
	Fri 24/4	Final meeting w. stakeholders and presentation	Present deliverables
Week 18	Mon 27/4		
	Tue 28/4		
	Wed 29/4	Return to LTH	
	Thu 30/4		
	Fri 1/5		

Figure 9-11. Gant diagram of executed deliver phase

Appendix B - Benchmarking sessions

Benchmarking is a critical part of the 'Discover' phase of product development using the double diamond method. In these benchmarking sessions, existing solutions will be valued and compared. On each benchmarked product, several aspects are analysed and valued separately.

B.1 Benchmarking – Laplandar

Vehicle specifications

What is the fundamental vehicle architecture and physical configuration of the system?

Bike type (2,3,4 wheel) – 3 wheels

Drive type (front, rear, mid) – old: front, new: back

Frame weight – 170kg

Frame material – steel, zinc primer, powder coated

Suspension (none, front, full) – front

Steering system – direct handlebars/fork

Bicycle Dimensions –

- Loading area 1.2 m^2

Wheel size - 16"

Range (km) – 45km

Load Capacity and Geometry

How efficiently and safely can the system transport parcels under real operational loads?

Max payload (kg) – 250 kg (but more works)

Cargo volume – EU pallet, 1.2 m^2

Load distribution (% front/rear) – 99% rear + 1 basket in front

Max axle load (kg) – 90 kg per axle (2 axles)

Centre of mass height(mm) – not available

Modularity and Cargo Interface

How effectively does the system support fast, safe and flexible cargo exchange?

Container system (fixed, modular) - modular (different boxes available)

Exchange system (rail, manual etc.) – manual, forklift, tipping function

Swap time (s) – (2 people minimum) 30 seconds for ordinary box

Locking method (pin, clamp etc.) – indents for the box wheels, trailer clasps

Powertrain & Drivetrain

How capable and reliable is the propulsion system in supporting loaded urban delivery operations?

Motor type (hub, mid, wheel) – old: wheel, new: mid

Motor power (W) – 1 kw – 250w

Motor torque (Nm) – 135 Nm

Throttle (yes/no) – no – automatic when pedalling

Gear system (derailleur / hub gear) - old: derailleur**,** new: planetary

Transmission (chain/belt/shaft) – specially designed chain

Battery type – LiFePO4 48V/10Ah/480Wh

Swappable battery (yes/no) - yes

Battery capacity (Wh) – 480 Wh

Charging time (h) – 3.5 h

Regenerative braking (yes/no) – no

Ergonomics

How well does the system support human use in terms of comfort, handling and physical workload during daily operations?

Weather protection – no, it's not aerodynamic

Mount/dismount time (s) – Not available

Total delivery time (s) – ca 60 s

Rider posture (upright, semi upright, forward) – Upright (person height: 155 cm – 200 cm)

Hand ergonomics (grip type) – Transversal volar grip, ergonomic design

Seating (saddle type, adjustability) – Adjustable city bike saddle

Loading height (mm) - 300 mm

Number of handling steps – Box in front and change boxes when emptied. 2 keys to activate bike, but does not need to turn off on delivery.

Performance

How effectively does the system perform in urban environments under real delivery conditions?

Turning radius (m) – 3.8 m

Required lane width (m) – 1 m

Braking distance (loaded, (m)) – Not available

Max Speed – 20 km/h

Average Speed – Not available

Acceleration - Not available

Sustainability

How does the system contribute to environmental impact reduction and long-term resource efficiency?

Energy consumption (Wh/km) - Not available

Material sustainability (recyclable, mixed, composite) – Not available

System longevity (years) – at least 2 years, the company is 5 years old "Skrotningpremie".

Price

What costs are associated with the product?

Vehicle unit cost – 7000 euro

Fixed costs – Modifications (crane, boxes, etc.)

Variable costs – energy consumptions

Safety and Compliance– How much risk is involved while using the product?

How well does the system minimize risk and comply with safety and regulatory requirements in real use?

Brake type (disc, hydraulic disc) – Hydraulic disc

Motor cutoff on braking (yes/no) – Yes

Visibility (out/in) – Good (mirrors, reflectors and turning lights)

Lighting system – Battery driven forward and rear lighting

Brake lights (yes/no) – yes

Turning light (yes/no) – yes

Stability at stop (kickstand, self-stable etc.) – Self stable

Theft protection – GPS coming soon

User authentication – Key for batteries

Road legality – Almost entire EU (not Netherlands)

Manufacturing and Maintenance

How feasible is the system to manufacture, maintain and repair?

Maintenance interval (km) – Not available

Modularity/Repairability – High (standard car component)

Spare part availability – Car stores

Tool complexity – standard auto tools

Display and control interface

How effectively does the control and information system support safe, intuitive and reliable operation?

Display type (LCD, LED, none) – Battery indicator ("Keep it simple")

Display size – small

Control type (buttons, touch etc.) – Buttons/switches

Operational modes – Pedal activated

Digital integration (GPS etc.) – Coming soon

Further Comments

Good alternative for budget friendly use cases – Standard components make it easily maintained without third party interference.

Pictures

https://drive.google.com/drive/folders/1YhmQ_oaMukAecaokn7DZMQTywXGWdppk?usp=drive_link

B.2 Benchmarking – Bullitt Bike

Vehicle specifications

What is the fundamental vehicle architecture and physical configuration of the system?

Bike type (2,3,4 wheel) – 2 wheels / narrow front cargo space

Drive type (front, rear, mid) – Rear, manual

Frame weight – 13,7 kg / ≥ 22 kg w. other components

Frame material – 7005 / T6 heat treated aluminum

Fork material – Cro moly steel

Other materials – Nuts/bolts: stainless steel

Suspension (none, front, full) – None, but thick pneumatic tires

Steering system – Direct steering w. steering arm

Bicycle Dimensions –

- Total width: 460 mm
- Total Length: 2430 mm
- Seatpost diameter: 31,6 mm (34.9 seatpost clamp)
- Bottom bracket: English thread 68 mm
- Stem extension: EasyUp - 100 mm extension
- Axle width of front hub: 100 mm
- Axle width of rear hub: 135 mm
- Top center of front fork – center of seatpost – 143.5cm
- Top center front fork to front wheel – 45cm
- Center seatpost to rearmost part of wheel – 59cm
- cargo length and width: 80cm x 40cm
- Ground clearance – frame: 24cm, kickstand: 19cm
- Cargo bottom tube dim: 88.5mm x 31mm
- Top tube dim: 45mm x 57mm
- Crankarm bottom beam dim: 44mm x 88.5mm
- Steering arm diameter: 19mm
- Fork diameter:32mm

- Fork fixture diameter:61mm
- Cargo bars by steering wheel bent: 36mm
- Center steering bar vertical: 41mm
- Rear seattube tube diameter: 44mm

Wheel size – 26tum – 47-559, 20tum – 47-406

Range (km) – Not available

Load Capacity and Geometry

How efficiently and safely can the system transport parcels under real operational loads?

Max payload (kg) – 180 incl. rider

Cargo volume – see bicycle dimensions

Load distribution (% front/rear) – 100% front

Max axle load (kg) – Not available

Centre of mass height – very low

Centre of mass length – slightly in front of handle bars

Modularity and Cargo Interface

How effectively does the system support fast, safe and flexible cargo exchange?

Container system (fixed, modular) - Fixed

Exchange system (rail, manual etc.) – manual

Swap time (s) – 30 s

Locking method (pin, clamp etc.) – Elastic bands

Powertrain & Drivetrain

How capable and reliable is the propulsion system in supporting loaded urban delivery operations?

Motor type (hub, mid, wheel) – Not electric

Gear system (derailleur / hub gear) - Shimano Alfine, rear hub gear, 8-speed

Transmission (chain/belt/shaft) – Chain

Ergonomics

How well does the system support human use in terms of comfort, handling and physical workload during daily operations?

Weather protection – fenders

Mount/dismount time (s) – 4s

Rider posture (upright, semi upright, forward) – semi forward

Hand ergonomics (grip type) – Transversal volar grip

Seating (saddle type, adjustability) – cushioned bike seat, adjustable bars and seat stem

Loading height (mm) - 35cm

Number of handling steps – 2 or 3

Performance

How effectively does the system perform in urban environments under real delivery conditions?

Turning radius (m) – 3.3m

Required lane width (m) – 62cm

Braking distance (loaded, (m)) – Not available

Max Speed – Not available

Average Speed – Not available

Acceleration - Not available

Sustainability

How does the system contribute to environmental impact reduction and long-term resource efficiency?

Energy consumption (Wh/km) - Not available

Material sustainability (recyclable, mixed, composite) - Not available

System longevity (years) – Not available

Price

What costs are associated with the product?

Vehicle unit cost – 50 000 sek

Fixed costs – Mods (cargo box, straps, etc.)

Variable costs – maintenance (no charging costs)

Safety and Compliance– How much risk is involved while using the product?

How well does the system minimize risk and comply with safety and regulatory requirements in real use?

Brake type (disc, hydraulic disc) – disc, slate t4 trp

Motor cutoff on braking (yes/no) – Not available

Visibility (out/in) – out: good, in: no side reflexes

Lighting system – dynamo front and rear

Brake lights (yes/no) – no

Turning light (yes/no) – no

Stability at stop (kickstand, self-stable etc.) – kickstand

Theft protection – not included

User authentication – none

Road legality – Sweden: Need side reflexes

Manufacturing and Maintenance

How feasible is the system to manufacture, maintain and repair?

Maintenance interval (km) – Not available

Modularity/Repairability – Good (multible possible configurations

Spare part availability – Good (available online)

Tool complexity – hex keys, very good , standard bike tools

Display and control interface

How effectively does the control and information system support safe, intuitive and reliable operation?

Display type (LCD, LED, none) – None

Display size – Not available

Control type (buttons, touch etc.) – Not available

Operational modes – Not available

Digital integration (GPS etc.) – Not available

Further Comments

Made for personal use

Pictures

https://drive.google.com/drive/folders/1dQQYopzHP3X43765SB6WOzVVRaUBBwLE?usp=drive_link

B.3 Benchmarking – Fulpra Quatro

Vehicle specifications

What is the fundamental vehicle architecture and physical configuration of the system?

Bike type (2,3,4 wheel) – 4 wheel

Drive type (front, rear, mid) – Not available

Frame weight – Not available

Frame material - Steel

Suspension (none, front, full) – full individual

Steering system - handlebars

Bicycle Dimensions –

- Width: 1 m
- Length: 3.25m
- Height 1.57 m

Wheel size - Not available

Range (km) – 40-60 km per battery set

Load Capacity and Geometry

How efficiently and safely can the system transport parcels under real operational loads?

Max payload (kg) – 325 kg

Cargo volume – 1.8 m^3

Load distribution (% front/rear) – 100% rear

Max axle load (kg) – Not available

Centre of mass height(mm) - Not available

Modularity and Cargo Interface

How effectively does the system support fast, safe and flexible cargo exchange?

Container system (fixed, modular) - Fixed box

Exchange system (rail, manual etc.) - Not available

Swap time (s) - Not available

Locking method (pin, clamp etc.) – Lockable doors

Powertrain & Drivetrain

How capable and reliable is the propulsion system in supporting loaded urban delivery operations?

Motor type (hub, mid, wheel) – Rear wheel

Motor power (kW) – 0.25W (assist 1-6 km/h)

Motor torque (Nm) – 320 Nm

Throttle (yes/no) – No

Gear system (derailleur / hub gear) - Not available

Transmission (chain/belt/shaft) – Not available

Battery type – 50V Li-ion

Swappable battery (yes/no) - Yes

Battery capacity (Wh) – 3600 Wh per set (2 batteries)

Charging time (h) – Not available

Regenerative braking (yes/no) – Not available

Ergonomics

How well does the system support human use in terms of comfort, handling and physical workload during daily operations?

Weather protection – Full canopy

Mount/dismount time (s) – Not available

Rider posture (upright, semi upright, forward) - Upright

Hand ergonomics (grip type) – Transveral Volar (flat handlebars)

Seating (saddle type, adjustability) – Adjustable saddle; rider height 160–198 cm

Loading height (mm) - 300 mm

Number of handling steps – Not available

Performance

How effectively does the system perform in urban environments under real delivery conditions?

Turning radius (m) – 6m

Required lane width (m) – 1 m

Braking distance (loaded, (m)) - Not available

Max Speed – 25 km/h

Average Speed – Not available

Acceleration - Not available

Sustainability

How does the system contribute to environmental impact reduction and long-term resource efficiency?

Energy consumption (Wh/km) – 60-90 Wh/km

Material sustainability (recyclable, mixed, composite) - Mixed

System longevity (years) – Not available

Price

What costs are associated with the product?

Vehicle unit cost – 16790 euro ≈ 180 000 sek

Fixed costs – Expensive mods (batteries, compartments, mounts)

Variable costs – Energy consumptions

Safety and Compliance– How much risk is involved while using the product?

How well does the system minimize risk and comply with safety and regulatory requirements in real use?

Brake type (disc, hydraulic disc) – Hydraulic disc

Motor cutoff on braking (yes/no) – Not available

Visibility (out/in) – Out: Medium (covered back, large windshield pane → blind spots, mirrors), In: good (full lighting and reflective details)

Lighting system – Front/back

Brake lights (yes/no) – Yes

Turning light (yes/no) – Yes

Stability at stop (kickstand, self-stable etc.) – Parking brake, self stable

Theft protection – Lockable doors

User authentication – Key

Road legality – EU legal for road use (bike regulations not available)

Manufacturing and Maintenance

How feasible is the system to manufacture, maintain and repair?

Maintenance interval (km) – Not available

Modularity/Repairability – Expensive and not repairable

Spare part availability – Medium availability online

Tool complexity – Not available

Display and control interface

How effectively does the control and information system support safe, intuitive and reliable operation?

Display type (LCD, LED, none) – Not available

Display size – Not available

Control type (buttons, touch etc.) – Not available

Operational modes – Pedal assist 1-6 km/h

Digital integration (GPS etc.) – GPS, 3/4G, Bluetooth, CANbus, cloud monitoring

Further Comments

Many types of modifications, but not good self assisted repairability.

Brochure:

https://drive.google.com/file/d/1riOUoi7wfEcadP9KXDq4rsreV0NxYiuY/view?usp=sharing

B.4 Benchmarking – eCarla Cargo

Vehicle specifications

What is the fundamental vehicle architecture and physical configuration of the system?

Bike type (2,3,4 wheel) - 3-wheel cargo trailer

Drive type (front, rear, mid) – Front hub motor

Frame weight – 43 kg (without floor plate & battery)

Frame material - Steel

Suspension (none, front, full) – n.a.

Steering system - Trailer drawbar + bicycle steering (towed trailer)

Bicycle Dimensions –

- Width: 0.952 m
- Length: 3.0 m
- Height: 0.795 m

Wheel size - 20”

Range (km) – 30–50

Load Capacity and Geometry

How efficiently and safely can the system transport parcels under real operational loads?

Max payload (kg) – 200

Cargo space – 1.5 m^2

Load distribution (% front/rear) – n.a.

Max axle load (kg) – n.a.

Centre of mass height(mm) – n.a.

Modularity and Cargo Interface

How effectively does the system support fast, safe and flexible cargo exchange?

Container system (fixed, modular) - Modular platform + accessory-based cargo solutions (platform-based trailer system)

Exchange system (rail, manual etc.) - Manual

Swap time (s) – n.a.

Locking method (pin, clamp etc.) – enclosed bars

Powertrain & Drivetrain

How capable and reliable is the propulsion system in supporting loaded urban delivery operations?

Motor type (hub, mid, wheel) – Hub

Motor power (W) – 250

Motor torque (Nm) – 45

Throttle (yes/no) – Yes (for use without bicycle)

Gear system (derailleur / hub gear) - n.a.

Transmission (chain/belt/shaft) –n.a.

Battery type – LiFePO4

Swappable battery (yes/no) – Yes

Battery capacity (Wh) – 720

Charging time (h) – 4h

Regenerative braking (yes/no) – no

Ergonomics

How well does the system support human use in terms of comfort, handling and physical workload during daily operations?

Weather protection – mudguards

Mount/dismount time (s) – n.a.

Rider posture (upright, semi upright, forward) – n.a.

Hand ergonomics (grip type) – n.a.

Seating (saddle type, adjustability) – n.a.

Loading height (mm) - 150

Number of handling steps – n.a.

Performance

How effectively does the system perform in urban environments under real delivery conditions?

Turning radius (m) – 2.1

Required lane width (m) – 0.952

Braking distance (loaded, (m)) – n.a.

Max Speed – Assist up to 25km/h

Average Speed – n.a.

Acceleration – n.a.

Sustainability

How does the system contribute to environmental impact reduction and long-term resource efficiency?

Energy consumption (Wh/km) – n.a.

Material sustainability (recyclable, mixed, composite) - mixed

System longevity (years) – 2 year warranty on frame / 1 year on battery

Price

What costs are associated with the product?

Vehicle unit cost – 9000 USD

Fixed costs – Modifications

Variable costs – Electricity

Safety and Compliance– How much risk is involved while using the product?

How well does the system minimize risk and comply with safety and regulatory requirements in real use?

Brake type (disc, hydraulic disc) – Overrun hydraulic disc

Motor cutoff on braking (yes/no) – n.a.

Visibility (out/in) – in: good**,** out: good (low cargo placement)

Lighting system – rear lights

Brake lights (yes/no) – n.a.

Turning light (yes/no) – no

Stability at stop (kickstand, self-stable etc.) – self stable (3 wheels + parking brake)

Theft protection – Lockable battery

User authentication – n.a.

Road legality – Approved as bicycle trailer in Germany

Manufacturing and Maintenance

How feasible is the system to manufacture, maintain and repair?

Maintenance interval (km) – n.a.

Modularity/Repairability – Standard bike components

Spare part availability – n.a.

Tool complexity – Standard bike components

Display and control interface

How effectively does the control and information system support safe, intuitive and reliable operation?

Display type (LCD, LED, none) – none

Display size – n.a.

Control type (buttons, touch etc.) – throttle handle

Operational modes – Bicycle mode / handcart mode

Digital integration (GPS etc.) – no

Further Comments

Requires bicycle to operate at higher speeds

Data-sheet:
https://drive.google.com/file/d/1KMsgGkM5jmgNijHEJ2UzpAdMpaV_qAMS/view?usp=sharing

Appendix C - List of parts

The list of parts is used as reference for manufacturers to determine what materials to buy, how to manufacture necessary components and how many are needed.

Design				Manufacturing				Reference
Part Name	**rt Details**	**Qty**	**Make/Buy**	**Material**	**Method (in order)**	**Supplier**	**Comment**	**Link**
Front deraileur mounting beam	cular hollow section (178x28.6x2)	1	Make	Steel	Cut, weld to frame		Top of tube slightly angled	
Upper seat frame mount	eet metal (4mm)	2	Make	Steel	Cut, drill, weld			
Cargo lock female	eet metal (4mm)	2	Buy/make	Steel	Cut, bend, weld		If found, standard components could be used	
Cargo rail	eet metal (2mm)	2	Make	Steel	Cut, bend, weld			
Loading Ramp								
Ramp	eet metal (4mm)	1	Make	Aluminium	Cut, bend, drill		Drill hole position dependant on ramp latches	
extension	eet metal (4mm)	2	Make	Aluminium	Cut, bend, weld, drill		Drill hole position dependant on ramp latches	
Ramp stiffener	eet metal (4mm)	3	Make	Aluminium	Cut, bend, weld			
Rotating ramp latch		2	Buy	Aluminium				https://www.barlowtrailers.co.uk/product/genui
Front Suspension								
Upper wishbone arm	Circular hollow section (20x2)	2	Make		Cut, weld			
Lower wishbone arm	Circular hollow section (20x2)	2	Make		Cut, weld			
Upright	Metal sheet (2mm)	2	Make		Cut, bend, weld, drill			
Disc brake caliper bicycle		2	Buy					https://www.amazon.com/Mechanical-Universal
10 mm front wheel axle		2	Buy/make		Cut, lathe, thread			https://www.amazon.com/Meuey-Lyot-Bicycle-M
20" BMX tyre		2	Buy					https://www.amazon.com/cubsala-Wheel-Yaphe
20" BMX front wheel with disc brake mount		2	Buy					
Bicycle brake disc			Buy					
Caliper mount		2	Make	Steel	cut, weld, drill			
340/350 mm coilover		2	Buy					https://www.amazon.com/Universal-Adjustable-
Fish eye rod end m10		12	Buy					https://www.skf.com/group/products/plain-beari
bracket	Sheet metal (2mm)	8	Make		Cut, drill, bend			
Rod end insert m10	m10 thread	4	Make	Steel	Turning, threading			
wishbone upright bracket	Sheet metal (2mm)	4	Make		Cut, drill, bend			
Upright braking/steering mount	Metal sheet (4.75 mm, 2mm)	2	Make		Cut, drill, weld			
Coilover bracket	Metal sheet (2 mm)	4	Make		Cut, drill, bend			
Coilover bracket plate	Metal sheet (4mm)	2	Make		Cut			
Rear Suspension								
Rear swingarm	Square hollow beams (25x25x2, 30x30x2)	2	Make	Steel	Cut, weld, drill			
34T Sprocket/chainring bolt on	/2" x 1/8", bmx	2	Buy					https://www.amazon.in/Lightweight-Professiona
180mm brake disc motorcycle	notorcycle	2	Buy					https://www.amazon.com/Brake-Rotor-Bicycle-
Disc brake caliper motorcycle		2	Buy					https://www.amazon.com/Motorcycle-Caliper-E
350/360mm coilover	0-50mm stroke, 120N spring	2	Buy					https://www.amazon.com/Gnyduw-MK-AR-350L
20" BMX rear wheel with disc brake mount		2	Buy					https://www.amazon.com/DONSP1986-inch-Re
20" BMX tyre		2	Buy					https://www.amazon.com/20-inch-Mountain-Bik
CaliperMount		2	Make	Steel	cut, weld, drill			
14mm rear axle	20mm Length	2	Buy/make	Steel	Cut, lathe, thread			
Sprocket carrier	0 steel rod/bar	2	Make	Steel/Aluminium	turning, milling, drilling			https://www.ajs-shop.co.uk/acatalog/REAR-SP
Coilover Upper Bracket	heet metal (4mm)	4	Make	Steel	cut,weld, drill			
Cargo							**Cargo box could be bought if good alternative is found**	
Trailer pin	1/4 "	2	Buy	Aluminium			Used for more than one subsystem	https://www.amazon.com/Locking-Trailer-Anti-L
Cargo lock male	Metal block (10x75x26)	2	Buy/make	Steel	Mill, drill, screw (to cargo wall)		If found, standard components could be used. Fastening height on cargo box dependant on cargo wheels	
Beam structure	Square hollow (25x25x2)	16	Make	Steel	Cut, weld		See drawings for specific beam lengths	
Box sheet and cargo floor	ACP panels (3-6mm) OR similar sandwich panels	6	Buy/make	Aluminium composite	Cut, heat weld/glue		Insulated sandwich panels, XPS foam core + thin skin (treated plywood, plastic, or aluminum)	https://www.sabinplastic.com/product/acp-4mm
Box door	ACP panels (3-6mm) OR similar sandwich panels	2	Buy/make	Aluminium composite	Cut		Insulated sandwich panels, XPS foam core + thin skin (treated plywood, plastic, or aluminum)	
Hinge	Choose based on availability	6	Buy	Steel				
Cargo wheel	Choose based on availability	4	Buy	Polyutherene	Screw			
Door toggle latch	Choose based on availability	2	Buy	Steel	Screw			
Steering								
Right Brake Lever	Motorcycle/Moped hydraulic brake lever right w parking lock	1	Buy				integrated parking lock	https://www.amazon.com.be/-/en/Hydraulic-Ma
Left Brake Lever	Bicycle disc brake lever w parking brake	1	Buy				integrated parking lock	https://www.amazon.com/Dia-Compe-DIACOMF
Handlebar Grip	Rubber grip	2	Buy					https://www.amazon.com/GPMTER-Handlebar-I
Quill stem	Diameter: 22.2mm, Length > 80mm, Clamp: 25.4mm	2	Buy				adjustable	https://www.amazon.com/WEERAS-Adjustable-
Headtube	(120x34x4), compatible with stem and headset	2	Buy					
Headset	compatible with stem and headtube	2	Buy					https://www.amazon.com/WEEROCK-Bicycle-I-
Steerer tube	threaded, from bicycle fork	2	Make		Cut			https://www.amazon.com/CDHPOWER-Steerer-
Steering connector	Sheet metal (5mm), circular hollow section (25.4 ID)	2	Make	eel	Cut, drilled, welded OR clamped		clamp or weld to steerertube	
Frame mount bracket	Sheet metal (4mm)	2	Make	Steel	Cut, welded			
Handlebar	Circular hollow section (25.4x4, 22x4)	2	Make	Steel	Cut, welded			
CenterLink	Sheet metal (10mm)	1	Make	Aluminium	Cut, drilled			
TieRod tube	Circular hollow section (20x2)	2	Make	Steel	Cut			
Rod end insert m10	m10 thread	4	Make	Steel	Turning, threading			
Fisheye Rod End m10		4	Buy					https://www.skf.com/group/products/plain-bear
3 speed shifter		1	Buy					https://www.amazon.com/SL-TX30-3-Speed-Mc
Handbrake clip	steel wire (2mm), metal clamp	1	Make	Steel	turning, welding		if brake lever dont have parking lock	
Drivetrain								
6/7/8 speed chain	1/2" x 3/32"	6	Buy					https://www.amazon.com/SHIMANO-HG40-116
BMX single speed chain	1/2" x 1/8"	4	Buy					https://www.amazon.com/KMC-Unbeatable-Stre
428 motorbike chain	1/2" x 5/16"	2	Buy					https://www.amazon.com/DYCTAHO-Motorcycl
Jackshaft	Solid circular bar/rod (20x760)	1	Make	4140 steel	cut to length, milling			
Freewheel adapter	solid circular bar/rod (40x40), Thread: 1.375" × 24 TPI (BSA/English)	3	Make	Steel/Aluminium	Turning, milling			https://www.amazon.com/Freewheel-Adapter-Tr
KeySprocket	5x5x16	1	Make	Steel				
KeyFreewheel	5x5x30	2	Make	Steel				
Shaft collar 20mm		1	Buy				to secure sprockets on jackshaft	https://www.amazon.com/Collar%EF%BC%8C4
Pillow block	20mm axle	2	Buy					https://www.amazon.com/Coavoo-Bearing-Mou
16T BMX freewheel	1/2" x 1/8"	2	Buy					https://www.amazon.com/Hycline-Freewheel-Co
20T Freewheel	1/2" x 3/32"	1	Buy					https://www.amazon.com/Box-Freewheel-Comp
sprocket	428 chain	1	Buy					https://www.amazon.com/-/es/WIHFHGZ-WIHFI
HubAdapter	Circular rod (70mm)	1	Make	Aluminium/Steel	Turning, milling, drilling			https://www.amazon.com/COEFEPIY-Holes-Ad
Rear Derailleur mount	m10x1.00 thread,	1	Make	Steel	cutting, welding		reuse derailleur mount from bicycle frame	https://www.amazon.com/2-Pack-Derailleur-Mo
Front derailleur	3 speed	1	Buy					https://www.amazon.com/Bicycle-Derailleur-FD
Rear Deraulleur		1	Buy					https://www.amazon.com/Derailleur-Huazu-RD-
Brake wire + cable	bicycle	2	Buy					
Shift wire + cable	bicycle	2	Buy					
Brake wire + cable	motorcycle	2	Buy					
48/38/28 crankset		1	Buy					https://www.amazon.com/PROWHEEL-28-38-4
Bottom bracket	68mm square taper, 127mm axle	1	Buy				with torque sensor if possible	https://www.amazon.com/BUCKLOS-Square-Ta
Pedal		2	Buy					https://www.amazon.com/Schwinn-Composite-1
100mm chain roller		2	Make	Nylon	3d print			
80mm chain roller		3	Make	Nylon	3d print			
Chain roller mount		2	Make	Steel				
Frame chain guard		3	Make	Nylon	3d print			

Powertrain								
Brushless DC Motor	BLDC 3kW 48V	1	Buy					https://www.oyostepper.com/goods-1359-3KW-
Motor mount	Sheet metal (5mm)	1	Make	Steel	cut, drill, weld			
Battery	48V 30AH LiFePO4 Battery	2	Buy					
Battery tray	Sheet metal (3mm)	1	Buy/make	Steel	cut, bend, weld			
11T Sprocket (spur gear)	428 chain, 5x5 keyway	1	Buy				12T also OK	
DC-DC converter	48V - 12V	1	Buy					https://www.amazon.com/Pro-Chaser-Converte
48V Motor Controller	48 V BLDC motor controller (VEC200 OR EZKontrol), 100A -500A	1	Buy					https://goldenmotor.bike/products/ezkontrol-48
Controller mount	Sheet metal (4mm)	1	Buy/make	Steel/Aluminium/plastic				
DC Circuit Breaker	48 V DC circuit breaker, 100A	1	Buy					https://www.amazon.com/Miniature-Pole-Isolat
Cycle Analyst	Display unit	1	Buy					https://ozo-electric.com/en/cycle-analyst/341-
Throttle	Compatible with 48 V BLDC controller	1	Buy					
Switch	motorcycle, integrated buttons	1	Buy					https://www.amazon.com/LHAIQQ-Electric-Acc
Pedal Assist Sensor	Hall-effect, compatible with 48 V BLDC controller	1	Buy					https://www.amazon.com/Cunyuer-System-Ass
High current battery cables	battery, breaker, controller		Buy					https://www.amazon.com/Silicone-Electrical-Te
Battery connectors	Parallel battery connector, connectors		Buy					https://www.amazon.com/LinsyRC-Connector-Y
Ring terminals			Buy					https://www.amazon.com/smseace-Insulated-c
Connectors	connectors: throttle, PAS, Cycle analys, switch		Buy					
DC-DC output wires	Lights		Buy					
Seating								
Recumbant seat	Adjustable seat w. mesh textile	1	Make	Textile, steel	Weld seating frame, sew padding/cover around frame		Seat made to resemble the CAD model. IMPORTANT: max width of seat 375 mm.	
Horizontal adjuster	Sheet metal (2mm)	2	Make	Steel	Drill, bend			
Trailer pin	1/4 "	1	Buy	Aluminium			Used for more than one subsystem	https://www.amazon.com/Locking-Trailer-Anti-L
Adjuster joining beam	Square hollow beam (25x25x2)	4	Make	Steel	Cut, weld to seat/adjuster		Beam length dependant on recumbant seat	
Back support beam	Square hollow beam (25x25x2), Circular hollow section (20x5)	1	Make	Steel	Cut, mill, weld		Beam length dependant on recumbant seat	
Safety features								
Adjustable mirrors	Mountable on handlebars	2 (left, right)	Buy				To ensure sight regardless of seating position	
Horn/bell	Mountable on handlebars	1	Buy				Needs to be load in traffic	
Headlights	yellow	2	Buy				Powered by batteries	
Rear lights	red	2	Buy				Powered by batteries	
Reflectors	orange	4	Buy				For visibility from sides	
Fasteners								
Screws	Hex socket head cap screw M10 x 40 Stainless Steel	12	Buy	Stainless steel				
	Hex socket head cap screw M10 x 30 Stainless Steel	11	Buy	Stainless steel				
	Hex socket head cap screw M5 x 14 Stainless Steel	16	Buy	Stainless steel				
	Hex socket head cap screw M5 x 10 Stainless Steel	16	Buy	Stainless steel				
	Hex socket head cap screw M10 x 130 Stainless Steel	4	Buy	Stainless steel				
	Hex socket head cap screw M10 x 70 Stainless Steel	2	Buy	Stainless steel				
	Hex socket head cap screw M6 x 25 Stainless Steel	4	Buy	Stainless steel				
	Hex socket head cap screw M6 x 35 Stainless Steel	4	Buy	Stainless steel				
	Hex socket head cap screw M8 x 22 Stainless Steel	4	Buy	Stainless steel				
	Hex socket head cap screw M6 x 40 Stainless Steel	19	Buy	Stainless steel				
	Hex socket head cap screw M10 x 55 Stainless Steel	6	Buy	Stainless steel				
Nuts	M10 lock nut	35	Buy	Stainless steel/nylon				
	M8 lock nut	4	Buy	Stainless steel/nylon				
	M6 lock nut	27	Buy	Stainless steel/nylon				
	M5 lock nut	32	Buy	Stainless steel/nylon				
Washers	M10/M8/M6/M5	Where needed	Buy	Steel				
Other fasteners	Specific fasteners for bought components are not listed here and needs to be aquired seperatly based on chosen products. Examples of these components are hinges, latches, headlights, mirrors, seat, cargo wheels, reflectors, and cargo locks but can include more.		Buy					

Figure 9-12. Master parts list

Appendix D – Requirements

The document containing requirements approved by the CEO of Eco Delivery.

Cargo Vehicle Requirements – CEO Sign-Off Document

This document consolidates the agreed functional, safety and business requirements for the next-stage vehicle concept. Please review and confirm alignment on targets and specifications before further development proceeds.

Stability & Handling

Requirement	Target Metric
Vehicle must remain stable under full load	No wheel lift or rollover at 30 km/h with 200 kg payload
Vehicle must remain stable during downhill braking	No tipping during emergency braking on 15% incline at 200 kg payload
Vehicle must be controllable at low speed	Stable steering at ≤5 km/h without oscillation
Vehicle must remain stable at standstill	Self-stable without rider support for ≥60 seconds at 5° incline
Low centre of gravity	Cargo floor height ≤300 mm from ground

Structural Robustness & Durability

Requirement	Target Metric
Frame must withstand rough roads	Safety factor ≥2 under maximum static load
Drivetrain must withstand dynamic loading	Rear axle rated ≥1.5× expected torque load
High operational reliability	Service interval ≥1000 km
Fast repairability	Wheel removal ≤5 minutes using standard tools
Electrical protection	Minimum IP65 rating battery enclosure

Payload & Cargo

Requirement	Target Metric
High payload capacity	Target payload 200 kg
Cargo must be enclosed and lockable	Fully covered box with integrated lock
Modular cargo compatibility	Compatible with 600×400 mm crates
Fast box exchange	Box swap ≤2 minutes by one operator

Powertrain & Energy

Requirement	Target Metric
Hill-climbing capability	Maintain ≥15 km/h on 15% incline with 200 kg payload

Maximum assisted speed	45 km/h (subject to legal confirmation)
Operational range	≥50 km under mixed urban conditions
Pedal operability without motor	Vehicle can be pedalled ≥5 km without assist
No throttle propulsion	Assist active only when pedalling

Safety & Compliance

Requirement	Target Metric
Injury risk reduction	No rigid steering column directly in front of torso
Controlled braking	Equipped with progressive braking system
Bicycle classification	Equipped with functional pedals
Width constraint	Maximum overall width ≤1000 mm

Manufacturing & Cost

Requirement	Target Metric
Local manufacturability	Frame made from carbon steel tubing available locally
Local serviceability	≥80% components available locally
Cost constraint	Unit manufacturing cost ≤4000 USD

Appendix E – Used 3d assets

Apart from authors own work, some parts were retrieved from others and are listed below. All work is appropriately used in accordance with relevant usage rights.

- Bottom bracket: https://grabcad.com/library/shimano-bb-un-52
- Crankset (modified): https://grabcad.com/library/bicycle-crank-set-170mm-1
- Front derailleur: https://grabcad.com/library/front-derailleur-2
- Hinges: https://grabcad.com/library/sk2-172s-1-1
- Caster wheels: https://grabcad.com/library/caster-wheel-136
- Toggle latch: https://grabcad.com/library/small-toggle-latch-1
- SKF rod ends: https://www.skf.com/group/products/plain-bearings/spherical-plain-bearings-rod-ends/rod-ends/productid-SAKB%2010%20F
- Throttle: https://grabcad.com/library/ebike-thumb-throttle-300x-1
- Motor switch: https://grabcad.com/library/motorcycle-switch-handlebar-electric-starter-flameout-button-switch-1
- Horn: https://grabcad.com/library/tuter-1
- Side mirrors (modified): https://grabcad.com/library/3-axis-bike-mirror-1