MECH 2412
Design Project - Rope Tow

GROUP MEMBERS (TEAM 8)

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1.0 Need Analysis

1.1.1 Need that initiated the project

According to the UN sustainable development goals, it is believed that a prospering country should have a balanced social, economic and environmental sustainable factor. Achieving this concept is what brings us to our project of helping the local residents living around the Trishuli river, to be able to cross it safely along with their belongings.

1.1.2 General Problem Statement

Due to the unsafe mountainous terrain along with the sparse population, the residents of Tibet have trouble traveling to their daily needs as it is not cost-effective to build a proper bridge. This leads the residents to use bridges that are prior built and generally far which also requires time-consuming trips. For overcoming this issue the residents made a simple hand-over-hand pulling mechanism cart hung over a long cable spanning over the river. Getting across in this means of transportation is very dangerous as well as very difficult since it requires the passenger to be physically fit to maneuver the cart.

1.1.3 Refined Problem Statement

(This part was added under the feedback of TA Solomon)
A cable cart is needed to be built for the citizens of the village in Tibet, who need a way to cross the river, this is due to other routes being either too long or too dangerous to get to their daily needs.

1.2 Stakeholder Analysis

A stakeholder is someone who can affect or who is affected by a project. Stakeholder engagement is essential to reach organizational goals effectively. The stakeholder analysis for this project is as follows;

1.2.1 List of stakeholders

- Residents of Tibet - As they will use the cart for their necessary daily tasks by getting across the river.
- Engineers designing the cart - Being responsible for coming up with a design that will be implemented in making the cable cart.
- Construction Workers - They will be putting the physical mechanism together which is high above the river.
- Project Manager - Overseeing the entire project from start to finish.
- Maintenance Workers - They are responsible for properly maintaining the cart and its components are safe to use.
- Regulatory Authorities - They are responsible for making sure that the cable cart is used within regulations such as maximum weight, adequate clearance from the river.
- Investors - Investing in the project to make it possible to construct the cable cart.
- Suppliers - Providing the necessary materials to construct the cable cart.
- Tourists - Bringing in publicity and financial benefit for the local area.

1.2.2 Importance of stakeholders

1. Residents of Tibet
2. Investors
3. Project Manager
4. Maintenance Workers
5. Construction Workers
6. Engineers designing the cart
7. Suppliers
8. Regulatory Authorities
9. Tourists

1.2.3 Specific needs of each stakeholder

Residents of Tibet:

- Carrying the daily necessities using the cable cart.
- Getting across the river for proper access to education, healthcare and markets.
- Simple to use/accessible.
- More time-efficient as opposed to crossing a bridge some distance away.
- Free for the residents.
- A sense of safety for going across the river.

Investors:

- Reliability of the project.
- Advertisement/Publicity.
- Cost as little as possible.
- Project timeline being followed.

Maintenance workers:

- Usual timely maintenance.
- Deferred/Inaccessible due to weather conditions may halt proper maintenance.
- Clear instructions to be followed.

Construction Workers:

- Safety of the workers during the construction.
- Proper resources are given to them.
- A clear and simple plan as to what they are building.
- Accommodation during the construction.

Engineers/Designers:

- Designing the cart in accordance with the terrain.
- Making the cart ergonomic, safe and durable to be used over time.
- Using materials to last over time along with rough weather conditions.
- The design of the cart follows project regulations and requirements.
- Cart to operate with minimal energy consumption of the passenger.

Tourists:

- The cart to be built a safe enough distance from the river surface.
- No possibility of falling objects/debris from the cart.
- The ability to still Kayak/raft in the river.

Project manager:

- Making sure that the maintenance/construction workers are always encouraged to follow the project plan and timeline.
- The budget and financial scope being maintained.
- Effective team communication & collaboration.
- Quality Assurance.

Suppliers:

- Required items are ordered in advance therefore there is ample time to process the order.
- Customer Satisfaction.
- On-time payments.
- Good Communication/Collaboration.
- Proper and quality materials are supplied.

Regulatory Authorities:

- All safety regulations are followed.
- Complying with local laws and regulations.
- Quality regulated materials being used.

1.3 Market Analysis

1**.** Are there any existing products on the market that can meet the needs of your stakeholders?

- A classic cable cart would help residents make the trip across the river along with their belongings. It would work despite the local weather conditions. One of these would be relatively affordable.

[A] If not, are there any products that solve a similar problem, but fail to meet some of the stakeholder's needs?

- There are ropeway cables that transport people between mountainous terrains using electrical carts, this, however, would not work because of the restrictions of the weight and cost along with the terrain not permitting to build an electrical cart. This would also not be ideal because of the potential hazards from water affecting the mechanism. Changing weather conditions (Harsh wind) may also cause possible disruption of service since electric carts are only fixed from the top. Furthermore, the cost associated with the operation and maintenance of an electrical cable cart system is unbearable for the lower class citizens living in this village. The classic cable cart also fails to meet some of the stakeholder needs such as safety which is one of the most important attributes to be considered in a river cross rope mechanism.

[B] Give a brief overview of these products and the companies who build them (functions, cost, availability, etc)

- The gondola lift is an example of cable transport. It uses a cable attached to the top of the cart and a motor to keep the cart in constant motion. Companies such as SkyTrans, Carvatech, and Graffer, are current manufacturers of these aerial lifts.This type of cable cart is commonly used at skiing resorts to bring the skiers up the slopes. It can sustain the weight of several people along with their equipment. The smaller 2 person lifts cost $900,000 USD while the largest 12 person lifts will cost $4.5 million USD, with the installation of the cart. .Also, according to (gondolaproject.com), "Smaller, less complex (~1km, MDG) CPT systems can be designed and built-in approximately one year's time." [23]

[C] Are there any specific needs of your stakeholders that are not met by existing products?
- As the existing products are made for a bigger volume of users it exceeds the cost of construction, time allocated for completion, material cost, amount of material needed and maintenance cost than our project requirements. Moreover, the labour needed to complete building the cable car and maintaining it after it is completed may not be readily available, while there would be an engineer overseeing the building of the cable car, an engineer may not be available to maintain it afterwards which may be needed due to its more complicated mechanism, and depending on how complicated it can be it may also need a trained person to run the cable car while our goal is for it to simple be enough so that the citizens of Tibet can use it without any complications.

1.4 Project Requirements

While designing the prototype of the cable car, we need to limit ourselves with some constraints, or project requirements, to go by so we meet the needs of all the stakeholders present in the project. The requirements that we set for ourselves are as follows:

- Low cost for investors: We need to make sure that the project does not go over a budget that would suit the investors.
- Can be used by anyone: Simple and easy to use mechanism allowing everyone to use and does not require the passenger to be physically fit.
- Use of the battery and motor components: To make the mechanism easy for everyone to use, we will be using a motor and a battery, with the drawings provided, so that the cable transport can be run without manual labour.
- Safety: As important as the simplicity of the design it is even more important in the safety of the design.
- Low maintenance and operational cost: The cable transport would be built in a rural area which most likely would not offer enough funds or labour to maintain or build the cable transport.
- Low Energy consumption: Being built in a rural area there is no guarantee that a lot of power would be available for the cable transport and the motor provided does not provide a big amount of power meaning that the energy consumption should be as low as possible.
- Readily accessible: Citizens would be using the cable transport daily to go from their houses to the places they need to be and back every day, whether it be schools or markets or workplaces, so the cable transport should be readily available.
- Free usage possibility: Being in a rural area funds may not be equally accessible to everyone in the area so it is optimal to have no fee for using the cable transport.

1.4.2 Project Objectives

Project objectives are the desired results we expect to achieve in a project. For this rope tow project, our primary objectives are illustrated in detail by the following chart.

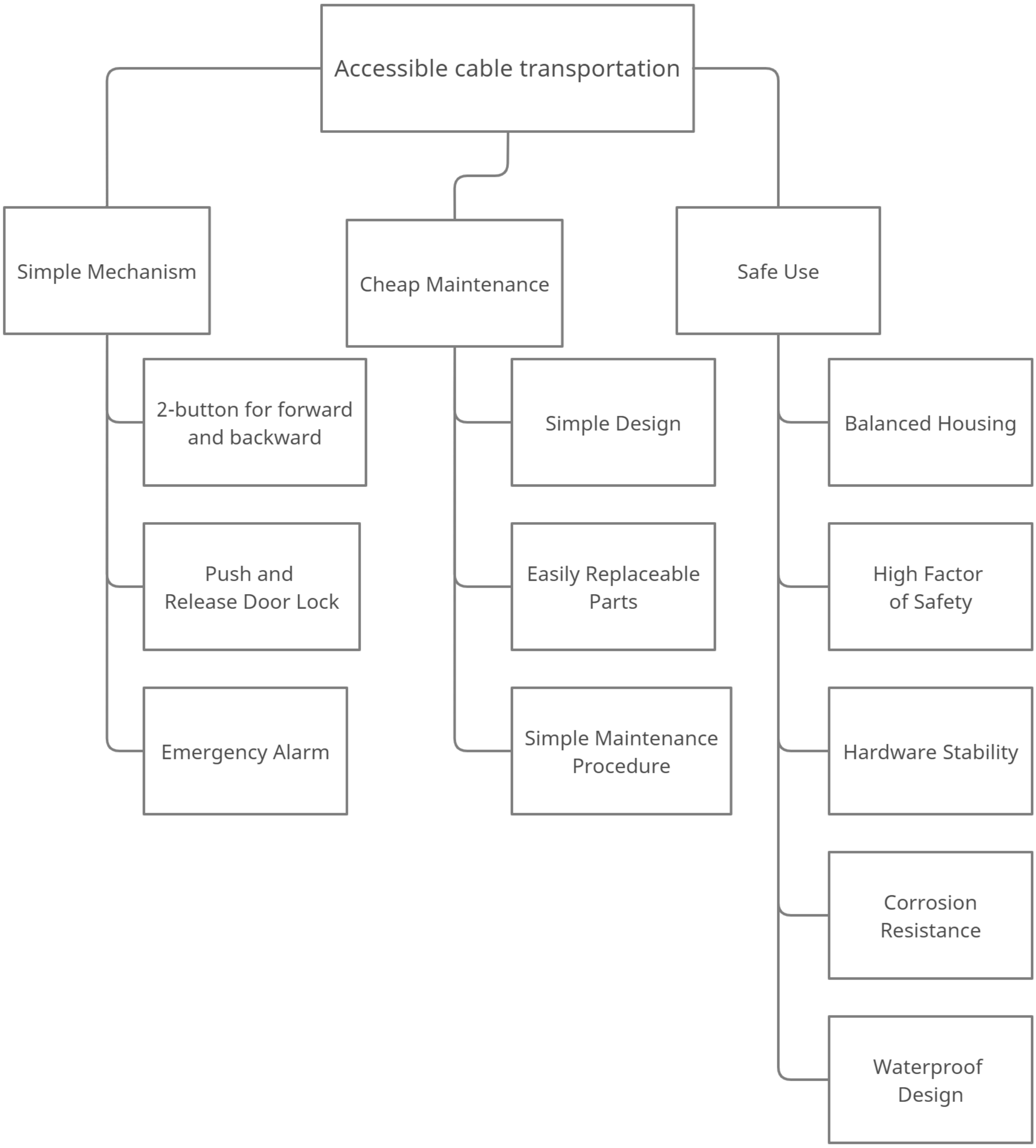


Figure 1: Project Objective Chart

2.0 Conceptual Design

2.1 Specification List

After completing the research phase, constructing a detailed specification list can provide an overview of all the requirements of the design. These requirements are categorized as Demands or wishes with detailed specifications. Our Cart Design would meet all the requirements listed out in the specification list shown below:

Category	Demand or wish?	Specification
Geometry		
• Height	D	- 1 m (3.28 ft)
• Breadth	D	- 2 m (6.56 ft)
• Length	D	- 3 m (9.84 ft)
• Symmetry	D	- For balancing out the weight distribution of the cart having
• Space requirement	W	- For fitting more inside the cart
• Arrangement	W	- Seating arrangement with enough leg space and storage space.
Technical		
• Power Supply	D	- Battery powered/alternate renewable powered motor moving the cart
• Efficiency	D	- Using soft iron core motors to cancel out voltage imbalance. Using recommended connection wires.
• Ventilation System	W	- Proper air flow within the covered portion of the cart
• Temperature Control	W	- Changing temperature during winter/summer
• Smart Display	W	- Having a IP45 rated monitor display to show the functions of the cart.
Material		
• Materials used	D	- Cast stainless steel
• Material Strength	D	- High tensile strength
• Material Availability	D	- Readily available
• Minimum amount of material used	D	- Approximately 200 kg
• Water proof	D	- Coating the body with a water shield protector
• Rust Proof	D	- Cast stainless steel has chromium infused which helps slow down rust. Alternatively a sacrificial metal can be used
• Thermal Resistivity	W	- Using adequate insulating materials within the walls of the cart with the interior

Safety ● Operator/User safety	D	- All safety regulations maintained
Ergonomics ● Type of operation ● Clear vision of surroundings ● Lighting ● Aesthetics	D D D W	- Minimalist easy to use switch mechanism for operating the cart - No visual obstruction of surroundings when the cart is operating. - Can be used for signalling or during night time operation - An appealing look for the cart would make it more attractive and attract tourists
Transport ● Lifting ● Clearance ● Speed	D D D	- Accommodate passengers and supplies up to approximately 150kg ~ 200kg - Safe distance from the river surface - Approximately 16km/h ~ 25km/h depending on the design and load
Maintenance ● Service ● Inspection ● Repair ● Painting ● Cleaning	D D D W W	- Bi-annual Service - Monthly inspection - When needed - Once every 5 years - Weekly Cleaning
Cost ● Manufacturing Cost ● Design Cost ● Labour cost ● Investment ● Depreciation	D D D D W	- Within a reasonable budget range of CAD $7,000 ~ CAD $ 15000 - Within a range of CAD $ 500 ~ CAD $ 1000 - Within a range of CAD $ 2000 ~ CAD $ 3000 (depending on the geographic location) - Primary government based funds or donations from charities - Due to the materials being used, the depreciation factor would be minimum
Durability ● Product life span	D	- 15-20 years

Table 1: Specification List

2.2 Functional Structure Diagram

One of the best ways to visualize how a design will function is through a functional structure diagram. What it does is show each stage of a design from start to finish, in our case it's when the rider turns on the cart and reaches the other side of the river. We tried to simplify it so it's easy to understand and follow while also showing the main stages of the ride by following the flow.

Our Functional Structure Diagram is as follows:

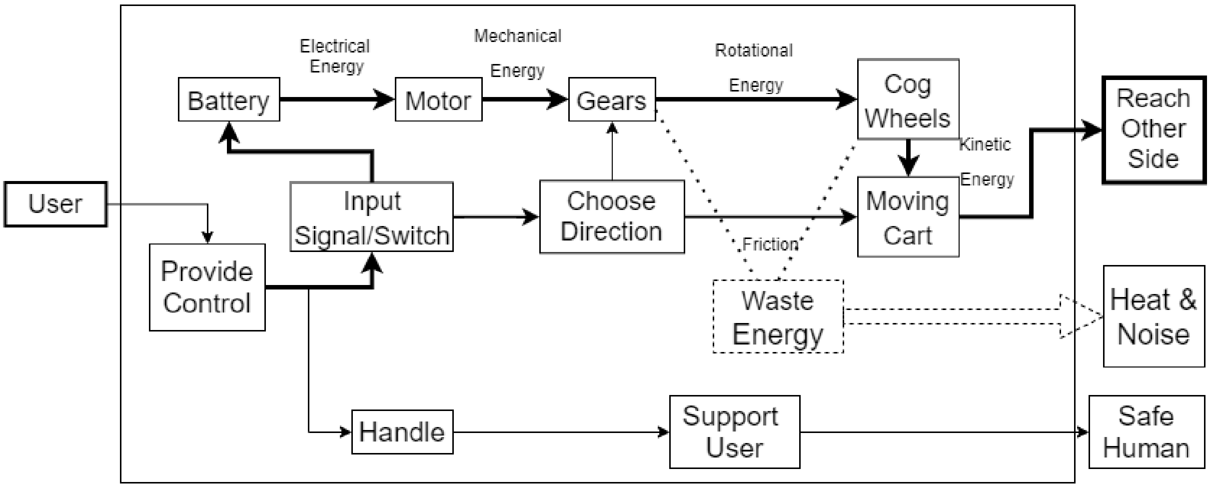


Figure 2 : Functional Structure Diagram

This part was added based off of the feedback received from the TA.

User: The user provides control.

Provide Control: This stage is where the user provides an input

Input signal/switch: This will allow the user to turn on the mechanism.

Choose Direction: This will allow the user to choose if it goes forwards or backwards.

Battery: The Battery is the power source for the cart which is rechargeable. It provides electrical energy to the motor.

Motor: Turns the gears by converting electrical energy to mechanical energy.

Gears: Rack and Pinion Gear system which will turn the cog wheels through rotational energy.

Cog Wheels: The cog wheels will turn over the cable which will cause the cart to move.

Moving Cart: The cart will be transporting from one side to the other

Reach Other Side: The user will reach the desired destination

Handle: The handle would provide the user something to hold onto during the journey.

Support User: Provide support for a smooth journey across the river.

Safe Human: User safely reaches the other side of the river

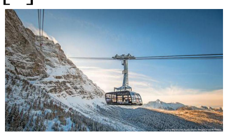
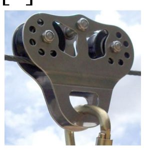
Waste Energy: Not all energy provided would be used, this represents the energy that wasn't useful in the process.

Heat and Noise: The type of waste energy released

The cycle starts from the user inputting a signal to the switch to start the motor from an ON/OFF switch and choose the direction from another switch. The motor then turns gears that turns cog wheels and moves the cart which gets the user to the other side. A safety handle is provided in the design so the user can hold on to it. Some waste energy is released in the process such as heat and sound from friction.

2.3 Morphological Chart

The morphological chart consists of the main features of the mechanism along with a few different options for each feature.

	Option 1	Option 2	Option 3	Option 4
Safety features	Handle [1] 	Emergency Stop Button [2] 	Seatbelt [3] 	Emergency Cable [4] 
Wheel system	On top of cable & attached to cart [5] 	Stationary wheels [6] 	Wheels turning on river floor [7] 	
Input signal device	Lever [9] 	Button [10] 	Touch Input [11] 	Switch Panel [12] 
Gear type systems	Helical Gearbox [13]	Rack and Pinion Gearbox [14]	Worm Gearbox [15]	Planetary Gearbox [16]

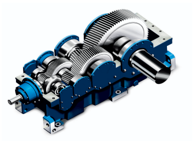
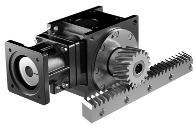
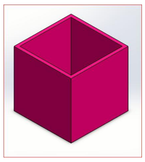
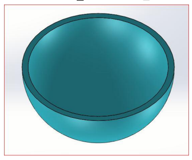
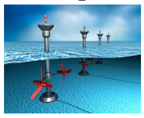
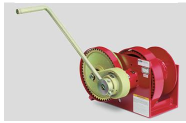
				
Cart structure	Bathtub [17] 	Box 	Hemisphere] 	Boat [18] 
Power Source	Battery [19] 	Solar power [20] 	Tidal power [21] 	Manual [22] 

Table 2: Morphological Chart

2.4 Conceptual Designs

Conceptual design 1

Conceptual Design 1 (see figure 2.1 in appendix) combines the safety handle [1], cable mechanism [5], box cart structure [18], manual power source [24], motor [21].
The main idea behind this design was to make the cart go faster using the manual power source (the hand pulley) if the user wished to, if they didn't need that then the motor would drive it automatically.

Conceptual Design 2

Conceptual Design 2 (see figure 2.2 in appendix) combines the safety handle [1], wheels turning on river floor [7], button [10], rack and pinion gear box [14], hemisphere [19], and solar power [22].

The mechanism is guided by the cable and moves by driving through the river bed. The wheels are turned by a gear chain and gear system which is attached to a motor. This motor is powered by a solar panel attached to the side of the cart. A safety handle is provided to assure that the user feels secure at all times.

Conceptual Design 3

Conceptual design 3 (see figure 2.3 in appendix) combines the emergency stop button [2], cable wheel mechanism [5], touch screen for input signal [11], rack and pinion gearbox system [14] in a bathtub cart structure [17] powered by a battery [21].

The motor enables to move the cart without any physical exertion on the body and it is fitted with a IP45 rating display. The rack and pinion gearbox allows the bathtub to be moved across the river surface and the gear does the same job at low cost also providing high torque.

Conceptual Design 4

In Conceptual Design 4 (see figure 2.4 in appendix), cables from two winches on either side of the cart are fixed to the columns on the shore. When the cart is moving in one direction, the respective winch starts pulling the cart in that direction while the other winch is freely moving without power.

This design combines an emergency cable [4] and bars to hold [1] for extra safety of the users, a wheel system on top of cable attached to the cart [1], a basic switch panel for easy control of the cart (Forward, Backward, Stop) [12], a Worm gear system [15] which can winch upto 2.5 Tonnes and battery power with an emergency reserve [21].

2.4.1 Weighting Scheme

The rank was determined based on an unbiased judgement on which objective was of greater importance. 8 was the most important while 1 was the least important. The ranking technique used is ordinal ranking.

Objective	Rank (Low-high, 1-8)	Justification
Cost	7	This is an important priority as it directly affects the production of the project. Without following the budget, the project may never be completed which will directly impact almost all stakeholders.
User Safety	8	Without a safe trip across the river, the residents will likely not even use the mechanism, deming it useless. This would impact all the stakeholders negatively.
Physical Dimension/Lifting Capacity	2	The physical dimension is more important than the aesthetics because it must be able to sustain a min load of one person. The dimensions lack any other significance and do not affect the stakeholders enough to be of any more importance.
Ease of operation	3	Ease of operation has little effect on the budget and safety of the mechanism. Ergonomics only affect the users of the mechanism directly therefore are not very important.
Low Maintenance	4	The maintenance workers are not high on the stakeholder list making low maintenance not a priority. Maintenance will lengthen the mechanisms lifespan therefore it ranks 4.
Energy Efficient	5	The energy efficiency directly impacts one of the more important stakeholders, the investors. A more energy efficient mechanism will generally cost them less in the future.
Weather	6	This directly impacts the maintenance workers and investors. The

proof/Durability		investors are of more importance in the stakeholder ranking, therefore this ranks 6.
Aesthetically pleasing	1	The physical appearance is the least of our priorities because of how little it affects the stakeholders. They all have little to no benefit from an aesthetically pleasing mechanism.

Table 3 : Objective Ranking

Highest is 4 and lowest is 1

Conceptual Design	Lowest cost (7)	User Safety (8)	Physical Dimension/ Lifting Capacity (2)	Ease of operation (3)	Low Maintenance (4)	Energy Efficient (5)	Weather proof/Durability (6)	Aesthetically pleasing (1)
(1)	3	2	3	3	2	4	2	2
(2)	1	2	4	4	1	4	2	2
(3)	2	3	3	4	3	2	2	3
(4)	2	4	4	4	2	2	3	3

Table 4: Conceptual Design Ranking

Design	Calculation	Total
Conceptual design 1	(7x3) + (8x2) + (2x3) + (3x3) + (4x2) + (5x4) + (6x2) + (1x2)	94
Conceptual design 2	(7x1) + (8x2) + (2x4) + (3x4) + (4x1) + (5x4) + (6x2) + (1x2)	81
Conceptual design 3	(7x2) + (8x3) + (2x3) + (3x4) + (4x3) + (5x2) + (6x2) + (1x3)	93
Conceptual design 4	(7x2) + (8x4) + (2x4) + (3x4) + (4x2) + (5x2) + (6x3) + (1x3)	105

Table 5: Weighing Scheme

2.4.2 Weighting scheme justification

From table 5, Conceptual Design 1 earned the weight rate of 94. It scored an average of 2/3 points in most categories except for the energy efficiency which it scored a 4, this is due to the hand pulley mechanism to help the motor move faster which reduces the up time of the motor. The design did get a good score in all the important aspects such as: cost, energy efficiency and somewhat in user safety, this made the design receive the second highest score.

Conceptual Design 2 earned a weight rate of 81. This one, when compared to the other designs, was the lowest for a few reasons. First, the safety rating, being the most important objective, was 2. This was due to the lack of safety features in the design. Also, due to the wheels and solar panels the maintenance rating was a 1. These scores alone were significant enough to lower the overall rating of design 2.

Conceptual Design 3 was rated a weight of 93. The reason it was ranked third out of all the designs was because of the cost factor, energy efficiency and weatherproof/ durability factor not being up to par. As the design had a rack and pinion gearbox it was an investment in the long run but for initial installation, it did not come cheap. Along with that, the IP45 touch screen added on to the cost. In the case of being energy efficient, it was battery powered so it was rated 2.

Conceptual Design 4 earned a total rating of 105. This design was rated 2/4 for the cost since it has a considerably big amount of machinery. The safety rating was 4/4 due to the emergency cable system as well as the safety handles. Lifting capacity was also rated 4 since the worm gear winch system can winch approximately 2.5 tonnes. This design has a basic 3 switch panel hence it was rated 4/4. Maintenance and energy efficiency were rated 2 as it requires more frequent oiling of the cables and draws more power due to its weight. It is also more durable due to the extra cable present, therefore it was rated 3/4.

2.5 Principle Solution

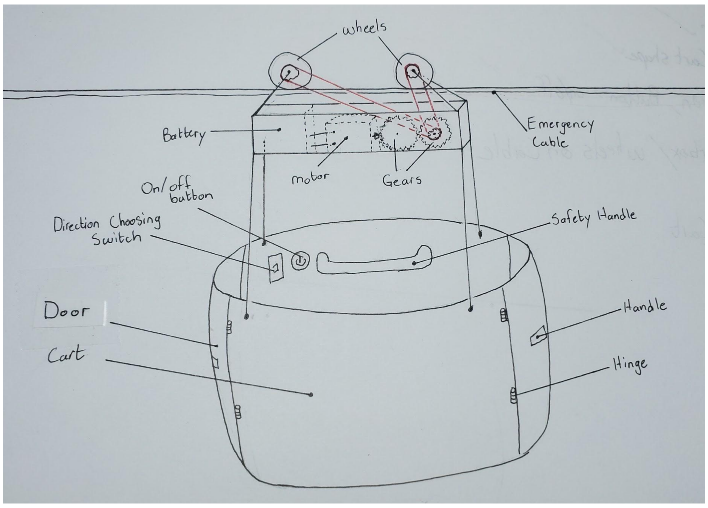


Figure 3: Principle design

For our principle design, we went with a more round/ organic shape of the cart to maximize the user experience. We chose this to reduce the shear stress on the corners of the cart when carrying a head load. In addition, the safety features for this cart includes an emergency cable and a safety handle. We are using a simple bi-directional switch to control the forward and reverse motion and also a button for ON/OFF. Also, the cart will be battery powered, connected to a motor turning a rack and pinion gearbox which, in turn will move the wheels on the cable moving the cart.

3.0 Embodiment Design

This section will talk about the development of our design from unto a 3D model using SOLIDWORKS

3.1 Preliminary Layout

This section will show the first design we had after coming up with the principal solution to the design

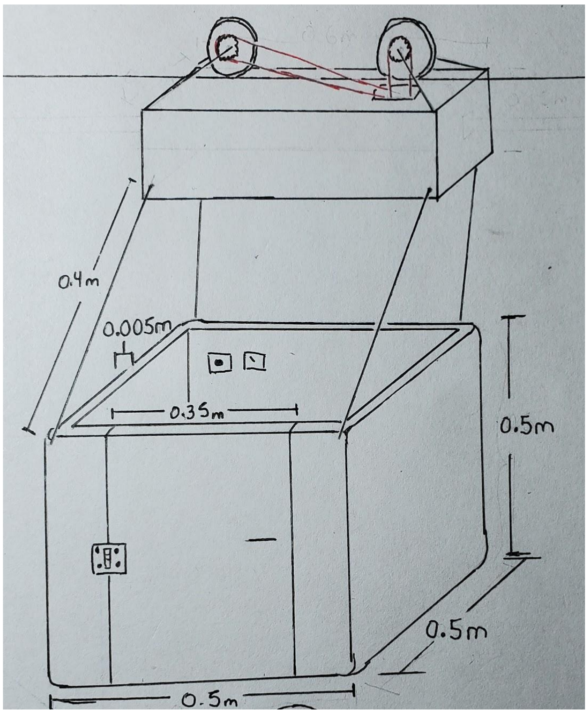


Figure 4 : Principal Design Layout

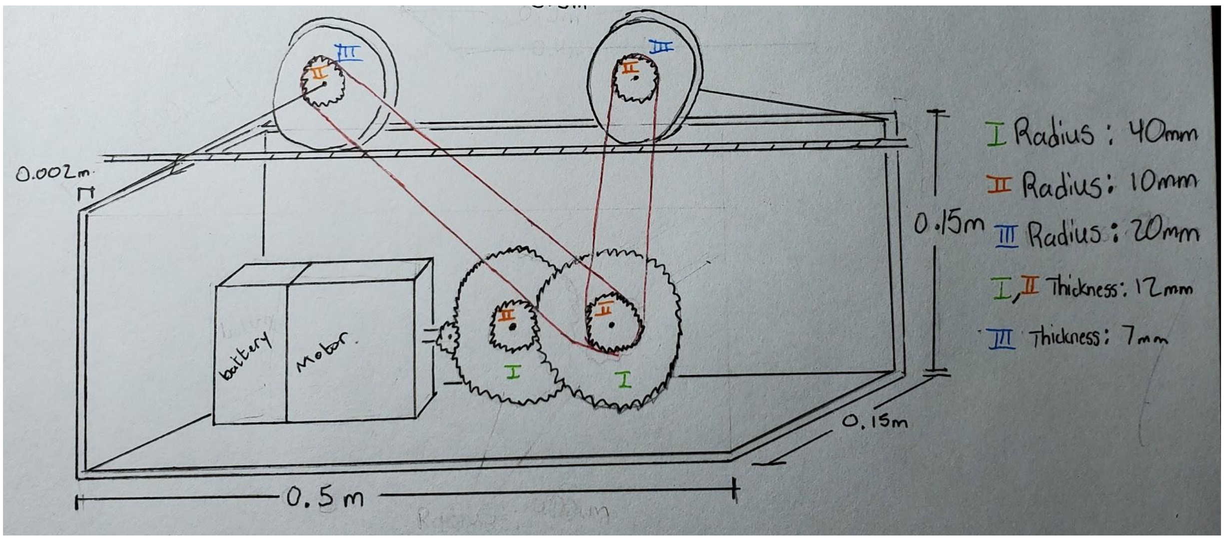


Figure 5 : Gearbox Layout

All components are made up of cast stainless steel. The two components that are of exception to this are the battery and the motor.

3.2 Strength Calculations

This section shows all the maximum stresses for all components and their respective factor of safety with regards to the material used.

Assumptions: Since the Yield Strength of Cast Stainless Steel wasn't registered in SOLIDWORKS, we calculated the Factor of Safety using a yield strength value we obtained from the internet which is equal to 240MPa (Available at:
http://www.matweb.com/search/datasheet_print.aspx?matguid=510db9e4e452434799516a259ae9deea
All the forces used had a value of 100N and all the torques used had a value of 1 Nm.

Design Calculations

Property	Value	Units
Elastic Modulus	190000	N/mm^2
Poisson's Ratio	0.26	N/A
Shear Modulus	79000	N/mm^2
Mass Density	7700	kg/m^3
Tensile Strength		N/mm^2
Compressive Strength		N/mm^2
Yield Strength		N/mm^2
Thermal Expansion Coefficient	1.5e-05	/K
Thermal Conductivity	37	W/(m·K)
Specific Heat	520	J/(kg·K)
Material Damping Ratio		N/A

Values for the Factor of Safety and maximum stress each component experienced.

Component	Max stress (Pa)	FoS (Yield Strength/ Max stress)
Gear Rods	2.55E+07	9.42
Small Gear	4.16E+07	5.76
Big Gear	6.30E+07	3.81
Cart	5.52E+07	4.35
Wheel	2.36E+06	102
Connecting Rods	6.60E+07	3.64

Lowest FoS	3.64E+00

Minimum Tooth thickness => For Big Gear: 4.3 mm, For Small Gear: 5.3 mm

Simulation Calculations

Big Gear

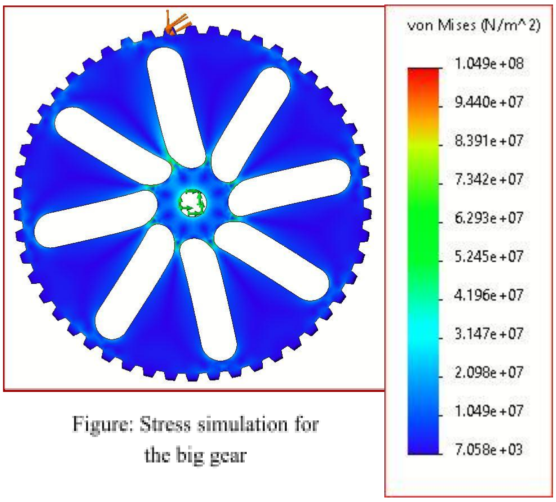


Figure: Stress simulation for the big gear

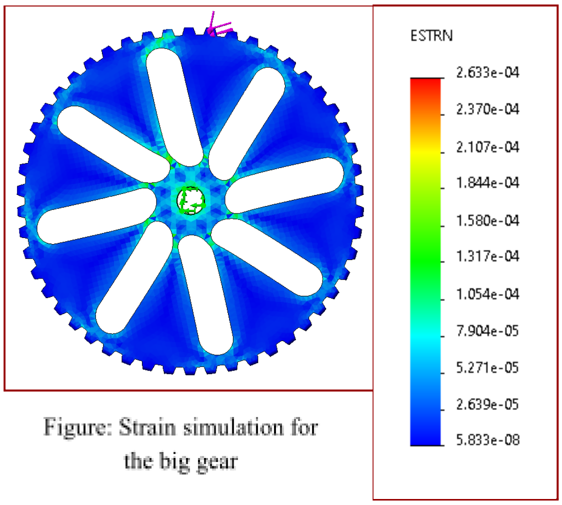


Figure: Strain simulation for the big gear

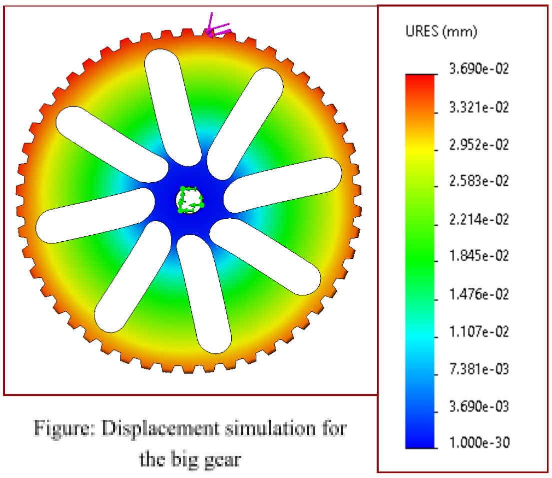


Figure: Displacement simulation for the big gear

Max Stress = 1.049E+08 Pa

Factor of safety = Yield Strength/Max Stress = 2.40E+08/1.049E+08 = **2.287**

Since the factor of safety is greater than 1, the part is acceptable. It will only fail at twice the working design load.

Small Gear

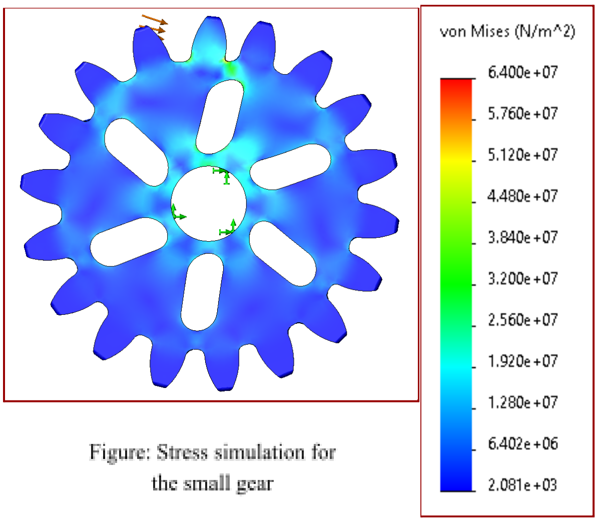


Figure: Stress simulation for the small gear

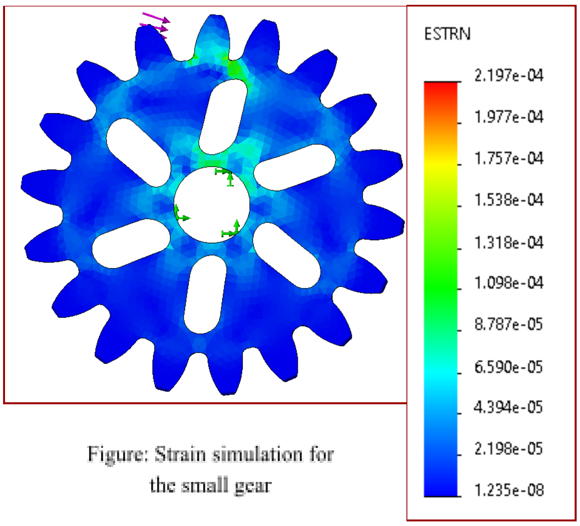


Figure: Strain simulation for the small gear

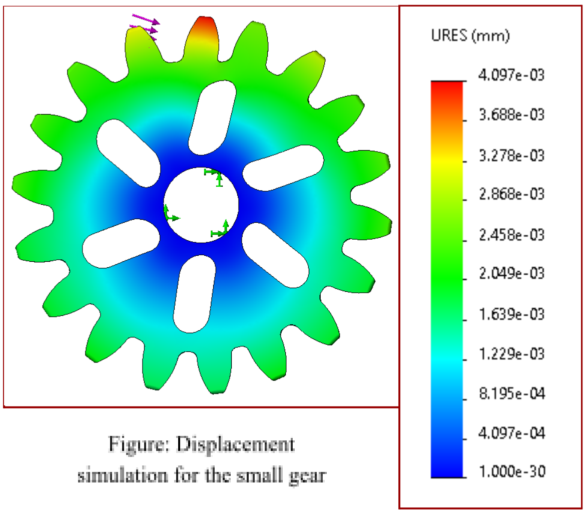


Figure: Displacement simulation for the small gear

Max Stress = 6.40E+07 Pa

Factor of safety = Yield Strength/Max Stress = 2.40E+08/6.40E+07 = **3.75**

Since the factor of safety is greater than 1, the part is acceptable. It will only fail at thrice the working design load. This means it can withstand three times the force applied to the gear. As the force applied here is 100N, the gear can withstand a force of upto 300N.

<u>Wheel</u>

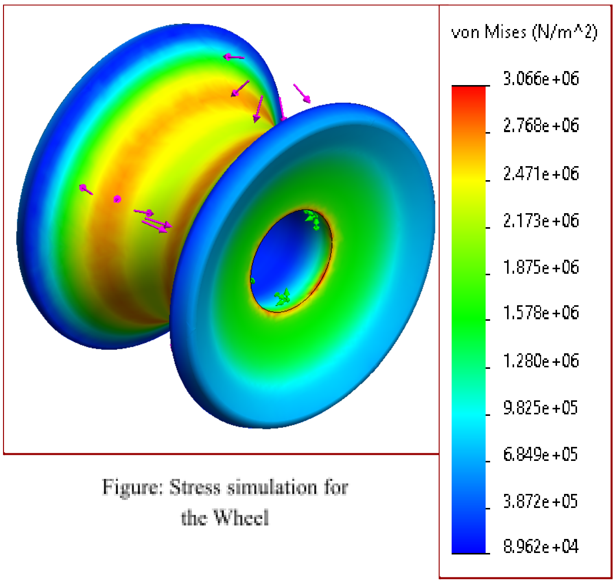


Figure: Stress simulation for the Wheel

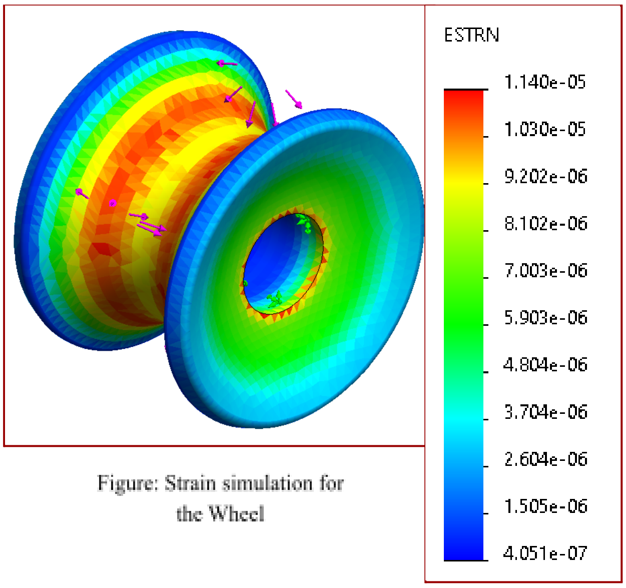


Figure: Strain simulation for the Wheel

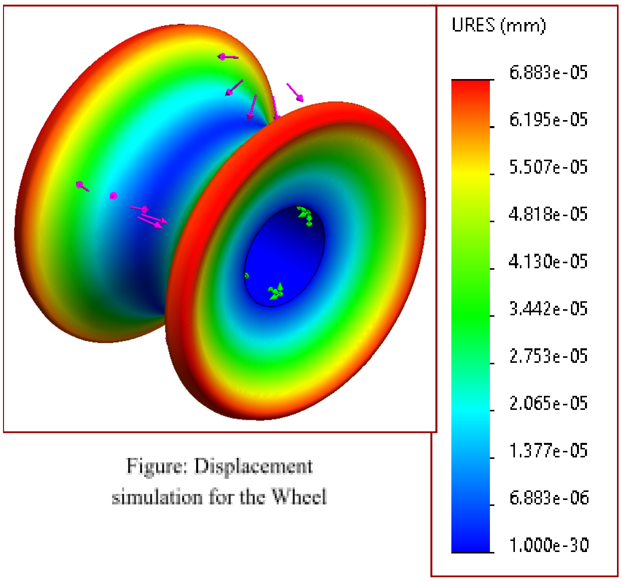


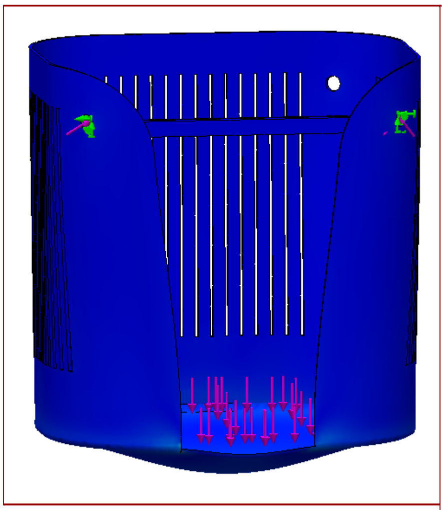
Figure: Displacement simulation for the Wheel

Max Stress = 3.066E+06 Pa

Factor of safety = Yield Strength/Max Stress = 2.40E+08/3.066E+06 = **78.2**

The factor of safety of this component is approximately 78. This means that 78 times as much force as the working load limit has to be applied to the wheel before it potentially fails.

Cart Body



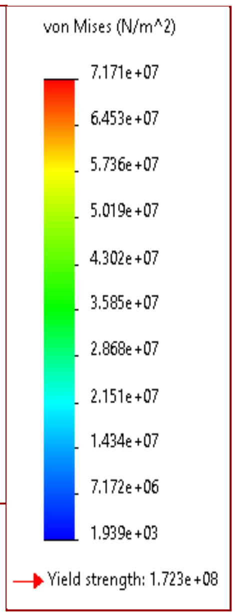
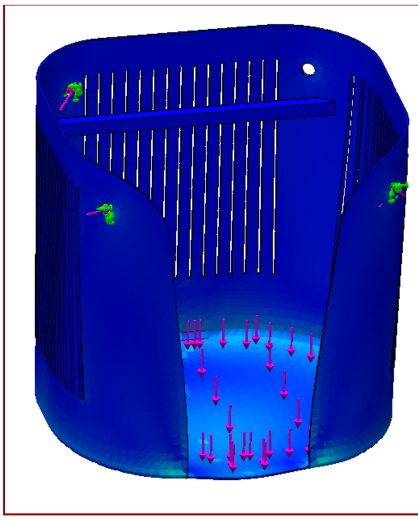


Figure: Stress simulation for the Cart Body



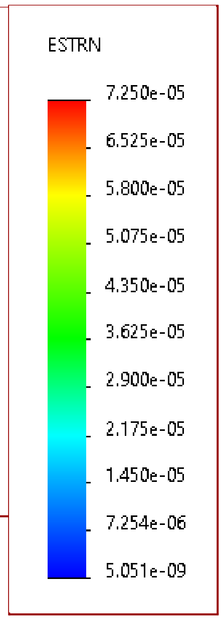
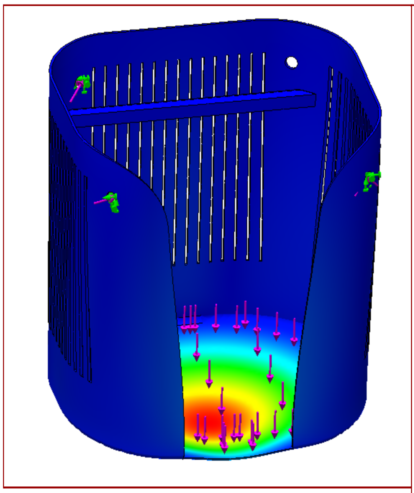


Figure: Strain simulation for the Cart Body



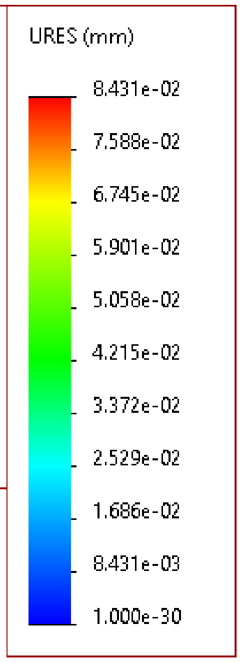


Figure: Displacement simulation for the Cart Body

Max Stress = 7.171E+07 Pa

Factor of safety = Yield Strength/Max Stress = 2.40E+08/7.171E+07 = **3.347**

Since the factor of safety is approximately 3, the cart body is feasible. It will only fail at thrice the working design load.

Connecting Rods

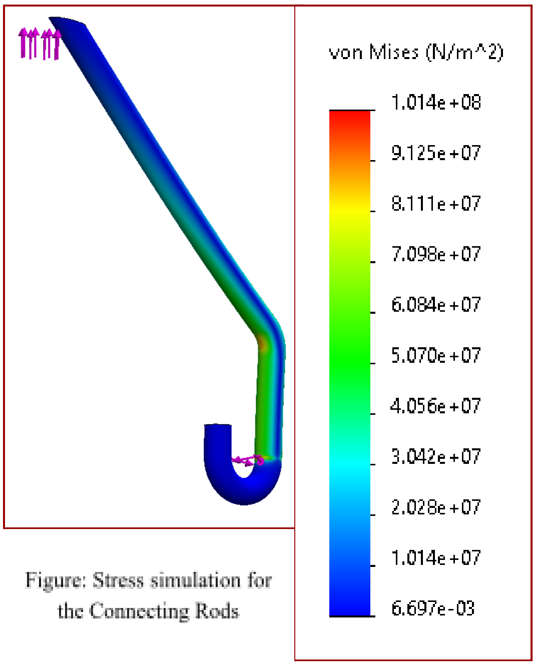


Figure: Stress simulation for the Connecting Rods

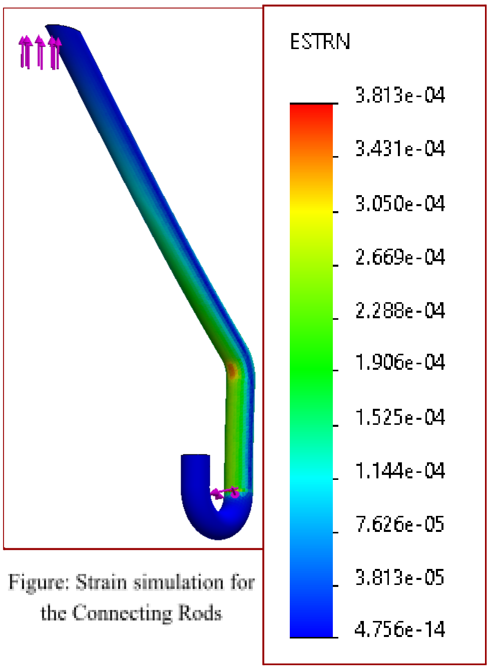


Figure: Strain simulation for the Connecting Rods

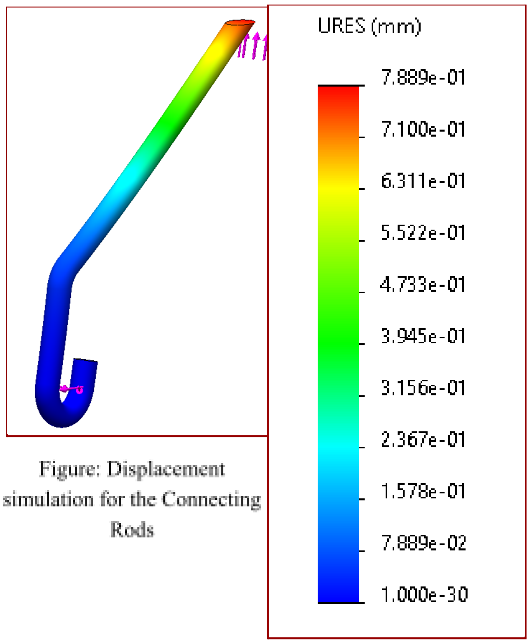


Figure: Displacement simulation for the Connecting Rods

Max Stress = 1.014E+08 Pa

Factor of safety = Yield Strength/Max Stress = 2.40E+08/1.014E+08 = **2.367**

Since the factor of safety is greater than 1, the part is acceptable. It will only fail at approximately twice the working design load. This means it can withstand two times the force currently applied to the connecting rod. As the force applied here is 100N, the connecting rod can withstand a force of upto 200N.

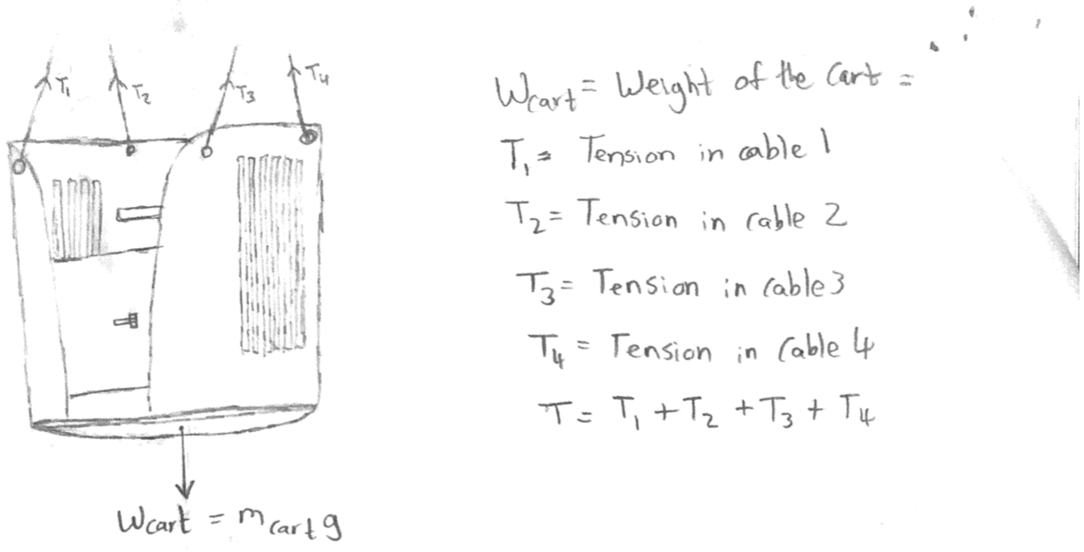


Figure 6 : Forces acting on the cart body

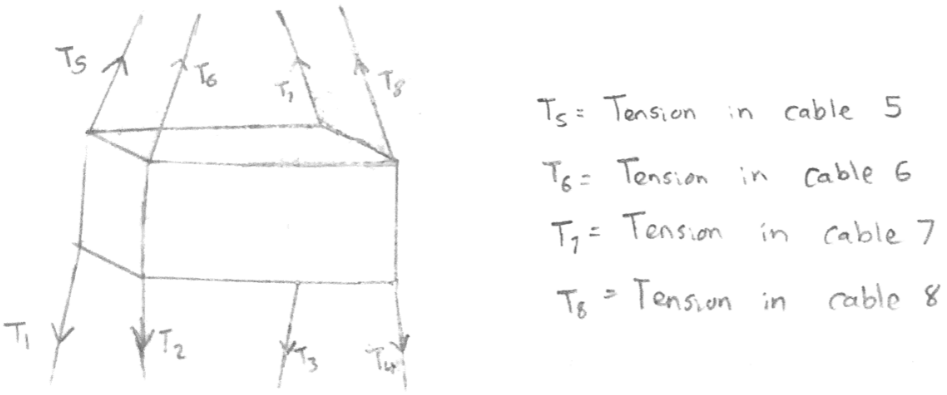


Figure 7 : Forces Acting on the Gear Box

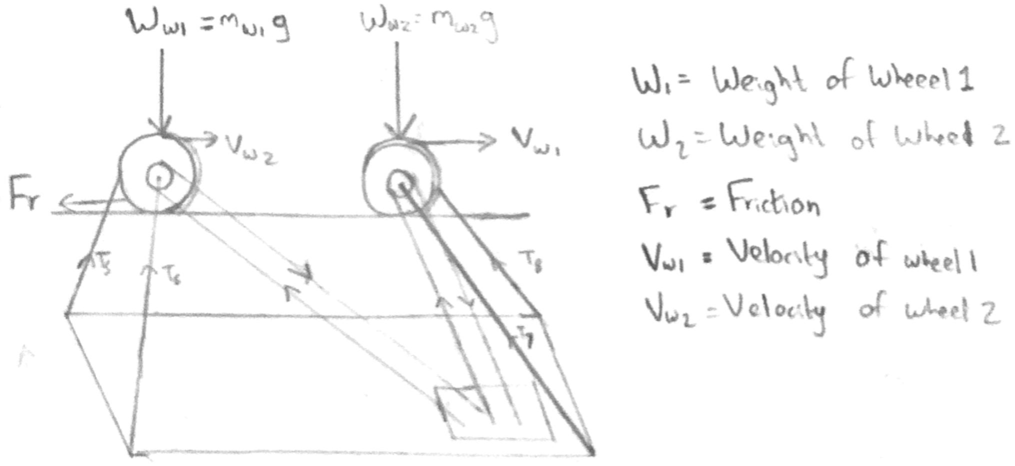


Figure 8 : Forces acting on the wheels

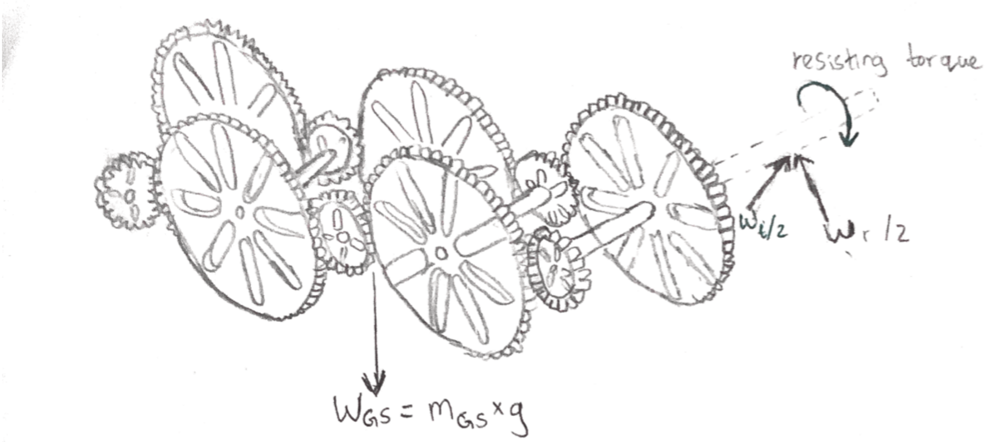


Figure 9 : Isometric view of forces acting on the gear and shaft

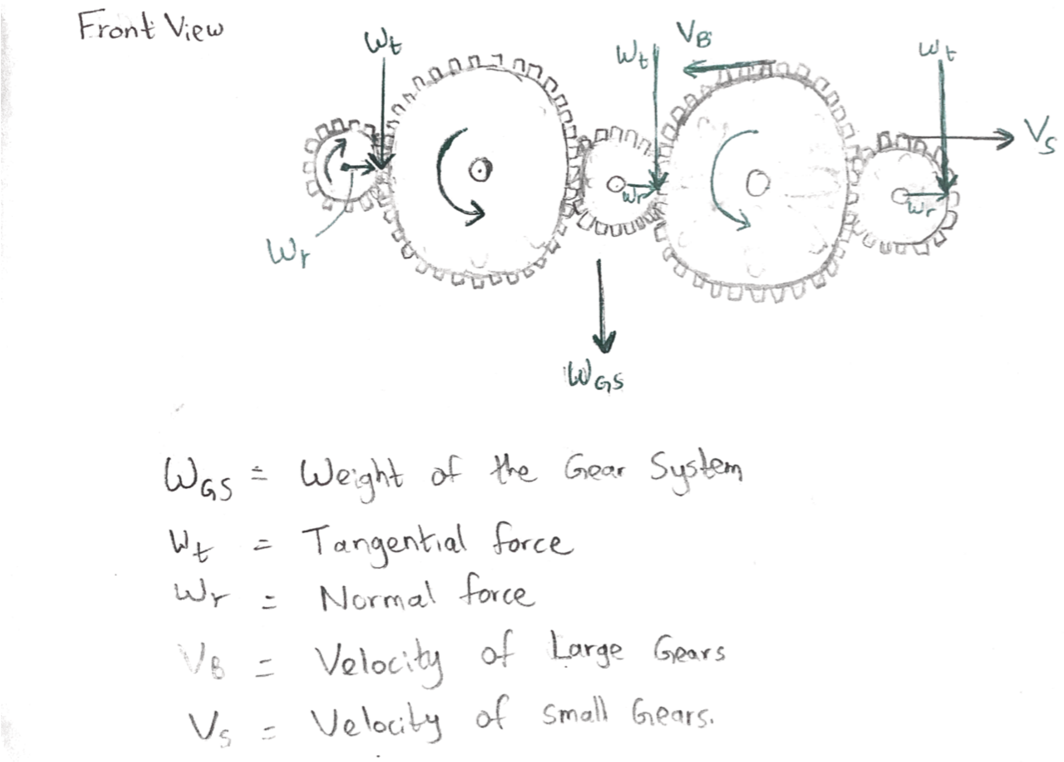


Figure 10 : Front view of forces acting on the gear and shaft

3.3 Review and Revise

Numerous changes were made to the design in order to improve upon the preliminary design.

The gear system ran through a series of strength issues. Initially the stress placed upon the gears was enough to cause failure on the teeth. As a result a change had to be made in order to increase the strength of the gear system. The idea was to maintain the same gear size ratio so as to not change the speed. The solution implemented was doubling up on the gears on the same axis so that the stress could be distributed throughout the two gears rather than one. The result was an increase in the stress tolerance of the overall gear system.

The gear box also ran into some weather proofing and durability issues. While a chain and gear system does function properly in the long term it will need to be greased regularly due to its exposure with the air. The solution that was implemented was the removal of the chain and allowing the cable to run through the gear box. This change resulted in a system which should require less maintenance and should increase the lifespan of the gears.

The cart of the system of the preliminary design needed to be changed as its mass exceeded the required mass of the entire system. The dimensions were decreased slightly while also maintaining enough space to fit the 5kg mass. Originally the length and width of the base were 0.5m by 0.5m. These values were decreased to 0.250m and 0.220m. The height of the cart also decreased from 0.5m to 0.241m. Finally, the thickness of the cart was decreased from 5mm to 2mm. These changes in dimensions still allowed the cart to withstand the forces applied from the load while keeping the mass within the required range.

The mass of the system continued to be an issue. Other changes within the system needed to be made in order to meet the 10kg limit of the mechanism mass. After a series of tests, holes were strategically implemented into the system to decrease the mass. Long rectangular holes were extruded onto the cart and some holes were also placed on the gears. This resulted in the mass of the system reducing greatly.

3.4 Definitive Layout

In this section, a new CAD model will be made that incorporates any changes made to the layout. The design will be displayed in the highest and lowest energy conditions. The pulley/passenger basket will be imported into the model to show how the design interfaces with the load.

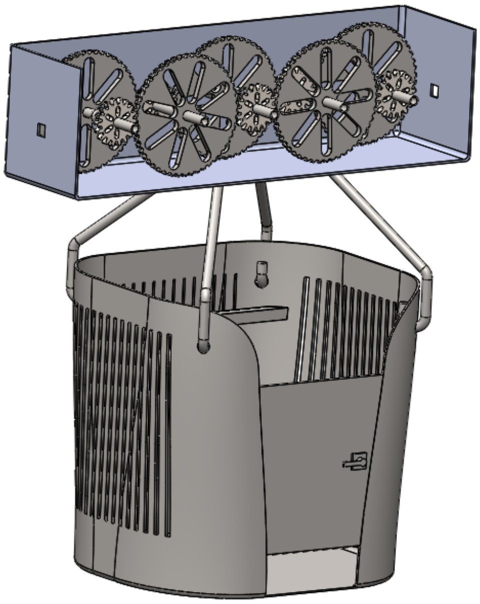


Figure 11 : CAD model for the principle design

3.5 Expected Performance

The mechanism is expected to weigh about 8 kg total, including the motor and battery, with a maximum load of about 300N before the design fails. But with the tested load of 100N it gave us a factor of safety of 3.64.

We made an assumption that the cart will move approximately at the speed of 3 m/s since it’s a relatively safe speed considering the cart is in free air. An assumption was made that there were no heat losses or friction during the calculations so all of the values that we have will be a little higher than in reality, considering this the factor of safety will most likely still be above 3 for the gears and above 2 for the other components.

The dimensions are:

- Cart: 250mmx250mmx220mm **(WxHxD)**
- Gear Box: 390mmx110mmx102mm **(WxHxD)**
- Gear rods: 8mm Diameter
- Big Gear: 150mm diameter
- Small Gear: 20 mm diameter
- Gear Rods: 8mm diameter
- Wheel: 13 mm
- Connecting Rods: 202mm

4.0 Prototype Images

The following are a series of images displaying the starting and ending positions of the mechanism. Since there is a lack of moving parts with the exception of the gears and wheels, the cable is the only indicator of motion. For the first three images, the mechanism is noticeably on the right-most side. The next three images show the mechanism on the left-most side.

Starting point:

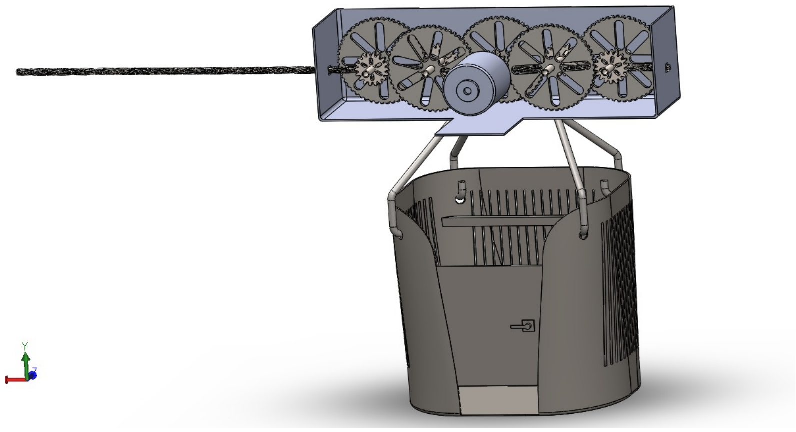


Figure 12

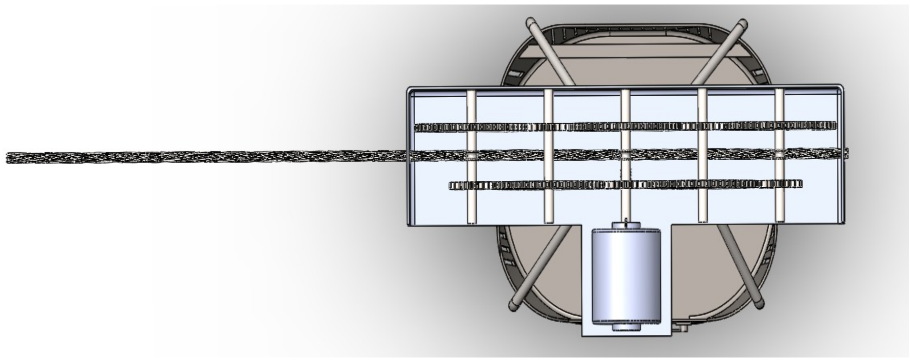


Figure 13

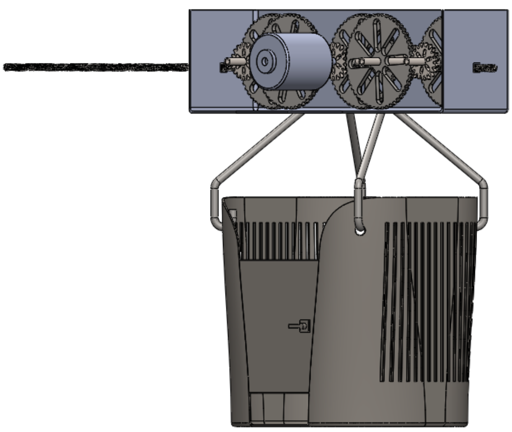


Figure 14

Ending Point:

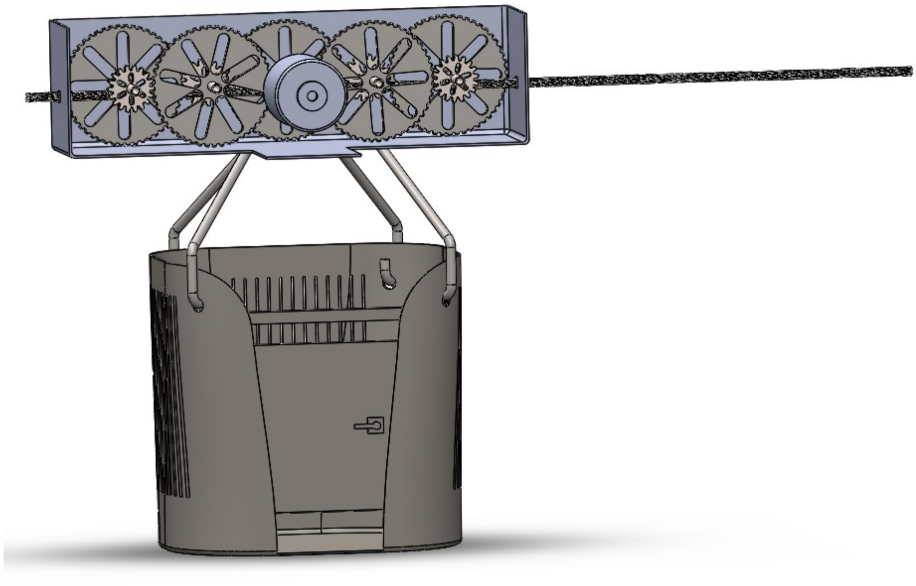


Figure 15

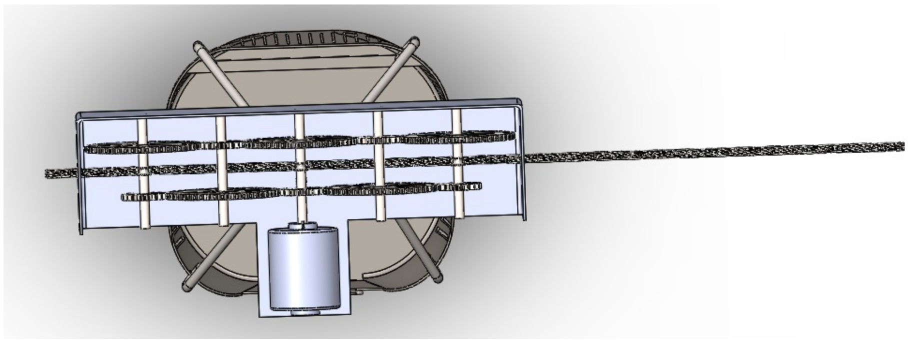


Figure 16

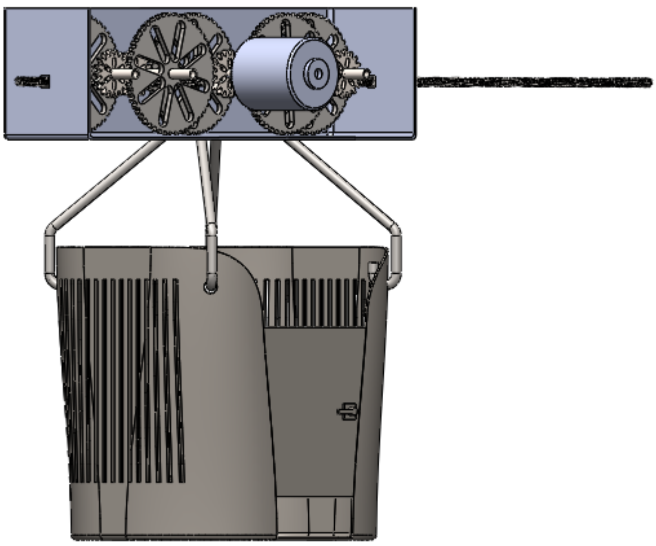


Figure 17

5.0 Testing Analysis

According to the requirements list, each of our components was made with the allowed material, which was cast stainless steel. Furthermore, the total weight of our design prototype weighs approximately 5.3 kg excluding the power unit. The mechanical structure was designed and created by everyone in the team demonstrating the rack and pinion gearbox mechanism.

The factor of safety obtained from the design calculations agrees with the factor of safety calculated using the simulation results as both calculations give relatively closer values for each part. Since the design calculations were done using simple beam calculations and approximated values, there is a small deviation from the actual values we later obtained with the help of SOLIDWORKS. A comparison of the Factor of Safety obtained through design calculations and from simulation calculations is shown below,

Component	FoS (Design Calculations)	FoS (Simulation Calculations)
Small Gear	5.76	3.75
Big Gear	3.81	2.29
Cart	4.35	3.35
Wheel	102	78.2
Connecting Rods	3.64	2.36

Initially during the simulation runs, we faced issues with the gears in our mechanism. Due to the unoptimized weight and dimension of the teeth and pitch diameter we were getting absurdly high stress levels at certain points in the gears which in return gave us a lower factor of safety. After decreasing down the dimensions, we were able to come to an optimal weight of the gears and decrease the applied stress on the center of mass allowing tolerable stress on the gear.

In the case of the connecting rods, the bend and the curve edges caused an issue in the beginning as the angle of bends needed to be precise for the optimal distribution of max stress acting on the bends.

6.0 Final Improvements

After we finished our prototype and final model, we wanted to see if we could improve our prototype even further by making it more efficient; as in be lower in mass while still achieving the same goal of not failing.
We used the topology simulation in SOLIDWORKS to see how we could've designed our parts better and see which parts were good as is and which parts could've used an improvement.
Each part will have its own sub section explaining what the results mean and if it's feasible to use them or not.

6.1 Big Gear

SOLIDWORKS was able to remove some parts from the cart that it deemed to be unnecessary for the design to cut down on some mass, as seen from the from the following figure

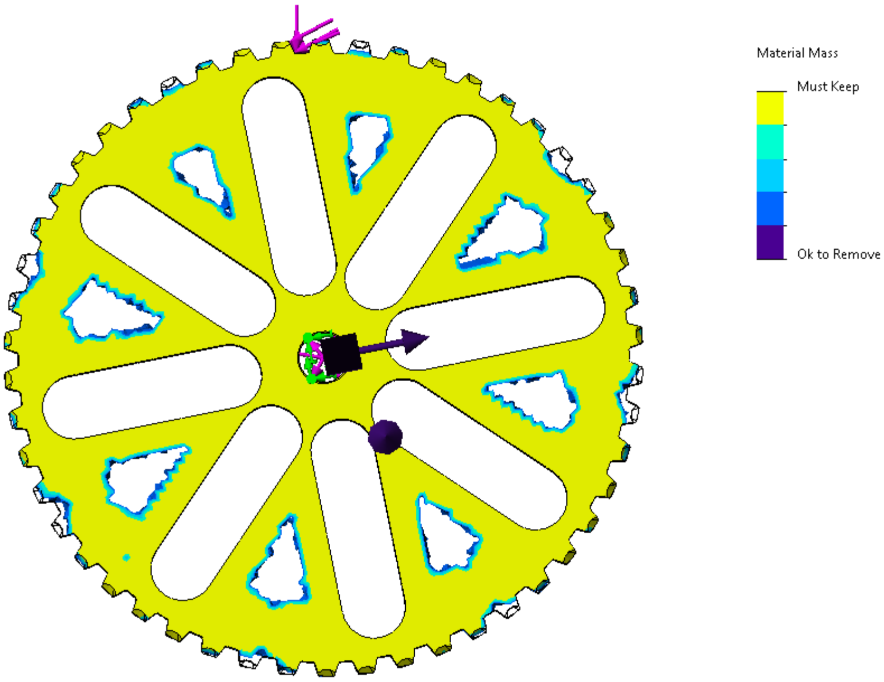


Figure 18

From the simulation, we can see that it would be optimal to insert triangular shaped holes around the gear too. The simulation did remove some of the teeth but obviously we will not do that as they are needed for the gear to work properly.
For the size of the triangle, it would be optimal to use the sizes next to the force applied at the top which is shown by the purple arrows. Since this is the part with the highest force/stress around it, it would be safest to use the hole size next to it.
This would reduce its mass from around 0.2 Kg to 0.14 Kg in each big gear which would come to a total of (0.06Kg Difference)*(5 Gears) = 0.3 Kg from the total mass of the prototype which is a decent of amount of mass that can be removed

6.2 Small Gear

While doing the simulation for the small the results shown by the simulation were quite unexpected as shown in the figure below.

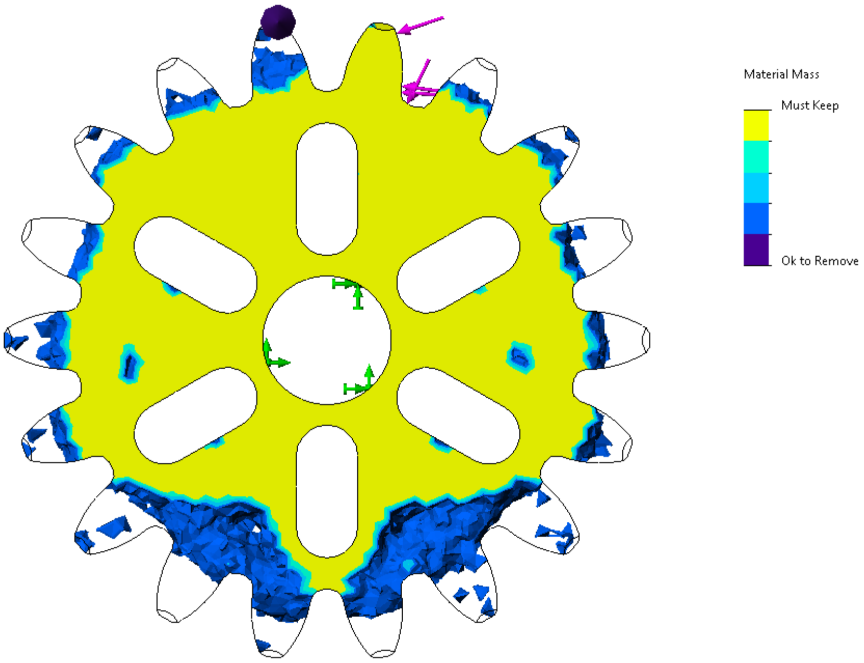


Figure 19

From my understanding this could have been caused by one of 2 reasons or the combination of both. Either the conditions were not set up properly or during the simulation the simulation couldn't find any adequate part to chip away so it started chipping away parts that were far away from the force applied.

Either way it is concluded that the original design doesn't need change as the simulation couldn't find an adequate part to remove to reduce the mass of the Small gear and stays at the mass of 0.03Kg

6.3 Gear Rod

Gear rod is the part that the rods will be connected to while spinning. For this part It was expected that it would be optimal to change some aspects of it to reduce the mass an adequate amount, what we found out from the results shown below is that there was no change needed to be made for the part.

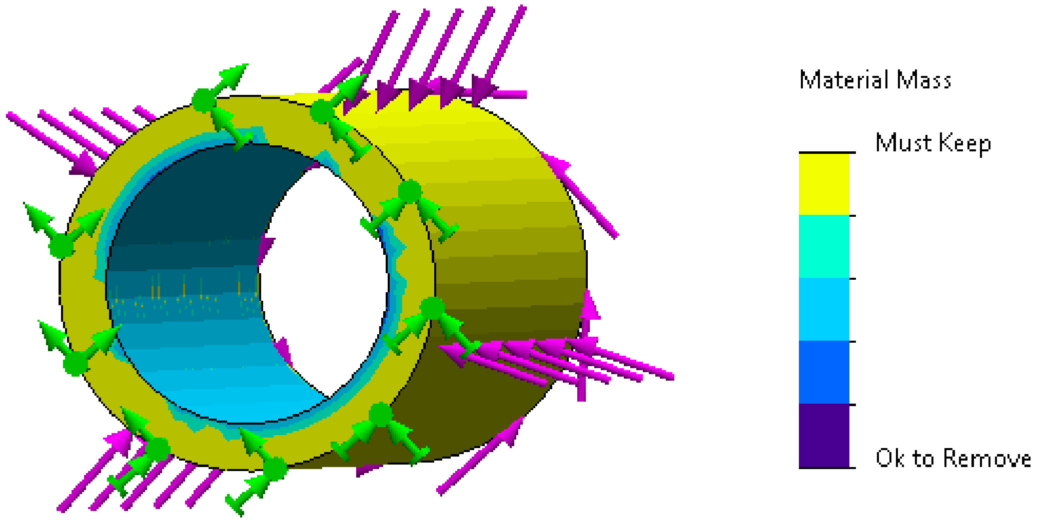


Figure 20

As the graph shows, the light blue colored parts could be removed but Ideally would stay there, since there is no drastic or noticeable change needed for this part it is good as is and stays at the mass of 0.017Kg

6.4 Wheel

This part didn't see much of a change by the topology simulation as shown from the figure below.

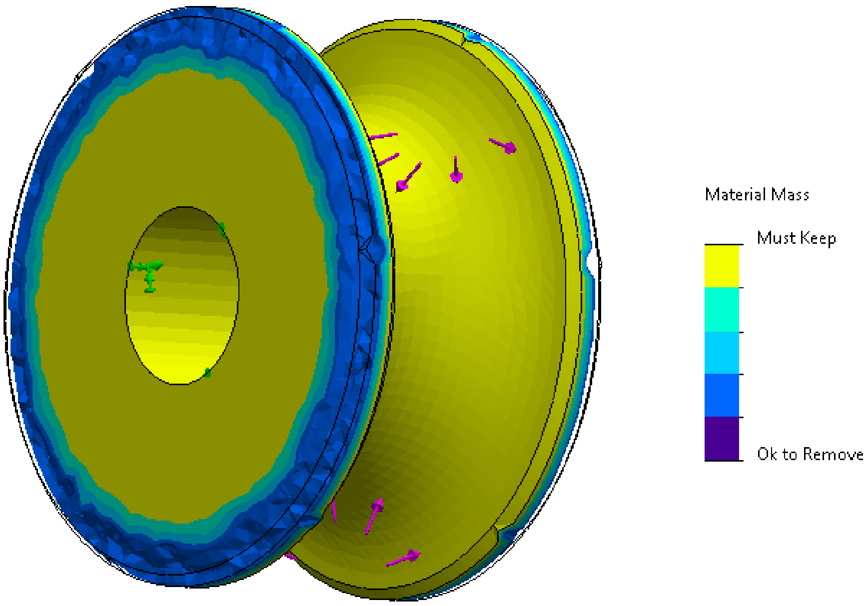
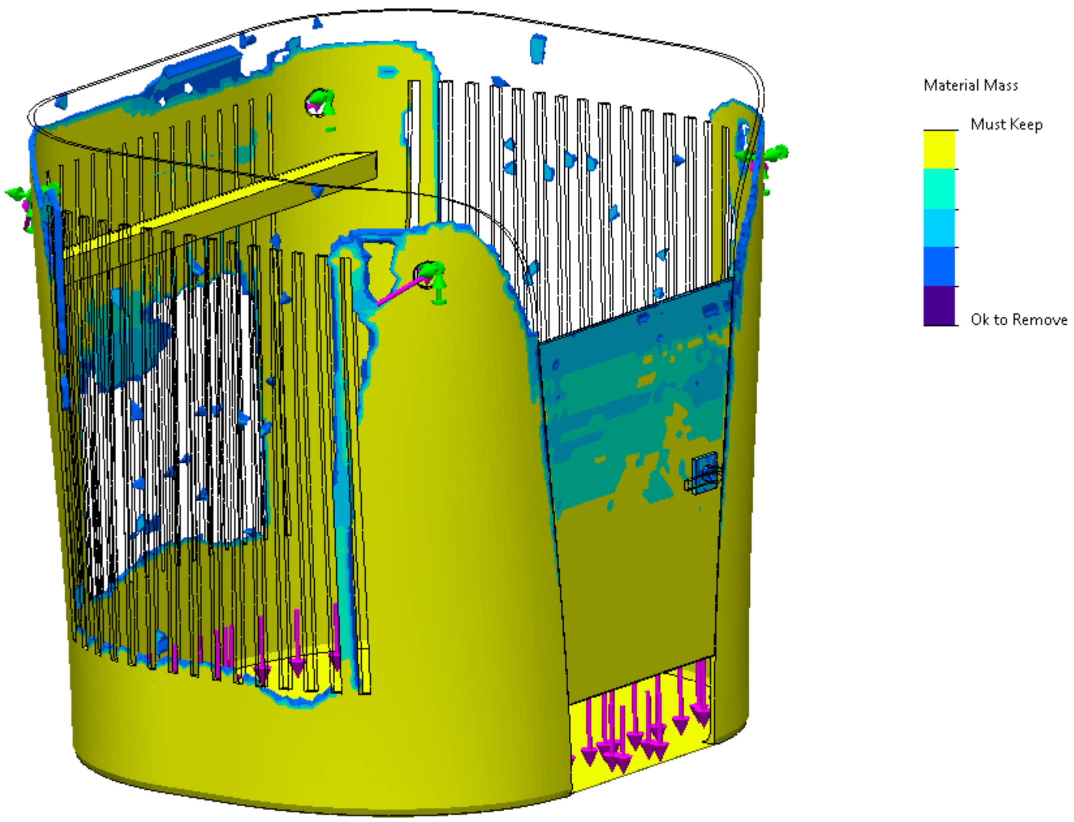


Figure 21

The simulation concluded that the tip of the wheel from the outer circular part could be removed or filleted more to remove some of the mass. The difference of mass is insignificant from the original amount is it goes from about 0.004 Kg to 0.003 Kg. It is a significant change in the wheel itself as it removes about 25% of the total mass, but compared to the total mass of the prototype or the system this doesn't change anything drastically. Hence nothing would be changed to the wheel from the original design.

6.5 Cart

For this part we got a result that was somewhat expected but is not a completely viable option as shown by the figure below



Figur 22

As shown from the figure above, the simulation suggested that the sides, the middle part of the back should be completely removed while some of the door could be removed as highlighted by the blue coloring. This result isn't viable since people might fall off due to the low wall height and children might fall from the back due to the hole there.

Although, this can be modified to fit the safety standard of the cart, we can reduce the height of the sides to about halfway or add bars with a larger distance between them than the original ones and do the same for the back hole too. The door can also be shortened an adequate amount , since this is the part with the most mass doing so will drastically lower the mass of it.

This will make the cart go from 3.3Kg to about 2.7Kg which is a very significant amount of mass and will help assign the mass to different parts of the prototype.

6.6 Connecting Rods

The simulation results of the connected rods were the most surprising out of all the simulations done on the other parts. This will be discussed with figures below.

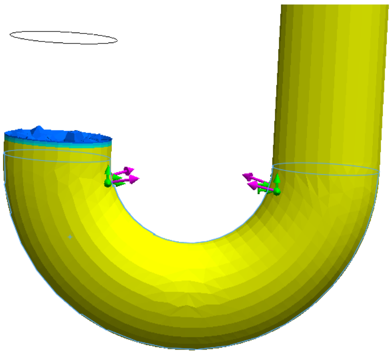


Figure 23

The first change was to shorten the start of the u-shape part since it was unnecessary.

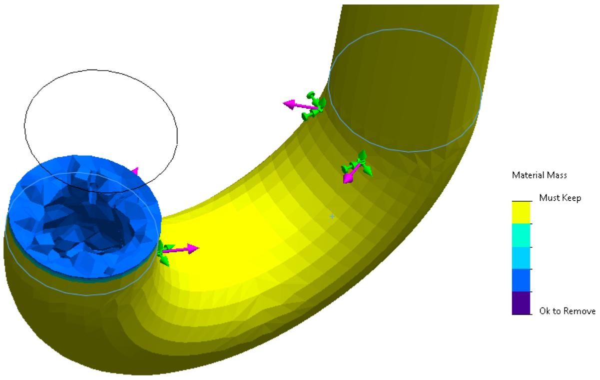


Figure 24

Second change was to make part of the connecting rod hollow, it's not clear where the hollow part stops but it will be assumed that it stops at the light blue circle on the right side of the part shown on the figure.

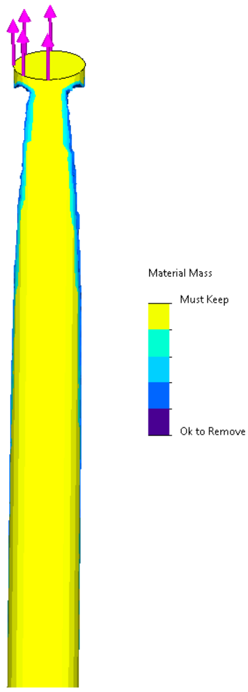


Figure 25

The last change is at the top of the connecting rod, the simulation results shows that we can remove some of the sides of the rod starting from about ⅓ of the rod until the end and decreasing the amount of material as it goes up but keep a small part at the top to hang on to the gearbox.

Some of these changes may be implemented easily such as the first one, but some will most likely need further study to ensure that the rod stays robust and doesn't fail

Conclusions

APPENDIX

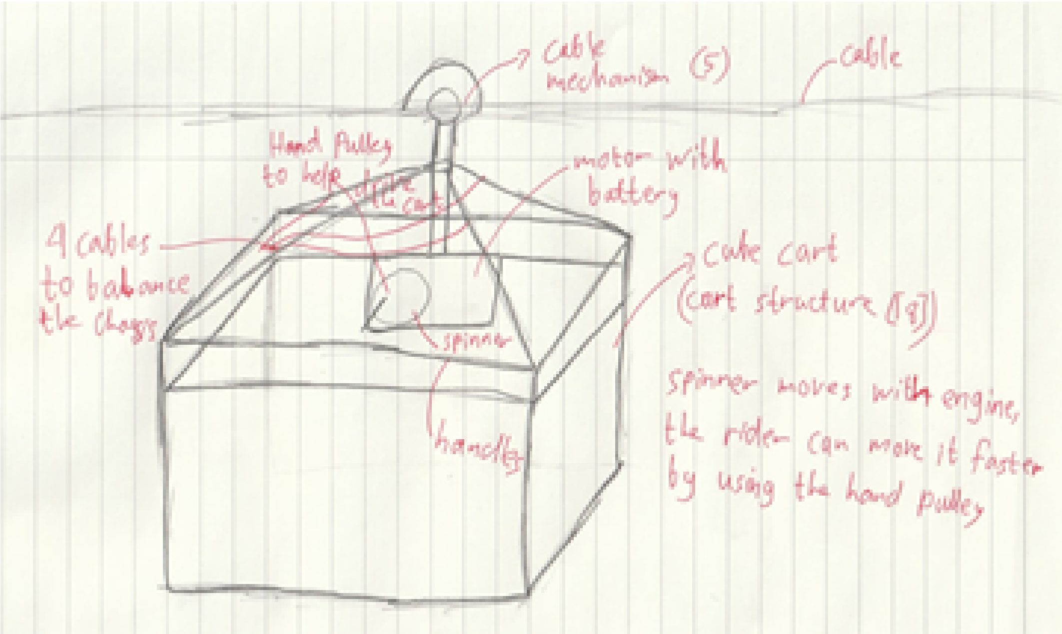


Figure 2.1 - Conceptual design 1

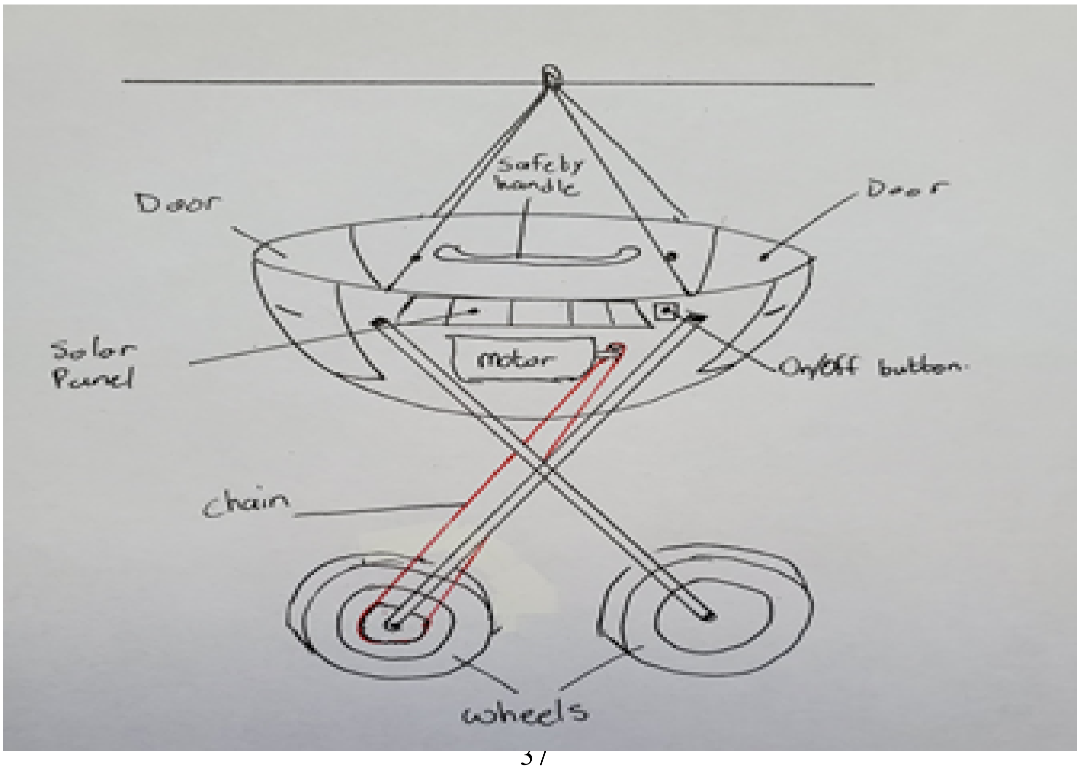


Figure 2.2 - Conceptual design 2

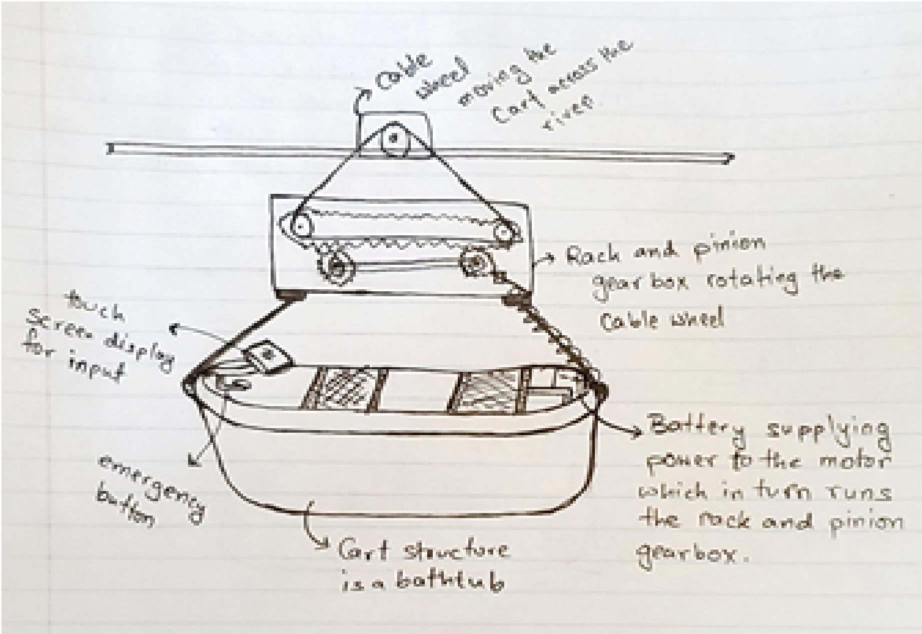


Figure 2.3 - Conceptual design 3

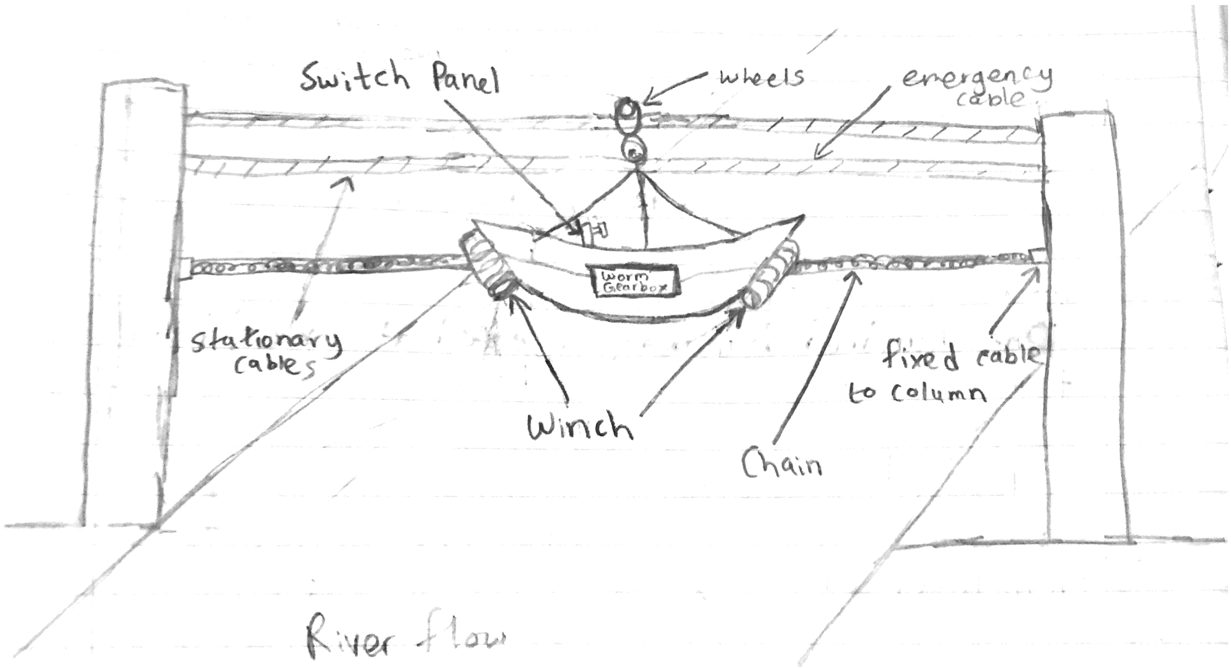


Figure 2.4 - Conceptual design 4

References

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[4] https://www.dw.com/en/accident-gondola-of-the-zugspitz-cable-car-rescued/a-45486129
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[9] https://minecraft.gamepedia.com/Lever
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[19] https://www.bra.org/item/battery-car/
[20]https://electrek.co/2019/02/22/teslas-solar-panel-gigafactory-panasonic/
[21]https://www.woodharbinger.com/tidal-energy-sustainable-resource/
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[23] https://www.newenglandskihistory.com/lifts/listbycost.php