Spring 2019

BiciTaxi

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ENTITLED

BICITAXI

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

______________________________ 6/14/19
Thesis Advisor: Dr. Tony Restivo Date

______________________________ 6/14/19
Department Chair: Dr. Drazen Fabris Date

BICITAXI

By

Alesis Gonsalves, Sean Flanagan, Tianhao Jiang, Brenden Stone

SENIOR DESIGN PROJECT REPORT

Submitted to
the Department of Mechanical Engineering

of

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in Partial Fulfillment of the Requirements
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Abstract

The purpose of this report is to provide an overview of the progress made concerning the development of a solution aimed at the transportation issues faced by residents of Puebla, Mexico, and specifically the community of Colonia Puebla. Colonia Puebla is a low-income community on the outskirts of Puebla. The overall goal is to develop and prototype a product that will alleviate some of the pressure due to the lack of accessibility of transportation and then field test said product in the target community. Ideally, the product would be able to stimulate a micro-economy to provide a source of income to residents. The project consists of an attachment that includes four subsystems, axle, trailer hitch, suspension and frame. The trailer hitch will connect frame to various types of bicycles. The suspension will alleviate bumpiness and axle will hold selected wheels.

Keywords: Mexico, Transportation system, micro-economy, bike attachment

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We would like to thank Dr. Laura Doyle for travelling with us to Puebla. Her experience abroad enabled our trip to be balanced between successful and enjoyable. We would like to thank Universidad Iberoamericana Puebla (UIP) for collaborating with and hosting our team. Specifically, we would like to thank Olivia Quiroz Centeno, Coordinator of International Academic Affairs at UIP, for organizing our team's trip to and stay at UIP. She ensured that our team was safely transported where we needed to go and had accommodations in Puebla. We would also like to thank Mercedes Núñez Cuétara, the Community Development Coordinator at UIP, for facilitating our team's contact with Valle de Paraíso, the target community. Her knowledge and connections within the community allowed our team to understand the specific needs of community members and how our team could address them. We also would like to extend a great thanks to Musi Lopez Molina, the Technological Innovation and Development Coordinator at UIP, for everything she did to facilitate our project in Puebla. Without her, our team would not have been able to construct our first prototype.

We would like to thank Juan at Yes Welding, who welded our aluminum frame in record time and at an hour of great need. His kindness allowed our team to complete fabrication and test our project. We would also like to thank Craig Sutterly, who directed us to Yes Welding and has been an invaluable source of industry advice and knowledge.

Many individuals gifted to us their time, knowledge, and resources to enable the completion of our project. We sincerely appreciate all that they have done to help us reach this point and hope that we may return the favor in kind.

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1. Introduction

In the United States, access to transportation is taken for granted. Individuals who have the means to transport themselves and their families do not think much of the challenges that face those who do not. If one does not own a car, one most likely uses some form of public transportation to get where they need to. However, when travelling any amount of distance with more than a couple bags of groceries or backpacks for school, the amount of stops public transportation uses can make the journey even longer more tiresome. This can be seen in Valle de Paraíso, a community located in the outskirts of Puebla, Mexico, where access to public or private transportation is limited.

This community grew when individuals moved closer to Puebla for the opportunity of a better life; Puebla and this community can be viewed on the map below in **Figure 1**. Homes have been constructed out of cinder blocks and rebar, and are typically built by the homeowners themselves. Many of the individuals living in this community have jobs in the inner parts of Puebla and rely on the public bus system to travel to them. However, they must first travel by foot through the unpaved dirt roads to reach bus stops. These dirt roads become severely muddy during the rainy season, and the few cars and motorcycles that drive on them during this time leave deep trenches. Many individuals will utilize a second pair of shoes specifically to walk in the muddy streets. Individuals also travel by foot to the market, which can be up to a 40 minute walk under the sun. Depending on the amount of groceries needed, a second trip is sometimes completed. There are also many stray dogs that roam the streets and some can be dangerous for pedestrians.

Figure 1. State of Puebla and Valle del Paraíso.

In an attempt to alleviate some of the stress brought on by daily travel, our senior design team sought to provide a frugal means of transportation between the bus stop and an individual's home. Our design consists of a two-passenger attachment capable of connecting to a standard bicycle. The attachment has storage capabilities and protects passengers from the sun, rain, and mud. We have been in constant communication with Universidad Iberoamericana Puebla, a local university in Puebla that regularly completes community-centered projects, to obtain an understanding of the needs of the community and to develop our design. We had been in contact with the university over fall and winter quarter, and visited both the university and Valle de Paraíso to get feedback on our design approach and to experience the conditions firsthand. The team's mission is to use the design in a ridesharing service run by members of the community. These people will ideally be able to duplicate our design and provide transportation services to other members of the community, and as a result, begin to generate a more developed microeconomy.

1.1. Background & Motivation

A main component in the team's ability to carry out the project was the connection with the Frugal Innovation Hub (FIH) at Santa Clara University, and being in direct contact with the Director of Programs and Partnerships for FIH, Allan Baez-Morales. Mr. Baez-Morales introduced several potential projects to the team even after an initial project fizzled.

The team's hope was that the project extended its reach outside of the USA. Mr. Baez Morales connected the team to a couple of contacts at Universidad Iberoamericana Puebla, who introduced the many hardships faced in Puebla. Universidad Iberoamericana Puebla will be referred to as IBERO for the remainder of the report. One of the university's community outreach programs specifically reached a community called Valle de Paraíso, a part of Colonia Puebla, where all residents live in extreme poverty.

About 100 residents migrated to Puebla to be closer to the city and to have a better life; these residents live mostly on the outskirts of the major city. This area, until very recently (within 2-3 years) has not been recognized by the government. Although the residents of Colonia Puebla are not residing there illegally (they have bought the land), they do not receive most resources provided by the city or government.

The university's outreach into this community includes programs for the residents such as extracurricular classes for the children such as dance and English, events, and various workshops. The university carries out these activities in a rented house called 'Casa Ibero.'

Our main contact for Casa Ibero was Jose Cervantez, and he expressed three major needs of the residents; transportation, electricity, and clean water. An example of a consequence of lack of transportation is access to public medical services (private clinics are closer, but too expensive) which are located within central Puebla, miles away from Valle de Paraíso. The team decided to tackle the transportation accessibility issue, and the design process began by evaluating the state of field for transportation solutions in developing countries.

1.2. State of the Field

The product most closely related to our needs was a rickshaw typically seen in India or touristy areas such as the piers in San Francisco, California. Shown in **Figure 2**, they are typically powered by a partial bicycle that is rigidly connected to the front, or they are carried like a wheel barrow. This method is typically slower than traditional transportation, but during peak traffic times, the compactness of the vehicle allows for maneuverability in between cars and trucks stuck on the road. A new rickshaw from the manufacturer can cost anywhere from 700 to 1,200 USD [1].

Figure 2. Bicycle powered rickshaw [2]. Reproduced without permission.

The soleckshaw was a step above a typical bicycle powered rickshaw in terms of harnessing power from the sun and transferring it to an assistive motor using a solar panel on top of the vehicle. It also recovered electrical energy through the braking system [3]. This vehicle was successful for about a year, but because of lack of maintenance, there are no more in operation [4]. **Figure 3** shows a typical soleckshaw.

Figure 3. Soleckshaw [5].Reproduced without permission.

The next human-powered transportation solution found was a surrey bicycle. This was appealing because of its multi-user drivetrain, which does not require each passenger to pedal, but in terms of synergy, if one person does not pedal, the overall torque is significantly reduced. The complexity of the drivetrain increases because it is accommodating more passengers. Surrey bicycles can hold 2-6 persons and range from 2,000 to 5,500 USD depending on the type of package chosen, specifically from the International Surrey Company. These additional packages can include anything from lights to electric assistive motors. The surrey bicycles typically do not have suspension systems, and can not go over unpaved terrain. **Figure 4** below shows two-, four-, and six-person surrey bicycles.

Figure 4. Surrey bicycles that seat two, four, or six person [6]. Reproduced without permission.

Various electric bicycles have come into production to satisfy urban consumer needs. Low operating and initial costs when compared to a car or other motorized vehicle, maneuverability, and minimal storage requirements prove it to be a viable transportation method for single riders. Novelty bike designs like the Triobike Taxi, shown in **Figure 5**, allow for greater transportation of people and cargo. The electric motor provides a means to travel longer distances more quickly and with less effort from the rider. Electric bicycles range from 3000 to 9500 USD according to EVO Elsykler, a Norwegian electric bike retailer [7]. Add-ons such as additional batteries and cargo bags are available as well. While this may be a large initial investment, it would provide a fuel efficient means of transportation.

Figure 5. The Triobike Taxi, an electric motor-assisted bicycle designed to transport individuals [8]. Reproduced without permission.

Table 1. Existing transportation solutions, cost, number of passengers, and manufacturer information.

Existing Product	Cost	# of Adults	Manufacturer	Sales Volume
Bicycle Rickshaw	700-1,200 USD[1]	2-3	Various Indian Manufacturers	7,000/Month[14]
Soleckshaw	415-480 USD[2]	2-3	CSIR/NARI	1,000/Month[13]
Surrey Bicycle	2,000-5,500 USD	2-6	International Surrey Company	------
Electric Bicycle	3000-9500 USD	1-3	Various international manufacturing	------

1.3. Project Objectives Statement

BiciTaxi's purpose is to provide an easily manufactured, reproducible bicycle attachment to be used as a taxi service for residents in Valle de Paraíso. There is also a business supported by the vehicle that helps residents fabricate their own BiciTaxi, and to generate an income by driving passengers in and around the local community.

2. Systems-Level Chapter

2.1. Customer Needs

The community of Colonia Puebla is mostly working to lower class. Industry is the main source of the economy for the city of Puebla and these jobs are concentrated towards the outskirts of the city. Although the city has many prestigious universities and is highly modernized, the state of Puebla is listed as having the third highest poverty rate among all states in Mexico.[9] With all of these demographic factors in mind, we recognize that a more affordable form of transportation into the city would be extremely valuable. Because there is no direct transportation to the city, it is difficult to get a job that is in the city and keep it, especially if it requires a lot of travel. Our goal is to develop a solution to an issue residents face daily. Ideally, this solution would be able to be maintained and serviced by residents to form a closed-loop system.

According to BMI Research's "Mexico Oil & Gas Report" for 2018, Puebla was one of the "hardest hit municipalities" when it came to fuel siphoning crime.[10] There are two reasons for this, a "lack of oversight" and increased "impunity for offences". The Mexican government gathered from reports that because multiple parties benefit from large and illegal transportation of fuel, it is likely that some state-run facilities are involved in the transactions. In addition, the increasing penalties for siphoning gas from 14 years to 25 years in prison has not necessarily deterred the crime, but has just put more people in prison facilities. In addition, Mexico will be liberalising fuel prices, which will increase fuel theft. In short, because of the unpredictability of supply, demand, and cost of the gas, transportation via non-fuel vehicles is an assumed need of the community.

2.2. System Level Requirements

2.2.1. Product Design Specifications

Below in **Table 2** is the product design specifications that were targets for the team's design. This table includes data for performance, safety, ergonomics, and accessibility.

Table 2. Product Design Specifications

Elements/ Requirements	Datum	Units	Target - Range
PERFORMANCE			
General dimension (size)	46 x 68.5 x 49.5	in x in x in	52 x 65 x 55
Weight	73.6	pound	40 - 60
Frame max deflection	1.373e-2	in	0.5
Versatility of connecting rod	1 (bicycle)	# of attaching vehicles	2 (bicycle and motorcycle)
Max terrain slope	N/A	deg	10 - 15
Terrain/road condition allowability	Paved/Gravel	Paved/Gravel/Dirt	All
Speed (laden, empty)	N/A	mph	15, 10
SAFETY			
Passenger distance from ground	18	in	10 - 15
Passenger brakes	No	Yes/No	Yes
Stray dog protection	No	Yes/No	Yes
ERGONOMICS			
Mud flap	Yes	Yes/No	Yes
Seat comfortability	Plywood	Material	Cushion
Suspension	Leaf spring (3 leaves)	Type	Leaf spring (1 or 2 leaves)
ACCESSIBILITY			
Duplication cost		USD/pesos	
Mitigation of stealable components	Removed electronics	Measures taken	
Local material acquisition	80%	%	100%

2.2.2. Quality Function Deployment

The quality function deployment helped determine what demanded quality from the customer-base that needed more attention. The demanded quality was ranked from 1 to 11, 11 being the most important, and then each one was assessed in terms of the quality characteristics to get a rank that depended on the complexity of the relationship between the two.

Weight/Importance	Direction of Improvement:	^	^	^	v	x	x	x	x	^				
	Quality Characteristics	Trailer Hitch Tensile Yield Strength	Load Capacity	Max Speed	Cost per Bicitaxi	Size	Leaf Spring Suspension	Developed Ergonomics	Aluminum Frame	Trailer Hitch Degrees of Freedom		Totals	Actual Importance	**Rank of Attention Needed**
	Demanded Quality													
10	Faster than walking			S								5	50	6
9	Easily Manufactured					W	M		S - -	M		17	153	10
11	Cheaper than other transportation				S				M			8	88	8
7	Protects from weather (i.e. mud, dust, direct sunlight, rain)							S				5	35	5
6	Lightweight		W	S +		M	-		S ++			16	96	9
1	Comfortable					M		S				8	8	1
5	Durable						M		M			6	30	4
4	Stable		M	M		M	M			W		13	52	7
3	Good handling		M							S		8	24	3
2	Adjustable		W	W						M		5	10	2
8	Holds multiple people	M	S	S - -	W	S	S ++	W	W			22	176	11

S	Strong Relationship	5
M	Moderate Relationship	3
W	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
-	Negative Correlation	
- -	Strong Negative Correlation	
v	Objective is to minimize	
^	Objective is maximize	
x	Objective is to hit target	

Figure 6. Quality function deployment.

The two most concerning quality/characteristic relationships was between 'holding multiple people' and 'max speed,' and between 'easily manufactured' and 'aluminum frame.' The strong negative relationship between holding multiple people and max speed can be evaluated from the testing below in **System Integration**; it was found that if the BiciTaxi was fully laden, that the maximum average speed was 3.3 miles-per-hour, which is only 0.3 miles-per-hour above average walking speed.[19]

The next strong negative relationship was between the ease of manufacturing and the aluminum frame. Aluminum welding is extremely difficult to the inexperienced welder. The melting temperature of aluminum at 1,221 degrees Fahrenheit is less than half of that of steel at 2,500 degrees Fahrenheit, however, the oxide layer (that prevents the aluminum from rusting) on the outside of the aluminum has a melting temperature of 3,700 degrees Fahrenheit.[20] The difference in melting temperature creates an insulation effect, and burning through the aluminum to get to the right temperature is common. One of the team members, Alesis Gonsalves, who only had knowledge of welding steel attempted to help weld the frame for the first prototype while in Mexico. Given the inexperience of welding aluminum both of the fabrication shop attendant and the team member, the welding was incomplete by the end of the trip in Mexico.

2.3. Functional Analysis

2.3.1. Functional Decomposition

The attachment's overall function is to provide transportation for individuals through the direction of a bicycle rider and help residents travel between their homes and bus stops. The attachment is human-powered and can be disconnected from the driving bicycle through trailer hitch.

The frame will house all of the components and provide structural support. It will connect to the bicycle via a coupling mechanism located at the front. The axle and back wheels will be mounted to the underside of the frame.

The suspension will provide cushion for the occupants and driver on uneven surfaces. It is desirable to minimize vertical oscillation of the attachment to provide the occupants with an enjoyable ride as well as reduce the amount of pulling force exerted by the driver. Unnecessary shocks to the electrical components could damage them over time, and could cause components to displace from their intended position.

The trailer hitch will connect the whole bike attachment to the bike seat. It allows two degrees of freedom so that the clamp is able to adjust its angle and position depending on road conditions or whether the rider needs to turn.

2.3.2. Project Constraints

Some constraints to be aware of include size, weight, and cost. A bicycle is an easily maneuverable device, and this attachment should accommodate that to a certain degree. The attachment should be large enough to comfortably fit two passengers, but small enough to allow the bicycle to turn. The weight of the attachment should be monitored. Excess weight will cause the driver more strain while in operation and limit the maneuverability of the attachment when disconnected. The cost should be kept low. The attachment is targeted at low to middle class individuals, and the design team does not want to financially burden them further.

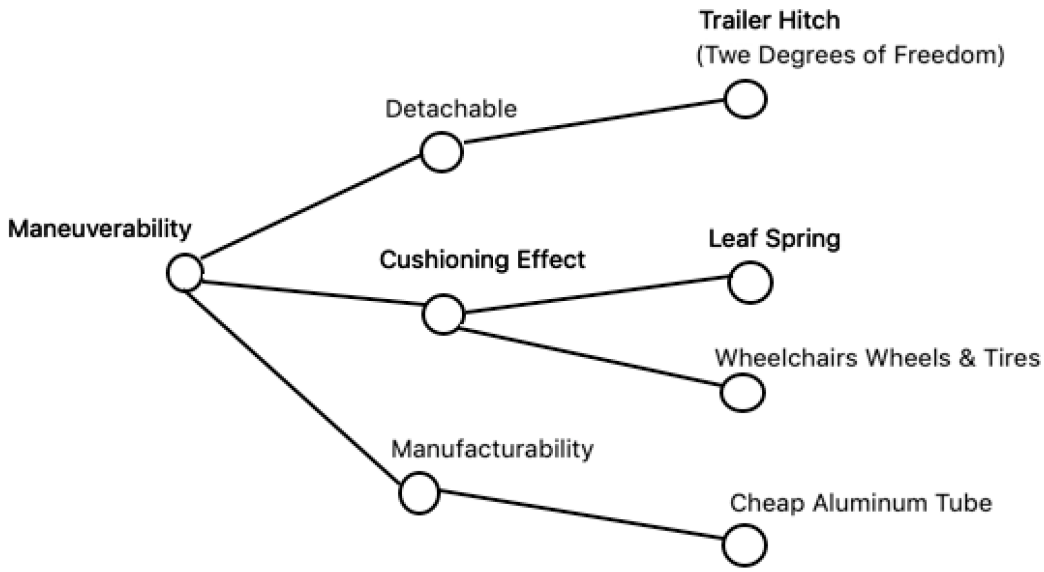


Figure 7. A classification tree for the BiciTaxi.

In **Section 3.7,** we will talk about eliminated subsystems detailedly and why we decide to remove them from initial design. However, we still hope these subsystems may add to the design in the future. The following table shows the concept of how electrical components work collaboratively and could help Puebla's residents.

Energy generation and absorption	Convert energy to translational energy	Accumulate energy	Apply translational energy to household electrical appliances
Solar panels	Motor	Battery	Boilers
Pedals	Chain		Smartphone chargers
	Solar panels		. . .

Figure 8. Concept Combination Table for Transportation System.

2.4. Benchmarks

Table 3. Benchmark Table on Customer Need.

#	NEED	IMP	Soleckshaws	Surrey Bicycles	Electric Bicycles
1	Attaches to a wide variety of bikes	3	*****	**	*****
2	Has a motorized attachment	5	**	*	**
3	Transports at least 2 people	4	****	****	****
4	Should be inexpensive	5	*	***	*
5	Is environmental friendly	3	****	****	****
6	Reduces the drudgery	2	***	*	***
7	Is easily accessible	3	**	****	***
8	Is able to store energy	5	*****	*	*
9	Is made from parts from local hardware store	2	**	****	***
10	Is able to be serviced with common hand tools	2	**	****	**
11	Is durable	3	**	***	**
12	Has lower energy consumption and is energy efficient	5	***	**	***
13	Is able to provide enough energy for household electrical appliances	5	*****	*	***
14	Is safe for both battery component and riders	4	***	*****	***

2.4.1. Survey

Considering that our contacts and intended customer base were both in Puebla, Mexico it proved to be easier to collect data remotely. The solution was to create an online Google survey to send out through Dr. Cervantes at UIP. This survey includes questions about demographics, current transportation needs and use, and current electronic needs and use. There is an English and Spanish version of the survey, which can be viewed in the **Appendix**. The goal of this survey was to gather what we believe to be relevant information about the daily lives and needs of the people of Colonia Puebla. After collecting enough relevant information, the hope was that the team would be better equipped to deal with the problems faced by community members. It was important that the team understood the issues before trying to solve them. Shown in **Table 4** are selected survey questions, the customer statement, and the interpreted need. As of 6/10/19, there have been no online survey responses. Printed surveys were discussed with Dr. Cervantes via email as a countermeasure due to the low rate of Internet accessibility in Puebla. Photocopies of completed printed surveys are included in the **Appendix**.

Table 4. Selected survey questions with customer statement and interpreted needs.

Question/Prompt	Customer Statement	Interpreted Need
12. If electricity wasn't an issue, what electronics would you have?	The most wanted electronics is water heater. The second one is lamp.	Household electrical appliances have huge demand.
15. Approximately how much do you spend on electricity annually?	Around 150$ for a family of four	Devices with low cost are favorable.
16. Approximately how much energy do you use daily?	The average is around 150 kWh.	Low energy consumption and energy efficient devices are favorable.
17. What do you use the most energy for on a daily basis?	Natural gas for heating and deficient electricity for illumination.	Energy for illumination and space and water heating is essential.
18. What are the most pressing issues you face day-to-day?	Deficient electricity and large cost for daily transportation to get to the city.	Lower cost transportation may help them get to the city and get daily necessities much easier.
20. If money were not an issue, what would improve your community the most?	Sufficient electricity supply and public transportation between city and rural areas.	Inexpensive public transportation and affordable electricity.

2.5. Key System Level Issues

2.5.1. Design Decisions

The design choices for each subsystem were determined by a concept scoring matrix in which different criterion were weighted and ranked. These criteria included, but was not limited to, cost, weight, strength, durability and weather resistance. Each option for the subsystem was ranked for its relative time to design, build, and test, the cost of prototyping and manufacturing, and any criterion specific to the function of the subsystem. Some criterion were omitted for parts that were going to be outsourced or bought fully actualized. Specific options and reasoning for each subsystem can be viewed below in the following subsystem sections.

2.6. System Level Design with Main Subsystems

For the frame of the bicycle attachment, there were three material configurations with a one or two passenger option, giving six choices; aluminum with one or two passengers, polyvinyl chloride, PVC, with one or two passengers, or wood with one or two passengers. The main differences between the materials was the manufacturing processes. Welding for the aluminum frame would have to be outsourced, the complexity of the PVC welding (adhesive) may or may not have to be outsourced, and the wood frame could be built on the SCU campus with various hardware. The two passenger aluminum frame design was used as the baseline for the calculations in the matrix found in the Appendix.

According to the matrix, a one passenger aluminum bicycle attachment would be the best configuration, however only having a one passenger attachment would be impractical. The two passenger aluminum bicycle attachment was the second best choice and was the one pursued.

For the suspension of the bicycle attachment, there were six choices; a leaf spring, independent suspension, MacPherson strut, air suspension, multi-link suspension, or Magneride suspension. Because of cost alone, independent suspension and the Magneride suspension systems were not pursued. The MacPherson strut was the option used for the baseline suspension system for the calculations in the matrix, which can be viewed in the Appendix. According to the matrix, and for the reasons listed above, the leaf spring suspension meets or exceeds the requirements in addition to the low cost. The leaf spring suspensions system will be the design option pursued.

Below is the system layout for subsystems and their specific characteristics.

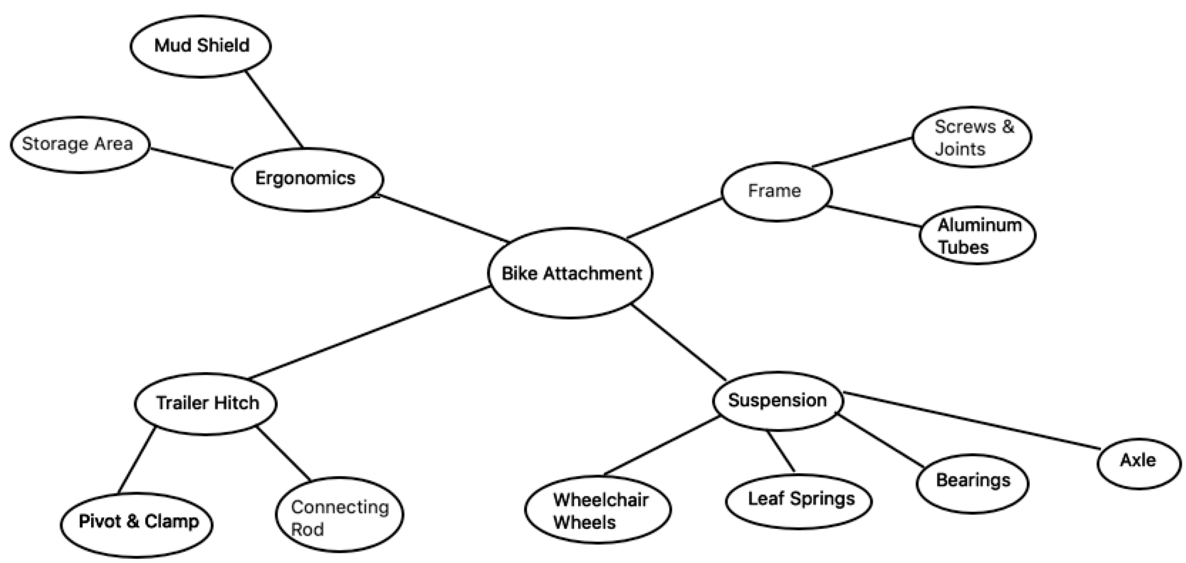


Figure 9. System Layout

2.7. Team and Project Management

2.7.1. Project Challenges

Sourcing welding in the US, welding in Mexico (aluminum), wheel bearings in Mexico, finding correct suspension length, frame dimensions.

2.7.2. Work delegation & Mediating techniques

Throughout our project, we would frequently delegate separate tasks to different members of the group. This ensured that each member participated in a significant and meaningful way. The frame, suspension, seat, and connecting rod were all assigned to a different member of the team. During weekly meetings, tasks were assigned and each member would list their work for the week in the activity reports.

Members of the subsystem were solely responsible for their contribution, but communication was obviously necessary for synergy between parts and to ensure that individual, as well as team goals were met. When an emergence or unexpected workloads presents itself, design team will come up with certain strategies to pick up the slack of other team members who had made a significant contribution elsewhere.

When self-initiative is deemed to be a problem, certain tasks will be delegated to team members. If that does not work either, the last method is to bring up issues to faculty members and seek help.

2.7.3. Budget

2.7.3.1 Prototype Expenses

		Expected	1st Prototype	2nd Prototype		
Frame	Aluminum Material	$ 500.00	$ 33.60	$ 131.23		
	Welding		$ 53.31	$ 640.00		
Wheels	Wheels	$ 80.00	$ 41.50	$ 435.89		
	Bearings		$ 18.38			
Suspension	Leaf Spring		$ 96.61	$ 63.42		
	Hangers		$ 63.47	$ 36.43		
Trailer Hitch	Trailer Gator	$ 300.00	$ 75.67	$ 17.44		
	Handlebar Swivel			$ 18.99		
Axle	Hardware		$ 32.08	$ 61.50		
Seat/Floor	Plywood	$ 50.00	$ 18.62			
R&D	Kid's Trailer				$ 32.70	
	Tools				48.41	
					$ 35.92	
	Total:	$ 930.00	$ 433.24	$ 1,404.90	$ 117.03	**$ 1,955.17**

Figure 10. Expected expenses versus first and second prototype.

Above is the comparison in price between our first and second prototypes. The first prototype was built in Puebla and most of the materials were obtained at Home Depot. We were also able to find a local supplier of aluminum which we used to build our frame. The second iteration of our frame was more expensive not only because we outsourced the welding itself, but we also bought the aluminum at a much lower price than it would be in America. In Puebla, we were able to use the machine lab at the university which drastically cut down on cost. Another reason for the increase in price for our second prototype is that we decided to use wheelchair wheels instead of bicycle wheels. This was done due to the greater strength of the wheels in anticipation of tough road conditions. Additional seat material was purchased for the second prototype, whereas the first iteration used only wood. Grand total of $1,955.17 does not include traveling expenses.

2.7.4. Timeline

This project ran the course of a full academic year at SCU. The fall quarter was devoted towards establishing the needs of the community and developing the design. The winter quarter was spent beginning fabrication of the design and preparing for the team's trip to Puebla, Mexico. The spring quarter was used to complete fabrication and conduct testing, as well as writing the final report. The team's Gantt chart is shown below in **Figure 11**.

	Task	Start	End	Est. duration (days)	% Complete	Task lead	Comments on progress	Timeline
	Entire Project	9/17/18	6/17/19	273				
1	**Field Research**	10/1/18	11/1/18	31	**100%**			
1.1	Brainstorming	10/1/18	10/5/18	4	100%	All		
1.2	Customer Needs Evaluation	10/2/18	10/9/18	7	100%	Brenden		
1.2.1	*Survey*	10/10/18	10/14/18	4	100%	Brenden		
1.2.3	*Survey Responses*	10/10/18	10/21/18	11	100%	Jose		
2	**Planning Products and Processes**	10/31/18	3/1/19	121	**87%**			
2.1	Product Specification	11/1/18	11/30/18	29	100%	Alex		
2.1.1	*Parts List*	11/1/18	11/28/18	27	80%			
2.1.2	*Budget for Parts*	11/1/18	11/30/18	29	80%	Sean		
2.2	Solidworks Models of Subsystems	10/30/18	1/1/19	63	**100%**			
2.2.1	*Frame*	10/30/18	11/6/18	7	100%	Brenden		
2.2.1.1	*FEA on Frame Solidworks Model*	11/1/18	11/6/18	5	100%	Brenden		
2.2.2	*Solar Panel to Motor*	3/31/19	4/14/19	14		Alex	*Eliminated*	
2.3	Research for Parts	11/1/18	1/17/19	77	**100%**	All		
2.3.1	*Frame*	11/1/18	1/17/19	77	100%	Brenden		
2.3.2	*Suspension*	1/10/19	1/17/19	7	100%	Alesis		
2.3.3	*Solar Panel (smaller for phone charg*	1/10/19	1/17/19	7		Alex		
2.3.4	*Bicycle to attachment synthesis*	2/1/19	3/14/19	41	100%	Alex	Taken over by Brenden for final prototype	
2.4	Part Aquisition or Manufacture	1/10/19	2/1/19	22	**93%**	All		
2.4.1	*Solar Panel*	1/17/19	1/31/19	14		Alex	*Eliminated*	
2.4.2	*Solar Panel Hardware*	1/17/19	1/31/19	14		Alex	*Eliminated*	
2.4.3	*Electronics*	3/31/19	4/14/19	14		Alex	*Eliminated*	
2.4.4	*Bicycle*	4/7/19	4/14/19	7	90%	Sean	Taken over by Brenden	
2.4.5	*Suspension*	1/17/19	6/4/19	138	100%	Alesis		
2.4.5.1	*Leaf Spring Suspension (1st prototyp*	1/17/19	4/14/19	87	100%	Alesis	Left with prototype in Puebla	
2.4.5.2	*Leaf Spring Suspension (2nd prototy*	4/14/19	6/4/19	51	100%	Alesis		
2.4.5.3	*Suspension Hardware (1st prototype)*	1/17/19	4/14/19	87	100%	Alesis	Left with prototype in Puebla	
2.4.5.4	*Suspension Hardware (2nd prototype*	4/14/19	6/4/19	51	100%	Alesis		
2.4.7	*Wheels*	1/21/19	6/4/19	134	100%	Alex		
2.4.7.1	*Wheelchair wheels (2nd prototype)*	3/17/19	3/24/19	7	100%	Alex		
2.4.7.2	*Bicycle wheels (1st protoype)*	3/24/19	3/31/19	7	100%	All		
2.4.7.3	*Wheels Hardware (1st prototype)*	4/7/19	4/21/19	14	100%	Alex	Bearings in Mexico	
2.4.7.4	*Wheels Hardware (2nd prototype)*	3/17/19	3/24/19	7	100%	Alex	Came with wheels	
2.4.8	*Axle*	4/7/19	4/14/19	7	100%	Alesis Brenden	Repurchase	
2.4.8.1	*Machine Axle Mount (1st prototype)*	3/24/19	3/31/19	7	100%	Brenden	Left with prototype in Pue	
2.4.8.2	*Machine Axle Mount (2nd prototype)*	5/29/19	6/4/19	6	100%	Alesis Brenden		
2.4.9	*Frame*	1/17/19	6/4/19	138	100%	Brenden		
2.4.9.1	*Cut aluminum (1st prototype)*	3/24/19	3/31/19	7	100%	Brenden		
2.4.9.2	*Cut aluminum (2nd prototype)*	4/14/19	6/4/19	51	100%	Brenden Alesis		
2.4.9.3	*Weld Frame (1st prototype)*	3/24/19	3/31/19	7	40%	Alesis		
2.4.9.4	*Weld Frame (2nd prototype)*	4/14/19	6/4/19	51	100%	Brenden	Taken over by Alesis Welded by Yes Welding	
2.4.10	*Trailer Hitch*	4/14/19	6/5/19	52	100%	Alex	Taken over by Brenden	
2.4.10.1	*Purchase swivel (1st prototype)*	3/17/19	3/31/19	14	0%	Alex		
2.4.10.2	*Purchase swivel (2nd prototype)*	3/17/19	3/31/19	14	100%	Alex	Need to redesign	
2.4.10.2	*Manufacture swivel (2nd prototype)*	4/14/19	6/4/19	51	100%	Alex	Taken over by Brenden	
3	**Preparation of Deliverables**	12/1/18	6/15/19	196	**33%**			
3.1	Bicycle attachment	12/10/18	6/5/19	177	**100%**	All	1st prototype in Puebla 2nd prototype at SCU	
3.1.2	*Solar to motor configuration*	3/31/19	6/15/19	76			*Eliminated*	
3.1.3	*Stationary configuration*	3/31/19	6/15/19	76			*Eliminated*	
3.2	Operation manual	4/7/19	4/21/19	14	**0%**	All	Need to send to Ibero	
3.3	Building and troubleshooting manual	4/7/19	4/21/19	14	**0%**	All	Need to send to Ibero	
3.4	Thesis	5/29/19	6/12/19	14	100%	All		

Figure 11. Gantt chart.

2.7.5. Design Process

For the project, different types of bicycles were analyzed. For the purpose of simplicity, a bicycle that was motorized versus one that relies on pedaling alone was compared. One of the major advantages that a motorized bike had over the purely mechanical was that it would be a faster and more convenient mode of transportation. This means that more trips could be made in a given amount of time and much more quickly. This would also allow for the person using the bicycle to expend less energy than they would with a mechanical one. This, again would allow for more trips to be made. A con for the motorized design, however, is that there is the added cost of fuel. Normally this would be of minor importance to to the large availability of fossil fuels such as gasoline, but this plays a larger role for the particular project because the area the design team is trying to help find the costs of such energy sources to be too large. In addition, motorized bike is also expensive for residents. Since each family has at least two kids and they all have bicycles according to our survey, to better solve these issues, the team decided to pay more attention to bicycle attachments.

2.7.6. Risks and Mitigations

This bicycle attachment will have several moving parts and operational risks. Care must be taken during manufacturing, testing, and operation to ensure the safe utilization of the attachment. Outlined in this document are areas of risk and how they can be minimized. First, categories consisting of moving parts, manufacturing processes, and chemicals will be examined. Next, three categories consisting of fabrication, testing, and operation will be examined. Prominent concerns include proper coverage of moving parts.

The attachment will have rotating components including drive wheels and trailer hitch. Care must be taken to ensure nothing is caught in the rotating components. The attachment will be designed with panels or covers to conceal the rotating parts from the occupants. This panels or covers will be removable for maintenance. Drive wheels will be concealed underneath the seat housing. The clamp of trailer hitch will be tightly connected to the bike seat.

If welding is to be used in the construction of the attachment, safe welding procedures must be followed to minimize the risk of injury. Only spot welding can be performed at SCU. Any complex welding jobs will be outsourced to a fabrication shop. The design and fabrication of this attachment will not include the explicit use of liquid or gaseous chemicals.

2.7.7. Team Management

For team management, certain tasks were delegated to each individual that would be completed before the next meeting, which were at least once a week on top of meeting during class hours. Issues regarding the division of work were encountered, so it was decided to create a log of hours worked that each individual could post. Each member was able to “clock in” and “clock out” whenever that individual was available. This method was helpful because it allowed all members to feel that they had made significant contributions as well as making sure other members were contributing. The team also took Meyers-Briggs test to determine each of their strengths and how each member could contribute to the workload. Each team member was also responsible for assigned subsystem designs and tests. Activity report was written once a week to check weekly progress and set goals for the following week.

3. Subsystems Chapters

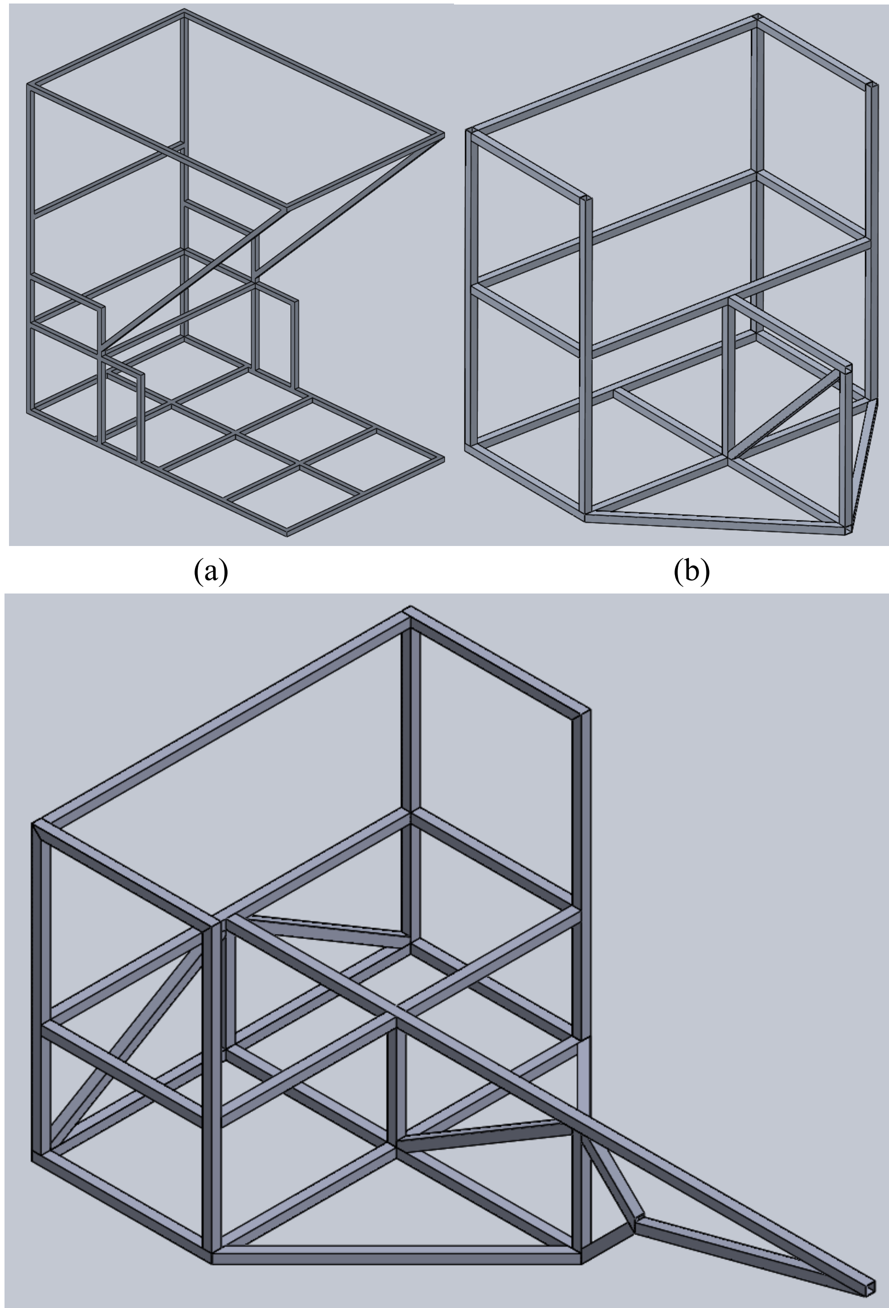
3.1. Introduction

For this bike attachment, there are four main subsystems, frame, suspension, axel and trailer hitch. In addition, there is one section detailedly explaining eliminated subsystems, which we decide to remove from the initial design. Each subsystem section will talk about the design process and supporting analysis, along with CAD model and some sketches. In the end, testing results will be analysed and photos of prototyping will be shown to demonstrate the feasibility and manufacturability of the bike attachment.

3.2. Frame Subsystem

The frame's purpose is to provide structural support for the BiciTaxi and to serve as a mounting point for all other subsystems. The frame is modeled off a typical rickshaw consisting of two passenger seats, a forward-protruding connection structure, and storage space. A SolidWorks assembly model image of the frame is shown in **Figure 12c**. The frame is constructed by welding thirty individual pieces of aluminum box tube that measure 1 inch x 1 inch with 1/16 inch thick walls. The frame design underwent several revisions, with at least one major revision each quarter. This progression is shown in **Figure 12**.

The frame design draws on aspects from the rickshaw, soleckshaw, and surrey bike. Initial designs stemmed primarily from the soleckshaw, and included a roof that would support a mounted solar panel. The solar panel and roof support were later removed as it was determined that electrical components were at high risk of being stolen once in service. The design was revised and a prototype based on this revision was constructed during the team's visit to Puebla, Mexico. Community members gave feedback on this design, which was used to further modify the frame. The two most significant pieces of feedback resulted in the reduction of the frame's dimensions and the addition of a protruding member to serve as a connection point between the BiciTaxi and the bicycle.



(a) (b)

(c)

Figure 12. SolidWorks model of the frame, showing the progression from the fall quarter (a), the winter quarter (b), to the spring quarter (c).

Welding was chosen as the preferred method of fastening in order to minimize the need for maintenance once completed and to increase the reliability of the connections. If bolts and brackets were used, vibrations during use may loosen connections and thus require maintenance or repairs. Bolted connections also posed the risk of a passerby loosening connections or removing parts. As this BiciTaxi was designed for use with bicycles, weight was a critical factor and sought to be minimized. Aluminum provides adequate strength but without significantly increasing the weight when compared to steel. Aluminum alloy 6063-T52 was selected as it is commercially available, machinable, and weldable. The shape of the frame was designed to be easily manufactured while satisfying passenger needs and withstanding loading stresses. Thus, curved members were avoided and perpendicular mates were used wherever possible.

3.2.1. Supporting FEA Analysis

A series of Finite Element Analyses (FEA) were conducted using SolidWorks to simulate the loading capacity of the completed frame. Loading conditions considered consisted of the fully laden weight, impact loading with fully laden weight, and with or without pulling force from the bicycle. Fully laden weight was modeled as two passengers weighing 220 pound each and 110 pound of cargo split evenly on both sides of the floor for a total of 550 pound. Impact loading doubled this value for a total of 1100 pound and simulates the BiciTaxi crossing uneven terrain. A pulling force of 50 pound was assumed to be provided by the driving bicycle. For simulating these loads, a SolidWorks assembly was created which consisted of the frame modeled as a single part, a floor mockup, and a seat mockup. The floor and seat mockups had split lines where the load was placed to imitate the weight of cargo or a person. **Figure 13** shows the SolidWorks FEA assembly with green arrows denoting a fixed connection and purple arrows denoting a force.

The frame was modeled as a single part because the individual parts will be welded together and act as a single piece. Initial simulations showed stress concentrations at the inside-facing corners of the seat-supporting vertical members. In response, diagonal members were added under the seat to reduce the stress concentrations as well as discourage lateral motion. These members also serve to keep cargo from sliding out. The difference before and after the addition of the diagonal members is shown in **Figure 14**. The maximum stress under fully laden conditions without the additional members was 2936 pounds-per-square-inch and 2222 pounds-per-square-inch with the additional members. Simulation results are tabulated in **Table 5**. The highest stress simulated was 4888 pounds-per-square-inch, or 37.46 percent of the yield strength of the aluminum alloy, and occurred during the impact loading with fully laden weight and pulling force simulation.

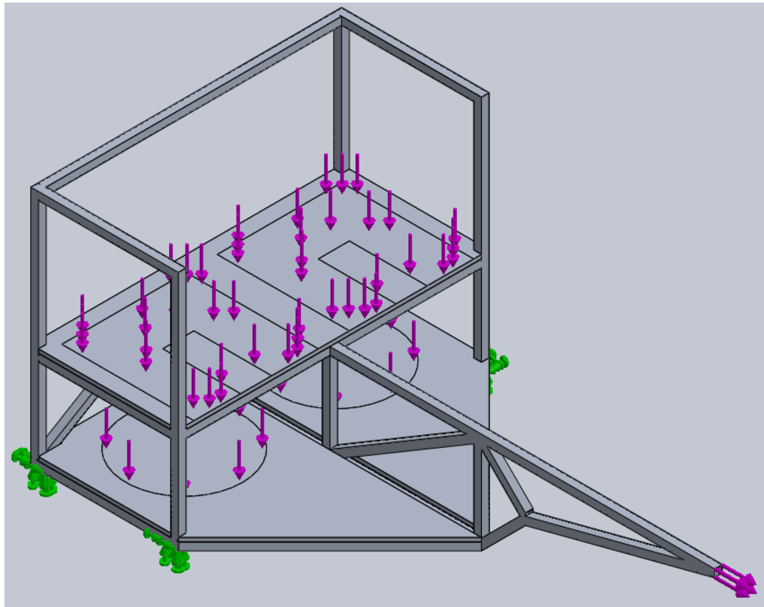
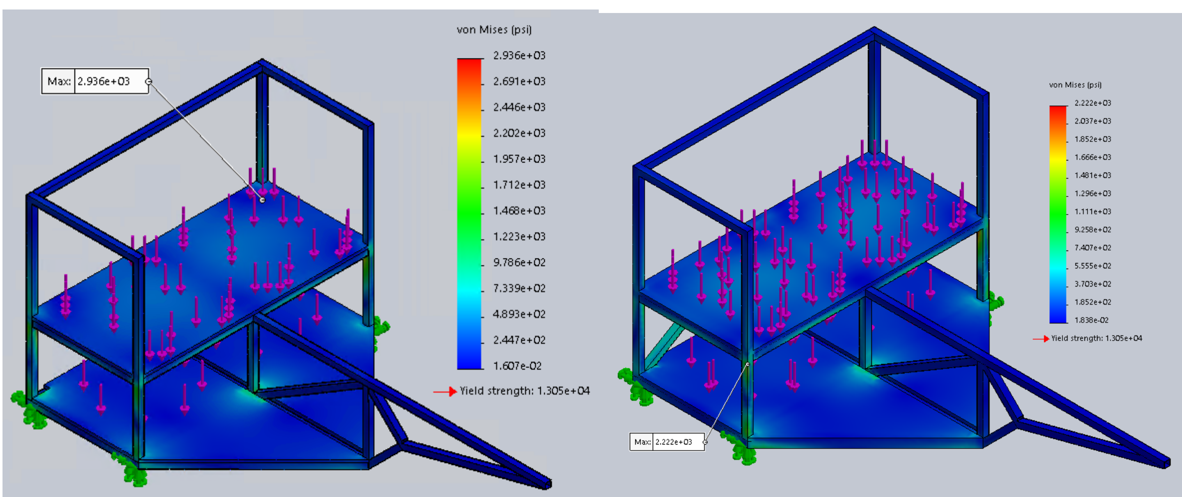


Figure 13. The SolidWorks assembly used for FEA, consisting of the frame modeled as a single part, a seat mockup, and a floor mockup. The purple arrows denote a force and the green arrows denote a fixed connection.



(a) (b)

Figure 14. SolidWorks FEA assembly without (a) and with (b) rear diagonal members. The maximum stress under fully laden conditions was 2936 pounds-per-square-inch (a) and 2222 pounds-per-square-inch (b).

Table 5. Results of frame FEA simulations. Fully laden consists of 2 persons at 220 pound each and 110 pound of cargo. Impact doubles the total load. A pulling force of 50 pound was used.

Load configuration	Pulling force	Maximum stress (psi)	Percentage of yield strength
Empty	Yes	450.2	3.45
Fully laden	No	2222	17.03
Fully laden	Yes	2668	20.44
Fully laden with impact	No	4443	34.05
Fully laden with impact	Yes	4888	37.46

3.2.2. Prototyping

A prototype was constructed during the team's trip to Puebla, Mexico, based on the winter quarter design. Fabrication took place in the IDIT engineering laboratory at Universidad Iberoamericana Puebla. Due to the large amount of welding that needed to be done as well as the lack of experience with aluminum welding, the frame was not able to be completed during the single week the team was there. The prototype shown in **Figure 15** was displayed as a mockup for community members to view and provide feedback on. This prototype is currently residing in the IDIT laboratory.

A second prototype was constructed after the team's trip to Puebla based on the spring quarter design. This iteration included a protruding section to reach over the rear bike wheel to the bike seat post as well as additional diagonal members to discourage lateral movement. After the pieces were cut to length, they were ready to be taken to a professional welding shop. The team found difficulty in contracting a welder, as potential shops either did not respond to inquiries or were too busy to take on this project. Eventually, the team made contact with Yes Welding in San Jose who expressed interest in the project. The frame was welded in only three days. This expedited lead time was extremely helpful to the team, as average lead times are around two weeks. The welded frame is shown in **Figure 16** with Juan from Yes Welding, the owner and senior welder.

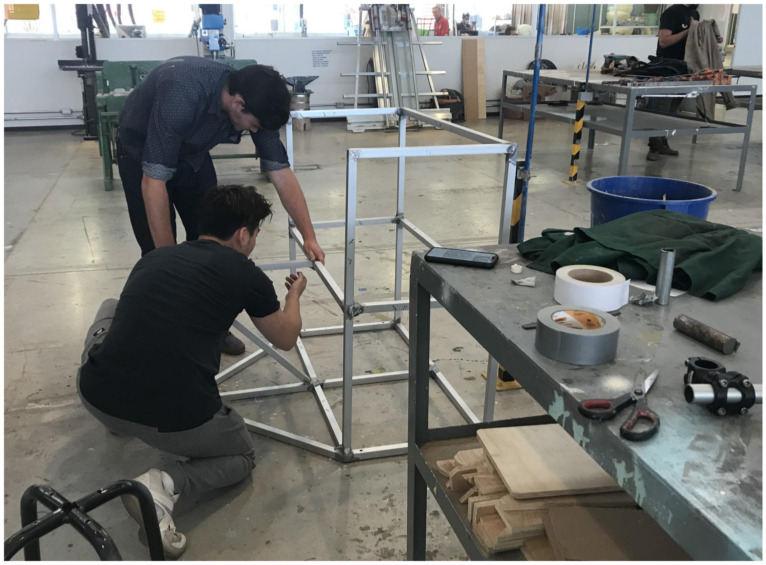


Figure 15. Frame prototype in the IDIT lab.

Figure 16. The BiciTaxi frame, welded by Juan from Yes Welding.

3.3. Leaf Spring Subsystem

3.3.1. Design

The main improvement the team made to a typical rickshaw is the suspension system. Since Valle de Paraíso is not paved, the terrain is rough, and there are potholes everywhere, so a suspension system to make the ride a bit easier felt necessary.

Using a decision matrix, which can be found below in the **Appendix**, the leaf spring suspension system was chosen out of a selection of independent suspension, MacPherson struts, air-suspension, multi-link suspension, and for extreme comparison, Magneride suspension.

Typical leaf springs have 2 to 3 leaves in addition to the master leaf.

Hardware for a leaf spring to connect it to the frame includes one hanger with 1 degree of freedom and another hanger with 2 degrees of freedom. A labeled schematic can be viewed below in **Figure 17**.

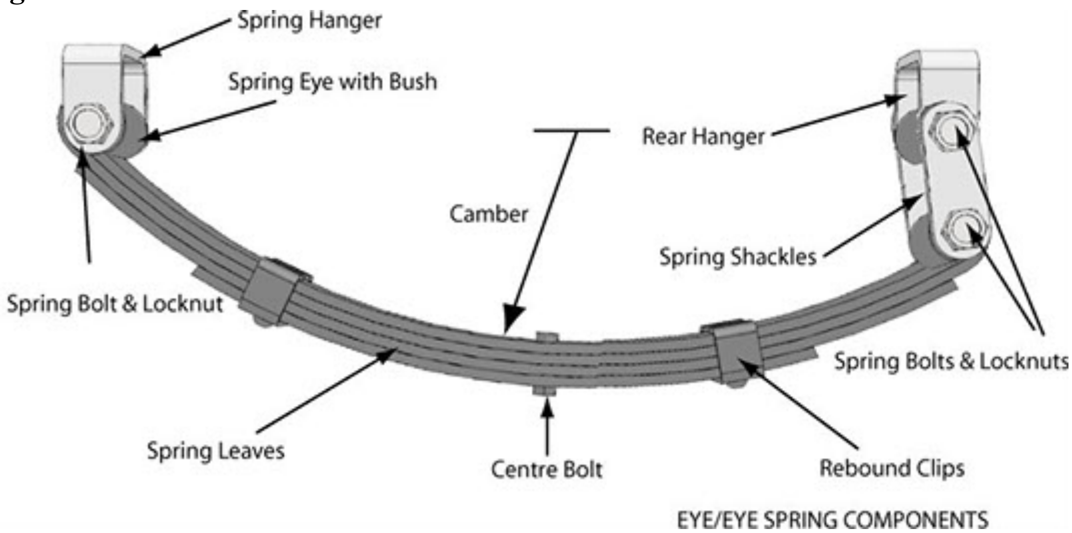


Figure 17. Labeled schematic of leaf spring suspension with hardware [11].

3.3.2. Supporting Analysis

Since the suspension was limited by the frame's dimensions, the shortest leaf spring that was found was 18 ⅜ inches from eyelet to eyelet. Each leaf spring could support 1,600 pounds, however this was too much holding power for the vehicle's application of 550 pounds. 2 leaves had to be removed. To determine if this was justified, *equation (1)* was used below and can be viewed in the sample calculation for a leaf spring.

$$\sigma_{max} = \frac{pFL}{Nb_N h^2} \tag{1}$$

where *b* is the width of the leaf spring, N is the number of leaves, *p* is a constant based on the supporting condition of the leaves, which is 3 for a simply supported beam, *F* is the force applied, *L* is the length from eyelet to eyelet, and *h* is the thickness of each leaf.

The sample calculation assumes half of an impact loading of twice the static loading limit of 550 pounds. The dimensions of the leaf spring can be viewed below in the **Appendix**.

Sample Calculation: Single Leaf Spring

$$\sigma_{max} = \frac{pFL}{2b \quad h^2}$$

$$\sigma_{max} = \frac{(3)(1100lb/2)(18.375in)}{(2)(1.75in)(0.323in)^2}$$

σ_{imp} =*83.03 ksi*

$\sigma_{static,max} = 41.52\ ksi$

SF = 1.2

For a maximum impact loading of 83.03 kilopound-per-square-inch, and a yield strength of 100 kilopound-per-square-inch, the safety factor is found to be 1.2.

3.3.3. Visual Aids

Figure 18 shows a sketch of a typical leaf spring suspension system.

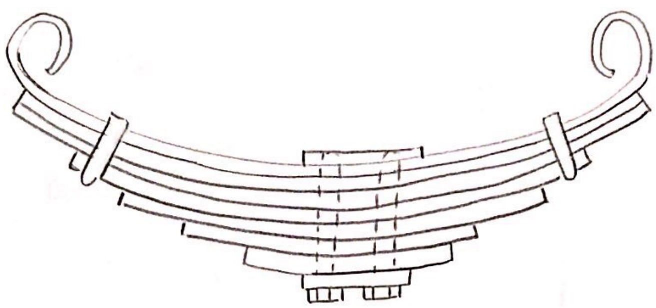


Figure 18. Sketch of leaf spring suspension (by Alesis Gonsalves).

Figure 19 below shows a sketch of a simplified frame with the leaf spring suspension attached to the underside of the frame.

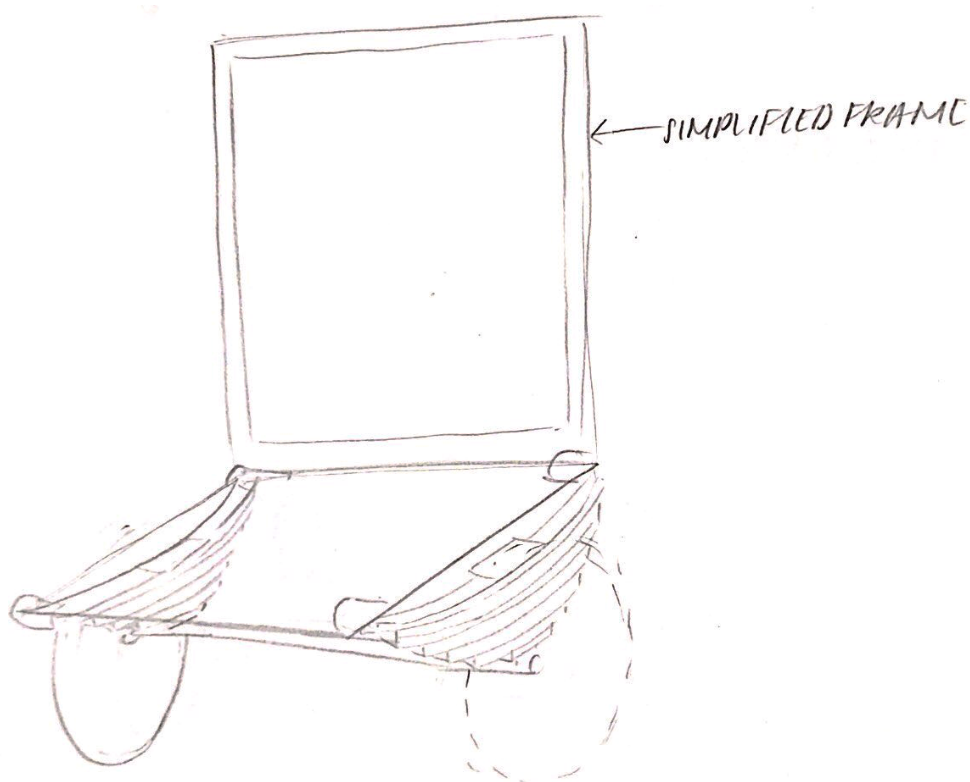


Figure 19. Simplified frame with leaf spring suspension (by Alesis Gonsalves).

Figure 20 shows a CAD rendering of the leaf spring SolidWorks model with hangers, u-bolt, and center-plate.

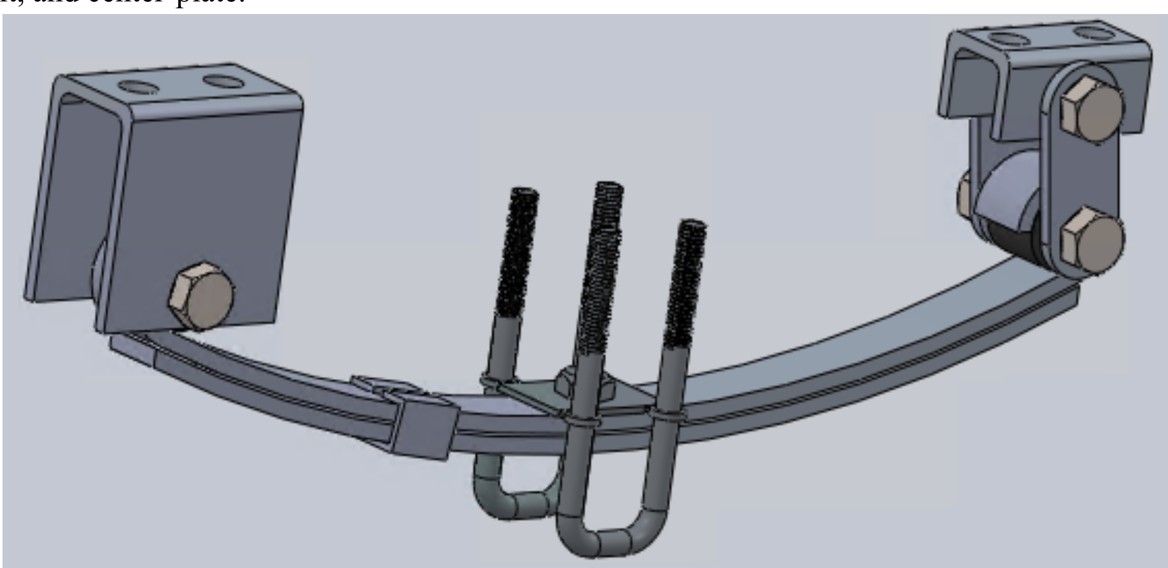


Figure 20. Solidworks model of preliminary leaf spring.

Figure 21 shows a CAD rendering of a single leaf spring.

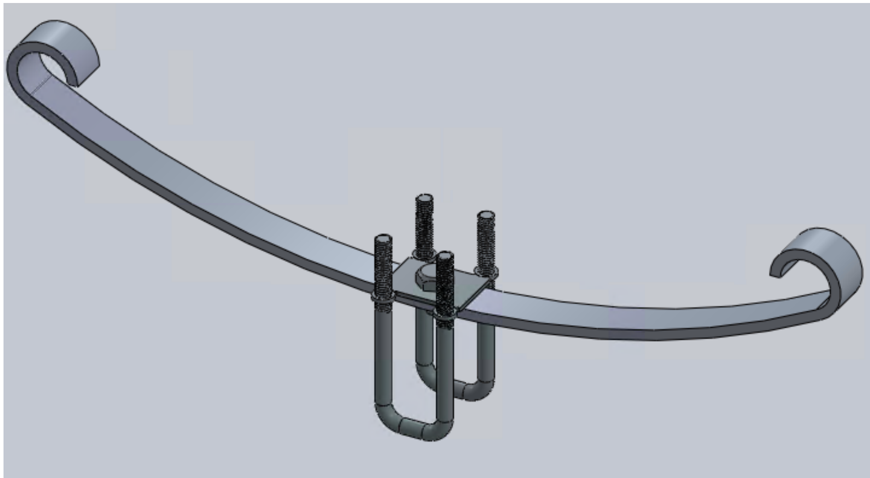


Figure 21. Solidworks of single leaf spring.

All parts for the first iteration were purchased in Mexico, assembled there, and left at IBERO, except for the suspension. No preliminary testing was done on leaf spring iterations before assembling the final prototype. The specification sheet for this purchased leaf spring can be viewed below in the **Appendix**.

3.4 Axle Subsystem

3.4.1 Design

The axle needed to be simplistic enough to coincide with the hardware of the leaf spring suspension system, but strong enough to counteract the force of the weight of the vehicle from the leaf springs as a normal force on the wheels. One of the free variables for the axle design was the material choice. Considering that the frame of the vehicle only weighed about 17 pounds, it was assumed that most of the weight would be in the leaf spring suspension and the axle and material choice would not be an issue in terms of weight. The second free variable for the axle design was the shape. The ends of the axle obviously had to have a circular cross-section to fit into the bearings of the wheels, but the middle portion of the axle could be varied. The final design iteration includes a purchased steel slotted c-channel and grade 8 bolts. The difficulty lay within the connection between the slotted C-channel and the bolts.

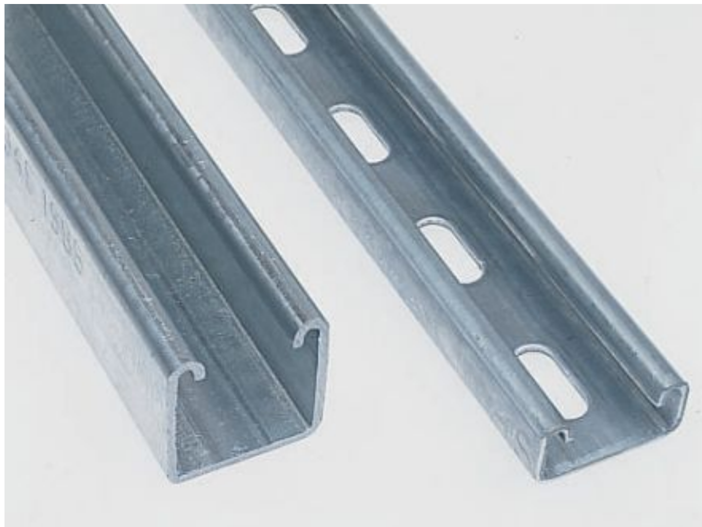


Figure 22. Typical slotted C-channel [12].

The third component of the axle is a machined part that holds the bolt parallel and inside the slotted C-channel, and is held by tightening screws through the slotted C-channel. This can be viewed below in **Figure 23**.

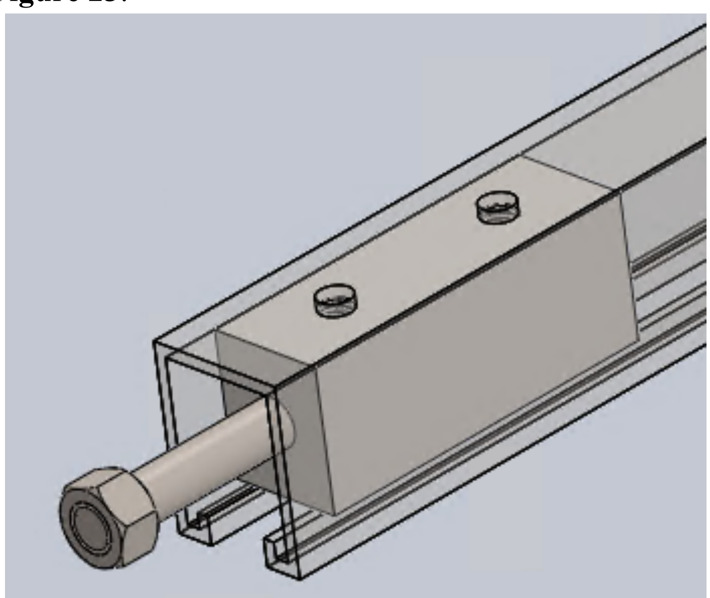


Figure 23. CAD of end of axle.

One side of the axle was not actually mirrored to the other because of the direction of the threads. Because of this, one of the threads needed to be reversed so that as the wheel turns around the bolt, the bolt would be tightened instead of loosened.

3.4.2. Supporting Analysis

The following design analysis is for an axle to wheel connection. The design as a whole, reminiscent of a trailer and rickshaw, includes a frame, connecting rod, and suspension subsystems. The suspension subsystem includes a leaf spring suspension, axle, and wheels. The axle is one of the most important parts of the suspension subsystem. The axle facilitates the movement of the wheels and ensures that the wheels are on the same axis of rotation. Because of the use of a leaf spring suspension combined with an uneven terrain, it was decided to not have the wheels rotate codependently, but rather independently. In the following design, both bearings and a disconnected axle were used in order for the axle to not rotate, and the wheels to rotate independently of each other. The most concerning modes of failure because of this configuration are yielding, impact loading, and fatigue, specifically at the wheel to axle connection. Finite element analysis, FEA, studies were done for a static loading condition, one for yielding and one for impact. Fatigue is assumed to be low-cycle, but a high-cycle analysis was done just in case. Studies were done assuming both people and cargo were being carried by the vehicle. **Figure 24** below shows a portion of the suspension system.

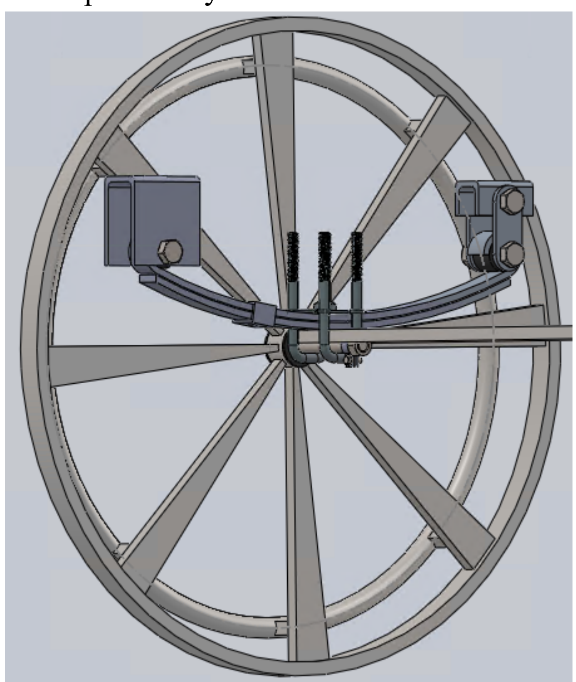


Figure 24. SolidWorks model of half of the preliminary suspension system.

Figure 25 shows the underside of the preliminary wheel to axle connection. The axle consists of a grade 8 bolt measuring ½”-13 x 4” rigidly connected to a steel channel.

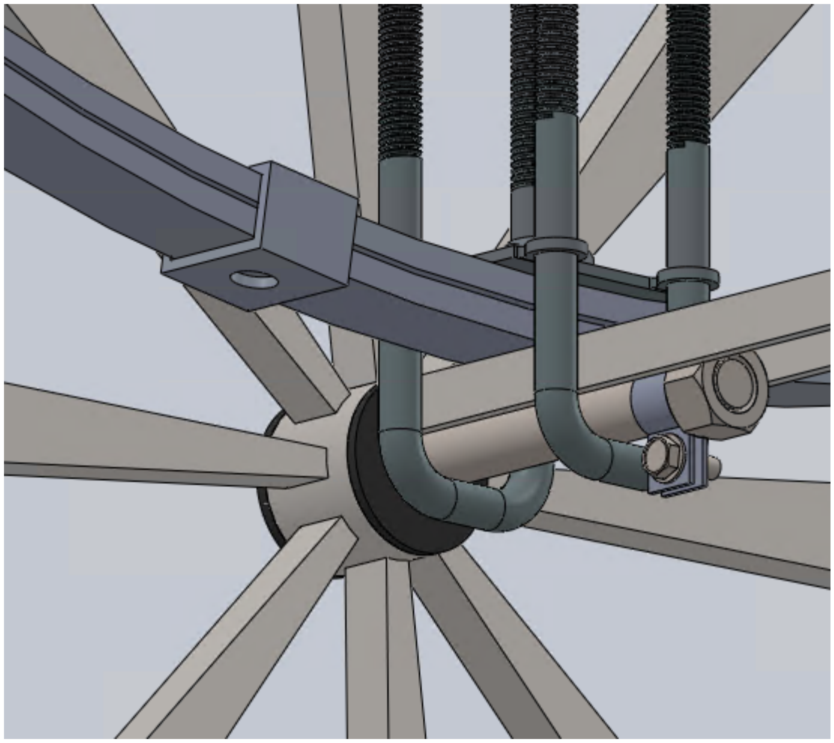


Figure 25. Underside portion of wheel hub connection to axle.

Assuming a maximum of 250 pounds per person, 125 pounds for the vehicle itself, and 125 pounds for cargo, including a factor of safety of 2, a total of 1000 pounds was used for a yielding loading condition on the localized portion of the suspension system. Each side will have experienced 500 pounds of force; 500 pounds on the bolt, 500 pounds normal force on the wheel. Impact loading was assumed to be up to twice that of the weight of the vehicle. The bolt and wheel were assumed to be made of carbon steel.

For the FEA analysis, the system was simplified to a connecting bolt, the wheel, wheel hub, and surrounding rubber washers to make sure there is enough clearance from the U-bolt straps to the wheel. This clearance can be viewed below in **Figure 26.** For the yielding study, 500 pounds force was applied in the downward y-direction and 500 pounds force applied to the wheel with the normal force of 500 pounds in the upward y-direction. For the impact loading the same study was done but with 1000 pounds force instead of 500 pounds.

Figure 26. Clearance between U-bolt straps and wheels.

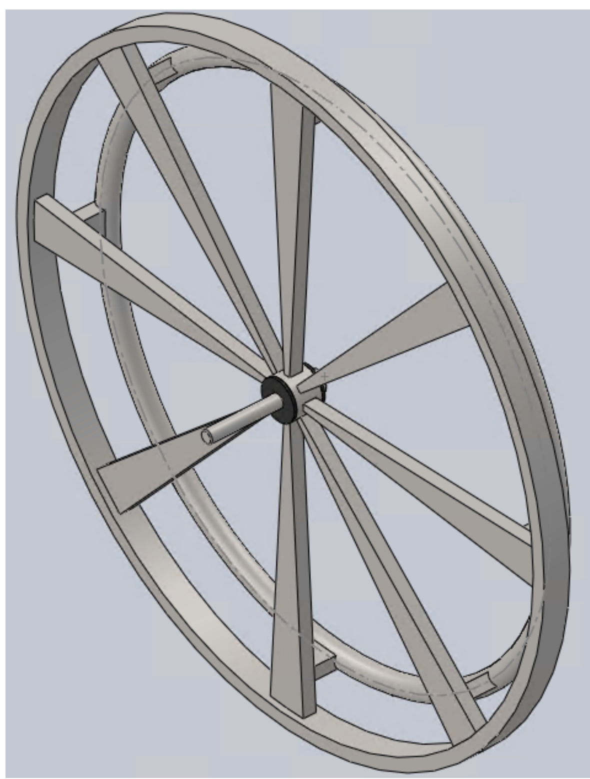


Figure 27. Simplified SolidWorks model for analysis.

According to **Figures 28** and **29** below, the stress is distributed evenly along the wheel. The yielding stress is increasing when moving towards the wheel hub. The wheel was not expected to deform because the specifications specifically read that each wheel can support 800 pounds. Extra attention was paid towards the joint between axle and wheel hub since that is the place where maximum stress is located and where it is most likely to yield.

Impact loading was expected to be, at most, twice that of static loading, resulting in 1000 pounds-force.

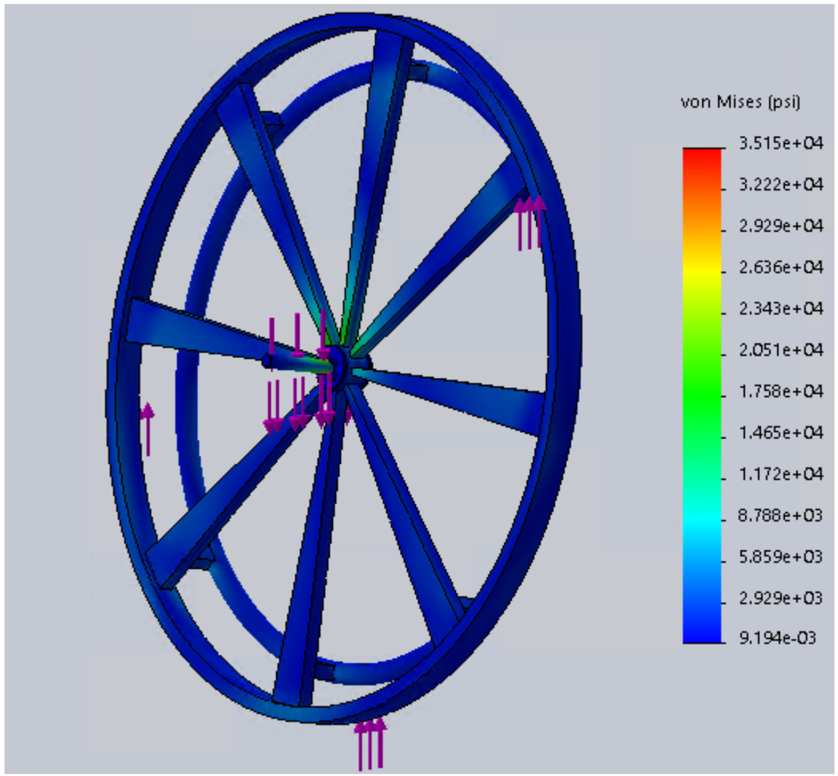


Figure 28. SolidWorks model of simplified subassembly under static loading.

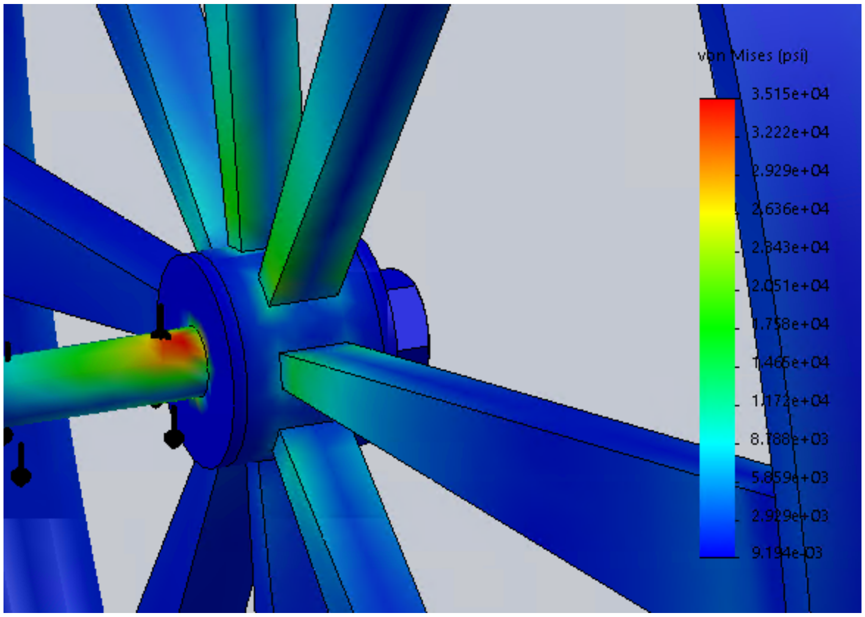


Figure 29. SolidWorks model of simplified subassembly under static loading.

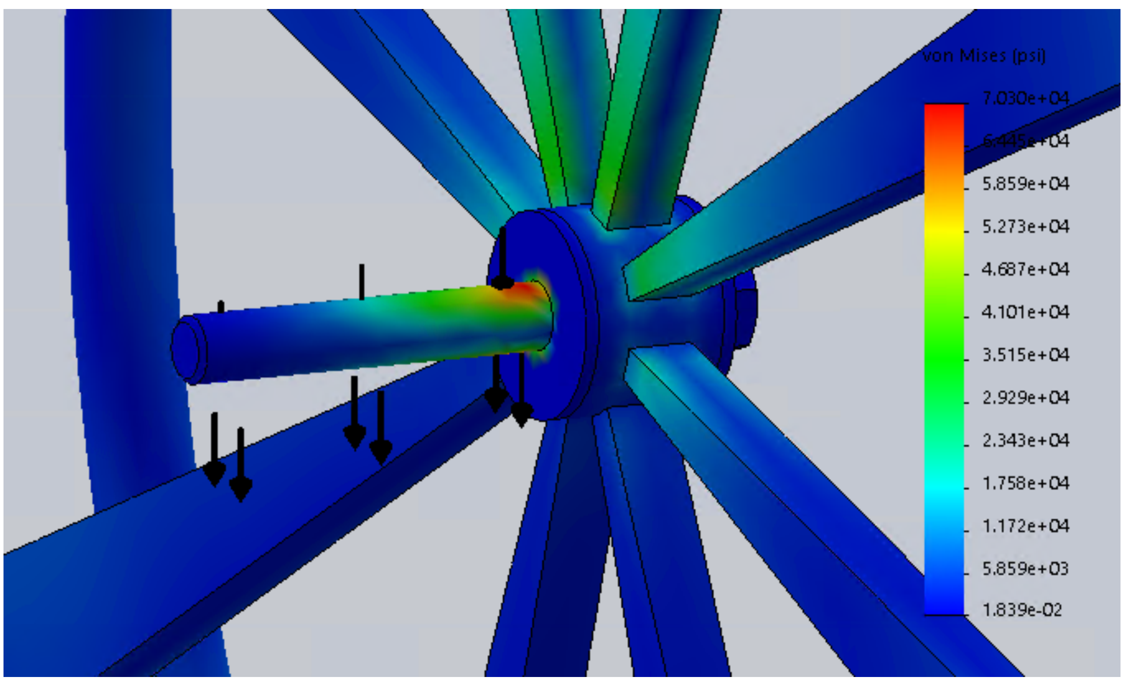


Figure 30. SolidWorks model of simplified subassembly under impact loading. Maximum stress is $7.030 * 10^4$ psi

A material starts yielding when the Von Mises stress reaches a value known as the yield strength. The yield strength for carbon steel is 53.70 kilopounds-per-square-inch, which is higher than the maximum Von Mises stress shown in **Figure 30** which is 35.15 kilopounds-per-square-inch. This result indicates that the material used to build the axle is solid enough to hold at least 1000 pounds and the axle would not deform under normal circumstances since it is within the elastic limit for carbon steel. Since the axle might age and the difference between von mises stress and yield strength is not large, strengthening the joint between wheel hub and axle could prolong the service life under high-cycle fatigue conditions.

However, for the impact strength, the model experienced stresses above the yield strength, meaning that it was plastically deforming. In order to keep impact loading from affecting the structural integrity of , the load limit was arbitrarily decreased to 500 pounds, so that an impact loading of twice the static loading will be at 1000 pounds or lower. A simple cost-benefit analysis determined that changing the loading condition was easier than manipulating the design. In addition to this, having a total loading limit of 1000 for static loading seemed reasonable considering the vehicle would only hold 2 persons, and cargo.

After the final prototype was built it was found that the vehicle itself weighed 73 pounds, so the load limit is actually more than what was determined after the FEA analysis.

3.4.3. Prototyping

Below in **Figure 31** is a photo of a portion of the axle prototype built in Mexico.

Figure 31. Suspension prototype in Mexico.

No preliminary testing was done on the axle for either iterations.

3.5 Trailer Hitch

The purpose of the trailer hitch is to connect the BiciTaxi to any small transportation systems such as bicycles and motorcycles. When residents in Puebla, Mexico need to transport their family members or friends to the bus station or school, they can easily attach it to their vehicles. The trailer hitch consists of two parts, which are the connecting rod and the clamp. The connecting rod connects to the frame and the clamp will be attached to the bike seat. According to our survey, each family has at least four people, which means the trailer hitch should be able to carry a total load of at least 800 pounds. Since residents there are poor and do not have enough money to purchase expensive finished products, material that is solid, cheap and easy to manufacture will be the best choice. As a result, aluminum alloy 6063-T52 was determined to be the best option to satisfy the above requirements. Although aluminum is hard to weld, the accessibility and low cost outweigh its inconvenience based on our field trip.

The trailer hitch design draws on aspects from a trail-gator tow bar, which is shown in **Figure 32**. Initial design called for welding this tow bar directly to the frame, but it did not work as expected because it was difficult to test the tensile strength on a curved part. So we changed the curved part to a straight section and added a triangular configuration underneath the straight aluminum tube to enhance stability and aesthetics. Figure # shows the final Solidworks design for the connecting rod.

Figure 32. Trail-Gator Tow Bar [14]. Image reproduced without permission.

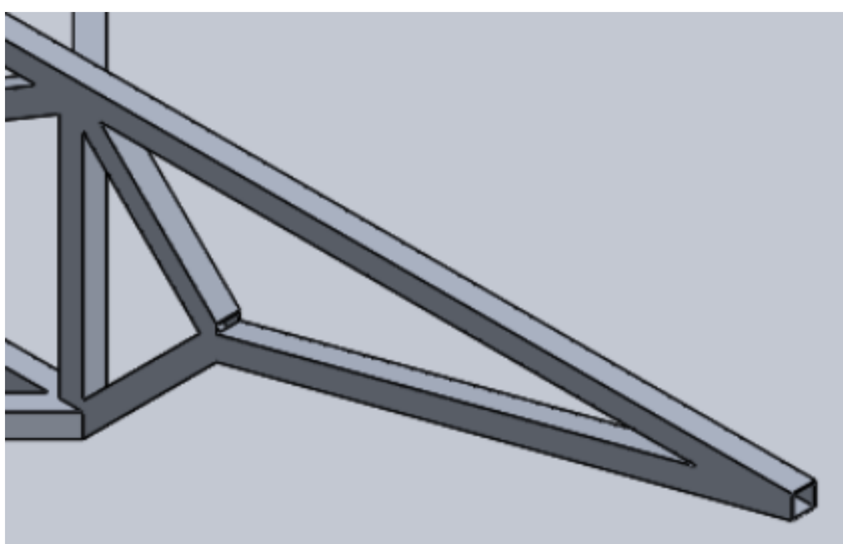


Figure 33. 3D CAD model of the connecting rod.

The clamp also plays an important role in the whole trailer hitch design. The road conditions in Colonial Puebla are not good. The unpaved and bumpy road will become muddy when the rainy season comes. In order to mitigate bumpiness and let passengers ride more comfortably, we decided to make the clamp have 2 degrees of freedom, which allows the clamp to move up and down and left and right at the same time. The **Figure 34** shows the SolidWorks design for the clamp. The bigger hole will go underneath the bicycle seat. The bolts at each side allow users to tighten the clamp based on different diameters. The smaller hole will be attached to the connecting rod by placing a cylindrical part in the middle of hole and fixing it by bolts.

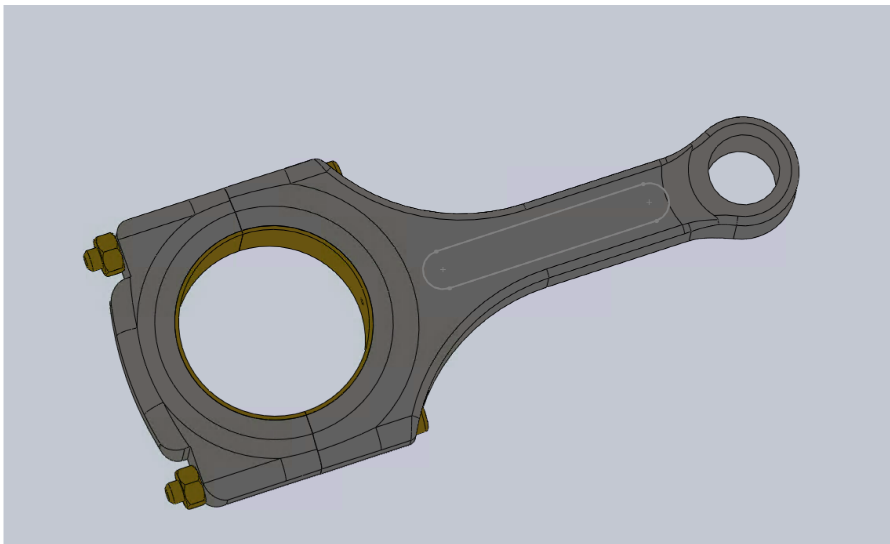


Figure 34. 3D CAD model of the clamp.

3.5.1 Prototyping

A bike component was purchased and modified to be used as a swivel joint with two degrees of freedom. The component used was a ZHIQUI 60-+60 degree adjustable handlebar clamp, shown unmodified in **Figure 35**. This component has two clamps, one on each end, with an adjustable locking swivel in the middle. Grooves inside the locking swivel and end caps prohibit free motion when the adjusting bolt is properly tightened, so the adjusting bolt and end caps were removed and replaced with a 1/2 inch bolt with washer, nut, and lock washer to enable a single degree of freedom. The clamp end with four internal hex bolts was clamped around the bike seat post. To connect the trailer hitch component to the frame, two protruding pieces of a flat hole-punched steel bar were attached to the tip of the frame and clamped using 3/8 inch bolts and additional pieces of flat steel bar. This flat steel bar had a thickness of 1/16 inch, with 3/8 inch holes spaced 3/4 inch center to center. The clamp end with two internal hex bolts was filled by a bolt with stacked washers, and this bolt passed through holes in the flat steel bar. The circular opening of the clamp was larger than the washer diameter and this extra space allowed for the second degree of freedom. This assembly is shown in **Figure 36** and **37**. In future work, holes could be drilled in the tip of the frame to allow the protruding flat bar pieces to be bolted directly to the frame.

Figure 35. The ZHIQUI 60-+60 degree adjustable handlebar clamp, unmodified. Image reproduced without permission.

Figure 36. Trailer hitch prototype assembly, side view.

Figure 37. Trailer hitch prototype assembly, top view.

3.6 Ergonomics

With regards to the ergonomics of our device, we wanted to ensure the ride would be comfortable for the passengers. We plan to add foam seating on top of wood to complete the seats. We also added back and foot rests to further ensure that the passengers are safe and do not experience discomfort.

3.6.1 Design

One of the decisions our group made was to put a storage area underneath the seats. Many of the people our project is geared toward will be travelling in and out of the city. We wanted to ensure that they would be able to transport whatever they need. We also wanted to ensure the ride would be able to comfortably sit up to two individuals, so the seating dimensions were made accordingly. We also needed a way to protect the passengers from weather conditions so a tarp was included into our design. This was done to protect the individuals from rain, dirt, and any other rough conditions that would be encountered.

3.6.2. Prototyping

For the first prototype, the main material used for the seat of the BiciTaxi. We made sure to include a storage area under the seat to ensure the passengers could safely store their belongings. In later iterations, foam padding and a canvas material were layered on top of one another to ensure a more comfortable ride. No preliminary testing was done for the ergonomics.

3.7 Eliminated Subsystems

Colonial Puebla not only lacks a dependable transportation system, but it also is in short of electricity. We thought that introducing solar panels that mounted to the roof and electric motor with battery under the seat would solve the problem. Two sets of pedals were also considered to provide an additional locomotive power. The attachment can be disconnected from the bicycle to generate electricity that would be stored in a rechargeable battery from the solar panel or via the pedals in a stationary configuration. This electricity would also help residents to charge small household electric appliances such as cellphones.

Based on our field trip and feedback from residents who live in Colonial Puebla, a lot of changes have applied to our design. Here are subsystems that we decide to remove.

The first one is solar panels. They are made from many parts and the most important are silicon cells. Those silicon cells are paired with a metal casing and wiring, which allows the solar cells' electrons to escape and supply useful power. The metal frame is usually made from aluminum and a glass casing is added at the front of the panel to provide durability and protection for the solar PV. The panel also has a casing for insulation and a protective back sheet, which helps to eliminate heat dissipation and humidity inside the panel. In addition, different kinds of wires are also required to operate the system.

Based on the benchmarking research, matrix and study on current bicycle solar panels that sold on the market, the Nekteck 21W Solar Charger was found and might be the best choice for the design.

Figure 38: Nekteck 21W Solar Charger [16]. Image reproduced without permission.

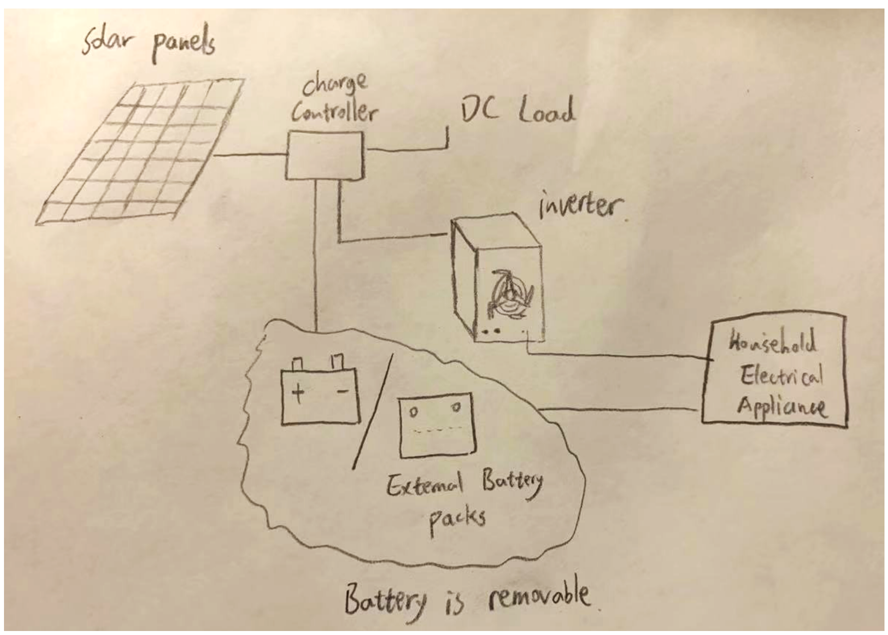


Figure 39: Solar panel electrical schematic.

Figure 39 shows the working principle of solar panels. The solar panels would absorb solar energy through its photovoltaic cells and the electricity produced by this stage is DC and must be converted to AC, which is suitable for use in home. Inverter would turn the DC electricity into 120 volt AC that can be used immediately or stored in the battery for future use. It is assumed that the duration of sunshine in Puebla city is 10 hours per day and the annual mean temperature is 62 fahrenheit, which is 17 celsius. The *equation (2)* for calculating electricity generated in output of a photovoltaic system is shown below:

$$E = A * r * H * PR \quad (2)$$

where A is the total solar areas, r is the solar panel efficiency, H is the annual solar radiation on tilted panels and PR is performance ratio,coefficient for losses.

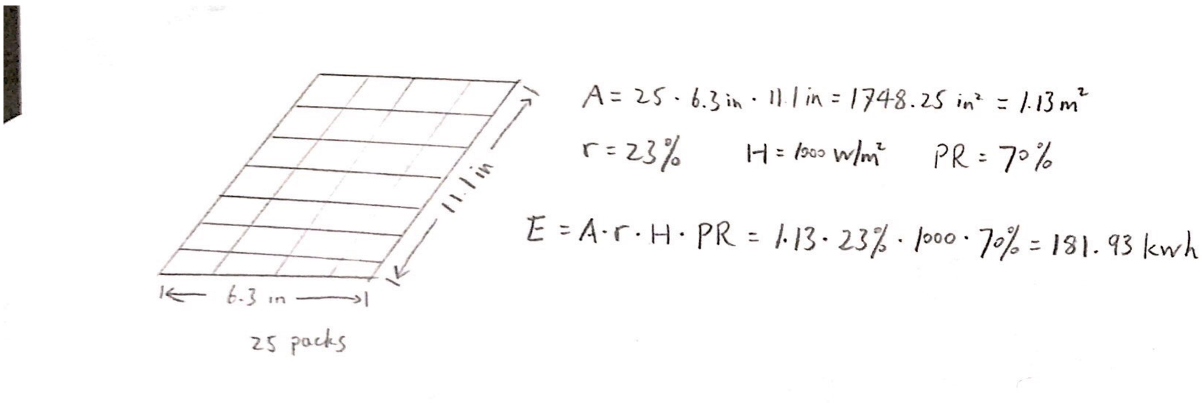


Figure 40. Electricity output

Moving forward, the design includes an assisted motor in order to reduce the amount of work required by the passengers during travel. These motors can vary widely in price, However it can be useful to look at and examples. One company sells a 750 watt motor kit for 650 USD. This same company sells a 1000 watt kit for 750 USD. Both of these kits require a 48 Volt battery to operate at a minimum and also contain room for additional features such as brake assist, the ability to assign a top speed, etc. Clearly these attachments are on the higher end and while they offer many possibilities they seem to be unnecessary for this particular project design. On the other end of things, there exists a 1200 watt drive kit for 270 USD. This kit is less extensive, but has greater power output with the same 48 Volt battery requirement. It includes pedal assist, throttle, and brake levers. This would be an example of an attachment more suitable for the project due to its simplicity and lower price.

Figure 41. Electric Motor configuration[17]

After the field trip, we realize that although they are very fond of our designs, these electrical components such as solar panels and motors are easily got stolen in these areas and they are expensive. They could not afford that kind of loss. As a result, these two subsystems are eliminated from the initial design.

For the drivetrain design, there were four options, all-wheel-drive (AWD), front-wheel-drive (FWD), rear-wheel-drive (RWD), and a three-wheel-drive (3WD), (modeled after a four-wheel-drive, 4WD, system). The AWD drivetrain have axles that move independently of each other, so the driver on the bicycle, as well as the passengers on the attachment will be assisting it forward, but independently. The FWD drivetrain puts all of the work on the driver of the attachment, which will require more work from the driver, increasing the need for an assistive motor. The RWD drivetrain assumes that only the passengers will be moving the attachment forward while the driver just steers, this can pose a problem if the passengers are children, elderly, or unable to pedal. The 3WD drivetrain has front and rear axles that are fixed to one another.

The AWD drivetrain is chosen to be the best option because it allows for a differential between axles and tires and does not allow solely on the driver or the passengers to power the vehicle. Besides, it is much safer and economical compared to other drivetrains.

Figure 42. Bicycle Drivetrain and Gears[18]

After actually carrying out the test, we think inconvenience might outweigh benefits because it's time-consuming and really hard to design without professional knowledge. As a result, drivetrain subsystem is removed.

Overall, the design team eliminates three subsystems to simplify the design and make it more suitable for those residents. However, we still hope prospective engineering students can keep working on this project and figure out some ways to secure these electrical components to make their lives much more easier.

4. System Integration

4.1. First Prototype

Below in **Figures 43** and **44** was the first initial design that included a solar panels and drive train. As mentioned in the eliminated subsystems section, the solar panels and drive train were put on standby in order ensure the completion of the mechanical function of the vehicle.

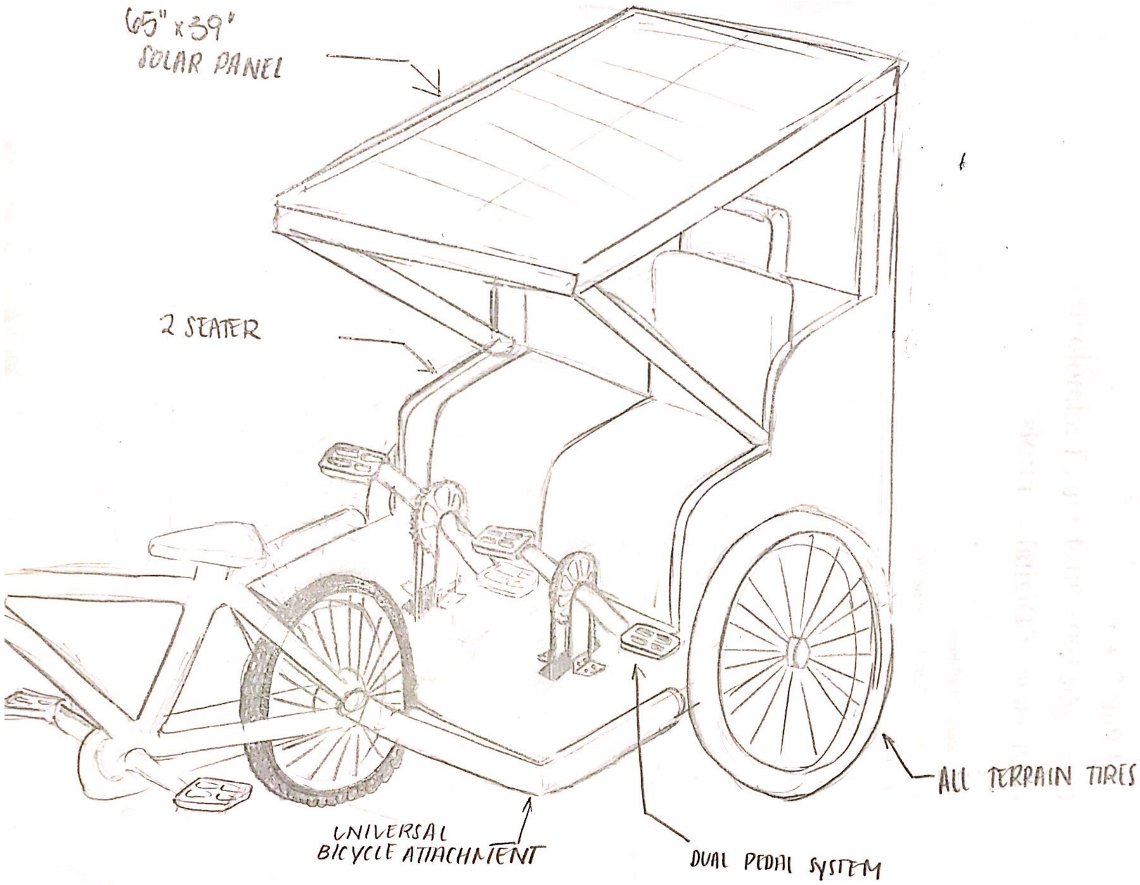


Figure 43. Expanded isometric view of the attachment

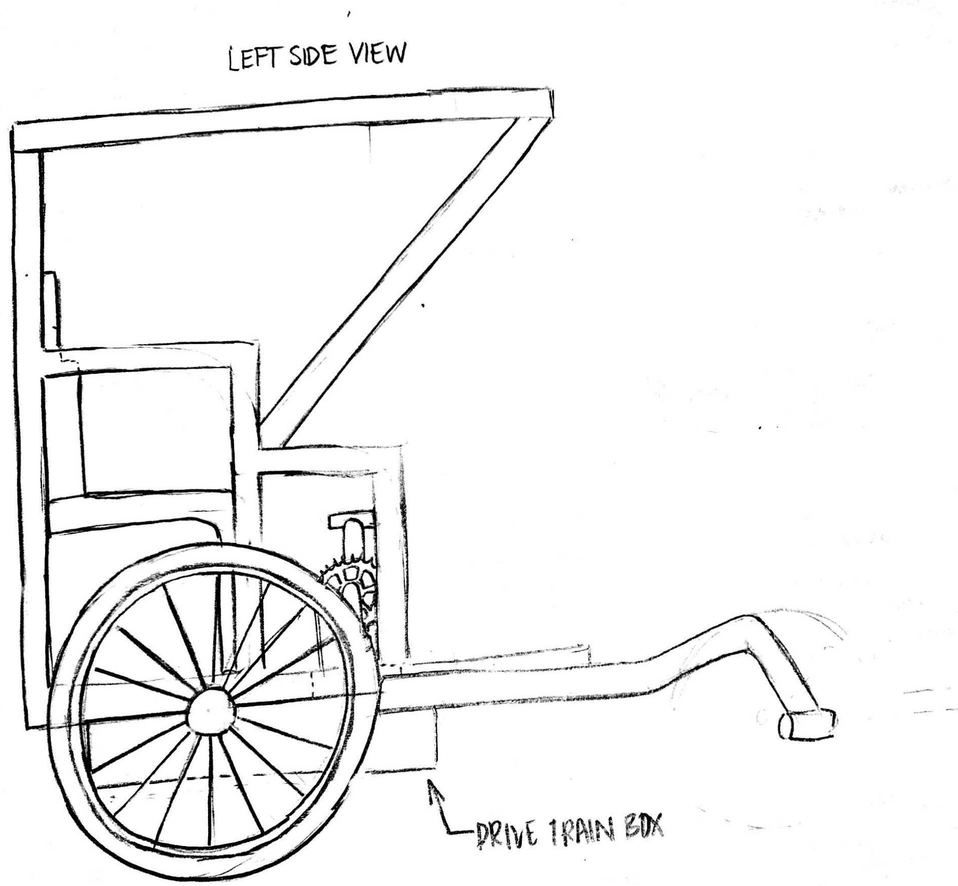


Figure 44. Left side view of attachment

The first prototype was built entirely in Mexico. All materials were sourced from local shops except for the suspension, which was brought down from the states. Bicycle wheels were purchased from a bicycle shop in Valle de Paraiso, Puebla, the aluminum stock was purchased in Puebla City, Puebla, miscellaneous hardware was purchased at Home Depot in Puebla City, Puebla and the prototype was manufactured at IBERO in Cholula, Puebla.

Figure 45. Purchasing wheels at the local bicycle shop in Valle de Paraíso.

Figure 46. View of finished first prototype

Figure 47. View of initial prototype.

4.2. Final Prototype

Figure 48. View of final prototype on street

The final prototype was built entirely in the Machine Shop of Santa Clara University. The wheelchair wheels and suspension systems were purchased online. Aluminum tubes, applied woods and other supplying materials were purchased at Home Depot. Under the approval of mechanical engineering department and advisors, tasks and experiments were carried out safely on the street to get data.

Figure 49. View of final prototype

4.2.1. Experimental Protocol

Table 6. Experimental Procedure

Evaluation	**Equipment**	**Accuracy**	**Trials**	**Expected outcome**	**Formulae or Assumptions**
Weight	Bathroom scale	2 pound	3	50 pound	Attachment can be balanced on scale. If not, will be dismantled and weighed separately.
Suspension deflection	Hand weights; measuring tape	0.5 in.	5	250 kg	Maximum carrying capacity. Load is placed to mimic 2 persons and cargo.
Speed (Fully laden)	Stopwatch; Tape measure	1 mph	5	6 mph	Bike and cart are not accelerating. Tested while on flat ground. Fully laden is considered to be 200 kg. V = dist/time
Speed (Empty)	Stopwatch; Tape measure	1 mph	2	8 mph	Bike and cart are not accelerating. Tested while on flat ground. V = dist/time

Because two leaves of the leaf spring were taken off, the team wanted to determine the amount of deflection would occur. A loading test was done at the Malley Recreation Center using 45 pound plates. Data was taken for an unloaded vehicle up to 225 pounds in 45 pound increments and measured from the base of the frame to the top of the leaf spring. This can be viewed below in **Figure 50**.

Figure 50. Deflection test for 225 pounds of load.

The loading experiment and deflection data can be viewed below in **Figures 51** and **52**.

Figure 51. Static loading testing at Malley Recreation Center at SCU.

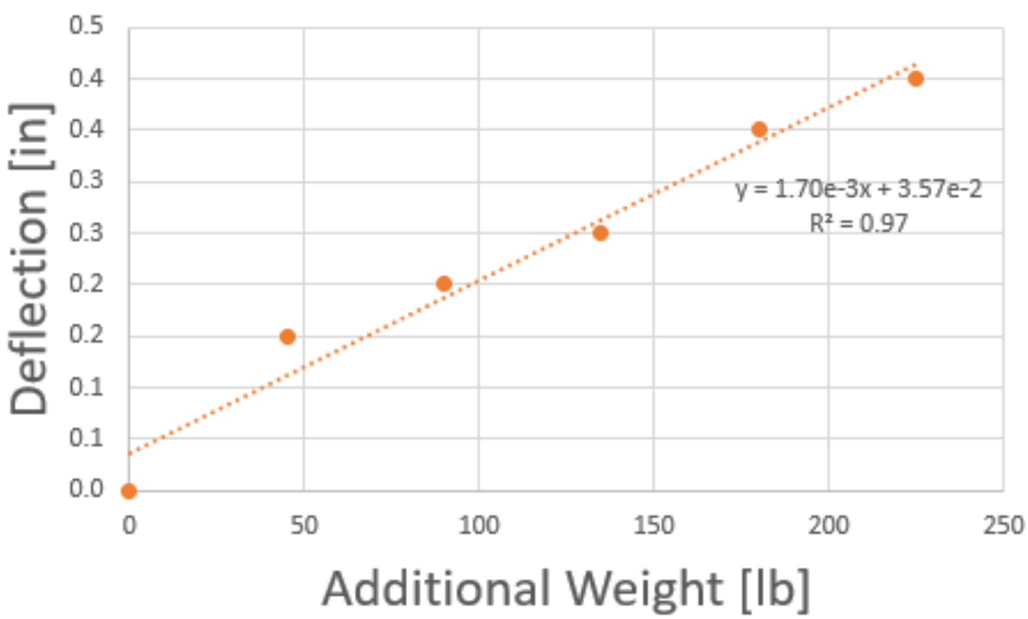


Figure 52. Weight versus deflection for static loading.

The data shows a linear relationship, meaning there is no plastic deformation occurring for this weight range.

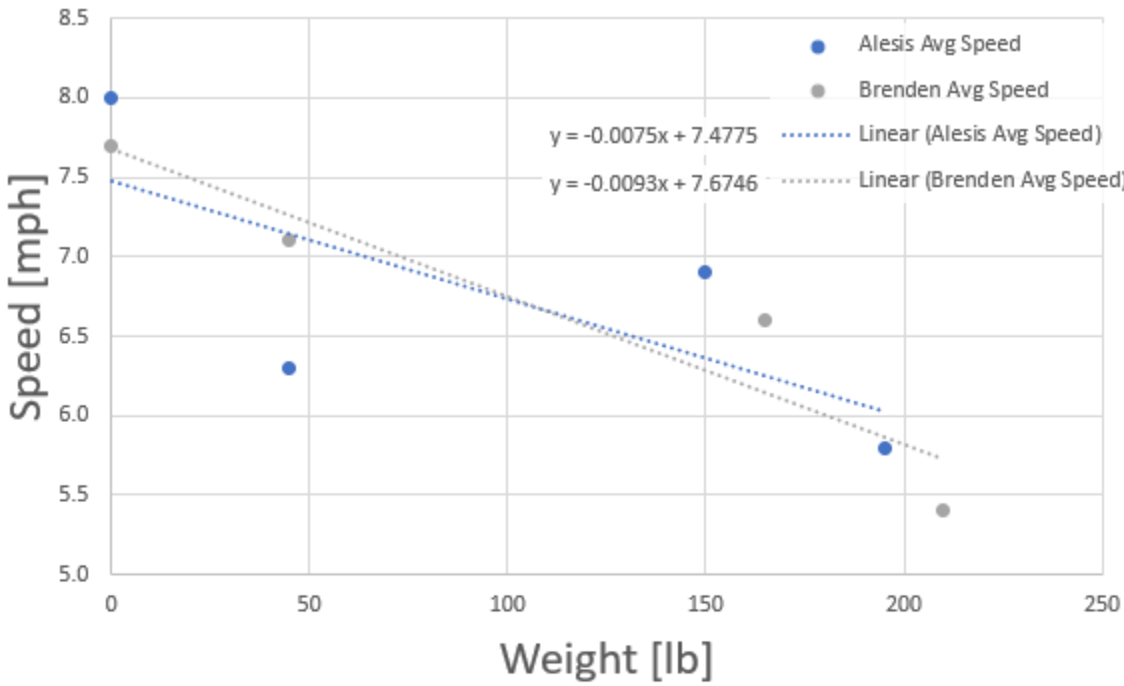


Figure 53. Weight versus speed for static loading.

Figure 53 also shows the linear relationship between weight and speed. As the weight increases, the speed decreases.

5. Business Plan for BiciTaxi

5.1 Executive Summary

BiciTaxi is a frugal solution for transportation accessibility designed for third world countries, but functional in any setting. BiciTaxi is a nonprofit that provides open-source hardware information for building your very own rickshaw.

5.2 Introduction/Background

Accessible transportation is a very relevant issue for developing countries in 2019. Most countries and respective states have a monopoly on public transportation because of how tax money is delegated between different municipalities. To alleviate some transportation accessibility stress and to encourage involvement in free enterprise and business development, BiciTaxi was developed. BiciTaxi is an improved rickshaw system equipped with an added suspension for a smoother ride and is easily manufactured for business scaling purposes. The target community of Valle de Paraíso, Puebla, Mexico was initiated by contact between Santa Clara University and Universidad Iberoamericana Puebla to problem solve around the issues of transportation accessibility and its translation to hinderance of life-improving opportunities.

Valle de Paraíso is a community of about 100 residents, where the average years of schooling is only 7 years, meaning almost no teens reach high school, but begin working instead. This is because schooling after 7 years is almost all private, and if there is a public school option, fees associated with the school are the responsibility of the parents. By using the BiciTaxi's business plan, drivers can earn up to 840 pesos (42 USD). This is if a 1 kilometer ride costs 20 pesos (~1.00 USD) and can be completed in less than 10 minutes, an 8 hour shift (with an hour break) with a consistent need for rides. 840 pesos for a 7 hour day, or 120 pesos an hour is 24 more pesos an hour than the average wage for general labor for Puebla, Mexico.

5.3 Goals and Objectives

BiciTaxi's original purpose was to get people from point A to point B more quickly than walking, but for a cost cheaper than that of traditional public or private transportation. After the development of the BiciTaxi was completed, it was realized that there was a need for multiple BiciTaxis and the need for capital to further the research and development (R&D) of the design. This prompted the design team to come up with a business plan that could be self-funded and would generate a microeconomy within the target community.

5.4 Description of Product

BiciTaxi is made from a lightweight aluminum frame, leaf spring suspension system, and attaches to virtually any bicycle. It has room for two people and one small child, and cargo such as grocery bags, backpacks, or luggage. The BiciTaxi base model includes a plywood seat and floor. Upgrades to this model include cushioned seating, mud flaps, sun shade, or solar panels to power an assistive motor or charge small electronics, such as a phone or tablet.

5.5 Potential Markets

The original market for BiciTaxi was Valle de Paraíso to be used a taxi-service as mentioned previously. The added suspension system provides a smooth ride, even over unpaved streets, like the ones found in this community. However, BiciTaxi can be a great transportation option for metropolitan or urban areas, such as the San Francisco pier, San Jose, or Mexico City.

The open-sourced design is also available to education establishments and can be a great project to have students follow along or improve upon in their design and fabrication courses.

5.6 Competition

The only upgraded competitor, Soleckshaw is currently not on the market. After failed attempts to maintain the vehicles, no Soleckshaws are currently in use. This was mostly due to no education around the design. BiciTaxi's mission is to directly involve the intended community in the manufacturing and R&D processes so that once the company leaves to start a project elsewhere, the users have knowledge of how to build, maintain, and profit from the BiciTaxi design.

5.7 Sales and Marketing Strategies

BiciTaxi's design and business model are categorized as open-source hardware, neither the product or services are sold. Donations are encouraged from individuals, education establishments, and companies that use any portion of our product, but it is not required.

Although the BiciTaxi's purpose is to help communities generate more stable income opportunities, the intended sales market is to other establishments that have a presence in that community. This is because the product will be more successful and accepted if the community trusts the entity. An example of this in the initial target community was Universidad Iberoamericana Puebla, a university 10 kilometers north of Valle de Paraiso. This university has a strong presence in the community, especially with the youth. The university offers classes like English, dance, hold community events, and various workshops for the residents out of Casa Ibero, a house rented by the university in Valle de Paraiso.

In terms of marketing media, since BiciTaxi is a nonprofit, most capital generated should go towards R&D and getting the information out to users, as opposed to billboards and commercials. Frugal means of marketing included social media and microblog websites such as Facebook, Instagram, and Tumblr. The team also has extensive knowledge on optimizing search engine results in favor of BiciTaxi, that way our design comes up first when searching for frugal transportation solutions or bicycle trailers.

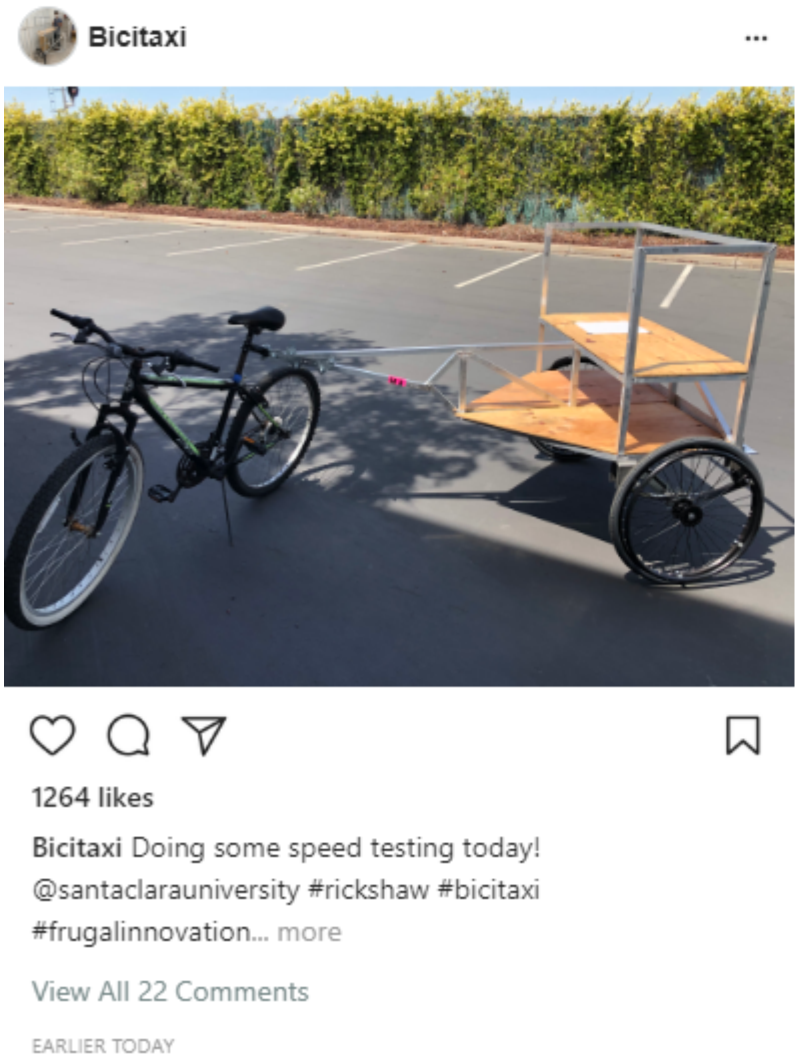


Figure 54. BiciTaxi Instagram post.[22]

5.8 Manufacturing Plans

The suspension, including the leaf spring, axle, wheels, and hardware can be found at various retailers online, the frame can be fabricated at an aluminum welding shop. The whole vehicle can be manufactured and assembled without a team member of the BiciTaxi team present, although that is an option. We have a toll-free number at 1-800-BICITAXI (1-800-242-48294) for help with vending information, manufacturing information, and maintenance assistance. BiciTaxi does not develop any BiciTaxis for public use or sale.

The BiciTaxi team also has posted numerous videos on manufacturing and assembling tutorials, as well as videos from communities all around the world who have built and use our product at youtube.com/channel/BiciTaxi.

5.9 Product Cost and Price

In Mexico, the total cost of materials for the BiciTaxi is $225 USD, without labor. In the US, the total cost of materials is $520 USD, without labor. Considering that the customer will be manufacturing parts by themselves or outsourcing, there is no price because BiciTaxi does not sell the vehicles.

5.10 Service and Warranties

The BiciTaxi owner typically will be able to perform maintenance themselves. As mentioned previously, BiciTaxi has a toll-free number for any questions regarding vendors, manufacturing and maintenance. A typical BiciTaxi, with correct manufacturing techniques should last up to 3 years of continual use before repair is needed. BiciTaxi is not held liable for any misuse or misinterpretation of information and specifications provided.

5.11 Financial Plan

Since BiciTaxi is a non-profit, we rely solely on users and manufacturers of the BiciTaxi design to further R&D and outreach programs. Assets of BiciTaxi include the ownership of the BiciTaxi brand, although the information is open-source hardware, there are no liabilities of BiciTaxi because no goods are sold, and there are no net assets after the capital is put into R&D and BiciTaxi team is compensated.

6. Engineering Standards and Realistic Constraints

6.1 Economical

Colonia Puebla, the community that the project focuses on is almost 15 miles from the city center. The economical interactions between urban cities and rural areas are limited. Promoting economics is one of the goals. Since traveling to city center is expensive, most of the residents find jobs near their community. The attachment that will be built is cheap and durable so that residents can use for a long time and do not need to waste money to purchase another one, annually. By introducing the attachment, it would be much easier for them to travel to the city center and find jobs with high salary and give back to the community. We also hope that this bike attachment would create a small uber-service in that area and stimulate the micro-economy in that community. It is believed that BiciTaxi drive has the potential to make 840 pesos (42 USD) a day, which is above an average day's pay in Puebla. Thus the economy would increase steadily as time goes on.

6.2. Environmental

Our design currently creates no emissions and is made up of environmentally friendly materials. We wanted to ensure that our design was cheap and affordable, while at the same time providing a transportation alternative that requires no fossil fuels. Gas is also very expensive in relation to people's income, so an alternative without the need for gas was a main focus. Providing this service and opportunity allows us to demonstrate ways in which people can eliminate their dependance on certain sources of fuel. We were also able to observe how closely connected the environment is to the responsibilities of engineers.

6.3. Sustainability

Going forward, we see our design being repeatable and sustainable. This is due to the cheap cost as well as the fact that the device requires no fuel. This will allow our device to have many iterations and can reach a wider variety of people. With the room for improvement that we see, we hope to maintain a relationship with the people of Ibero so that the project can have a bright future. The community seemed very interested in our design, so we hope that the project is successful in the coming years.

6.4. Manufacturability

Manufacturability was the biggest concern for our target market in Mexico. The team understood that sourcing parts locally was a necessity and that the cost of manufacturing the vehicle, relative to the resident's income would have to be very low. Ibero's assistance in acquiring materials and connecting us with local material shops was crucial to the building of the prototype. It was understood that the prototype and further duplication would be under the university's supervision and terms.

While in Mexico, all material was found within 10 kilometers of Valle de Paraíso. Main component hardware, such as for the axle, nuts, and bolts were found at Home Depot, wheels and wheel hardware were acquired at two local bicycle shops, one in Valle de Paraíso, and one in inner Puebla City.

The prototype was built in the IDIT lab at Ibero and transported from the university to Casa Ibero in Valle de Paraíso. As of yet, there is no place for manufacturing within the community

6.5. Social Impact

The goal of our project is to provide a transportation resource to the people in Valle de Paraíso in Puebla, Mexico. We also hope to create a small micro-economy within the community through a business model centered around our device. Many of the residents must walk inconvenient distances to get to the bus stop, so we hope to improve transportation access by creating a bicycle attachment that can provide a quicker round trip.

6.5.1. Background on Area of Interest

Puebla is located in east-central Mexico. This state has the fourth highest population in the country. A good portion of the population lives on the outskirts of the major city and the community these residents formed is known as "Colonial Puebla". Basically, this community have encountered numerous accessibility issues with necessary public utilities such as electricity, water, and public transportation. The living and traveling for these residents are difficult, as the roads are unpaved, dusty, and since there are about 5 months of rainy season, the roads become muddy and bicycles or motorcycles have difficulty getting through. A mild example can be viewed below in **Figure 55**.

Figure 55. Unpaved road of Valle de Paraíso.

Colonial Puebla is about 30 minutes by car from the city center. It is also quite far away from the bus stop, which is around 2 miles, and gasoline can become fairly expensive relative to Puebla's average income. This is mostly because of the amount of gas theft present in the state, which causes gas prices to skyrocket without any apparent reason. From a survey the team sent out last quarter, it was found that almost every family has a bicycle or motorcycle.[1] Residents prefer using motorcycles because they can travel farther distances and save energy. The problem is that motorcycles can only transport 2 people at most, but almost all families have at least 2 or more children. From the reasons mentioned previously, a minimally invasive transportation system with large capacity and high efficiency would win great popularity. During the team's trip to Puebla, residents of the community communicated to us that it would be better to focus on the mechanical function of the vehicle because electrical components, such as solar panels, could be easily stolen.

6.5.2 Assumptions and Scope of Influence

It was assumed that community members will quickly assimilate project into their daily lives, but in reality it will most likely take several weeks if not months for the project to become a familiar entity. It is also assumed that there are individuals who would rather ride than walk, and that there are individuals who want to provide these rides, in reality many may feel that they would rather walk than pay to ride, in which case there may be little to no demand for individuals to provide rides. There can also be social implications where individuals do not want to provide rides as they view the service as beneath them or dishonorable, in which any stigma associated with the project or the associated American influence must be overcome by community members in order for it to be successful.

It is also assumed that this attachment will not be stolen or damaged, some individuals associated with IBERO spoke of items being stolen in Valle de Paraíso simply because they were unique, interesting, or different, as well as the thief thinking the item could bring them some benefit, monetarily or not. The project has a reasonable size and weight, so the reality of it being stolen is unlikely, but not completely written off. The team has also assumed that individuals who make this duplicates of the vehicle have access to materials and can weld (or are affiliated with IBERO), our project group had the luxury of working with IBERO and in their engineering lab with full access to it's capabilities as well as travelling to specific stores to purchase materials, others who build this project may not have the same access.

In terms of adaptability, it was previously assumed that this project will be used solely with a bicycle, although motorcycles are also very common and the project could easily be adapted to suit one, but for prototyping purposes it will be fitted with a bicycle. The scope of this project is focused on Valle de Paraíso, and does not include the rest of Puebla City. However, this project could be adapted to communities with similar conditions, whether they are in Mexico or other countries, considering rickshaws or BiciTaxis are used in metropolitan areas as well as rural/suburban areas.

6.5.3 Potential Impact

Valle de Paraíso neighborhood has about 100 residents, on average each family has 3 children. The average amount of schooling for these children and teenagers is 7 years, even though the nearest high school is a 10 minute walk away. The issue is not related with transportation, but with finances; most, if not all schools after the 7th grade level are private and if they are public; uniforms, transportation, and textbooks need to be provided by the student's family, which can be an impossible feat for most. Our hopes with our BiciTaxi is generate a small economy within the community in addition to a solution for local transportation. Children being able to complete their schooling because of the generated income is just an example of the impact that our design and business model can provide.

The team came up with a survey and the response yielded a sample size of 25 persons, which is about 25 percent of the population. 8 out of 25 persons were unemployed, 8 were working part time, and 1 was receiving pension, leaving 8 residents who actually had a full time job. Like many residents in the Bay Area who use alternative methods to supplement their income, such as using Uber or Lyft, it is believed that even residents with full time jobs would like another opportunity to make more money. And for the unemployed and part time workers, they can bring their monthly income up to something closer to Puebla's standard of living.
For the actual income generation, if a 1 kilometer ride costs 20 pesos (~1.00 USD) and can be completed in less than 10 minutes, an 8 hour shift (with an hour break) with a consistent need for rides, can generate 840 pesos (42.00 USD) a day. Although this is ideal, it is not realistic considering the target market in Valle de Paraíso may not even be able to afford 20 pesos, especially when they have become accustomed to their pedestrian commute and may not see the value in faster travel.

Based on the team's trip to Puebla, and multiple analyses during the quarter, the team believes that BiciTaxi would be a great concept for people who live in Colonial Puebla. Materials for building this project are cheap, environmentally friendly, and can be locally sourced. Manufacturing the project is also easy to carry out with the help of local universities. Since the community has expressed a need for available transportation between city and rural areas, as well as self-sustaining business model, the team hopes our project will generate a micro-economy and help residents live better.

6.6. Political Impact

Most of the political impact the project had on the community was just counteracting the political impact that had taken place previously. The Mexican government has a monopoly on public transportation and road maintenance. Although there is a bus route that reaches to Valle de Paraíso, most will walk to their destination because of the amount of baggage that they might have, either from the market, or backpacks from school.

The hopes with BiciTaxi, is that families can travel to and from daily destinations with their cargo in a faster amount of time and is cheaper than a bus, taxi, or other ride-share service.

Because the design will be self-sustaining with the proposed business model mentioned previously, the hope is that parts of the income generated from the service will go back into the community for roads and better infrastructure. In addition to the reversal of negative impacts of the lack of care of the government, the hope is that the residents of Valle de Paraíso will take advantage of their free enterprise economy, which allows residents to own small businesses.

7. Summary and Conclusions

The community Colonial Puebla is located in the outskirts of the main city area. Residents there are in short of reliable transportation system that can help them travel between their homes and the city center or bus stops. Considering the lack of rickshaw-like vehicles and configuration in today's market, the design team believes that this can be a desired concept in rural areas such as Colonia Puebla. Because of the need for more available transportation, the design team hopes to alleviate some living pressure that caused by lack of transportation system for those residents. After filtering design choices and reviewing key components to subsystems, it is believed that the product specification will produce enough sufficient proof of concept as a prototype. In summary, the aluminum bike attachment will be able to transport at least two people. The trailer hitch will allow users to connect this bike attachment to any kinds of bicycles, even motorcycles. The suspension system will cushion the bumpiness and make the residents have a more comfortable ride. Based on test results, the bike attachment was able to hold at least 225 lb without deflection and design team members could easily ride the bicycle when fully loaded. Since electricity shortage is also a big problem for Puebla residents, the design team also hopes prospective mechanical engineering students can keep working on this project and add electrical components such as solar panel, motor and battery to the bike attachment to assist those residents by using the power stored in battery to charge small electric household appliances.

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Appendix

A.1. Calculations

A.1.1. Hand Calculations

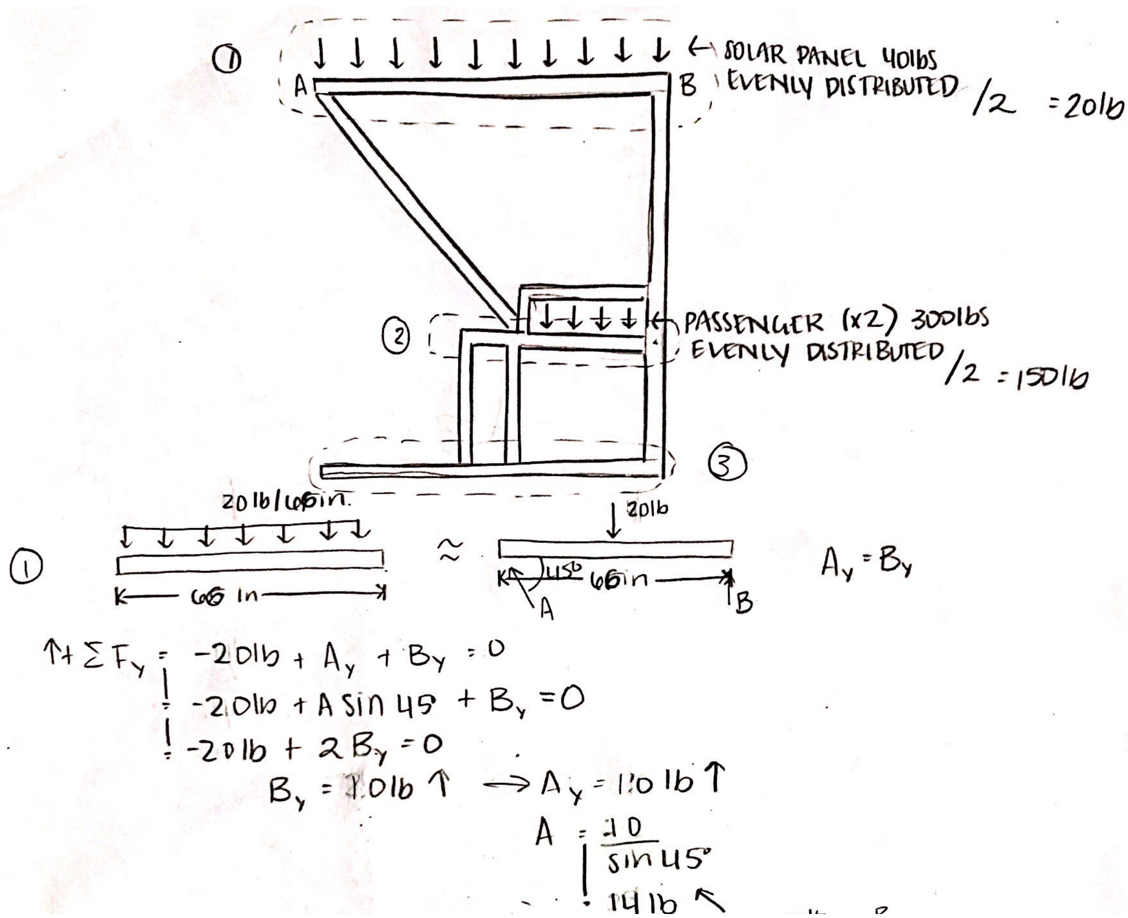


Figure A1. Static analysis calculation part 1.

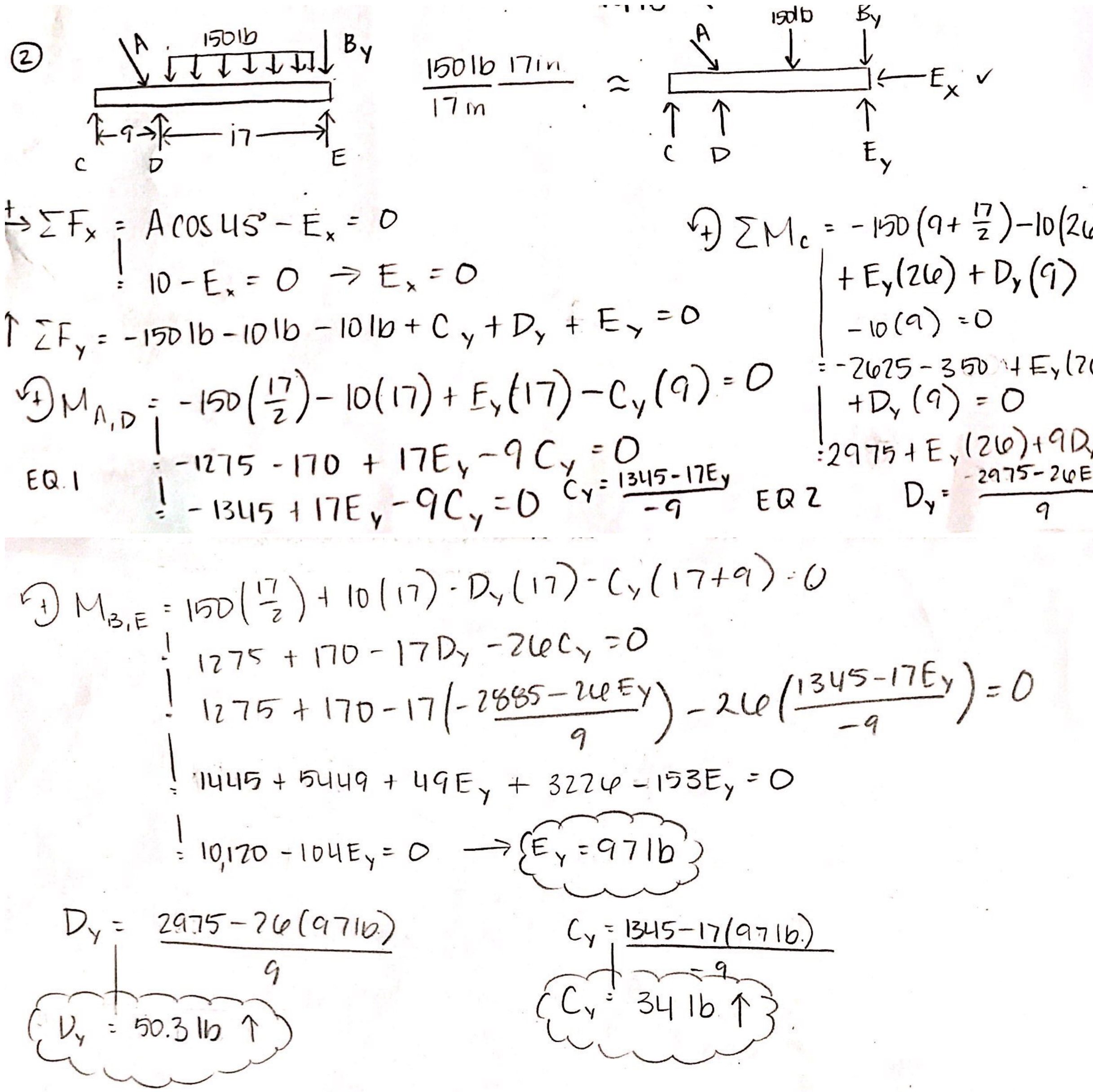


Figure A2. Calculation part 2.

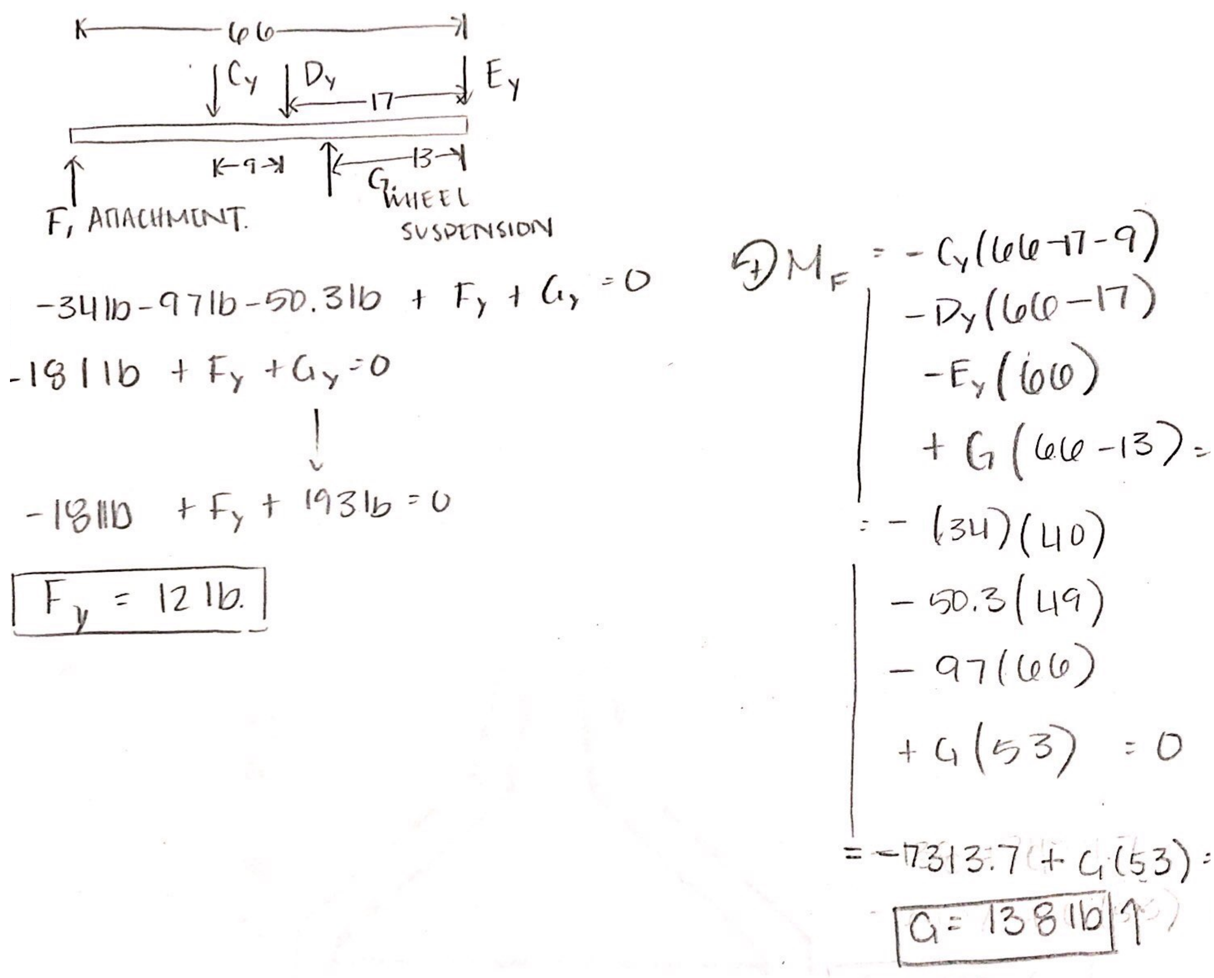


Figure A3. Calculation Part 3.

A.2. Detailed Drawings

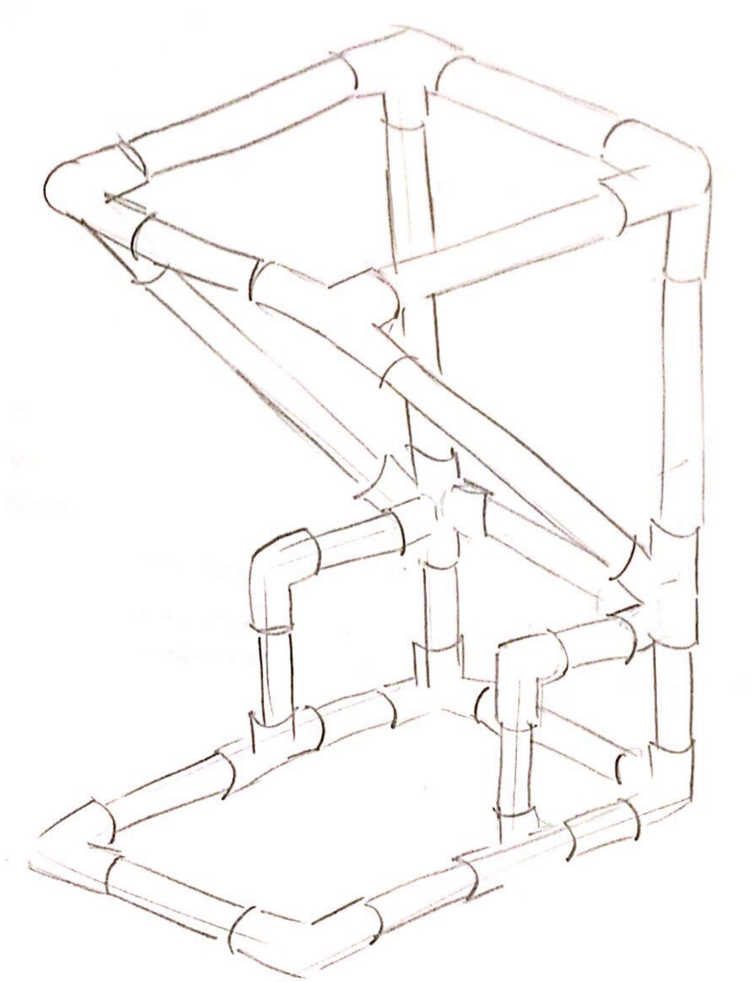


Figure A4. PVC option for frame material by Alesis Gonsalves.

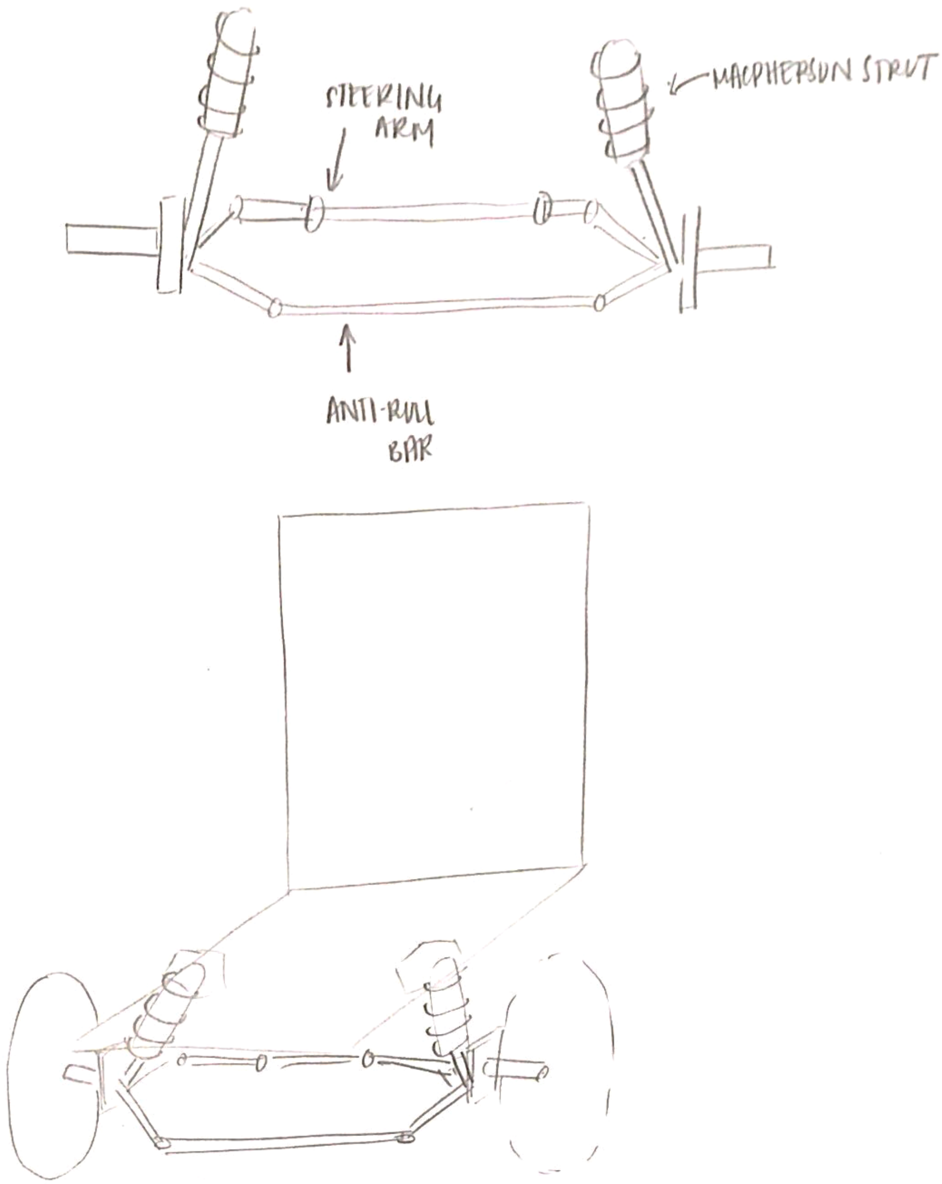
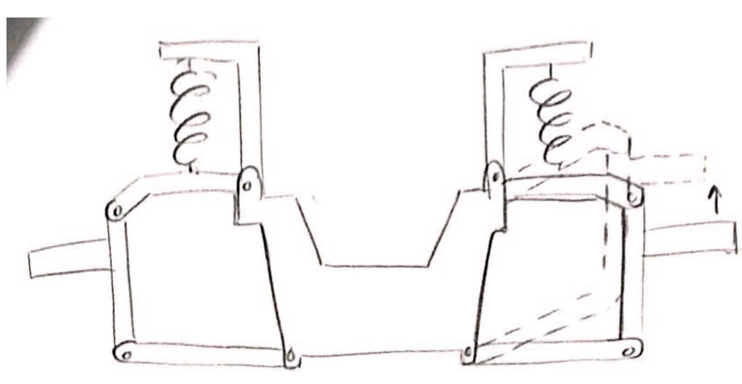


Figure A5. MacPherson strut option for suspension by Alesis Gonsalves.



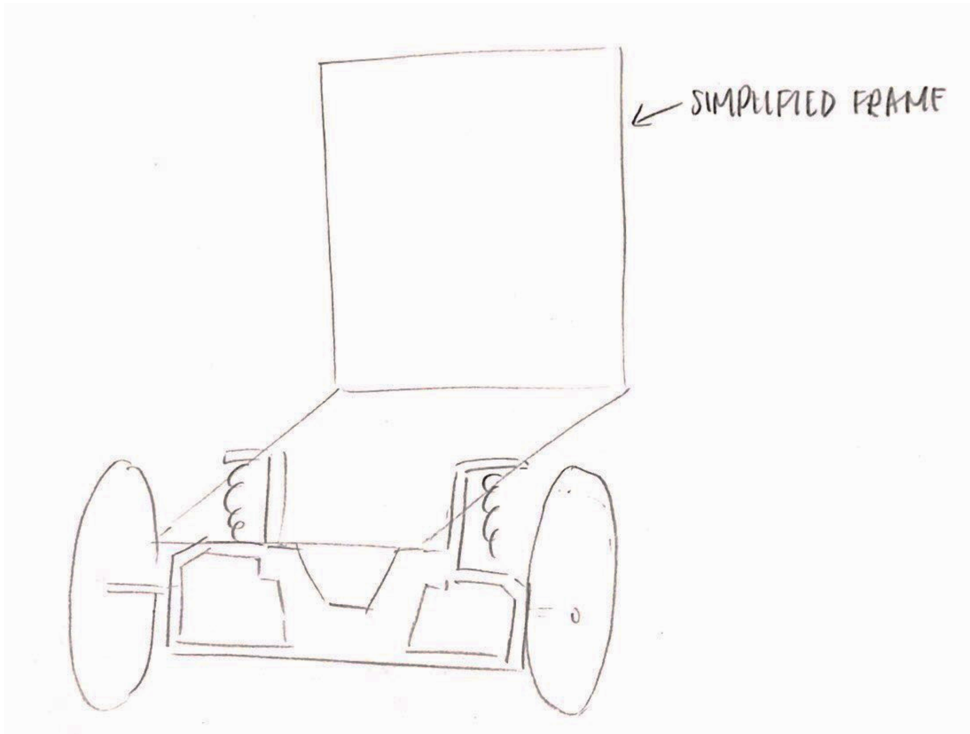


Figure A6. Independent option for suspension by Alesis Gonsalves.

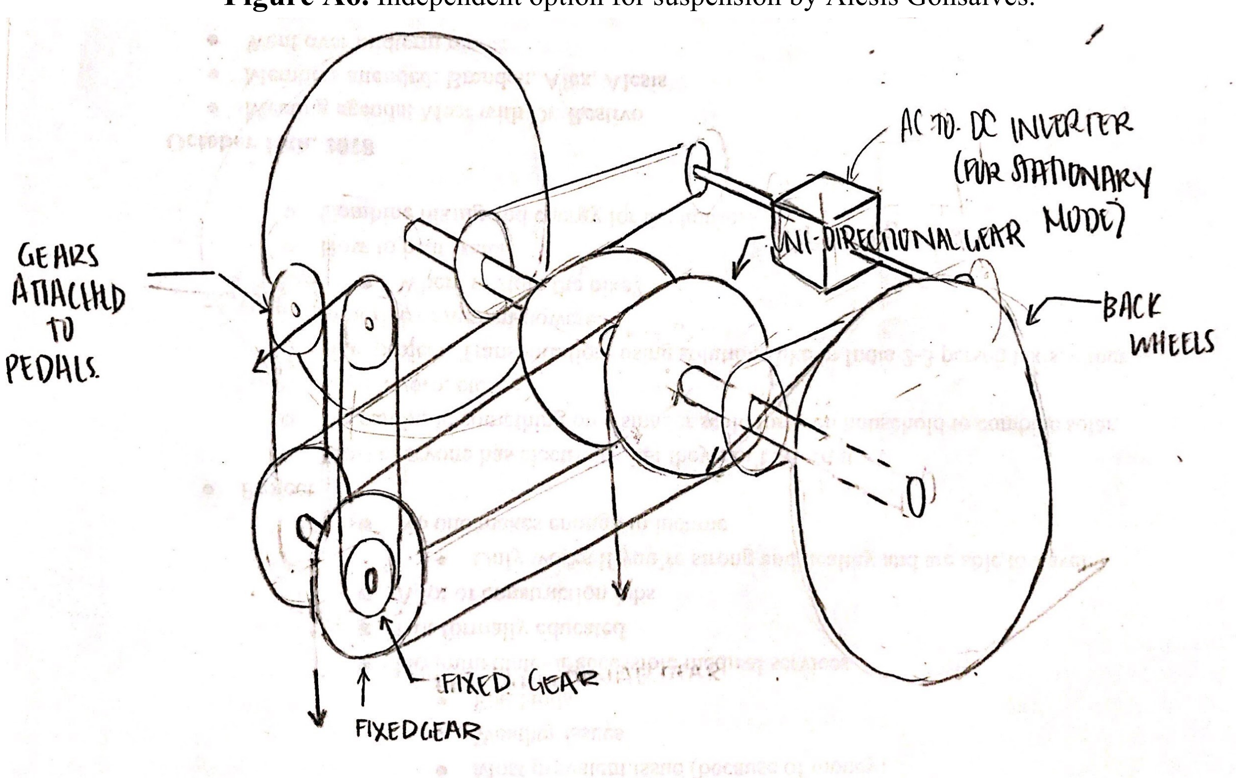


Figure A7. Isometric view of drive train by Alesis Gonsalves

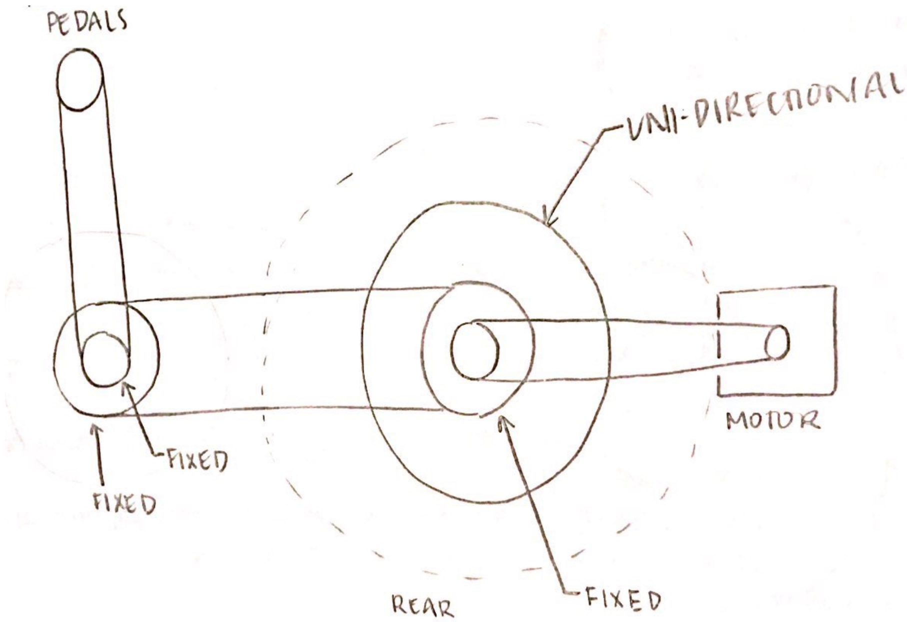


Figure A8. Right side view of drive view by Alesis Gonsalves

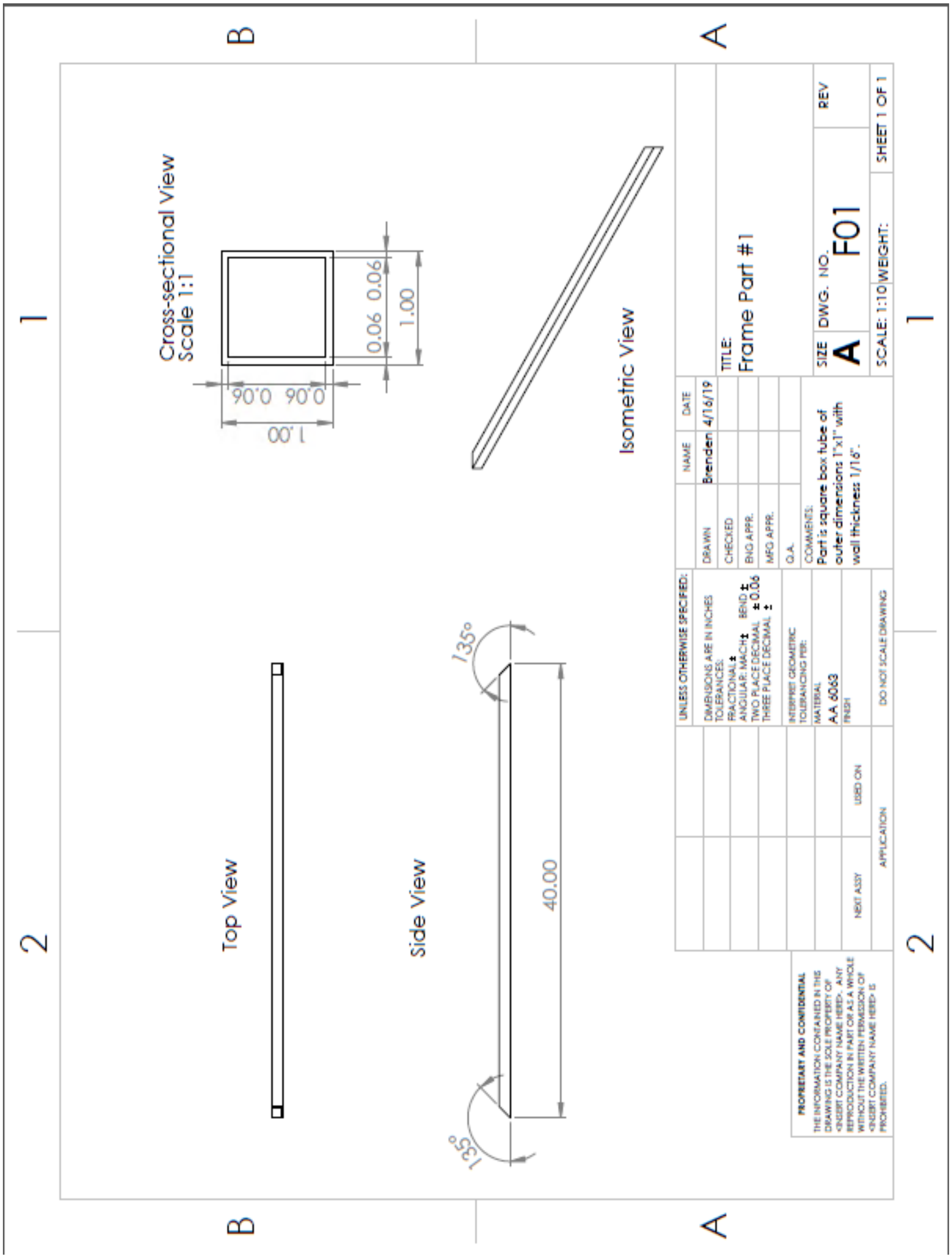


Figure A9. Part drawing for frame section

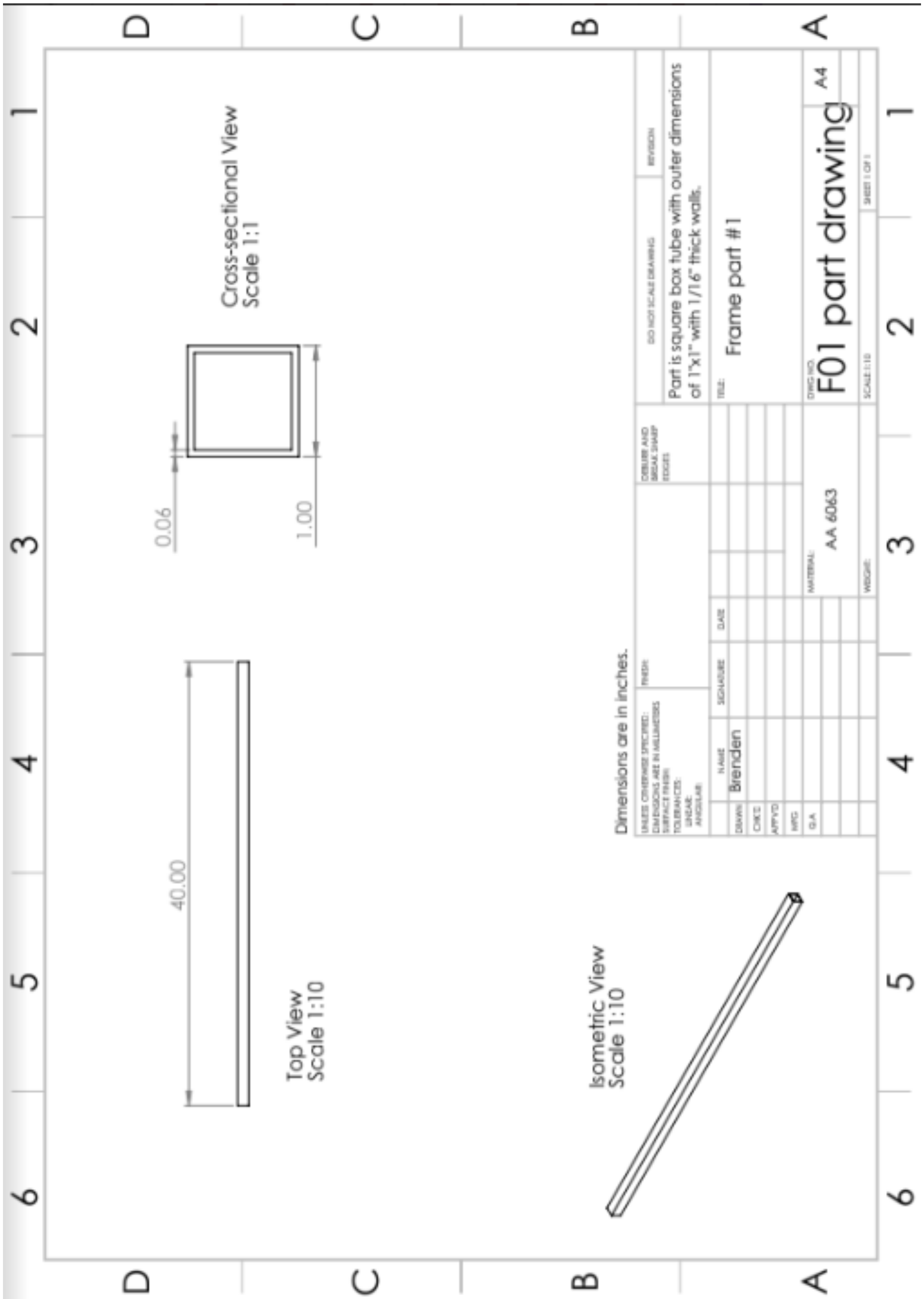


Figure A10. Part drawing for frame section

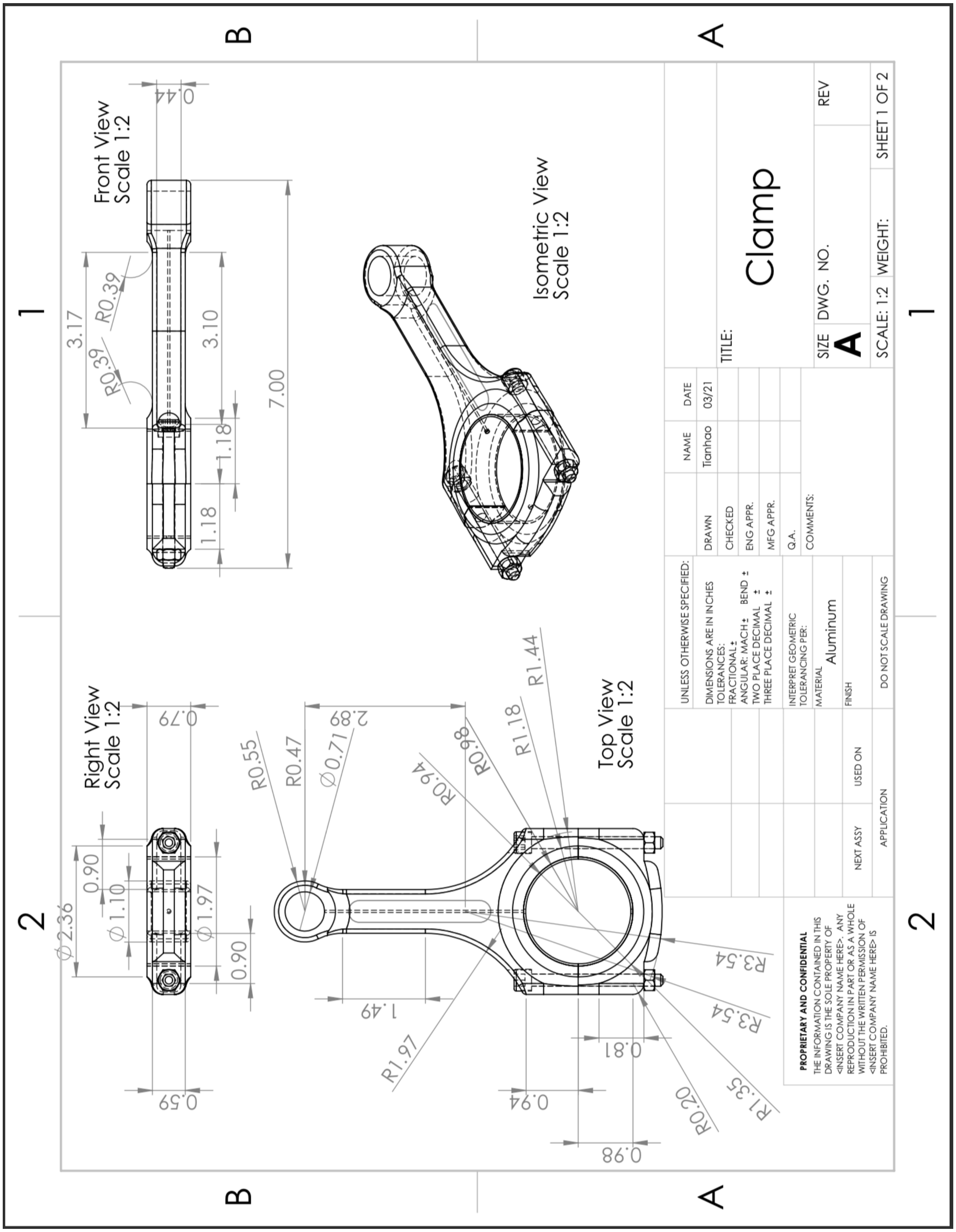


Figure A11. Part drawing for clamp

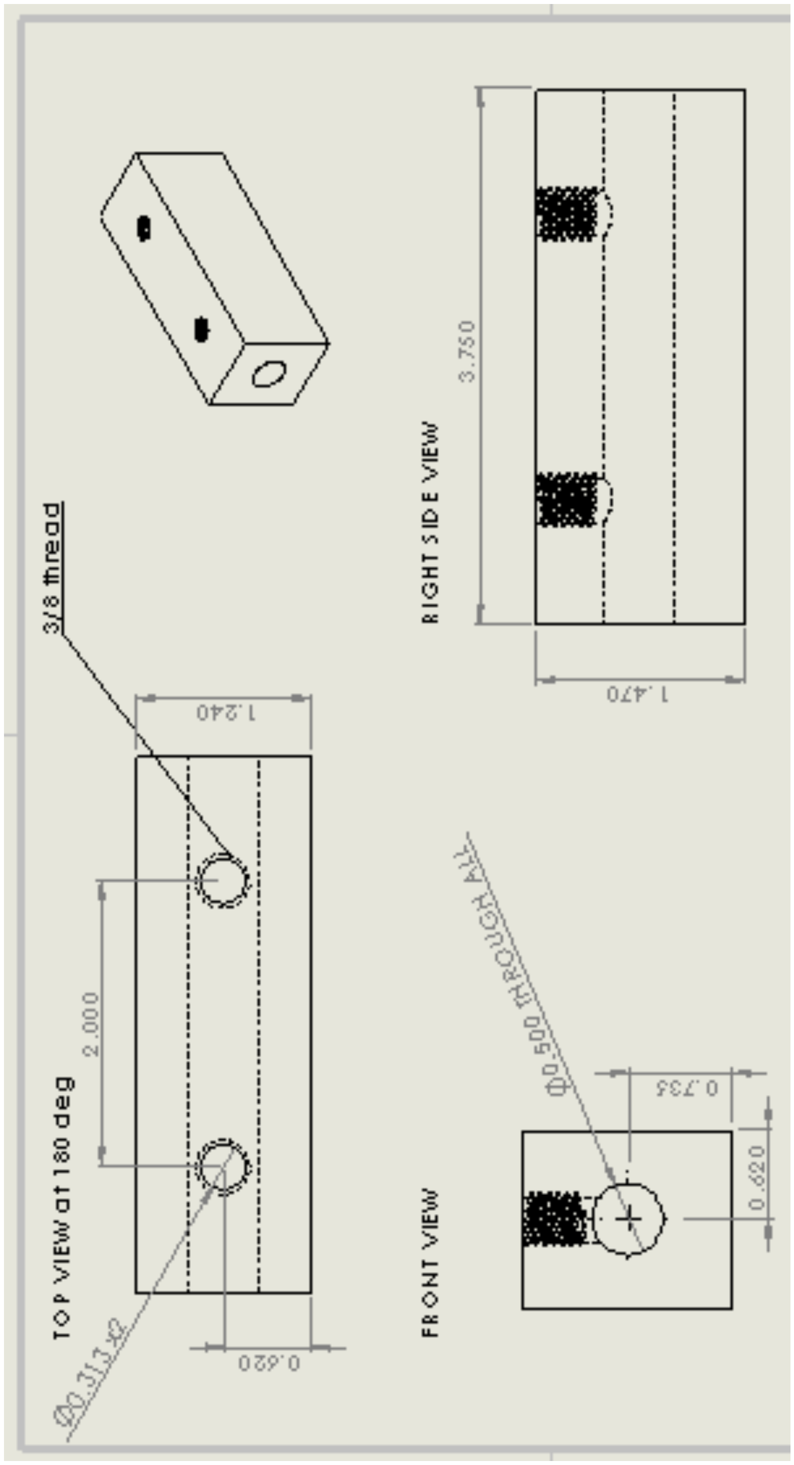


Figure A12. Drawing of machined block for axle.

A.5. QFD

A.5.1. English Survey

This survey is aimed to understand the needs and lifestyle of a person living in the communities of Puebla, Mexico. Only answer questions you feel comfortable giving responses to. Any answers provided would be greatly appreciated, and would assist in developing a senior design project conducted by mechanical engineering students at Santa Clara University.

1. What is your age?
2. What is your employment status? Full-time, Part-time, Unemployed, Student
3. What is your approximate annual income?
4. How far do you have to travel to get to work/school?
5. How far do you have to travel to get to the nearest hospital?
6. What means of transportation do you use? Check all that apply. Car Bus Taxi Uber/Lyft Motorcycle Motorized scooter or bicycle Bicycle Walk Other:
7. Do you own a car? Mark only one oval. Yes No
8. Do you own a bicycle? Mark only one oval. Yes No
9. Approximately how much do you spend on transportation costs annually?
10. What electronics do you own? Check all that apply. Refrigerator Electric oven Electric stove Microwave Toaster TV Fan Desktop computer/laptop Other:
11. What electronics in your home are most important to you? Check all that apply. Refrigerator Electric oven Electric stove Microwave Toaster TV Fan Desktop computer/laptop Other:
12. If electricity wasn't an issue, what electronics would you have?
13. Do you use a natural gas or wood stove to cook? Mark only one oval. Natural gas Wood Both natural gas and wood Other:
14. How many people are in your household?
15. Approximately how much do you spend on electricity annually?
16. Approximately how much energy do you use daily?
17. What do you use the most energy for on a daily basis?
18. What are the most pressing issues you face day-to-day?
19. What would be more beneficial to you, more electricity or more accessible transportation? Mark only one oval. More electricity More accessible transportation
20. If money were not an issue, what would improve your community the most?

A.5.2. Spanish Survey

Esta encuesta tiene como objetivo comprender las necesidades y el estilo de vida de una persona que vive en las comunidades de Puebla, México. Solo contesta preguntas a las que te sientas cómodo dando respuestas. Cualquier respuesta proporcionada sería muy apreciada y ayudaría a desarrollar un proyecto de diseño para personas de la tercera edad dirigido por estudiantes de ingeniería mecánica en la Universidad de Santa Clara.

1. ¿Cuántos años tiene usted?
2. ¿Cuál es su situación laboral? Mark only one oval. Tiempo completo Medio tiempo Desempleado Estudiante
3. ¿Cuál es su ingreso anual aproximado?
4. ¿Qué tan lejos tiene usted que viajar para ir al trabajo / escuela?
5. ¿Qué tan lejos tiene usted que viajar para llegar al hospital más cercano?
6. ¿Qué medio de transporte utiliza usted? Check all that apply. Coche Autobús Taxi Uber/Lyft Motocicleta Scooter motorizado Bicicleta Caminar Other:
7. ¿Tiene usted un coche? Mark only one oval. Sí No
8. ¿Tiene usted una bicicleta? Mark only one oval. Sí No
9. ¿Aproximadamente cuánto gasta usted anualmente en costos de transporte?
10. ¿Qué electrónica tiene usted? Check all that apply. Refrigerador Horno eléctrico Estufa eléctrico Microonda Tostadora Televisión Ventilador Computadora de escritorio/ ordenador portátil Other:
11. ¿Qué aparatos electrónicos en su hogar son los más importantes para usted? Check all that apply. Refrigerador Horno eléctrico Estufa eléctrico Microonda Tostadora Televisión Ventilador Computadora de escritorio/ ordenador portátil Other:
12. Si la electricidad no fuera un problema, ¿qué electrónica tendría usted?
13. ¿Utiliza usted una estufa de leña o gas natural para cocinar? Mark only one oval. Gas natural Madera Tanto gas natural como madera. Other:
14. ¿Cuántas personas hay en su casa?
15. ¿Aproximadamente cuánto gasta usted anualmente en electricidad?
16. Aproximadamente, ¿cuánta energía usa usted diariamente?
17. ¿Para qué utiliza usted más energía a diario?
18. ¿Cuáles son los problemas más apremiantes que enfrenta usted día a día?
19. ¿Qué sería más beneficioso para usted, más electricidad o transporte más accesible? Mark only one oval. Más electricidad Transporte más accesible
20. Si el dinero no fuera un problema, ¿qué mejoraría más a su comunidad?

A.5.3. Survey Results

Age	Employment	Monthly income (peso)	montly income (dollar)	Distance to work/school	Distance to nearest hospital	Methods of travel	Owns car	Owns bike	Monthly transportation costs (pesos)	Electronics in home
38	full time	2400	117.6	works at home	20 min	bus	no	no	50	stove, tv, washing machine
57	full time	does not know		works at home	30 min	bus	no	no	0	fridge, microwave, tv, other, stove
56	full time	5000	245	works at home	35 min	bus	no	no	100	fridge, oven, stove, microwave, tv
24	unemployed	X		X	X	bus	no	yes	400	stove, tv
38	part time	15,000	735	walking	20 min	bus	yes	no	200 personal, 325 family	fridge, oven, stove, microwave, tv, computer
19	unemployed	X		X	15-20 min	bus	no	yes	15	fridge, stove, tv, computer
30	unemployed	X		15 min	1 hour	bus	no	no	50	fridge, stove, tv
38	full time	5000	245	30 min	45 min	bus	no	no	500	fridge, oven, tv, computer
19	unemployed	X		X	15-20 min	bus	no	yes	48	fridge, stove, tv, computer
35	full time	4000	196	30 min walk	35-40 min walk	bike, walk	no	yes	0	fridge, oven, microwave, tv
58	part time	2400	117.6	2 streets	30 min (walk?)	bus	no	no	96	stove, tv, blender
33	full time	6000	294	10 min walk	X	bike, walk	no	yes	0	fridge, tv
33	part time	2000	98	around the colony (alrededor de la colonia)	40 min (walk?)	bus, walk	no	no	200	fridge, microwave, tv, blender
75	Pension	X		X	40 min	taxi, walk	no	no	1000	fridge, microwave, tv, fan, blender, stove
56	part time	X		15 min, car	5-7 min, car	car, taxi, uber	yes	no	6000	fridge, oven, microwave, toaster, tv, fan, computer
20	part time	2000	98	1 street	30 min, bus	bus, bike, walk	no	yes	120	fridge, oven, stove, microwave, tv, computer
53	full time	X		X	30 min	bus	no	no	200	fridge, tv
45	full time	4000	196	1 street	20 min, car	car, bus	yes	no	800	fridge, oven, stove, toaster, tv
28	full time	600	29.4	30 min walk	45 min	bus, taxi, bike, walk	no	yes	160	tv, fridge
54	part time	X		30 min walk	20 min walk	bike, walk	no	yes	0	tv
49	full time	X		X	30 min, bus	bus, taxi	no	no	80-100	fridge, microwave, tv
59	full time	X		X	30 min - camio'n	bus, walk	no	no	very little	fridge, tv
29	part time	4000	196	5 min walk	25 min	bus	no	no	500	fridge, stove, tv, stereo
"many"	full time	2000	98	10 min	30 min	car	yes	no	1000	fridge, tv, computer
25	part time	2000	98	10 min	30 min	bus	no	no	200	fridge, tv
			low 29.4			19/25 bus	4/25 yes	8/25 yes		
			high 735			5/25 bike				
						8/25 walk				

Age	Most important electronics	Electric item - electricity not a problem	Cooking fuel	Household size	Electric bill for 2 months	Electricity or transportation	What uses the most energy daily	Daily issues	What benefit community without money an issue
38	washing machine	dryer, fan	gas	4	$220-250	transportation	work machinery (esthetic?)	dogs, insecurity	clean the streets, recycling
57	fridge, stove, other	X	gas	3	300	electricity	fridge	insecurity	fix the streets
56	fridge, stove, fan	X	gas	2	650-800	electricity	fridge	insecurity	drainage and drinking water, pavement
24	stove	X	gas	2	100	transportation	tv	travelling in transport	pave the streets
38	stove, washing machine	X	gas and wood	6	280	transportation	fridge, washing machine	X	give work, youth courses
19	fridge, stove, tv	fan	gas	4	150	electricity	fridge, stove	X	pave streets, light, trash cans
30	fridge, stove	X	gas	5	200	transportation	fridge	light	pave the streets
38	fridge, computer	X	gas	3	250 or less	transportation	fridge	transportation, insecurity	recreation and sport areas
19	fridge, stove, tv	microwave	gas	4	120-150	transportation	fridge, stove	que no pasa seguido la basura y hacen tiradero los perros	streets, more garbage containers
35	fridge, stove, tv	loudspeakers?	gas	6	150-180	transportation	fridge	transportation, no RUTA cards	agua
58	stove, tv, blender	fridge, oven	gas	4	120	transportation	blender	streets	pavement
33	fridge, tv	loudspeakers?	gas	3	200-250	electricity	stereo	streets in the rain	streets (pavement?)
33	fridge, blender	X	gas	2	220	transportation	fridge, lights	dogs, trash	pavement
75	fridge, stove	X	gas	3	220	electricity	lights	diseases	streets, dogs, trash, education
56	computer	large tv	gas	3	1600	transportation	computer	people	education
20	fridge, stove	X	gas	3	150	transportation	fridge, tv	streets	streets (pavement?)
53	tv	X	gas	4	200	electricity	stereo, tv	dogs, trash	pavement
45	stove	heater	gas	3	80	transportation	fridge	dogs and trash	pavement
28	fridge	fridge	gas	4	150	transportation	lights	insecurity	the insecurity
54	tv	X	gas	3	250	transportation	TV	water	to pave, pavement
49	fridge, microwave, tv	heater	gas	2	350	transportation	tv	streets, insecurity	pavement
59	fridge	X	gas	5	450-500	transportation	fridge	dogs	pavement
29	tv, stereo	X	gas	5	320	transportation (when it rains)	X	X	expand water and drainage networks, more security, pavement
"many"	fridge, tv, computer	tv	gas	4	250	transportation	tv, fridge	potholes	pavement
25	fridge, tv	fridge	gas	4	400	transportation	tv	none	pavement, water, collect trash
	16/25 fridge					6/25 electricity	13/25 fridge	6/25 insecurity	19/25 pavement
	12/25 stove					19/25 transportation	7/25 tv	3/25 transportation	
							2/25 stove	6/25 dogs	

Figure A13. Survey Results for Valle de Paraiso.

A.6. Concept Matrices

A.6.1. Frame

Design Project = Bicycle Attachment | System= Frame | Date= 6-Nov-18

CRITERIA	TARGET or FACTOR	1 = Baseline		One passenger - Aluminum		Two passenger - Aluminum		One passenger - PVC		Two passenger - PVC		One passenger - Wood		Two passenger - Wood	
						DESIGN IDEAS									
Time – Design	10	10		1		1		2		3		3		4	
Time – Build	40	40													
Time – Test	20	20		20		20		20		20		20		20	
Time weighting	20		20		7.33		7.33		8.00		8.67		8.67		9.33
Cost – Prototype	$ 1,000.00	$ 1,000.0													
Cost – Production	$ 1,000.00	$ 1,000.0		$250.00		$ 350.00		$ 250.00		$ 350.00					
Cost weighting	25		25		3.13		4.38		3.13		4.38		0.00		0.00
Weight	10	3	30	4	40	3	30	4	40	3	30	5	50	4	40
Compactness	3	3	9	4	12	3	9	2	6	1	3	3	9	3	9
Stiffness	8	3	24	3	24	3	24	2	16	2	16	1	8	1	8
Yield strength	12	3	36	3	36	3	36	2	24	2	24	2	24	2	24
Tensile strength	7	3	21	3	21	3	21	2	14	1	7	2	14	2	14
Critical buckling load	15	3	45	4	60	3	45	2	30	1	15	2	30	2	30
		3	0		0		0				0		0		0
		3	0		0		0				0		0		0
		3	0		0		0				0		0		0
		3	0		0		0				0		0		0
		3	0		0		0				0		0		0
		3	0		0		0				0		0		0
	TOTAL		165.0		227.5		198.3		163.9		127.0		171.3		160.7
	RANK														
	% MAX		72.5%		100.0%		87.1%		72.0%		55.8%		75.3%		70.6%
	MAX	227.5													

Figure A14. Concept matrix for the frame subsystem.

A.6.2. Suspension

Design Project = Bicycle Attachment | System= Suspension | Date= 8-Nov-16

CRITERIA	TARGET or FACTOR	1 = Baseline		Leaf Spring		Independent Suspension		MacPherson Strut		Air Suspension		Multi-Link Suspension		MagneRide Suspension	
						DESIGN IDEAS									
Time – Design	1	1													
Time – Build	1	1													
Time – Test	1	1													
Time weighting	15		15		0.00		0.00		0.00		0.00		0.00		0.00
Cost – Prototype	$ 400.00	$400.00		$400.00		$ 4,000.		$ 400.00		$ 1,000.		$ 700.00		$ 2,000.	
Cost – Production	$ 1.00	$ 1.00													
Cost weighting	14		14		7.00		70.00		7.00		17.50		12.25		35.00
Weight	12	3	36	2	24	4	48	3	36	3	36	3	36	3	36
Comfortability	7	3	21	3	21	4	28	3	21	4	28	2	14	5	35
Durability	11	3	33	5	55	2	4	3	4	2	22	3	33	3	33
Weather proof	11	3	33	3	33	2	22	3	33	2	22	3	33	3	33
Stability	10	3	30	4	40	4	5	3	5	3	30	2	20	4	40
Handling	6	3	18	4	24	4	5	3	5	3	18	2	12	4	24
Simplicity	9	3	27	5	45	2	18	3	27	5	45	4	36	4	36
Adjustability	5	3	15	2	10	2	10	3	15	4	20	2	10	5	25
			0		0		0				0		0		0
			0		0		0				0		0		0
			0		0		0				0		0		0
			0		0		0				0		0		0
	TOTAL		213.0		274.0		99.0		168.0		232.5		210.8		256.0
	RANK														
	% MAX		77.7%		100.0%		36.1%		61.3%		84.9%		76.9%		93.4%
	MAX	274.0													

Figure A15. Concept matrix for the suspension subsystem.

A.6.3. Drivetrain

Design Project = Bicycle Attachment | System= Drivetrain | Date= 7-Nov-18

	TARGET or	DESIGN IDEAS									
CRITERIA	FACTOR	1 = Baseline		AWD		FWD		RWD		3WD (4WD)	
Time – Design	1	1									
Time – Build	1	1									
Time – Test	1	1									
Time weighting	15		15		0.00		0.00		0.00		0.00
Cost – Prototype	$ 1.00	$ 1.00									
Cost – Production	$ 1.00	$ 1.00									
Cost weighting	14		14		0.00		0.00		0.00		0.00
Weight	13	3	39	2	26	3	39	3	39	2	26
Braking	10	3	30	3	30	3	30	3	30	3	30
Size	6	3	18	2	12	3	18	3	18	2	12
Handling	9	3	27	4	36	3	27	3	27	5	45
Stability	9	3	27	4	36	5	45	3	27	5	45
Durability	12	3	36	3	36	3	36	3	36	3	36
Weather proof	12	3	36	5	60	4	48	3	36	4	48
		3	0		0		0		0		0
		3	0		0		0		0		0
		3	0		0		0		0		0
		3	0		0		0		0		0
		3	0		0		0		0		0
	TOTAL		213.0		265.0		272.0		242.0		271.0
	RANK										
	% MAX		78.3%		97.4%		100.0%		89.0%		99.6%
	MAX	272.0									

Figure A16. Concept matrix for the drivetrain subsystem.

A.6.4. Solar Panels

Design Project = Bicycle Attachment | System= Solar Panels | Date= 7-Nov-18

	TARGET or	DESIGN IDEAS											
CRITERIA	FACTOR	1 = Baseline		Goal Zero Nomad 14 Plus		Biolite Solar Panels 10+		Nekteck 21W Solar Charger		X-DRAGON Solar Charger, 20000 mAh Solar Power Bank		Sunjack 14W +10000mAh QC 3.0 Power Bank	
Time – Design	1	1											
Time – Build	1	1											
Time – Test	1	1											
Time weighting	15		15		0.00		0.00		0.00		0.00		0.00
Cost – Prototype	$ 50.00	$ 50.00		$150.00		$ 160.00		$50.00		$40.00		$90.00	
Cost – Production	$ 50.00	$ 50.00		$150.00		$ 160.00		$50.00		$40.00		$90.00	
Cost weighting	15		15		45.00		48.00		15.00		12.00		27.00
Weight	5	3	15	4	20	4	20	3	15	2	10	4	20
Durability	10	3	30	2	20	2	20	3	30	4	40	3	30
Size	5	3	15	4	20	4	20	3	15	2	10	4	20
Energy Generation	13	3	39	3	39	2	26	3	39	2	26	2	26
Electrical Hardware	10	3	30	2	20	3	30	3	30	4	40	2	20
Efficiency	10	3	30	5	50	5	50	3	30	3	30	4	40
Functionality	10	3	30	4	40	4	40	3	30	3	30	3	30
Portability	7	3	21	4	28	4	28	3	21	2	14	4	28
			0		0		0		0		0		0
			0		0		0	3	0		0		0
			0		0		0	3	0		0		0
			0		0		0	3	0		0		0
	TOTAL		210.0		222.0		216.0		225.0		218.0		217.0
	RANK												
	% MAX		93.3%		98.7%		96.0%		100.0%		96.9%		96.4%
	MAX	225.0											

Figure A17. Concept matrix for the eliminated solar panel subsystem.

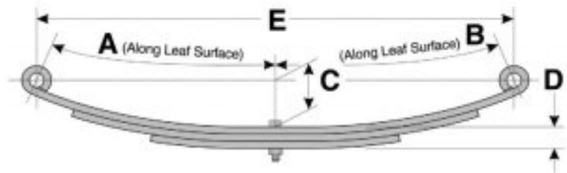
	Design Project =	Bicycle Attachment				System=	Motor			
		TARGET or	DESIGN IDEAS							
	CRITERIA	FACTOR	1 = Baseline		(EMP) 48V 750 W		Ebike		48V 1000W	
(hours)	Time – Design	1	1							
(hours)	Time – Build	1	1							
(hours)	Time – Test	1	1							
	Time weighting	15		15		0.00		0.00		0.00
(dollars)	Cost – Prototype	$ 50.00	$ 50.00		$650.00		$ 270.00		$ 750.00	
(dollars)	Cost – Production	$ 50.00	$ 50.00		$650.00		$ 270.00		$ 750.00	
	Cost weighting	15		15		195.00		81.00		225.00
	Weight	5	3	15	4	20	4	20	3	15
	Durability	10	3	30	4	40	2	20	2	20
	Size	5	3	15	3	15	4	20	2	10
	Efficiency	13	3	39	4	52	2	26	3	39
	Price	5	3	15	2	10	4	20	4	20
				0		0		0		0
				0		0		0		0
				0		0		0		0
				0		0		0		0
				0		0		0	3	0
				0		0		0	3	0
				0		0		0	3	0
		TOTAL		114.0		-28.0		55.0		-91.0
		RANK								
		% MAX		91.9%		-22.6%		44.4%		-73.4%

Figure A18. Concept matrix for the eliminated motor subsystem.

US-1004 Trailer Leaf Spring

Model: US-1004

by Dayton Parts



larger image

Eye/Eye Utility and Boat Trailer Springs										
Part No.	Width	Dim. A	Dim. B	Dim. C	Dim. D	Dim. E	Bushing	Leaves	Grading	Capacity
US-1004	1 3/4	10	10	3	0.97	18 3/8	9/16"	3	3/323	1,600

Figure A19. Specifications for leaf spring suspension.[21]

A7. Senior Design Presentation Conference Slides

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BiciTaxi:

Transportation Accessibility for Puebla, MX

Sean Flanagan
Alesis Gonsalves
Tianhao Jiang
Brenden Stone

May 9th, 2019

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Overview

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SANTA CLARA UNIVERSITY

Background: Frugal Innovation Hub

- Allan Baez-Morales
  - Facilitator
  - Translator
- Universidad Iberoamericana Puebla
  - Communicator
  - Connection to the community
  - Frugal Innovation

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Background: Valle de Paraíso

- Lack of public transportation

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The Design Requirements

- Transportation
- Frugal
- Manufacturability
- Weatherproof
- Synergy with available transportation solutions
- Sustainable

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Design Decisions

- Surrey Bicycles
  - Multiple Individuals can power the bicycle simultaneously
  - Price ranges from 2000 - 5000 USD
  - Drivetrain
    - Mechanical Power

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Design Decisions

Soleckshaw

- Advanced version of rickshaw
- Ride farther and faster with less effort
- Parts get stolen easily
- Ultimately failed in India
  - Lack of maintenance

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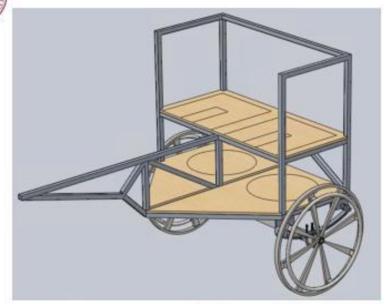

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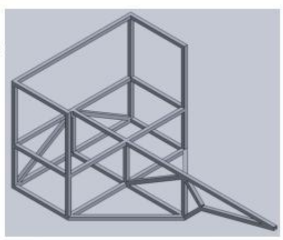
Subsystems: Frame

- Square Box Tube
  - Aluminum Alloy 6063-T52
  - 1" with 1/16" walls
- Welded Connections



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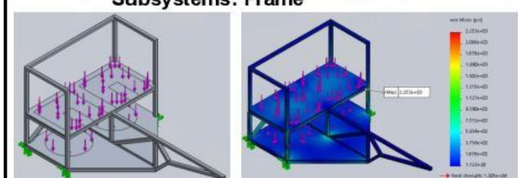
Subsystems: Frame



- Maximum load of 550 lb (250 kg)
- Produces maximum stress of 2,250 psi (17% of yield strength)

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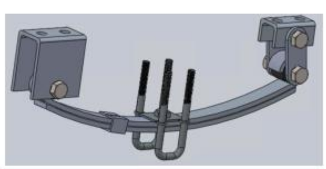
Subsystem: Suspension

- Leaf Spring
  - Frugal
  - Simple
- Number of leaves
- Extent of complexity
- $120 USD in the US
  - Half that price in Mexico



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Subsystem: Suspension

$$\sigma_{max} = \frac{pFL}{Nb_N h^2}$$

$\sigma_{max} = 371\ ksi\ or\ 2.56\ GPa$

$\sigma_{act} = 146\ ksi\ or\ 1.01\ GPa$

$\sigma_{imp} = 292\ ksi\ or\ 2.02\ GPa$

$SF = 1.26$

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Subsystem: Suspension
Axle
Ease of Manufacturing
Critical Point
Replaceable
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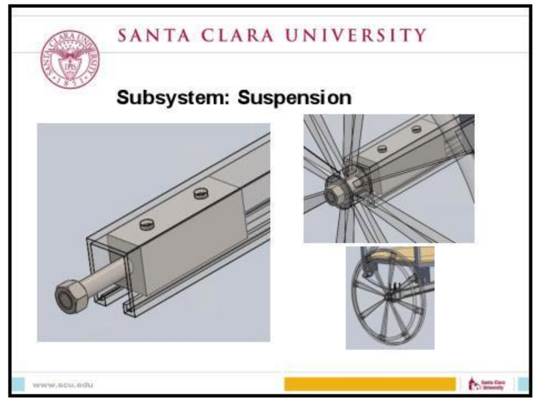
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Subsystem: Suspension
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Subsystem: Suspension
Wheels
Wheelchair
Comes with bearings
Max yield stress 35.15 ksi
Bicycle wheels
Fitted with bearings
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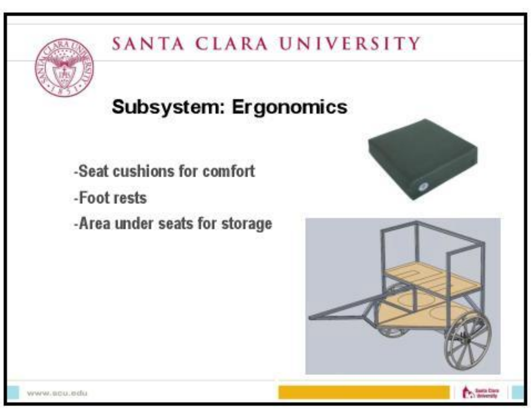
Subsystem: Trailer Hitch
Clamp & Trail-Gator Tow Bar
Aluminum
Tensile Strength
Swivel
2 degrees of freedom
www.scu.edu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Subsystem: Ergonomics
-Seat cushions for comfort
-Foot rests
-Area under seats for storage
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Solar panels
Electrical Motors
Drivetrain
PEDAL POWER GENERATOR
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Community

- Universidad Iberoamericana Puebla
  - Casa Ibero in Valle de Paraiso
  - Q&A Panel with community
- Prototype
  - First iteration
  - Learning experience
  - Second iteration in the works

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Future Endeavors

- Business Model
- Secure Electronic Components
  - Solar Panel
  - Motor
- Brakes
- Covering
  - Above and around
  - Mud shield

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Experimental Procedure

- Prototype in Mexico
  - Proof of concept
- Future testing
  - Static loading
  - Average speed
    - Empty
    - Fully laden
  - Impact loading
    - Not safe with amount of weight

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Conclusion

- Combination of rickshaw and trailer
  - Fitted to bicycle
  - Holds two people and cargo
  - Duplicable
  - $225 USD compared to $1,500 USD
- 1st Iteration of prototype is in Mexico
- 2nd Iteration of prototype in the works
  - Shorter
  - Wheelchair wheels

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  - International Academic Affairs
- Musi Lopez Molina
  - Technological Innovation and Development

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Thank you!
Questions?

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