Material Transport System for Farmers on Ile-a-Vache

Engineering Design I

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EDEM Foundation - Material Transport System

Improve the material-carrying capacity of motorcycles on the island of Ile-a-Vache

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Patrick Lucien	EDEM Foundation (www.edem2.org)

Background. The U.S. Naval Academy is working to develop a cooperative partnership with the community of Ile-a-Vache, a small island, approximately eight miles long and three miles wide, located just off the southwest coast of Haiti (Figure 1.1).

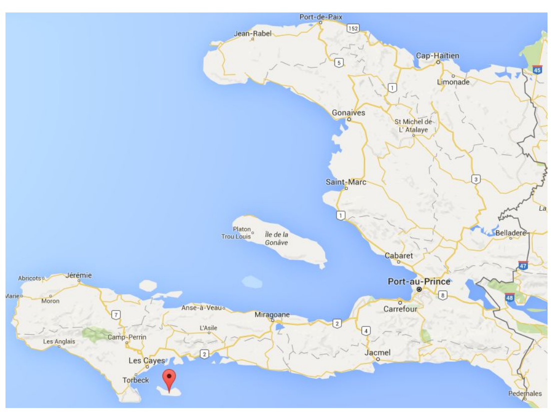

Figure 1.1: The location of Ile-a-Vache, Haiti (marked with the red indicator).[1]

[1] Google Maps

Until very recently, there were only a handful of motorized vehicles on the island. The last three to five years have seen a significant increase in the number of motorcycles on the island. These motorcycles are used to carry people and small items over the dusty, sometimes uneven roads of the island (Figure 1.2). Larger items are shipped by boat to the nearest beach and carried on foot or motorcycle to their destination.

Figure 1.2: An example of motorcycle taxi services on Ile-a-Vache.[2]

Objectives. The goal of this project is to design a system that can increase the carrying capacity of local motorcycles while maintaining maneuverability, to the extent possible.

Designs must be compatible with a variety of motorcycle makes and models, made from inexpensive, locally-available materials, and safe for use by the motorcycle drivers. The system must not significantly hinder the driver's ability to navigate the paths and trails of the island.

[2] Photo by LCDR Lust

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1 Problem Definition and Need Identification

1.1 Customer's Problem Statement

The problem statement initially communicated from the project description was:

Improve the material-carrying capacity of motorcycles on the island of Ile-a-Vache.

1.2 What is the problem? What about the current situation is unsatisfactory?

There is an opportunity to make a positive impact on the lives of the people of Ile-a-Vache, Haiti. The people who live on the island primarily depend on subsistence agriculture and use the surplus as trade with the local market. But recent environmental influences, from the Earthquake in 2010, to the effects of El Nino, have created a massive food shortage reaching the entire island. The inhabitants depend on trade to and from a market in the town of Madame Bernard, located on the northern coast on the island, but the challenge is transporting crops from farm to the market while maintaining their value.

In an effort to address local food insecurity, the EDEM Foundation has set up a farm on Ile-a-Vache, Haiti. Some of the produce is used for subsistence on the island, while some of it is sold as a source of income. The produce must be transported across the island on dirt roads that are in poor condition. The primary transportation system, a three wheeled cart, has gone into disrepair due to the poor road conditions and overuse. The current alternative method is to contract a motorcycle "taxi" to transport the goods. This is unsafe, as it requires multiple people to ride a small motorcycle with a large sack between them. This method also requires extra manpower and has a limited carrying capacity.

Figure 1.3 shows the current path the food takes from the farm to the market. It is a 3.84 mile journey following the primary trail and has a maximum grade of 3%. Figure 1.4 shows the boat trip from Madame Bernard to Les Cayes with the area in Figure 1.3 highlighted for context.

Figure 1.3: Path from EDEM Farm to Madame Bernard[3]

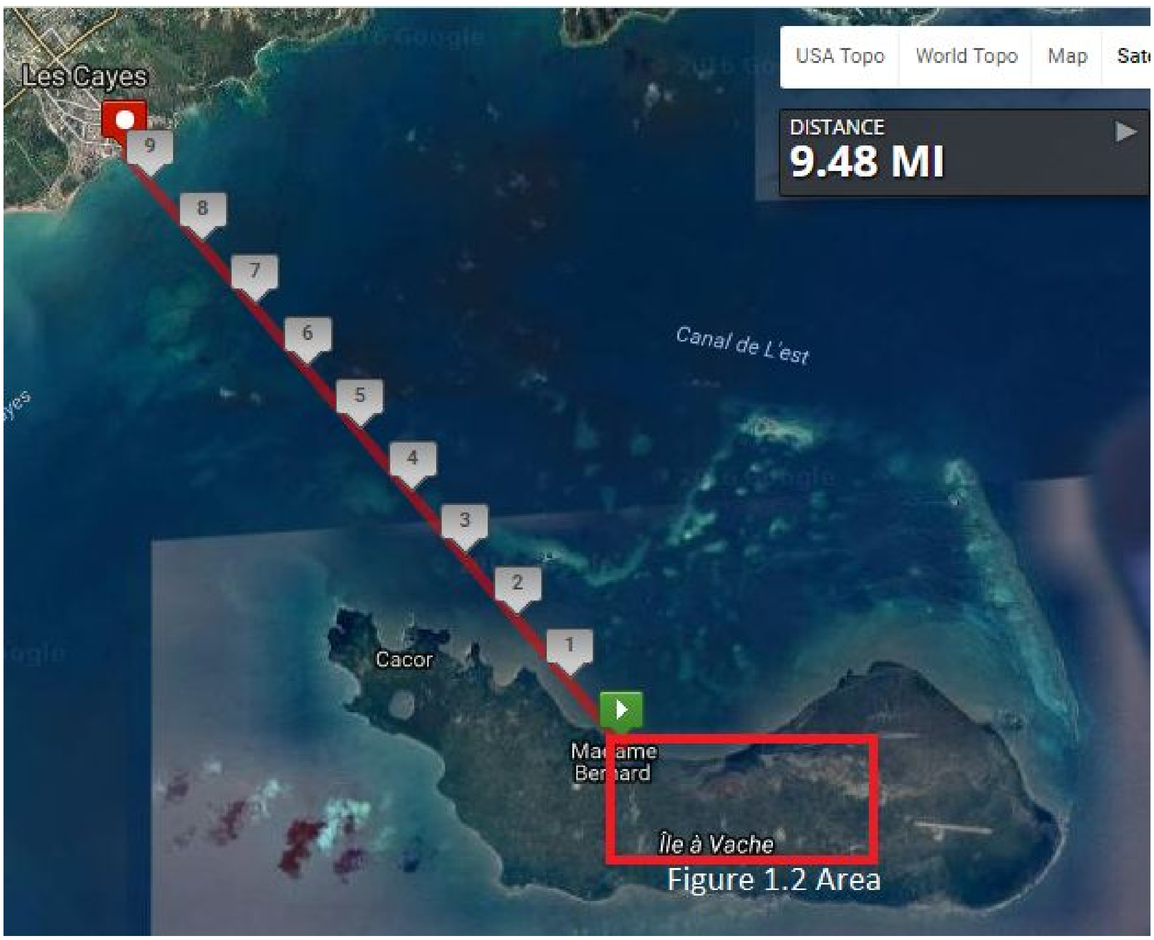

Figure 1.4: Boat Route from Madame Bernard to Les Cayes[4]

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[3] Map My Run
[4] Ibid

1.3 Customer Identification

The EDEM Foundation and motorcycle taxi drivers are the primary customers for this project (Figure 1.6).

Mr. Jean Patrick Lucien is the founder and director of the EDEM Foundation, an organization committed to "provide an environment of mentoring, learning, and support services for the incubation and growth of successful individuals, enterprises and institutions that will create a sustainable community on the island of Ile-a-Vache."[5] (Figure 1.5).

Figure 1.5: Jean Patrick Lucien, Director of the EDEM Foundation[6].

The EDEM Foundation is interested in the project due to the potential of a new transport system to improve the food distribution process, thus increasing farm profitability. EDEM will be paying for the materials and manufacturing the system according to specifications provided by the team, making them a large stakeholder in the design process.

Given the way materials are currently transported, the direct end-user of the product will not be EDEM farm employees, but rather "motorcycle taxi" drivers.

Figure 1.6: "Motorcycle taxi" drivers on the island of Ile-a-Vache[7].

[5] http://www.edem2.org/
[6] http://www.edem2.org/
[7] Photo by LCDR Lust

The “motorcycle taxi” drivers are contracted by the farm to transport the produce across the island because it is the fastest method. Given that they are the end users of the product, their customer requirements must be combined with EDEM’s requirements to produce a design that is beneficial to both parties.

1.4 Gathering Information from Customers

Once the customers were identified and the problem statement was written, information was gathered from the customers about what they wanted from the design or system. This was done mostly through emailed interview questions. Mr. Lucien’s responses are summarized below.

1.4.1 Customer Interviews

Initial interview with Mr. Lucien

On September 2, 2016 Mr. Lucien was sent a series of questions to allow the team to ascertain a better understanding of their situation and what they want and need. They are concerned with transporting everything from produce and water to farm supplies and building materials.

Currently materials are transported by any of three ways: a boat, on the back of a donkey or carried by someone on a motorcycle. If going to the local market the supplies only need local transportation. If going to Les Cayes, the large market on the main island of Haiti, both local and boat transportation are required. The difficulty with the roads is that they are narrow with a maximum width of 3 m and the surface is only compacted dirt so they wash out when it rains.

The chariot owned and operated by the EDEM Foundation is only two years old and it is already in disrepair and unable to be used. When it was operational the system damaged produce before it could reach the market. This lowers the amount they actually sell thereby lowering their profit.

Mr. Lucien mentioned that, ideally, they were looking to carry twenty five-gallon jugs of water or 500 lbs of peppers, plantains or some other produce. They also would appreciate a storage system that would be a part of the transportation system. This way they can store any of the produce that they did not sell that day.

1.4.2 Customer complaints

The chariot that is currently on Ile-a-Vache is a Haojin Superman, a three wheeled motorcycle that has a flatbed for storage and transport. There are no customer complaints or comments elsewhere about this model however Mr. Lucien did give us the EDEM foundation's issues with the product.

Figure 1.7: The Haojin Superman HJ250ZH-6A[8]

They included:

- Breaks frequently
- Difficult to repair
- Difficult to replace necessary parts
- Damages produce during transit

1.5 Revised Customer's Problem Statement.

With the information gathered through the communications with the intended customer of the project the problem statement was revised as such:

> *Design a towed cart for farmers and taxi drivers to effectively transport crops and other materials via motorcycle on the Haitian island of Île-à-Vache.*

At this point, the design space has been narrowed down to a towed cart. The cart will need to travel nearly four miles one way, which will demand speed and and minimal manpower. A cart towed by the motorcycles that are already on the island will be the quickest, most efficient way to transport material.

[8] Haojin, "Haojin Superman HJ250ZH-6A," Guangzhou Joujin Motorcycle Co., Ltd., http://en.haojin.com.cn/en/displayproduct.html?proID=963676 (accessed October 2, 2016).

1.6 Initial Draft of Customer Requirements

Based on information received from Mr. Lucien, an extensive list of customer requirements was developed. In order to spread them across various aspects of the project, Garvin's Eight Dimensions of Quality[9] were used as categories for inspiration. The initial customer requirements are included in Table 1.1.

Table 1.1: Initial Customer Requirements List

Dimension	**Description**	**Kano Class.**
Performance	Capable of carrying 500+ lbs	Spoken
	Able to self-contain cargo	Unspoken
	Able to ride on 4' wide dirt roads	Spoken
	Be statically and dynamically stable	Expecter
Features	Interface with a motorcycle	Spoken
	Have a universal attachment system	Unspoken
	Intuitive attachment system	Expecter
	Simple design with detailed engineering drawings	Unspoken
	Light enough to be moved manually	Unspoken
	Cost less than $250 to purchase parts and assemble	Expecter
	Double as a modular storage system	Exciter
Reliability	Last through assembly, hookup, and first use	Expecter
Durability	Last longer than 2 years	Spoken
Serviceability	Use standard member dimensions and hardware	Unspoken
	Use materials that are easily acquired	Expecter
	Be repairable by spot welding	Unspoken
Conformance	Conform with all government regulations	Unspoken
	Comply with safety and environmental standards	Unspoken
Perceived Quality	Appear sturdy	Unspoken

[9] G. Dieter and L. Schmidt, *Engineering Design, 5th Ed., McGraw-Hill, New York, 2013, pg. 82*

Due to the nature of the project, the critical customer requirements will change over time. In the initial design stage, it will be important to focus on meeting performance and features requirements. During prototyping, the focus will shift to testing the performance and reliability of the design. Through iterative design, more and more customer requirements will be implemented while maintaining the core requirements of the design. At the conclusion of testing, the final design will need to be translated into a set of engineering drawings. At that point, conformance and serviceability become the primary focus.

1.7 Gathering Information on Existing Products

1.7.1 Overview

In many developing countries throughout the world today, the motorcycle and the dirtbike provide a very common means of transporting not only material goods but people as well. The concept of transporting material goods introduces the question of how much can one carry before the desired performance of the transporter is hindered, and the variation in design of current methods for transporting goods using a motorcycle addresses this issue. A simple search for images of current motorcycle transport systems yields many different designs, examples of which are included in Figures 1.8 and 1.9. A brief look at current designs for material transportation using a motorcycle shows that many designs rely on supporting the bulk of the weight on the back wheel(s), most likely because it offers better control and handling for the motorcycle than if the weight was on the front wheel.

Figure 1.8: A current method of material transportation using a motorcycle[10]

Figure 1.9: Another current method of material transportation using a motorcycle[11]

1.7.2 Consumer and Product Literature

Haojin Superman. The Haojin Superman, Figure 1.10, is a familiar model for the customer, as this vehicle has been used in the past on the island of Ile-a-Vache to transport produce and materials from farm to market. The available research for this model is limited, as it is a Chinese model. It is a three-wheeled vehicle that is essentially a motorcycle with a transportation bed on the back. The drive shaft connects directly to the back two wheels, providing power for the vehicle while the front wheel provides control and steering. The maximum power that the Haojin Superman is rated for is 11.5 kW (15.4 hp), and the maximum torque that it is rated for is 19.5 Nm. Although a price has not been found for this model, it is included here because it is a design that has

[10] Jammin Global Adventures, http://jamminglobal.com/category/colombia (accessed October 2, 2016).
[11] Youngisthan.in, http://www.youngisthan.in/travel/old-transportation-vehicles-of-india/9390 (accessed October 2, 2016).

been used in a limited capacity by the customer before. In addition, it has a rated load of 11,023 lbs, which greatly exceeds the customer requirements for this project.

Figure 1.10: The Haojin Superman HJ250ZH-6A[12]

Lumina Motorcycle Trailer. Although the Lumina Motorcycle Trailer, Figure 1.11, is very expensive and does not have a comparably large footprint, it is included here because it embodies the typical design of many consumer motorcycle trailers on the market today. This motorcycle trailer costs $1395 and is made of aluminum. It has 14 ft^3 of space allotted for storage and is rated to carry a maximum of 500 lbs. In addition, it is able to attach to the motorcycle via a swivel coupler, which provides the necessary degrees of movement for operating a motorcycle while the trailer is attached.

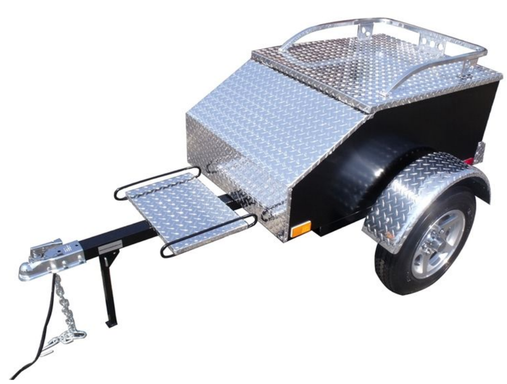

Figure 1.11: The Lumina Motorcycle Trailer[13]

Haul-Master Utility Trailer. The Haul-Master Utility Trailer, Figure 1.12, is a cheap and simple design on the market that has a lot to offer in terms of carrying capacity. Costing

[12] Haojin, "Haojin Superman HJ250ZH-6A," Guangzhou Joujin Motorcycle Co., Ltd., http://en.haojin.com.cn/en/displayproduct.html?proID=963676 (accessed October 2, 2016).
[13] The USA Trailer Store, "Lumina Motorcylce Trailer - Black," The USA Trailer Store, http://theusatrailerstore.com/lumina-motorcycle-trailer (accessed October 2, 2016).

$240, this trailer measures in at 40.5 in. in width and 48 in. in length for the footprint of the trailer, although it is important to note that this trailer is a frame and requires plywood to be laid down for the decking of the trailer. The trailer also has a rated weight capacity of 1090 lbs. It incorporates a three leaf suspension system and is made of steel so it is relatively durable.

Figure 1.12: The Haul-Master Utility Trailer[14]

1.7.3 Patent Literature

A preliminary patent search was conducted on the U.S. Patent Office website (http://patft.uspto.gov/) using the keywords *motorcycle* and *trailer,* or *trailer* and *hitch* and *motorcycle*. The searches produced 7 and 395 hits including the following:

US patent 3,362,596 awarded to Bostwick in 1968 for a method of attaching a pack box to the rear axle of a motorcycle. Bracing helps move the load forward on the bike and prevents excessive loading on the axle. The patent paperwork includes a diagram that might prove useful in the concept generation stage.

US patent 8,708,085 awarded to Wilson in 2014 for a convertible motorcycle trailer. The trailer attaches to a movable plate mounted to the motorcycle, which adjusts for different heights and lengths of tongues. The patent paperwork includes a drawing, Figure 1.13, which may be fruitful in the concept generation stage.

[14] Harbor Freight Tools, "Haul-Master 1090 lb. Capacity 40-½ in x 48 in Utility Trailer," Harbor Freight Tools, http://www.harborfreight.com/1090-lb-capacity-40-12-in-x-48-in-utility-trailer-62645.html (accessed October 2, 2016).

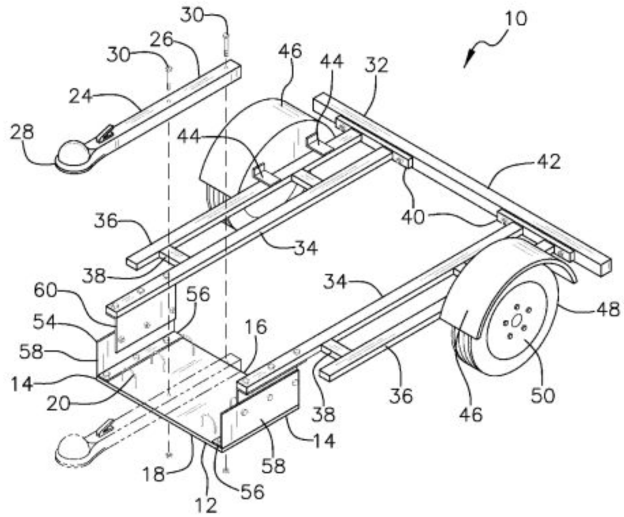

Figure 1.13: The patent description of *Convertible Motorcycle Trailer*, patent number 8,708,085.[15]

1.7.4 Applicable Codes and Standards

There are no prohibitions in the Code of Laws of the United States of America (U.S.C.) specifically regarding motorcycles and trailers. It was, however, determined that Federal Motor Vehicle Safety Standards (FMVSS) apply broadly to utility trailer. These standards exempt small utility trailers from most requirements, such as lighting and braking.

MD Transportation Code §13-927 applies within the State of Maryland and states that in order to utilize homemade trailers on public roads, it must be registered with a vehicle identification number (VIN) which can be obtained through an application process that requires a side and rear photo. A VIN plate will then be provided. We intend to test on private land and off road, and therefore while being
mindful of this restriction, should not run afoul of the law.

1.7.5 Global, Economic, Environmental, and Societal context

Global. Many developing nations struggle with food insecurity. These countries are limited in their own resources and have little international influence. They trade with neighboring countries to supplement their diets and to purchase any materials they may need, but many primarily live on subsistence farming. A main barrier to trade is the

[15] https://www.google.com/patents/US8708085

transportation of goods from farm to market. These communities are severely limited in resources, and their main methods of transportation rely only on cattle or motorcycles. But there is always challenge to transport a large weight of vegetables.

Economic. The island is limited in their ability to trade. The only resources they can receive are via the market on the northern side of the island. However, basic metal parts are readily received from the mainland of Haiti. Additionally, welding materials are readily accessible on the island, so constructing basic structures from metal tubing will not be difficult.

Environmental. The design of the cart may have a negative effect on the paths it needs to travel over. There is a design constraint of having to fit the cart on a four-foot-wide trail. Even at three-feet-wide, the wheels of the cart will cut corners and potentially run over crops. To compensate, the tires may need to be wider to spread out the load and the hitch may to have rotational motion. Additionally, the design for the cart will need to be robust. It will be continuously exposed to the elements; the hot sun, heavy rain, and sharp turns. The rocky roads and trails the cart is expected to travel over will stress and strain the cart and present design challenges. In order to limit the amount of environmental impact the cart will have the size must be limited to smallest roads they will be travelling over.

Societal. The underlying purpose of this project is to provide the people of Ile-a-Vache a design that will ease their day-to-day life. The finished product will increase the income of the farmers, as less vegetables will be crushed when transported to and from the market, increase the utility of the motorcycle taxi drives, as they now can carry more weight and equipment, and increase the available time for the farmers to grow the crops, rather than riding the crops back and forth making multiple trips.

1.7.6 Engineering Models

At this point in the design process, there is a basic steel frame design that is proposed. The tested models in Appendix A show a 3 X 4 stressed, steel frame. The maximum stress on the steel frame with a 600 pound, evenly distributed load is 34.88 MPa, while the yield strength is 415 MPa. This yields a factor of safety of 11.9. This stress is located at the 45 degree joints coming up from the axle and their connection to the top-frame. The maximum displacement is 1 mm in the center of the top-frame.

1.8 Quality Function Deployment

1.8.1 Customer Requirements

Based on information from the customer and feedback from the System Requirement Review presentation and the project mentor, the customer requirements list was distilled to a few critical points. These requirements were prioritized based on their necessity to the performance of the final design. The revised list of customer requirements is included in Table 1.2.

Table 1. 2: Revised Customer Requirements

A successful design should:	Priority
Have long-term durability	5
Have a high carrying capacity	5
Be simply designed	5
Have a low material cost	4

1.8.2 Customer Assessment of Competing Products

The competing products were assessed according to their characteristics and how Mr. Lucien responded to our questions on how the current system, the Haojin Superman, is doing.

Table 1.3: Customer assessment of competing products.

Customer Requirements	Haojin Superman	Lumina Motorcycle Trailer	Haul-Master Utility Trailer
Durability	2	3	3
High Carrying Capacity	5	1	5
Simple design	2	3	5
Low Cost	3	1	5

The products were scored against the customer requirements on a scale from one to five where a score of one was given for poor performance and a score of five was given for a great performance. The Haojin Superman was capable of carrying plenty but was complicated and fell apart quickly. The Lumina Motorcycle Trailer had about average durability and design but was entirely too expensive and could not carry nearly enough. The Haul-Master Utility Trailer was the closest in design to what was initially being looked at. It is a very simple design that does not cost too much and can carry plenty. Its drawback is the limited durability due to lack of shock absorbers which is necessary when the only roads it will be used on are dirt. These scores give the design team an idea of what will work, what will not and what to target for.

1.8.3 Engineering Characteristics

From the shorter list of customer requirements, a list of engineering characteristics was developed in order to drive the design in areas areas most important to the customer. These are included in Table 1.4.

Table 1.4: Engineering Characteristics

Customer Requirements	Engineering Characteristics	Units	Direction of Improvement	Rank Order
Simple Design	Unique Parts	#	↑	1
Durability	Time in service	days	↑	2
High Carrying Capacity	Footprint	m^2	↑	3
Low Cost	Cost	$ USD	↓	4

Rank order was determined by methods outlined in Dieter and Schmidt, Section 3.6.2[16]. Simple design was determined to be the most important engineering characteristic. This is logical because a simple design will lower costs, improve repairability, and ease assembly, which were all included in the initial customer requirements list. Durability is the second most important characteristic. This was primarily due to the customer's stated problems with the reliability and longevity of the current system. Next came the high carrying capacity, which is required to move the volume of produce the customer desires. Lastly, the cost must be low because competing commercial products can be had for a very low price.

[16] G. Dieter and L. Schmidt, *Engineering Design, 5th Ed., McGraw-Hill, New York, 2013, pg. 99-110*

Beyond the engineering characteristics, there are certain requirements that must be met by the design. Those constraints are as follows:

- Have an intuitive interface with a motorcycle
- Comply with all U.S. government, safety, and environmental standards
- Require few imported materials and be repairable on island
- Have a parts list and assembly directions that can be used to effectively manufacture the designed cart

1.8.4 Technical Assessment

The performance of each of the benchmark systems with regard to the established engineering characteristics was determined, when possible, and included in Table 1.5. Surprisingly, most of the specifications listed on the information sheets do not describe the *goodness* or completeness of search. This is perhaps due to the variability associated with setting different system parameters such as the sampling frequency, search path, etc. As such, the performance of each benchmark design with regard to the engineering characteristics outlined in the previous section was difficult to obtain for all categories. When necessary, a qualitative assessment was made.

Table 1.5: Technical assessment and target values for each engineering characteristic.

Engineering Characteristic	Time in Service	Footprint	Unique Parts	Cost
Units	days	m^2	#	$USD
HAOJIN	-	3.25	-	-
Haulmaster	-	2.45	-	$240
Moto Trailer	-	2	-	$1395
Targets	730	1.469	-	$500

1.8.5 Target Values for Engineering Characteristics

The target value for the time in service is 730 days. This is derived from the previous system's time to failure and the warranty of competing products. A successful design will exceed the previous system's life cycle. The target value for the footprint came from the customer's desire to carry 5 gallon water jugs. The customer desire is to carry 20- 5 gallon water jugs, so this requires a footprint of 1.469 m^2 if all of the water jugs are standing up. The dimensions are made from discrete increments of jug diameter (~11 in) to minimize wasted footprint space. The target for the number of unique parts will come from a physical decomposition of a competing product and is unknown at this time. The goal will be to reduce the number of unique parts to a bare minimum while maintaining performance and desired features. The target price point comes from a quote of a similar competing product, which is the Haul-Master Utility Trailer. If this design cannot compete in price with similar products, there will be no advantage to using this product over one that is commercially available, so the target price will be approximately $500 for the design of the trailer alone.

1.9 Deliverables

For the coursework portion of this project several reporting milestones exist, with the timing noted in the Project Management portion of this report. Each report presents a deeper understanding of the problem. These progress reports will be shared with the customer for their situational awareness.

In addition to the final report, calculations, and engineering models, a functional drawing, bill of materials, and sufficient instructions for a cart suitable for use on Ile-a-Vache will be provided to the EDEM foundation upon project conclusion. The drawing, bill of materials, and instructions will allow for the inhabitants of Ile a Vache to build and repair the transport system.

2 Concept Generation

2.1 Physical Decomposition

Prior to concept generation, the current features of a trailer benchmark design were reviewed and compiled in Table 2.1.

Table 2.1: Compilation of benchmark subsystems, features, and functions.

Subsystem	Features (parts included)	Function (what does this subsystem do)
Motorcycle Interface	Steel tubing Hardware (nuts/bolts/washers) Welding	Connect bike to trailer system Provide interface to allow the system to be pulled
Hitch	Hardware (nuts/bolts/washers) Bike Side Component Frame Side Component	Connect the trailer frame to the bike interface Provide 3 axis motion (pitch, roll, yaw) for stability
Frame	Steel Tubing Steel Plates Welding	Supports the load of the cargo Provides secure anchor points for other subsystems
Suspension	Leaf Springs (2) Bushing Kit (2) U Bolts (2) Axle	Absorb vertical vibrations between the ground and the frame Connect the wheels to the frame
Wheels and Tires	ATV wheels (2) ATV tires (2) Bolts (8)	Support the weight of the trailer and cargo Provide an interface for transportation between the trailer and the ground

Table 2.2, the morphology chart, is an exploration of the design space for each subsystem. Various solutions to achieve the stated function of each subsystem were proposed and compared against one another to form the ideal component combination to meet our engineering characteristics.

Table 2.2: Morphology Chart

Subsystem	Potential Solutions			
Bike Interface	Friction Clamp	Burley Hitch	Wrap Around	
Hitch	Ball Joint	Universal Joint	Lock N' Roll	Pintle
Frame	Simple Frame	Shelf Frame		
Suspension	Leaf Spring	Coil Spring	Coil Spring from Car	Hydraulics
Wheels and Tires	Mountain Bike Wheels	Motorcycle Wheels	ATV Wheels	Car Wheels

2.2 Design Concepts and Selection

To review, the four most important ECs are included in Table 2.3.

Table 2.3: Top Engineering Characteristics.

Customer Requirement	Engineering Characteristic	Units	Direction of Improvement	Rank Order
Simple Design	Unique Parts	#	↓	1
Durability	Useful Life	days	↑	2
High Carrying Capacity	Footprint	m^2	↑	3
Low Cost	Cost	$USD	↓	4

The following constraints, established previously, also need to be addressed by any feasible design:

- Have an intuitive interface with a motorcycle
- Comply with all U.S. government, safety, and environmental standards
- Require few imported materials and be repairable on island
- Have a parts list and assembly directions that can be used to effectively manufacture the designed cart

2.2.1 Bike Interface

The function of the bike interface is to connect the bike to the entire trailer system and provide a connection that can be used to pull the trailer. Because the goal of the trailer is to be able to carry several hundred pounds of materials the bike interface must be such that it does not harm the bike by breaking off what the trailer is attached to. It also must be simple enough to be easy to attach and remove.

Figure 2.1: Friction clamp[17]

The friction clamp attaches to any straight piping on the frame. It is easy enough to work with to be relatively intuitive. It is capable of attaching to multiple sizes of piping and placements on a bike. However not every bike will have a very obvious sturdy attachment place. If the wrong one is chosen too much force will be placed on a single member and it could break. With this in mind it was determined that this was not the best option for the interface.

Figure 2.2: Burley Hitch[18]

[17] http://www.trail-a-bike.com/products/parts/adams-blocksleeve-hitch/

[18] https://burley.com/product/burley-classic-hitch/

This hitch is from a popularly used commercial brand used to tow child carriers behind pedal bikes. It hinges in order to take into account the different angles that could be between the two bars of the frame extending from the back axle. This is helpful for being adaptable however because it attaches to the upper bar of the frame the hitch may get in the way of some suspension systems which would inhibit its use. This is a more complicated design which, if damaged, would be more difficult to repair, most likely they would need to buy a completely new hitch which is less than desireable. They are relatively cheap however the piece’s durability is dubious because it is made of plastic.

Figure 2.3: Wrap around[19]

This hitch uses two symmetrical bars that connect to a bolt on either side of the bike. The attachment shown here shows it being at the axle however as long as it is a load bearing point the bars may be attached at other places on the bike. This is easy to fabricate because it is only three bars of tubing welded together and bolted on which also makes it fairly inexpensive.

Table 2.4: Bike interface performance

Rank Order	Engineering Characteristic	Units	Friction Clamp	Burley Hitch	Wrap Around
1	Unique Parts	#	Few	Many	Few
2	Useful Life	days	Limited Warranty	Limited	Repairable
3	Footprint	m^2	N/A	N/A	N/A
4	Cost	$USD	45	35	30

[19] http://bicycle.newbalanceoutlet.us/bicycle-cargo-trailer-hitch/

Using the engineering characteristics and the basic functional requirements as a basis for choosing the right interface the wrap around is the best option. There are very few unique parts, only the tubing and the bolts to attach it to the bike. If it does break it is easy enough to fix with a quick welding job. This is also customizable for each bike. The customer just needs to determine at which point they want to attach the interface then bolt it on. The materials also will be inexpensive making this the clear choice.

2.2.2 Hitch

The function of a hitch in any towing application is to connect the tow vehicle with the cargo holder. In this situation, where the roads are unpaved and in poor condition, it is critical that the hitch provide adequate relative motion between the motorcycle and trailer in three axes. In order to maintain stability going up the 3% grades on the trail, there will need to be freedom of motion in the vertical plane. In order to facilitate turning on the winding path, there will need to be freedom of motion in the horizontal plane. In order to keep both wheels of the trailer on the ground at all times, the hitch will also need to provide torsional freedom about the towing axis. A successful hitch will be strong enough to carry the axial force required to move the trailer and will maintain trailer stability through freedom of motion in desired axes.

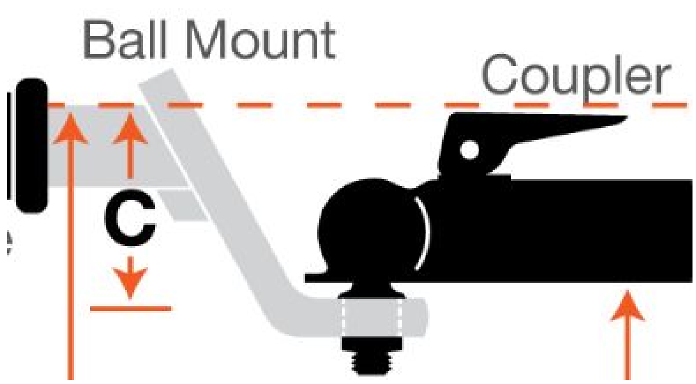

Figure 2.4: Ball Joint Hitch

The ball joint hitch is commonly used in automotive towing applications. It is designed to operate with a significant amount of tongue weight to keep the ball inside the coupler. It provides excellent range of motion in the horizontal plane, but is very limited in the vertical and torsional modes. The ball mount is generally a large and heavy apparatus because it is truck mounted. This type of hitch is not ideal for our situation because it does not have a large enough range of motion and the motorcycle cannot tolerate a heavy tongue load.

Figure 2.5: Universal Joint

The universal joint is also used in automotive applications, but generally not for towing. It is commonly used to connect turning shafts that are not axially aligned with one another. It provides excellent range of motion in the horizontal and vertical modes, but has no motion in the torsional mode. It would require an additional piece of hardware (swivel joint) in order to meet functional requirements. Since this joint is not typically transferring force in the axial direction, its towing strength is unproven. This joint would require additional testing, which slows the design process. The requirement for additional hardware and testing make this a less-than-ideal solution to the hitch problem.

Figure 2.6: "Lock N' Roll" Hitch

The "Lock N' Roll" hitch is just one brand of a family of specialty hitches that exist for off-road towing. This family of hitches utilizes three separate mechanisms to provide motion in all three directions. Since they are designed specifically for towing, they have more than adequate strength for our application and are warrantied as commercial products. However, the complexity of this hitch and the cost are too high for this situation. This hitch is designed for conditions much more severe than our design will face and is too expensive as a result of this quality.

Figure 2.7: “Pintle Hitch”

The pintle hitch is a popular towing method in agriculture due to its extremely high strength. It provides movement in all three axes by having space between the interlocking rings. Though it is limited torsionally, its horizontal and vertical motion is well-suited for the trailer application. It’s weakness is the freedom of motion between parts, which can cause the parts to strike one another at the onset acceleration and deceleration. The simplicity, strength, and motion of this design make it appealing for our potential design. Table 2.5 summarizes each hitch option’s performance as it relates to our engineering characteristics.

Table 2.5: Hitch Design Performance

Rank Order	Engineering Characteristic	Units	Ball Joint	Universal Joint	Lock N’ Roll	Pintle
1	Unique Parts	#	Few	Few	Many	Few
2	Useful Life	days	Multi-Year Warranty	Multi-Year Warranty	Multi-Year Warranty	Multi-Year Warranty
3	Footprint	m^2	N/A	N/A	N/A	N/A
4	Cost	$USD	< 100	< 100	~ 300	< 75

The best hitch to meet the engineering characteristics and functional requirements of the subsystem is the pintle hitch. It is by far the simplest hitch design, which is aligned with our most critical engineering characteristic. All of the hitches have comparable warranties than span many years, so no single hitch stands out above the rest. The hitch does not have any impact on the footprint of the design, so that metric is not important in determining the superior option. The cost of the pintle hitch is also less than other hitches. It meets the motion requirements and fits in most closely with the desired engineering characteristics, so the pintle hitch is the selection the team will move forward with.

2.2.3 Frame

The function of the frame is to securely support the cargo being carried, as well as provide a rugged base for the attachment of the hitch and suspension systems. In this design, the frame will have to cope with humid conditions, repeated stressing, and be simple to build. A successful frame will adequately carry load, while being lightweight so as to not diminish the amount which can be carried.

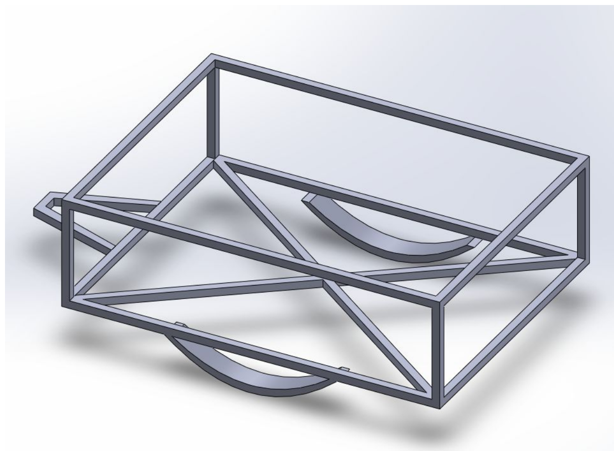

Figure 2.8: Simple Frame

A simple frame made of 1 inch square tubing, as in Figure 2.8, is a proper option for this application. While not optimized for specific applications, the general design allows for greater versatility and less weight than a highly specialized frame would. By using a mild steel, such as 1018 or A500, the frame will be low cost and durable, and easy to weld together. A drawback of an untreated steel is that in the environment of Ile-a-Vache corrosion will likely become an issue, requiring a sealant of paint to maintain longevity.

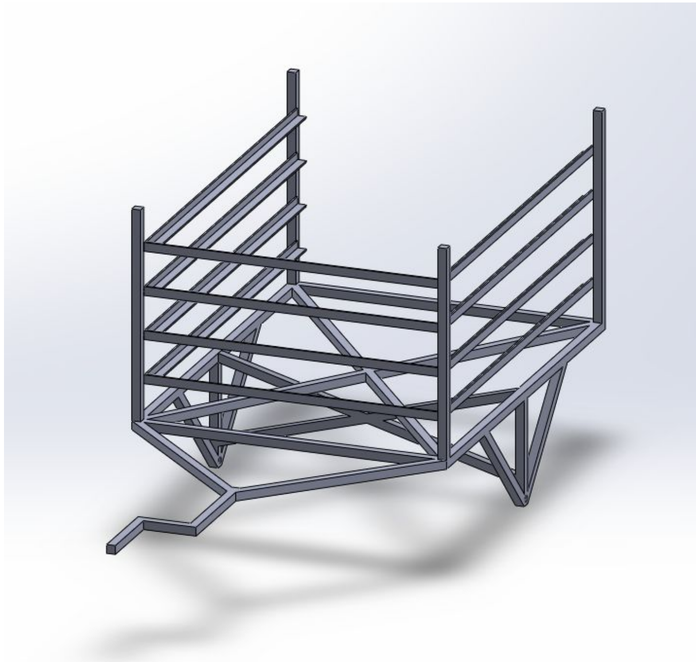

Figure 2.9: Shelf Frame

A specialized shelf frame, such as in Figure 2.9, would perform the same basic functions of the simple frame, but with specialized shelving allow for a greater practical footprint than the simple frame. With the increased storage capacity comes added weight and a higher center of mass, which is a key factor in the stability of the trailer. This design of a shelf frame incorporates angle iron to make the shelves, which increases the specific parts on the frame.

Table 2.6 Frame Performance

Rank Order	Engineering Characteristic	Units	Simple Frame	Shelf Frame
1	Unique Parts	#	3	10
2	Useful Life	days	repairable	repairable
3	Footprint	m^2	1.12	5.60
4	Cost	$USD	100	200

The best option for a frame is currently a simple frame. In order to make sure the trailer is manufacturable and meets the minimum performance requirements of the customer, a simpler design provides less cost, difficulty and time to manufacture. Once a proven system is developed, this base frame can then be modified to better suit specific applications in the detail design phase of the project.

2.2.4 Suspension

The function of the suspension system is to absorb the vibrations between the ground and the frame. In this design, the suspension will lessen the impact on the cargo in the cart, and it will lessen the pitch and roll of the cart across bumps. This will both preserve the cargo from damage and ease the vertical strain on the hitch. The cart will be dragged across rough terrain, dirt and uneven roads. Proper suspension will provide the cart with the desired durability and carrying capacity.

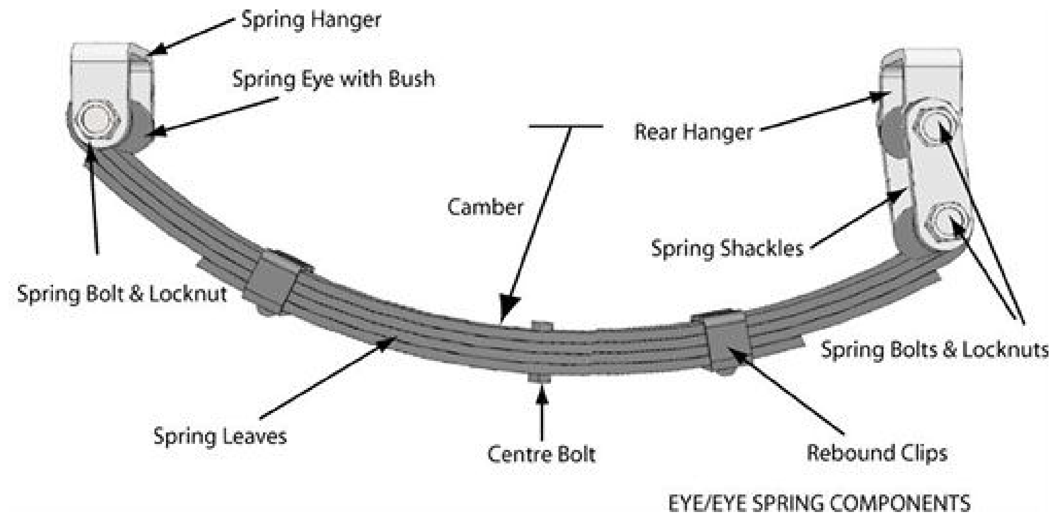

Figure 2.10: Leaf Spring Suspension

Leaf springs take the form of an arc and consist of layers of slender sheets of metal. The suspension is functional due to its shape. The arc allows the sheets of metal to deflect up and down, as the axle of the wheel goes over bumps. The frame will not feel the full effects of the bumps as the energy is absorbed by the springs. Leaf springs are rigidly attached at one end and are free to move on the other. In the figure above, the eye to the left is rigidly attached, while the eye on the right can swing. This allows the spring to deflect during absorption. Leaf springs are commonly used for automotive suspension. The primary issue with the leaf springs will be trying to find springs that are light enough for the 600 pounds we are looking at carrying. A temporary solution will be to take off leaves until the proper springiness is reached.The main advantage is their simplicity, stability, and the distribution of load across two or more points. These three advantages make leaf springs a viable option for the design.

Figure 2.11: Coil Spring Suspension

Coil spring suspension systems absorb shock through a coil. Similar to the the leaf spring, the coil spring physically will deflect, based off the spring constant, to reduce the vibrations on the frame. The coil spring is traditionally found in today's automobiles and motorbikes. Unlike the leaf springs, coil springs concentrate all their force on a single point. The coil spring also requires more parts and does not provide as much stability to the wheels and axle. To compensate, control beams must be added to ensure that the axle stays in place. However, coil springs are easily purchased and are relatively easy to install. Lastly, there is a large market for coil springs, and finding a spring with the proper stiffness would not be an issue, contrary to the leaf springs. Therefore it is a viable option for the design.

Figure 2.12: Coil Spring with Car frame and Wheels

Mentioned above, coil springs are used in automotives quite often, yet a challenge is to provide enough stability between the axle and the frame. Car suspension systems are robust to the point where this is no longer a concern. A third option to provide suspension to the cart is to use the rear of a pre-existing vehicle as a completed and tested interface between the axle and the frame. Additionally, the axle could include a differential to allow for the wheels to spin at different speeds around turns. However, this will not be standardized and there is no control over the quality of product. With the cost and design simplicity in mind, this does not look to be a viable option.

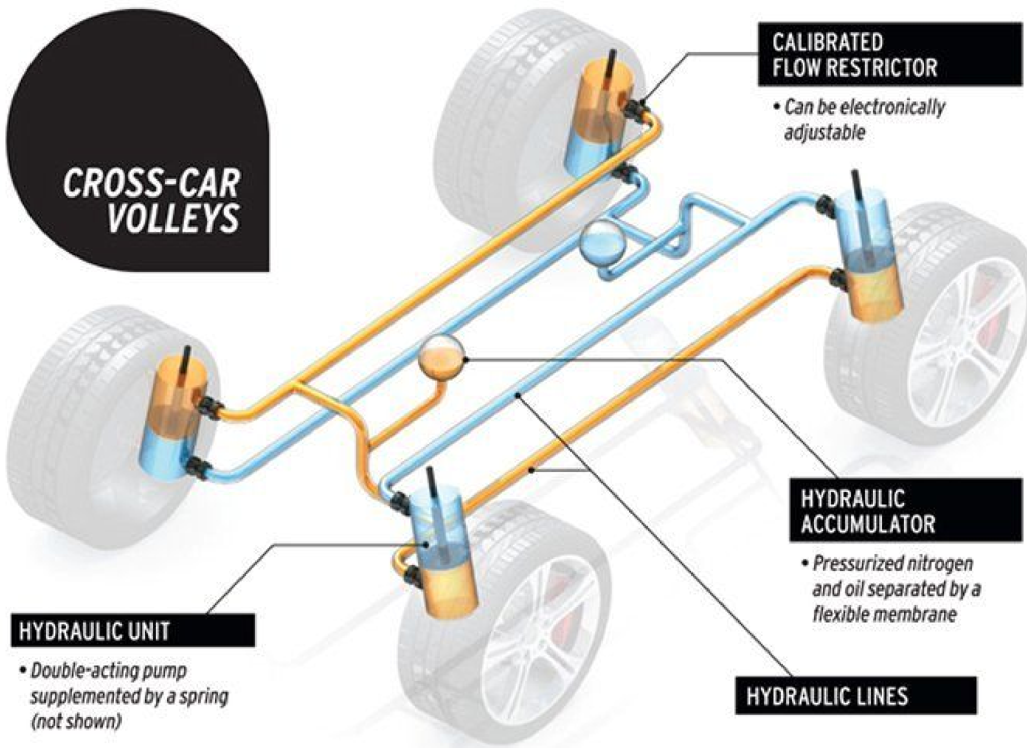

Figure 2.13: Hydraulic Suspension

Hydraulic suspension systems use pressurized air and oil to absorb shock and vibrations between the frame and the axle. First, the application of air (nitrogen gas due to its low corrosion risk) provides more flexibility than leaf or coil springs, providing better shock protection between the cargo and the ground. Additionally, a hydraulic system integrated into the suspension could also be used for brakes. However, the complexity of the suspension system, as well as the extra parts, make this not a viable option.

Table 2.7: Suspension Performance

Rank Order	Engineering Characteristic	Units	Leaf Spring	Coil Spring	Coil Spring with Car	Hydraulic
1	Unique Parts	#	Few	Few	Many	Many
2	Useful Life	days	Multi-Year Warranty	Multi-Year Warranty	Variable	Multi-Year Warranty
3	Footprint	m^2	N/A	N/A	N/A	N/A
4	Cost	$USD	~$120	~$150	>$1500	~$1000

The best suspension system to meet the design requirements is the leaf spring. First, in terms of simplicity of design, the leaf springs are by far the easiest to replace and assemble. The parts are common to where they can be ordered to Ile-a-Vache, if not readily available on the pre-existing carts. Additionally, they are easily replaceable if one of the leaves fails. The leaf springs are also the most durable of the considered springs. They contact the frame in two points, providing extra stability. Lastly, leaf springs are the cheapest option of the four considered. The leaf spring outperforms the other three types in all areas, and the selection the team will use in the final design.

2.2.5 Wheels and Tires

The wheels serve as the means of motion for the trailer, providing a rolling interface between the trailer frame and the terrain on which it will be operating. The trailer will be operating on unpaved and uneven paths, and the wheel-tire subsystem will be the only point of contact between the rest of the trailer and these paths. Not only will the wheels and tires have to be durable enough to withstand the rugged environment in which they will be operating, they will have to perform well in that environment so that the trailer can achieve its intended design purpose as an effective material transport system.

Figure 2.14: Standard Mountain Bike Wheel and Tire

One option that was considered to serve as the interface between the trailer and the ground is the standard mountain bike wheel and tire. This option seemed very intuitive considering the terrain on which the trailer would be operating and that it is the cheapest option. Mountain bikes have been proven effective means of transportation and recreation on uneven dirt paths. However, the limitation that this option offers is the rated load of the wheel. Although suited well for operating on the terrain in question, mountain bikes relatively light and meant to carry only a relatively small amount of weight. The wheels are engineered to carry only a few hundred pounds of net weight, making this option less viable.

Figure 2.15: Standard Motorcycle Wheel and Tire

Another option that was considered for this subsystem is a motorcycle tire and wheel. This option also seemed very intuitive because motorcycles have been an effective means of transportation for the inhabitants of Ile-a-Vache, so motorcycle wheels and tires have been proven to be a sufficient interface with the terrain on the island. Also, because motorcycles are a common means of transportation on the island, there is a potential source of spare wheels and tires that the farm owners could use in constructing the trailer; otherwise, motorcycle wheels present the most expensive option. Unlike mountain bike wheels, motorcycle wheels can support a net weight over 1000 lbs, which is more suited for the rated load that the trailer would be carrying.

Figure 2.16: Standard ATV Wheel and Tire

The third option that was considered for this subsystem is an ATV wheel and tire. This option combines several favorable aspects of the mountain bike and the motorcycle tire. ATV wheels and tires are designed to not just withstand but perform on rugged terrain. Moreover, they are rated to to support a load on the same magnitude as the trailer is being designed to support. Although less commonly found on the island of Ile-a-Vache than the motorcycle wheel, this wheel-tire system offers several advantages over the other options.

Figure 2.17: Standard Car Wheel and Tire

The last option that was considered was the standard car wheel and tire. Considering the market for automobiles, there would be a substantial amount of models from which to choose. In addition, car tires are commonly used on various trailer systems on the market and are the most heavy-duty based on the rated load that they must support. On the other hand, car tires are generally less common on Ile-a-Vache, and even though there is no question that this wheel-tire system could support the design load of the trailer, a car tire is designed primarily for operation on even paved terrain.

Table 2.8: Wheel/Tire Design Performance

Rank Order	Engineering Characteristic	Units	Mountain bike Wheel/Tire	Motorcycle Wheel/Tire	ATV Wheel/Tire	Car Wheel/Tire
1	Unique Parts	#	2	2	2	2
2	Useful Life	days	Limited	Multi-year	Multi-year	Multi-year
3	Footprint	m^2	N/A	N/A	N/A	N/A
4	Cost	$USD	~240	~500	~350	~350

The best option for the wheel-tire subsystem is the ATV wheel/tire. Specifically designed for rough handling in rugged terrain, this wheel suits the demands that the trails on Ile-a-Vache have to offer. The wheels are also tested and capable of supporting the weight that the trailer is designed to carry. In addition, it provides an option that, although not the cheapest, is not the most expensive. It is important to note that this project requires the wheels to provide sufficient performance for transportation, not peak performance, especially when considering which model to use and the price of the model.

2.3 Summary of Selected Design Performance

The performance of each of the design concepts was predicted with respect to the Engineering Characteristics established in the previous stage of design. Those performance parameters are summarized in Table 2.8.

Table 2.9: Top Engineering Characteristics with predicted performance for selected design

Rank Order	Engineering Characteristic	Units	Bike Interface	Pintle Hitch	Frame	Suspension	Wheels and Tires
1	Unique Parts	#	Few	Few	3	Few	2
2	Useful Life	days	Multi-year	> 730	∞	Mulit-year Warranty	Multi-year
3	Footprint	m^2	N/A	N/A	1.14	N/A	N/A
4	Cost	$USD	~30	< 70	100	~120	~350

In addition to performing well with regard to the established Engineering Characteristics, each subsystem design must potentially satisfy the design constraints to be considered a viable solution. Table 2.9 summarizes the potential of each design to meet the established constraints.

Table 2.10: The satisfaction of each of the design constraints for each subsystem.

Constraint	Motorcycle Interface	Hitch	Frame	Suspension	Wheels and Tires
Have an intuitive interface with a motorcycle	Yes	Yes	Yes	Yes	Yes
Comply with all U.S. government, safety, and environmental standards	Yes	Yes	Yes	Yes	Yes
Require few imported materials and be repairable on island	Yes	Yes	Yes	Yes	Yes
Have a parts list and assembly directions that can be used to effectively manufacture the designed cart	Yes	Yes	Yes	Yes	Yes

The final design for the trailer in summary is: the simple frame design, attached to the motorcycle via a pintle hitch and bike interface, mounted on ATV wheel-tire subsystems with leaf spring suspension. This design best meets all of the engineering characteristics for the final design, as summarized by Table 2.9. Moreover, each subsystem that was selected meets each of the design constraints for this project, as summarized by Table 2.10.

3 Project Administration

3.1 Project Management

Figure 3.1 includes all of the project-specific tasks and milestones anticipated at this time. Near-term tasks are known with higher certainty than those later in the semester or next semester.

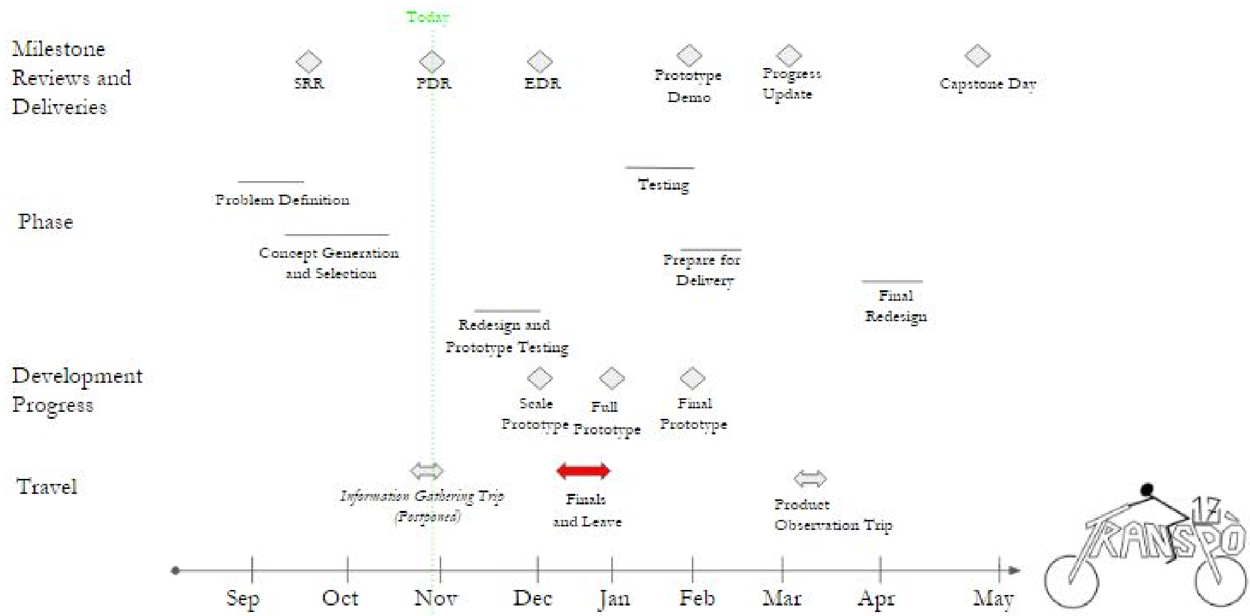

Figure 3.1:Transpó17 Master Schedule

It is important for our team to note that we must have a final design by February 1, 2017 in order to allow for translating directions, and the actually building of the design in Ile-a-Vache. This is reflected in our testing period during November. Table 3.1 offers a more detailed look at the schedule.

Table 3.1: Transpó17 Schedule

Event	**Due**
Capstone Day	26 April
Reiterate Design	7 April
Built and Observe in Haiti	13-17 Mar
Progress Update Review/Report	6 Mar
Written Directions to EDEM	17 Feb
Prototype Demonstration(Full Scale)	30 Jan
Detail Design Complete	30 Jan
Prototype Built	10 Dec
Embodiment Design Presentation/Report	2 Dec
Testing of Prototype and HaulMaster	15-30 Nov
Preliminary Design Presentation/Report	24 Oct
Research Trip to Haiti	*18-22 Oct (postponed)*
System Requirement Presentation/Report	19 Sep

Subsystems will be tested as acquired to ensure performance meets criteria. After subcomponent testing subsystems will be integrated and tested together, and then fully assembled and tested as a full prototype. Upon completion of embodiment design a more detailed schedule of testing will be established.

3.2 Budget

There are no previous teams that were addressing this project, which means there is no previous budget off of which to base the budget for this project. Looking forward, this project will be looking more into acquiring a Haul-Master Utility Trailer, which costs a total of $240, for further research and design. Additionally, a fair portion of the budget will be devoted to acquiring the parts for the trailer that will be constructed. Preliminary research has yielded some figures for major costs for the total system, which are presented below in Table 3.2. Table 3.2 gives a good idea of the price of materials that it will take to construct one prototype, but the estimated total cost of materials will have to account for any unforeseen costs. Based on this, the estimated cost of materials for this project is $2000.

Table 3.2: Approximate costs of some essential design parts

Part(s)	Approximate Cost ($USD)
Axle	$120
ATV wheels and tires (2)	$350
Leaf springs (2)	$240
Pintle Hitch	$70
1”x1” Square Tubing for frame	$100

Anticipated travel for this project will include a trip to Haiti for each team member. Each team member will travel to the island of Ile-a-Vache over the course of two trips. The first trip will be a research-based trip to fill in any last gaps on how the final design will be used, and the second trip will be focused primarily on observing how the final design is operating after being in use. Both trips are projected to be approximately 5-7 days. The price of a round-trip plane ticket from BWI airport to the airport in Port-au-Prince is approximately $600. Travel funds will also be required for transportation from Port-au-Prince to Ile-a-Vache as well as for meals and lodging. An estimated total cost of $1,500 per person yields an estimated total travel cost of $7,500.

The total requested budget for this project is $9,500.

Appendix A - Preliminary Engineering Model of the System

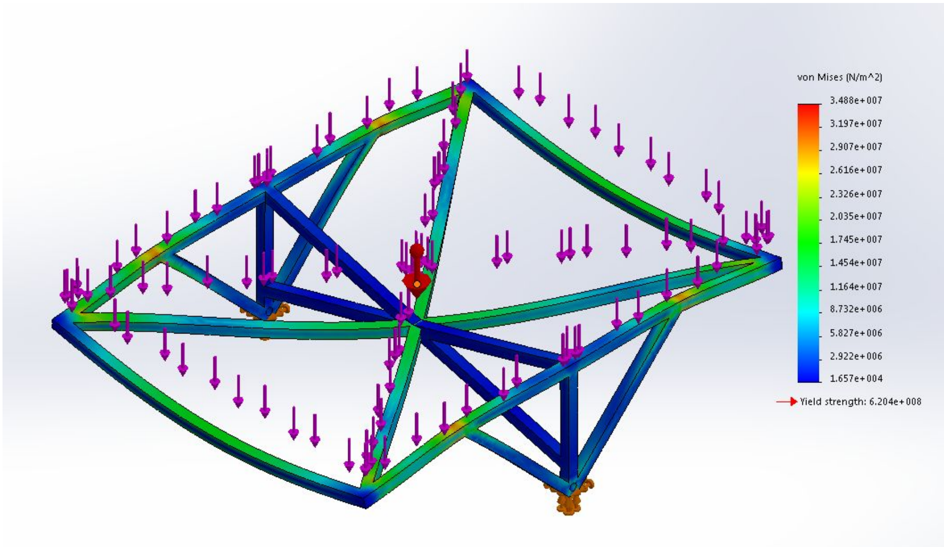

Figure A.1: Stress Analysis -- Max stress = 34.88 MPa

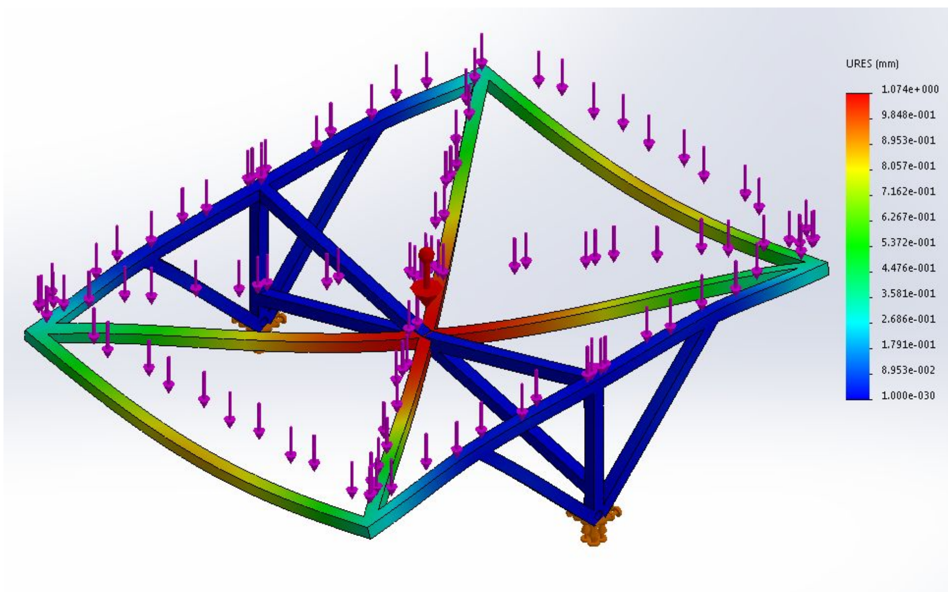

Figure A.2: Displacement Analysis -- Max displacement = 1mm

Appendix B - Team Charter

Team Members:

M. Patrick Serbent - Leader	207.837.2134
Scotty B. Davids - Technical Support Detachment Liaison	303.304.1470
Nick T. Morris - Safety Officer	207.232.2406
Ashley M. Luchtenberg - Design Communication Editor	757.810.9873
Ryan R. Waterman - Purchaser	757.620.1012

Advisors
LCDR Ethan Lust - RI114b - 757.636.8727
Mike Spencer - RI238b - 410.273.5209

Weekly Meeting Schedule
Mon - 1430 - RI 363c
Wed - 1430 - RI 363c
Thur - 1330 - RI 112
- 1430 - RI 363c

Team Goals
- develop strong working relationships amongst the team members
- develop an understanding of Haitian language and culture
- develop requisite communication skills to build project in foreign nation
- create a successful design

Conflict Resolution
By staying focused on the end goal and maintaining respect for one another, conflict resolution will happen through rational discussion with teammates and unafflicted members. We will constantly critique how each member is performing and how the team could do better. From the onset, we will establish a level of trust and respect between each group member.

Personal Goals

Davids -

1) Be a contributive team member
2) Learn about the complex relationship between design and aid implementation
3) Gain hands-on experience in the design process

Luchtenberg -

1) Be able to communicate effectively with the customer through knowledge of Creole
2) Gain practical experience in being a part of a design team
3) Build a product capable of meeting the needs of the inhabitants of Ile-a-Vache

Morris -

1) Gain a conversational knowledge of Creole to facilitate a more impactful trip
2) Foster an environment where all team members are well versed in all areas of the project
3) Witness a functional design at work in Haiti

Serbent -

1) Effectively perform the role of Team Leader, coordinate within and outside the team effectively
2) Create an effective product capable of providing real insights into the needs of Ile-a-Vache
3) Successfully navigate the design process in order to feel comfortable designing in the future

Waterman -

1) Gain professional experience in the technical design field
2) Build a successful design that is able to benefit the lives of the inhabitants of Ile-a-Vache
3) Learn about the group dynamic behind being in a long-term design team