2020 Baja SAE Braking System

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Moxit Patel

April 2020

Thesis Advisor:

Professor Allen Arthur

TABLE OF CONTENTS

LIST OF FIGURES 3
LIST OF TABLES 3
ABSTRACT 3
PROBLEM DEFINITION AND RESEARCH 3
PROBLEM STATEMENT 3
BACKGROUND 4
RESEARCH 4
TYPES OF BRAKES 4
CURRENT STATE OF THE ART 5
END USER 7
SUMMARY OF RESEARCH 7
CUSTOMER FEATURES 8
QUALITY FUNCTION DEPLOYMENT 9
PRODUCT OBJECTIVES 10
DESIGN 11
PROJECT MANAGEMENT 11
BUDGET 11
SCHEDULE 12
PLAN TO FINISH 12
WORKS CITED 13
APPENDIX A: BAJA SAE RULES 14
APPENDIX B: SAMPLE SURVEY 15
APPENDIX C: SURVEY RESULTS 16

LIST OF FIGURES

Figure 1: Typical Automotive Braking System (2)
Figure 2: 2014 Braking System Design (5)
Figure 3: 2016 Braking System Design (6)
Figure 4: 2017 Braking System Design (7)
Figure 5: House of Quality
Figure 6: HOQ Correlations
Figure 7: HOQ Competitive Analysis
Figure 8: Final Designs & Model
Figure 9: Customer Survey
Figure 10: Survey Question 1 Results
Figure 11: Survey Question 2 Results
Figure 12: Survey Question 3 Results

LIST OF TABLES

Table 1: Proposed Budget
Table 2: Actual Budget
Table 3: Proposed Schedule
Table 4: Actual Schedule

ABSTRACT

The purpose of this project is to design and build an adequate braking system for the UC Bearcat Baja SAE car. A braking system involves complex components that are vital for the stopping of a vehicle. This project will allow me to contribute to many aspects of the Baja car and also apply my skills and knowledge gained throughout my studies at UC. The rules, design, budget, timeline, and testing will be show in this report.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

It is crucial to have the ability to accelerate and decelerate a vehicle that is going to be used in off-road terrain at competitions. Brakes are one of the most important aspects of a vehicle's functionality. The team is going to design and build a new Baja SAE car that will follow the new guidelines and rules outlined by the SAE organization. I will be responsible for designing the braking system and the pedals (Throttle & Brake).

In the past, team members have designed braking systems and pedals in SolidWORKS and performed stress analysis based on the amount of force the driver applies on the pedals. The entire system has been designed to provide the best comfort for the driver; therefore, I will improve the design by reducing the weight, cost, and making it ergonomically safe but also, keeping the reliability and performance of the system. I will work closely with the steering, drive train, front/rear suspension team members to create this design.

BACKGROUND

About Baja SAE

Baja SAE is a competition in which engineering students are tasked with designing and building a single-seat, all-terrain sporting vehicle. It is to be a prototype for a reliable, maintainable, ergonomic, and economic production vehicle that serves a recreational user market. The main purpose of the competition is to provide engineering students with a challenging project that involves the design, planning and manufacturing tasks found when introducing a new product to the consumer industrial market. Students work together as a team not only to design, engineer, build, test, and compete with a vehicle within the limits of the rules, but also to initiate financial support and manage their education.

In 1973, a precursor to the SAE Mini Baja was developed by Dr. William R. Shapton called the Recreational-Ecological-Vehicle (REV). At the time, the vehicles in the REV competition ranged from $1600 to $5000 (1). This competition lasted for only a few years until it got replaced by the SAE Mini Baja due to the cost. In 1976, the SAE Mini Baja competition was originated at the University of South Carolina under the supervision of Dr. John F. Stephens based on the learning experiences of the REV competitions (1). The purpose of introducing the SAE Mini Baja was to "design the most competitive vehicle for the least cost (1)." Some of the details and rules of the competition have changed over the last 25 years, but the overall goal is the same.

RESEARCH

TYPES OF BRAKES

The modern automotive brake system has been refined for over 100 years and has become extremely dependable and efficient. The typical brake system in modern cars consists of disc brakes in the front and drum brakes in the rear connected by a system of tubes/hoses the link the brake at each wheel to the master cylinder, as shown in Figure 1 (2). Heat and friction are the two main principles used by both these types of brakes. The brakes apply friction, or resistance, to a turning wheel which in turn cause the vehicle to slow down and eventually stop. This creates heat as a consequence (3). Several factors are considered when determining the rate at which a wheel can be slowed down; these include the vehicle's weight, braking force, and total braking surface area (3). It also depends on how well the system converts the wheels movement to heat, and afterwards, how quickly the heat is removed from the brake components.

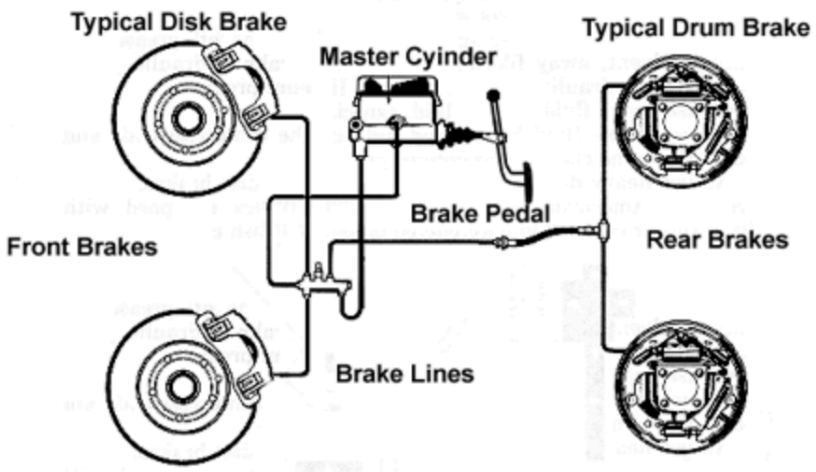


Figure 1: Typical Automotive Braking System *(2)*

Disc brakes are used in many applications such as cars, trains, and even big cargo planes. The main components of a disc brake system are the brake pads, rotors, piston, and calipers (2). Within the caliper are two brake pads, one on each side of the rotor. When the brake pedal is pressed, a piston inside the master cylinder pressures the brake fluid through the brake lines. Thereafter, the caliper clamps the brake pads around the rotor causing the wheel to slow down (4). The main difference between disc brakes and drum brakes is the amount of exposure each gets to the outside environment. In disc brakes, the rotor is fully exposed to outside air; however, in drum brakes, the backing plate is enclosed inside a drum causing heat to build up inside the drum.

Drum brakes were used at all four wheels while designing braking systems during the early automotive season. The components of the system are housed in a round drum that rotated along with the wheel; therefore, they are called the drum brakes. Drum brakes consisted of brake shoes, a backing plate, brake drum, wheel cylinder, return springs, and an automatic or self-adjusting system. Once the brake pedal was pressed, brake fluid is forced under pressure into the wheel cylinder. This forces the brake shoes against the drum which in turn slows down the wheel (3). When the pressure on the pedal is released, return springs pull the brake shoes back to its rest position. As the surface of the drum wears, the shoes have to travel a greater distance to come in contact. Therefore, when a certain distance is reached, the self-adjusting mechanism automatically reacts and brings the rest position of the brake shoes closer.

CURRENT STATE OF THE ART

2014 Baja SAE Braking System [Kyle Murray]

In 2014, a new design was developed based on discussion with competitors and teammates. The overall goal for the braking system was to bring a Baja SAE vehicle to safe and stable stop while reducing the weight dramatically. Initially, a budget limit of $2000 was placed with a weight restriction of 15 lbs. During the design phase, it was chosen that the rear wheels will be slowed down by a single inboard brake instead of 2 outboard brakes at the wheel. In the front, the brakes were going to be located at the wheel because the front wheels will be performing majority of the

braking. Each brake was designed to be a disc brake rotor with a hydraulic caliper (5). Many of the components of the braking system were purchased, but the pedals were manufactured in house. The entire braking system cost was $1100. Figure 2 below shows the pedals and disc brake assembly.

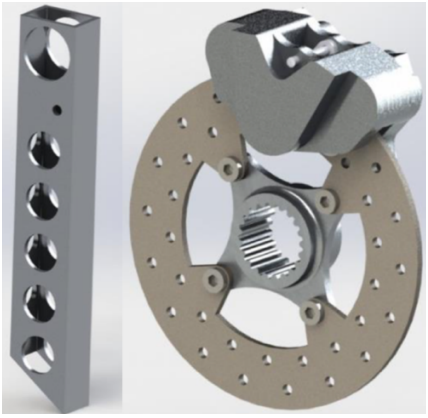


Figure 2: 2014 Braking System Design (5)

2016 Baja SAE Braking System [Richard T. Best]

The 2016 Baja team's main design goals for the braking system were to reduce weight, reduce cost, and ease of maintenance (6). Disc brakes were chosen for the car because they are exposed to the outside air which causes the heat to dissipate faster. For the rear, inboard brakes were used so that it gives easy access to the caliper and to the rotor in the event they need to be changed. The goal weight was set at 14 pounds and fortunately, they beat it by 0.29 pounds. The budget was set at $1100 for the braking system; however, they spend $150 extra and spent a total of $1250 (6). Comparing to 2014, many components were bought and only the pedals were manufactured. Figure 3 shows the difference between inboard brakes and outboard brakes.

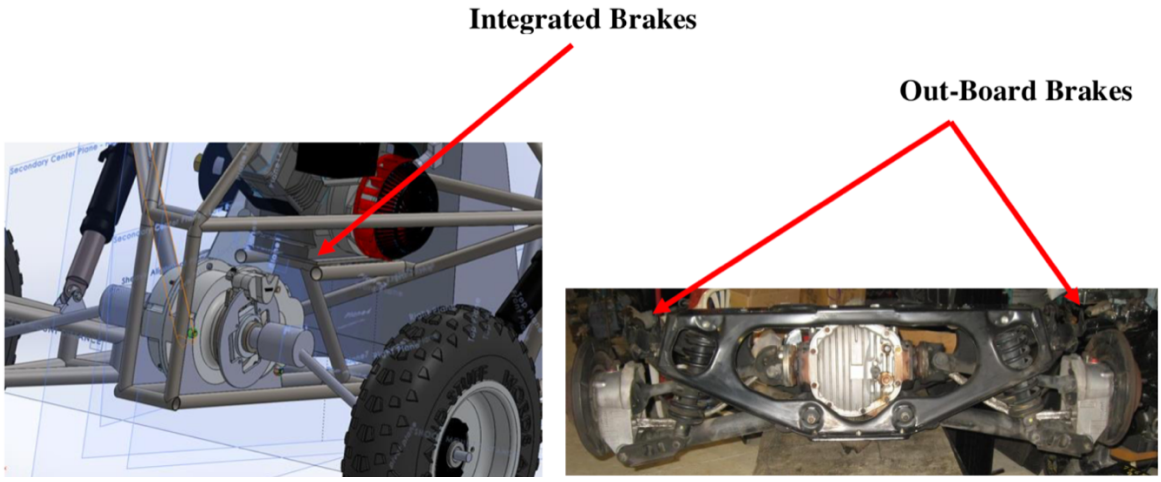


Figure 3: 2016 Braking System Design (6)

2017 Baja SAE Braking System [Kyle Cobbs]

Similar to 2014 and 2016, the 2017 Baja team also chose to design the braking system by using disc brakes. Not only did they design the braking system and pedals, but also, they designed the

floorboard that was attached to the pedals. The 3 main equations they used to calculate and choose the correct product were Pressure = Force/Area, Force = Pressure*Area, and Torque = Force*Distance (7). Multiple tests were run to ensure that the brakes are safe and working. The brakes were also tested when the car reached full speed. It was calculated that the stopping distance was 8.5 feet (7). Figure 3 below shows the pedal and floorboard design that was used in the 2017 Baja SAE car.

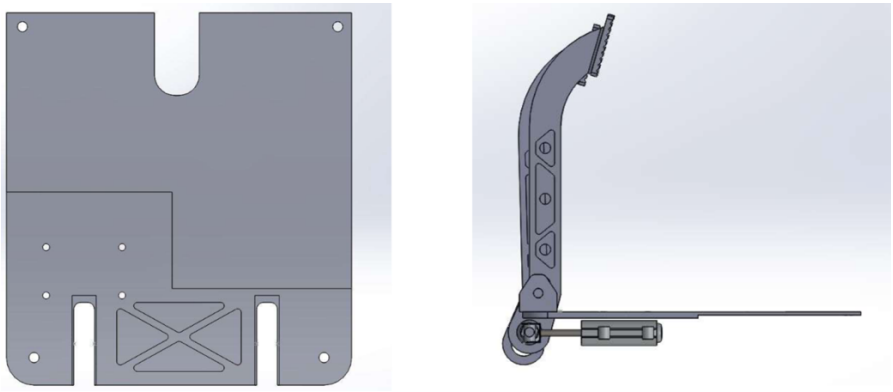


Figure 4: 2017 Braking System Design *(7)*

END USER

Since this is a team project, the goal of the project is to build a Baja car that meets the guidelines and rules outlined by the Baja SAE rulebook and perform well at the competition held at the end of the year. The braking system and pedals will be utilized by team members while competing at the Baja SAE competition; therefore, it is important for the design to be cost efficient and ergonomically safe for the driver.

SUMMARY OF RESEARCH

The main objective for this year's UC Baja team was to design a vehicle that not only met all the new rule changes outlined by the SAE rulebook, but also to reduce the weight and cost of the vehicle. To achieve these goals, the team is designing and building a brand-new vehicle. This will require teamwork, dedication, and hard work from each member of the team.

Based on previous year's designs and Baja vehicles, it can be concluded that disc brakes are the most cost efficient and weight reducers. Since there is a lot of heat involved while competing with the Baja vehicle, it is much favorable that we design a braking system that is exposed to outside air and not fixed inside a drum. The closer we place the brakes to the wheels, the better its performance. This is because during the brake test at the competition, it is a must for all 4 wheels to lock up. After researching and learning about braking systems, disc brakes at the wheel and rectangular-shaped pedals reduce the cost of the system and overall weight.

CUSTOMER FEATURES

In the following list, you will find the features that the end user of the Baja SAE car would expect to see, as defined by our team. It is important to note that this list does not represent an order of any kind.

1. Weight of the System
2. Cost of the System
3. Stopping Power
4. Ergonomics
5. Reliability
6. Pedal Response

Engineering Characteristics

In the following list, you will find the characteristics that satisfy the features outlined in the previous section, as defined by our team. It is important to note that this list does not represent an order of any kind.

1. Lightweight Material Selection
2. Affordable Materials
3. Design Concept
4. Design Quality
5. Braking Distance
6. Leg Room
7. Overall Size of Pedals
8. Ease of Maintenance

QUALITY FUNCTION DEPLOYMENT

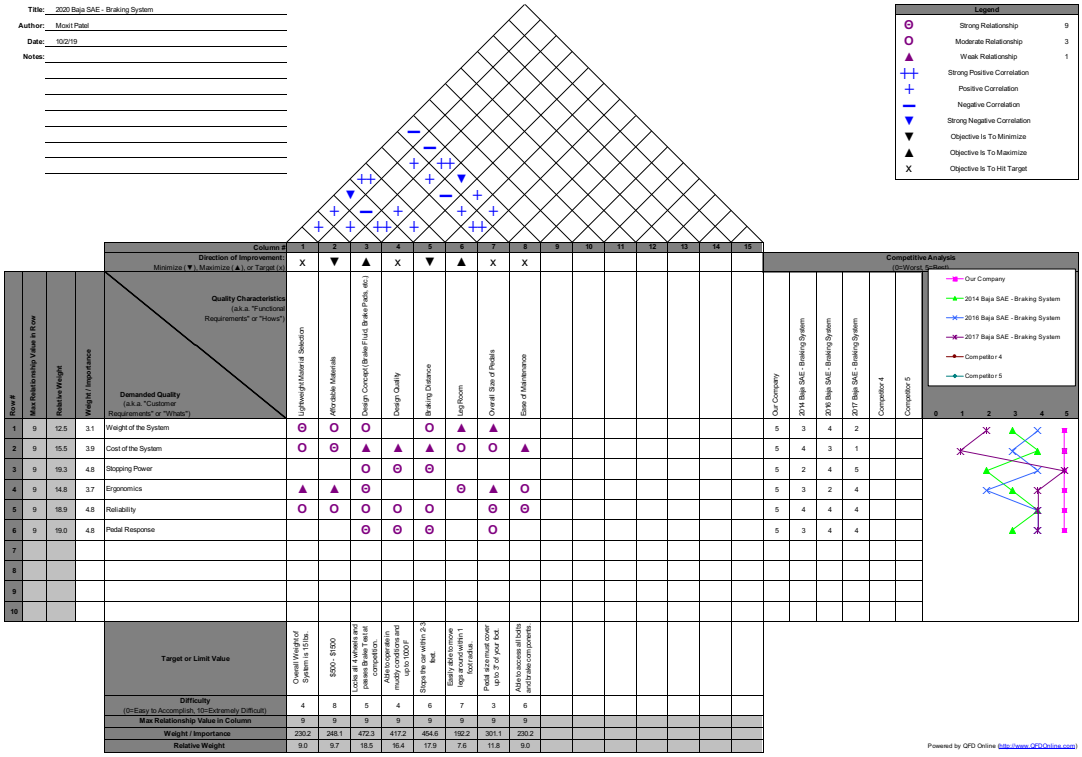


Figure 5: House of Quality

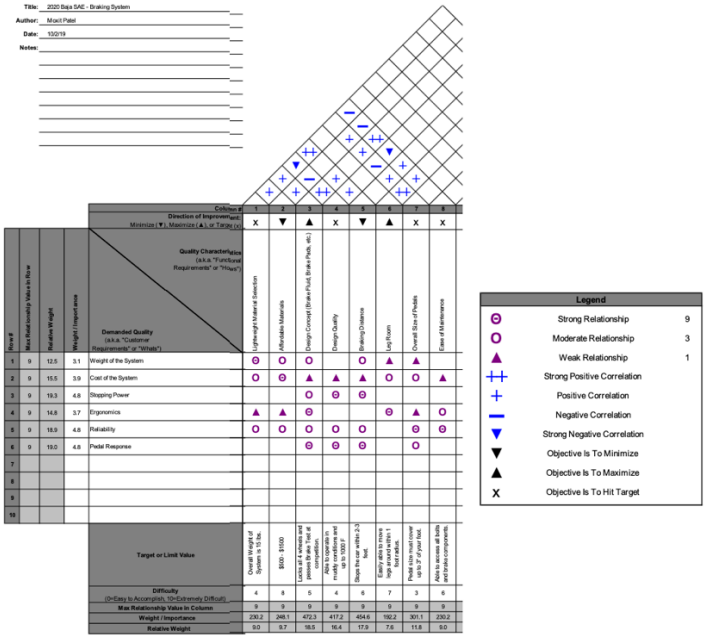
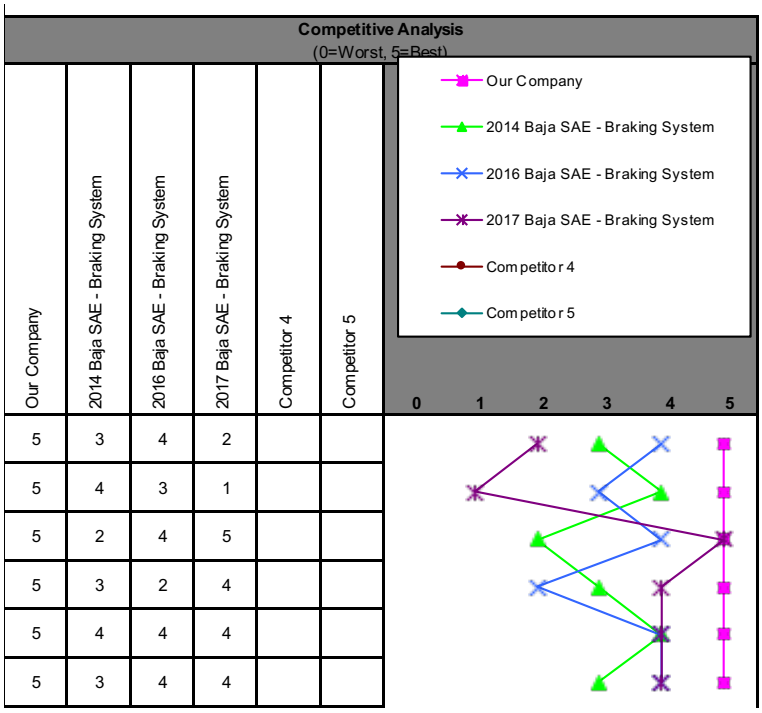


Figure 6: HOQ Correlations



Our Company	2014 Baja SAE - Braking System	2016 Baja SAE - Braking System	2017 Baja SAE - Braking System	Competitor 4	Competitor 5
5	3	4	2		
5	4	3	1		
5	2	4	5		
5	3	2	4		
5	4	4	4		
5	3	4	4		

Figure 7: HOQ Competitive Analysis

PRODUCT OBJECTIVES

Based on the results of the House of Quality (shown in Figures 5 - 7), the engineering characteristics are listed below in order of weighted importance, starting with the most important specification to the least:

1. Design Concept (18.5 %)
2. Braking Distance (17.9 %)
3. Design Quality (16.4 %)
4. Overall Size of Pedals (11.8 %)
5. Affordable Materials (9.7 %)
6. Ease of Maintenance (9.0 %)
7. Lightweight Material Selection (9.0 %)
8. Leg Room (7.6 %)

DESIGN

The brake pedal was designed to meet the requirements of the pedal ratio needed to add 200 lbf to the master cylinders. Both the gas and brake pedals have been salvaged from the 2013 Baja Car. According to the design shown below, the pedal is attached to a balance bar which in turn applies pressure to the master cylinder. Master cylinders are fastened to the mount plate shown. There are two tabs on either side of the mount plate which are welded onto the frame assembly. The rotors and calipers will be assembled as shown in the figure.

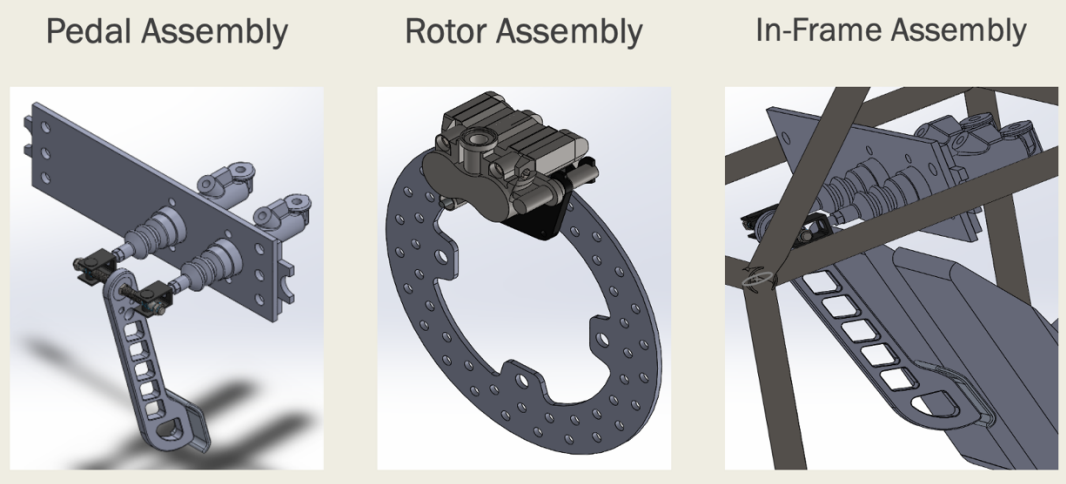


Figure 8: Final Designs & Model

PROJECT MANAGEMENT

BUDGET

Table 1: Proposed Budget

Category	Projected Cost ($)
Material	$800
Tools	$100
Hardware	$100
Testing	$200
Total	$1,200

Table 2: Actual Budget

Part Name	Part #	Quantity	Unit Price	Total Price
Front Rotors (RH & LH)	5244314	1	$78.95	$78.95
Front Calipers (LH)	1911540	1	$13.99	$13.99
Front Calipers (RH)	1911541	1	$14.99	$13.99
			Total Cost	$107.93

SCHEDULE

Table 3: Proposed Schedule

	September	October	November	December	January	February	March	April	May
Project Planning									
Research									
Design									
Modeling									
Order Materials									
Manufacture									
Testing									
Tech Expo									
Presentation									
Graduation									

Table 4: Actual Schedule

	September	October	November	December	January	February	March	April	May
Project Planning									
Research									
Design									
Modeling									
Order Materials									
Manufacture									
Testing									
Tech Expo									
Presentation									
Graduation									

PLAN TO FINISH

- The project is incomplete due to the COVID-19 outbreak.
- Pedal Assembly has been assembled to the Balance Bar.
- Master Cylinders have been selected; they need to be assembled onto the Mount Plate once it is ready.
- Tabs need to be cut and welded onto the Frame Assembly
- Rotors & Calipers have been ordered and received; they need to be assembled onto the Hub Assembly once ready.
- Parts that still need to be purchased/selected:
    - Fastening hardware
    - Brake Fluid
    - Brake Lines & Fittings
    - Hoses
    - Fluid Reservoirs
- All the parts that have been started to manufacture are in a box in the black cabinet by the 2013 Baja Car. (Ex. Pedal w/balance bar, gas pedal, master cylinders, mount plate, calipers, rotors, etc.)

WORKS CITED

1. **SAE.** About Baja SAE Series. *SAE International.* [Online] [Cited: September 6, 2019.] https://www.sae.org/binaries/content/assets/cm/content/attend/2018/student-events/baja-sae/history.pdf.
2. **Ofria, Charles.** A Short Course on Brakes. *Carparts.* [Online] [Cited: September 30, 2019.] https://www.carparts.com/brakes.htm.
3. **Brauer, Karl.** Brakes: Drums vs. Disc. *Edmunds.* [Online] Edmunds.com, May 11, 2009. [Cited: September 30, 2019.] https://www.edmunds.com/car-technology/brakes-drum-vs-disc.html.
4. **Leanse, Alex.** How Disc Brakes Work? *YourMechanic.* [Online] November 30, 2015. [Cited: September 30, 2019.] https://www.yourmechanic.com/article/how-disc-brakes-work.
5. **Murray, Kyle.** *2014 University of Cincinnati Baja SAE Braking System.* Cincinnati : CEAS Library, 2014.
6. **Best, Richard.** *2016 Bearcats Baja Braking System.* Cincinnati : CEAS Library, 2016.
7. **Cobbs, Kyle.** *2017 SAE Baja - Brakes.* Cincinnati : CEAS Library, 2017.

APPENDIX A: BAJA SAE RULES

B.7.1 - Brake System

The vehicle must have a primary hydraulic braking system that acts on all wheels and is operated by a single foot pedal. The pedal must directly actuate the master cylinder through a rigid link (i.e., cables are not allowed). The brake system must be capable of locking and sliding all wheels, both in a static condition as well as at-speed on pavement and on unpaved surfaces. Brake pedals shall be fabricated or machined from steel or aluminum and be designed to withstand a maximum brake pedal force of 450 lbf (2000 N).

B.7.1.1 - Independent Circuits

The braking system must be segregated into at least two (2) independent hydraulic circuits such that in case of a leak or failure at any point in one system, effective braking power shall be maintained on at least two wheels. Teams are encouraged to construct each circuit to have its own physically separate fluid reservoir. A dammed, single reservoir serving two circuits is currently permitted. Teams using a dammed, single reservoir shall prove to the NTI that the reservoir is appropriately dammed.

B.7.1.2 - Brake Location

The brake(s) on the driven axle must operate through the final drive. Inboard braking through universal joints is permitted. Braking on a jackshaft through an intermediate reduction stage is prohibited.

B.7.1.3 - Cutting Brakes

Hand or feet operated “cutting brakes” are permitted provided the section B.7.1 is also satisfied. A primary brake system must be able to lock all four wheels with a single foot. If using two separate pedals to lock two (2) wheels apiece; the pedals must be close enough to use one foot to lock all four wheels.

Any and all brakes, when actuated, shall cause the brake light to illuminate.

B.7.1.4 - Brake Lines

All brake lines shall be securely mounted to the vehicle and not project below the vehicle frame or suspension components.

All brake lines shall be routed and oriented such that they are not pinched by steering or suspension parts, nor engaged with sharp edges.

All brake lines shall have full range of motion within the steering and suspension system.

At no time shall the brake lines be loaded in tension or become engaged with the vehicle’s tires and wheels.

All brake lines shall be designed for the pressures expected in the braking system and be chemically compatible with the brake fluid in use.

No brake line may be constructed of plain, plastic tubing.

APPENDIX B: SAMPLE SURVEY

Customer Survey
2020 Baja SAE – Braking System

Name: _____ Date: _____

The Baja SAE All-Terrain Vehicle will be built according to the rules and regulations outlined by the SAE Organization. Also, the car will be taken to an International competition held in April of 2020. The results of this survey will be used to prioritize various features to maximize customer satisfaction.

How important is each feature in a Braking System?

Please circle the appropriate answer.	**1: Low importance**				**5: High importance**	
Weight of the System	1	2	3	4	5	N/A
Cost of the System	1	2	3	4	5	N/A
Stopping Power	1	2	3	4	5	N/A
Ergonomics	1	2	3	4	5	N/A
Reliability	1	2	3	4	5	N/A
Pedal Response	1	2	3	4	5	N/A

How satisfied are you with current Braking System?

Please circle the appropriate answer.	**1: Unsatisfied**				**5: Very Satisfied**	
Weight of the System	1	2	3	4	5	N/A
Cost of the System	1	2	3	4	5	N/A
Stopping Power	1	2	3	4	5	N/A
Ergonomics	1	2	3	4	5	N/A
Reliability	1	2	3	4	5	N/A
Pedal Response	1	2	3	4	5	N/A

How much would you be willing to invest in this vehicle?

$0 - $500 $500 - $1000 $1000 - $1500 $2000 +

Figure 9: Customer Survey

APPENDIX C: SURVEY RESULTS

Question 1: How important is each feature in a Braking System?

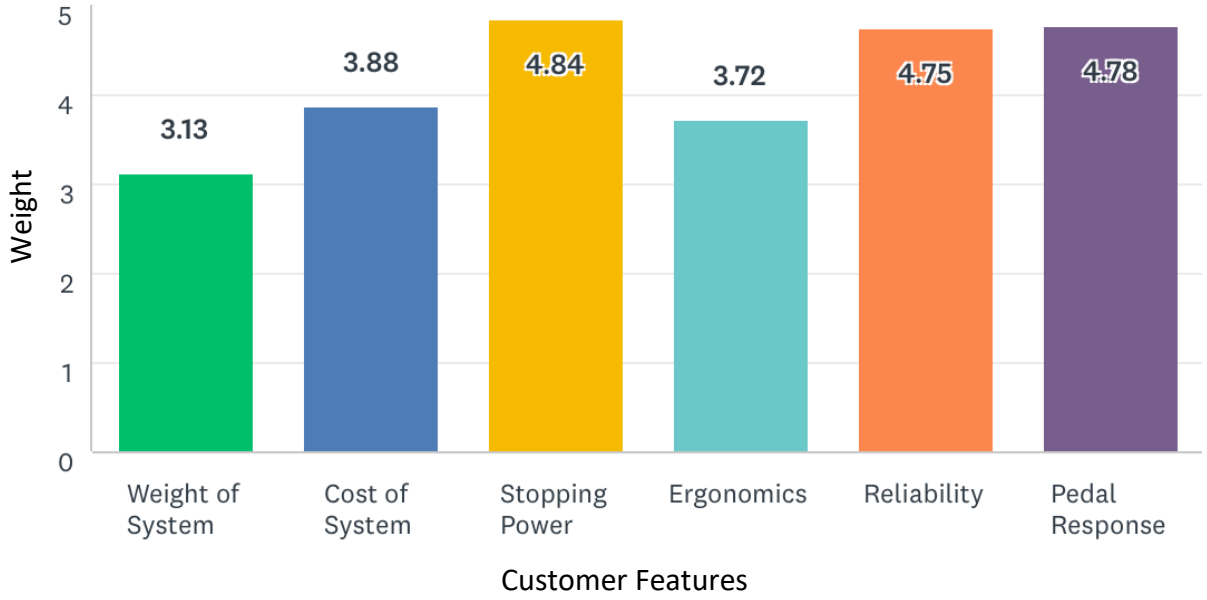


Figure 10: Survey Question 1 Results

Question 2: How satisfied are you with the current Braking System?

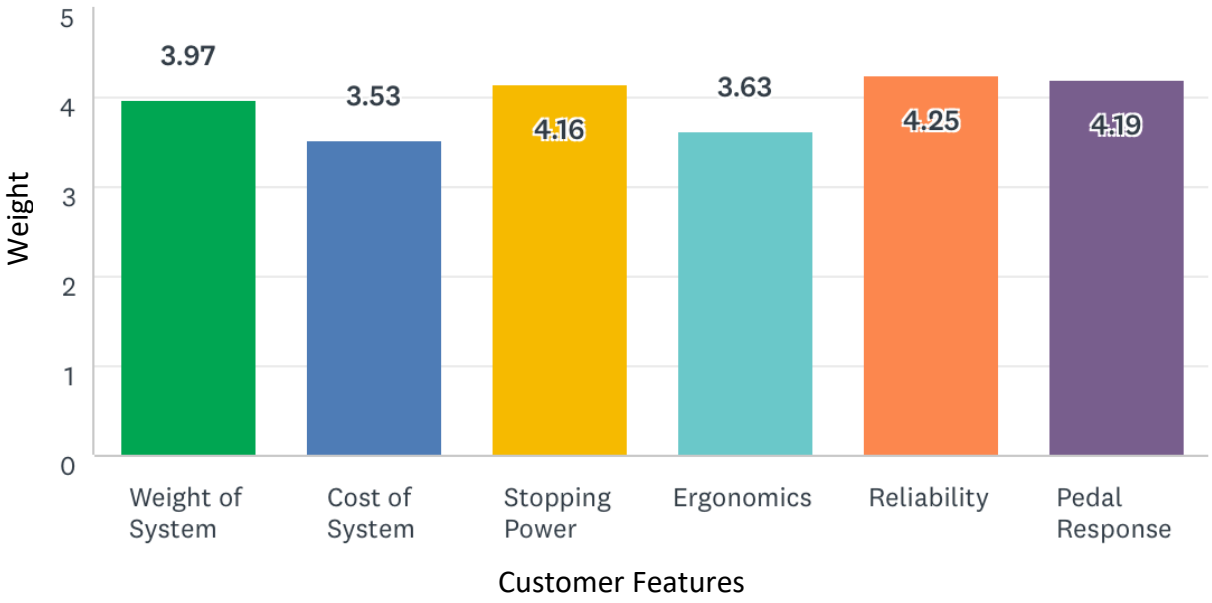


Figure 11: Survey Question 2 Results

Question 3: How much would you be willing to invest in this vehicle?

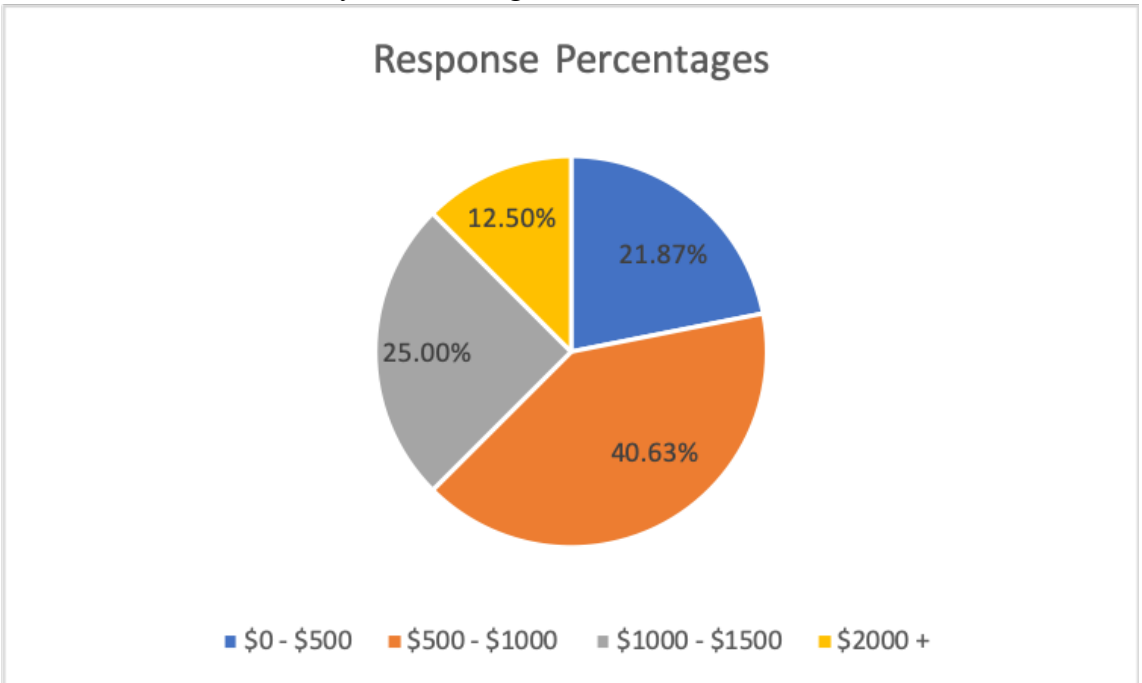


Figure 12: Survey Question 3 Results