FINAL REPORT

BUSINESS PLAN

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MAE-540- 2017- Group 1

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1. BUSINESS OPPORTUNITY

1.1 Business objective

The goal is to develop a compact, reliable and user friendly anti-theft device for bicycles at an affordable cost as low as $25. The product is named as ‘iGuard’.

1.2 Product description

When bicycle is parked in public places, one would worry that someone would steal their bicycle or even the bicycle parts. So, secure the bicycle with the ultimate secure product - iGuard and say goodbye to thieves and unwanted intruders.

The iGuard is designed in the form of a bottle holder (as a disguise), which can hold a normal sized bottle. The iGuard comes at a price as low as 25$, so it is best suited for college students.

Figure 1: The iGuard fitted to the bicycle and holding a bottle

Material: PLA
Size: 140 X 110 X 75 mm / 5.5 X 4.33 X 3 Inch
Battery Information: A 9V non-rechargeable and easy to replace
Features:

- Notification alerts i.e. text and email alerts as soon as the bicycle is tampered.
- Alarm will sound as soon as bicycle is tampered to alert the bystanders.
- The iGuard is compact and user friendly.

The iGuard utilizes the IoT technology to enhance its functionality. The iGuard works with the help of shock sensor, Arduino microprocessor and the Blynk app. The price of all the electrical components is included in the cost of the product. The Blynk app is available for free on App store and Google Play store. So, the user must download this app on his smartphone to receive the notification alerts.

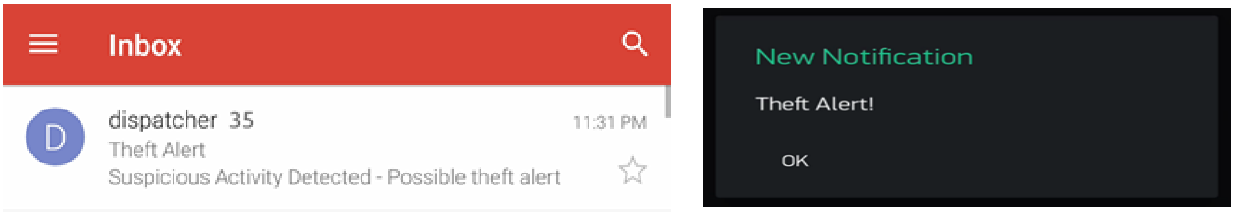

Figure 2: IoT: E-mail and Blynk notification

1.3 Market analysis

A market analysis was performed to study what types of products are already out there and identify their market gaps (if any) that exist. Figure 3 below shows the current state of the market and highlights a key area.

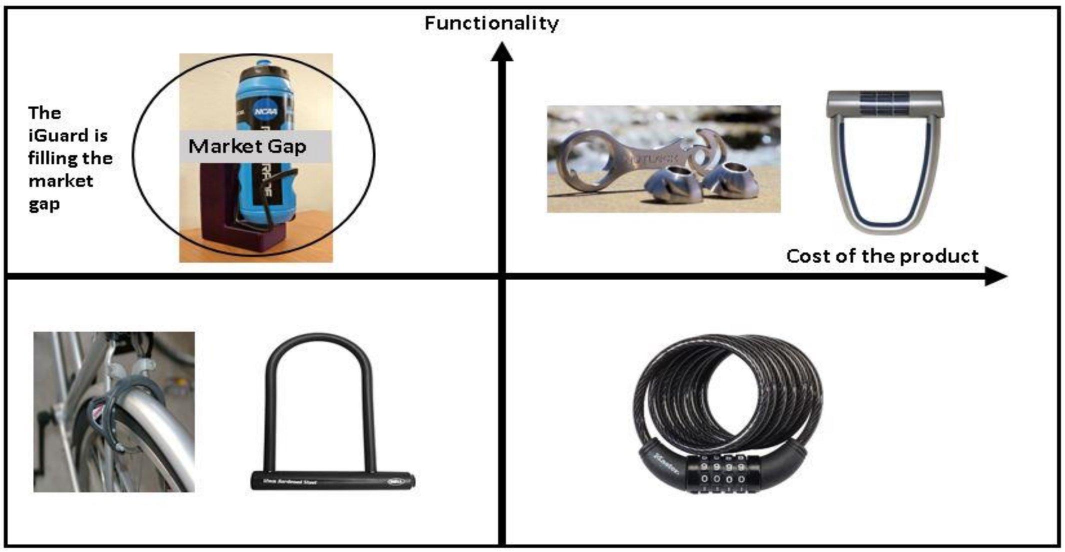

Figure 3: Market Gap

Name of the Product	Price	Functionality
iGuard	$25	Notification alerts, Alarm using IoT
U lock	$20-50	Mechanical Lock
O lock	$10-15	Mechanical Lock (only protects the rear wheel)
Chain Lock	$30-80	Mechanical Lock (very easy to cut)
Nut lock	$80	Mechanical Lock (expensive)
Skylock	$200	Very expensive

Table 1: Solutions for bicycle theft

A market analysis is as shown in the figure on the previous page. A recent product in the market is Skylock - which has variety of functionalities but priced at a whooping rate of $200, which targets high end users. The same is a case of Nutlock, which uses a unique key combination to unlock. O-Lock and U-Lock target low end users. However, the thieves have the tools necessary to break into these mechanical locks and hence are rendered ineffective. Chain lock is highly priced and can easily be cut by the thief.

The iGuard is the most affordable product with multiple functionalities such as triggering of alarm, text and email alerts

Most of the bicycle locks available in the market are expensive and mostly protect some parts of the bicycle. But, the iGuard has functionalities that are found only in expensive products and is also priced at a very reasonable price. Therefore, iGuard – a low-cost alternative fills this gap that currently exists in the market and remains affordable to the consumers.

A market survey and analysis was conducted to identify the need of our potential customers and what attributes we can incorporate into our product to best serve their needs. From the survey, over 118 responses were recorded among students at Arizona State University.

From the survey, it was evident that price had the highest impact on customer opinion – where a lower price was obviously preferred to a higher one. The preference of deterrence method was an immobilization technique. However, this was closely followed by GPS and Alarm showing that this method did not have a significant impact on consumer decisions.

Survey results also showed that there was almost no significant preference to battery life, however non-rechargeable battery was preferred over a rechargeable option. For physical attributes, consumers preferred a plastic housing with no preference towards product size.

For Survey results, refer to appendix 3

1.4 Capital and personnel resources

When it comes to large scale production, the equipment used would be plastic injection moulding and this equipment would cost nearly $24000. The rent for this place is $1200 monthly and adding to other utilities comes to $17000 annually. The sensor used would be a shock sensor and an Arduino Uno board, so basically most of the electronics would incur a price of $15 per product. The marketing would involve a banner and paper hand-outs for advertising. The warehouse needs to be set up and the product must be transported with ease. The sales would increase by 10 percent every year. The product is marked up at $33 and is discounted a value of 10 percent. Hence the selling price of iGuard is $30.

2. FINANCIAL DATA

2.1 Capital equipment and supply list

Item	Use	Cost (per year)
Electronic workstation	Manufacturing	$1400
Line worker	Manufacturing	$ 150400
Office	Property/Rent	$15,300
Energy costs	Property	$1400
Sensor/Electronics Cost	Manufacturing	15/part
Marketing	Marketing	$100
Distribution/Supply Management	Distribution	$300

Table 2: Capital equipment and supply list

The total capital equipment cost is $168900. Table 2 shows the cost incurred for capital equipment and supply list. An initial amount of $200 will be required for the tools at each workstation. In addition, there is maintenance and repair at the entire supply chain which would ramp up the annual cost on electronic workstation to about $1200. The trainee/line worker should be highly skilled with the manufacturing equipment and must undergo a training which would cost about $400. These highly skilled line workers will be paid $50000 annually. As 3 skilled employees work in a factory, the cost on their yearly expense would come to $150000.

2.2 Break-even analysis

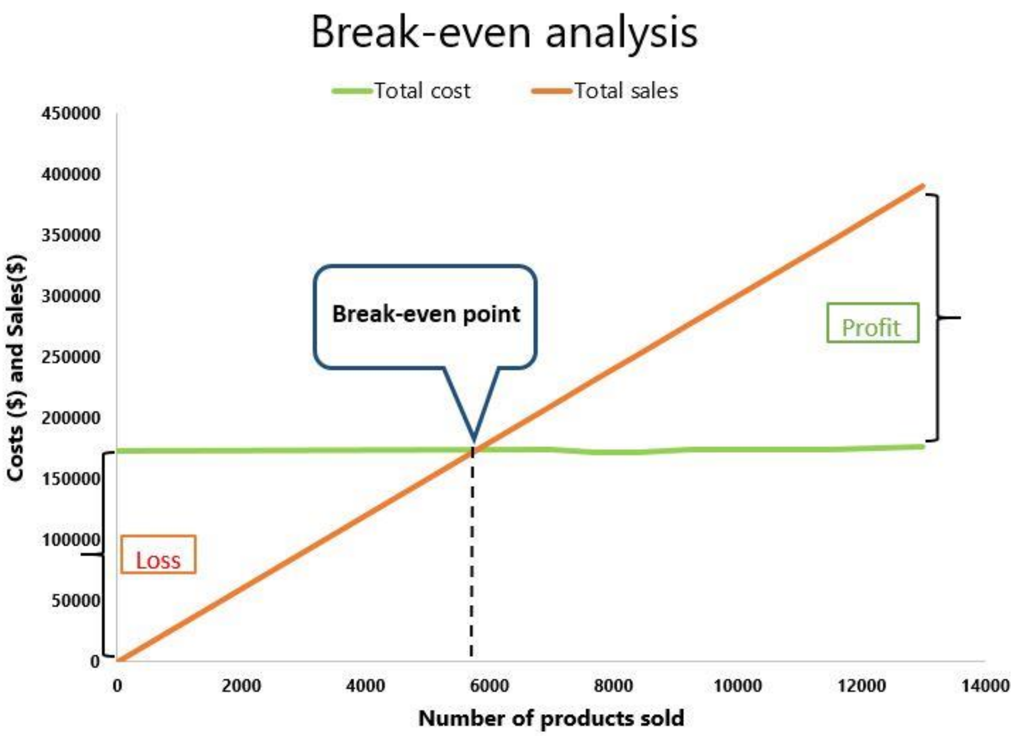

Figure 4: Break-even analysis chart

Figure 4 shows the break-even analysis of the iGuard. The break-even will happen at the beginning of the third year. A funding of $50000 would be received from the Kickstarter campaign. This amount will be used to set up the warehouses. The base location the team has planned on is Tempe AZ. This location is chosen as the initial bicycle survey was targeted at students of Arizona state university and these students become the primary customers. A shop is also set up at Arizona state university and many perks and discounts will be made available to the Sun Devils. University of Arizona is also in consideration after we successfully launch iGuard at ASU. We are then planning on expanding the business to other locations across the US. This product was tested and from the feedback, it is estimated that about 7000 products would go in the first batch of manufacturing and subsequently there would be a 10 percent increase in the production. The research facility lab would be set up next to warehouse and would provide more insights on improving surface finish and making the product more compact.

2.3 Summary of Pro-forma income and cost projections

Year	0	1	2	3	4	5
Units sold per year	0	7000	7700	8400	9240	11500
Sales price per unit	0	30	30	30	30	30
Fixed cost per year	168900	168900	168900	168900	168900	168900
Variable cost	2000	2000	2500	3000	5000	5500
Total cost	170900	170900	171400	171900	173900	174400
Total sales	0	210000	231000	252000	277200	345000
profit/loss	-170900	39100	59600	80100	103300	170600
Net amount	-170900	-131800	-72200	7900	111200	281800

Table 3: Pro-forma income and cost projection

The fixed cost details are shown in Table 2. The variable cost is accounted due to inflation, changing markets, manufacturing equipment costs, material costs and increase in rate of pay for the employees. Table 3 shows a summary of pro-forma income and cost projections. The sales increase by 10 percent every year and the company would be in profit and would break even at the beginning of the third year.

3. SUPPORTING DOCUMENTS

3.1 Existing patents

- **Vehicle security - US 20030107479 A1**
  This patent is about an alarm system used with vibration sensor to act as a theft deterrent. This product uses two rechargeable batteries to power the device and could be placed on the bicycle frame, seat or handlebar. The iGuard would not breach the patent because it isn't just a product to sound an alarm. iGuard is much more than that — it differs from the aforementioned patented device in the design and the IoT functionality aspects.

- **Proximity-based bicycle alarm - US 20160121951 A1**
  This patented system is basically an alarm system that uses a touch sensor electrically connected to a vehicle frame. Based on the proximity of the thief/intruder to the bicycle frame, the sensor outputs an electric signal to the alarm to alert the bystanders. iGuard does not use a touch sensor and does not involve proximity at all. It is disguised as a bottle holder and moreover, sends notification to the user of an attempted theft. The said device does not infringe the patent of the proximity based bicycle alarm.

- **Bicycle theft monitoring and recovery devices -US 20130150028 A1**
  In this patent, claims are made for asset monitoring and tracking. iGuard differs from this one, as it does not have a GPS on the vehicle. iGuard does not come with an app to track the bicycle's location and does not log the activities and provide asset status on a display.

- **Anti-theft system and method - US 7961081 B2**
  The claims made here include accelerometer sensor to detect the movement of a 'movable object'. The system includes a GPS receiver, pager and sends text using GSM, GPRS, and SMS. iGuard uses a shock sensor, does not use a pager, GPS and none of the services mentioned above.

3.2 Technical analysis and benchmarking

Changes are made to the original design of the housing. The basic concept from the original model was maintained, but it is integrated with a water bottle holder to utilize the water bottle mounting system which is already present on most of the bicycles and as an attempt to disguise the anti-theft device. Electrically, our product underwent a major design change from the original 6-axis IMU sensor to a shock sensor.

3.2.1 Bottle Holder design

The objectives for the mechanical housing are:

- Store the electronics and hardware setup of the product.
- Securely mount to majority of the bicycles. The bottle holder design utilizes the water bottle mounting holes that are on most bicycle frames as a way to easily and securely integrate the product onto the user's bicycles.
- Make it difficult for a thief to disable the product, so it is designed to look like a water bottle holder as a disguise with the idea that a thief will not know about the product.

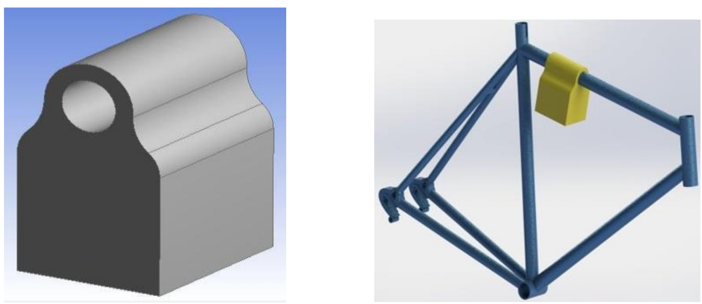

Figure 5: Initial Design

Figure 6: Current Design

The updated design will integrate with a metal water bottle holder. This is because the 3D printed PLA material would not be well suited to the fatigue cycles of a water bottle holder as the bottles are repeatedly inserted and removed.

A large back cover is implemented to allow the users to replace the battery and easy access to the sensors for troubleshooting. This is ideal at the prototype level; however future iterations of the product will minimize the access to the device electronics to avoid thieves from tampering or damaging the components.

The housing thickness from the previous design was maintained for this updated design. From a structural standpoint, the two designs should be very similar and therefore the optimization efforts from before were assumed to be valid. This assumption was verified in an FEA simulation to verify the stress in the housing is within the limits of our chosen materials.

For optimization results (DOE, Sensitivity and response surface) refer to Appendix 1.

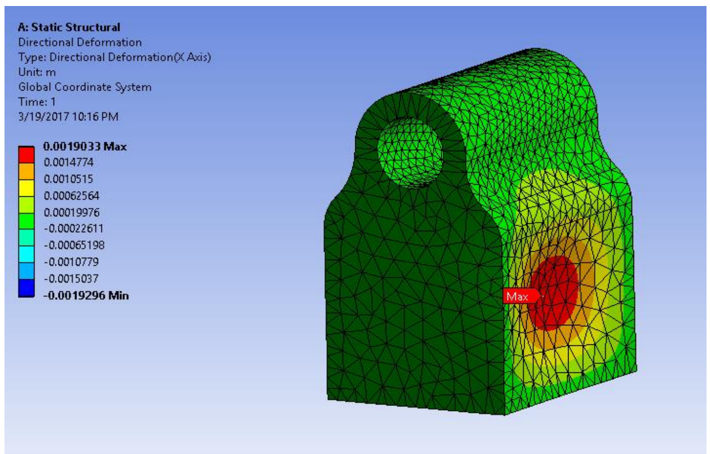

Figure 7: FEA Simulation of initial design

The final design is 3D printed with purple PLA plastic from a Maker-Bot extrusion printer that was available at Arizona State University. The metal bottle holder that would be integrated with iGuard, is a standard bottle holder available at most bicycle shops.

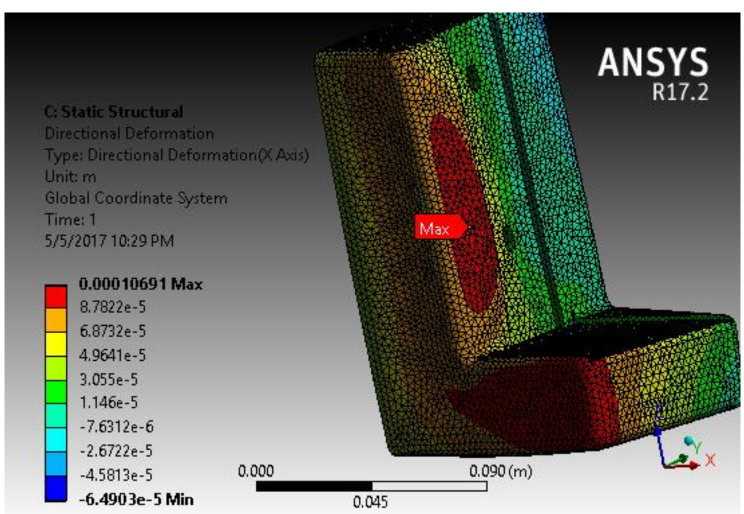

Figure 8: FEA simulation of current design

3.2.2 Sensor and IoT

Shock sensor is now used in place of the 6-axis IMU sensor.

- **IMU**

The Inertial measurement unit (IMU) contains a MEMS accelerometer and a MEMS gyroscope. Depending on the application, either a 9DoF or a 6DoF IMU can be chosen. A 6DoF captures acceleration and gyroscope readings each in X, Y, Z direction. The original idea being that if the bicycles was being stolen or tampered with, the IMU would detect the motion, sound an alarm, and send the user a notification after a predetermined threshold was met.

- **Shock Sensor**

The shock sensor is a simpler device. It utilizes a Gaoxin Switch. This switch consists of a centre terminal (Terminal A) and a secondary terminal that is a spring that surrounds the centre post (Terminal B). When a sufficient force or shock is transferred to the switch, the spring terminal moves and shorts both terminals together sending a signal to our Arduino Controller.

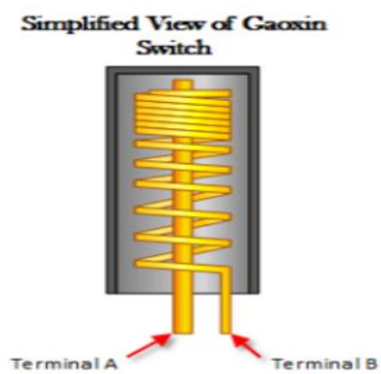

Figure 9: Internals of shock sensor (Gaoxin Switch)

Reasons from switching the IMU to the shock sensor is given below as a summary of the trade study conducted between the two sensors.

Attribute	IMU	Shock Sensor
Reliability	★★★	★★★
Affordability	★★★	★★★★
Accuracy	★★	★★★★★
Development time	★★★★	★★★

Table 4: IMU vs Shock Sensor

The simple design of the shock sensor makes it a very simple, and reliable choice. Testing showed that this device produced very consistent results. On the other hand, the output of the IMU sensor is very noisy. The IMU sensor was able to detect motion of large magnitude. However, the quick and low magnitude events associated with bicycle theft are difficult to recognize. The sensitivity of the shock sensor enabled these motions very easy to pick up.

Another reason for using shock sensor is the simplicity of the output whereas the IMU was able to give six separate values associated with motion. The primary objective is to detect the disturbances experienced by the bicycles and this is possible using the binary output of the shock sensor.

The Arduino board can be programmed to count the number of times the terminals are shorted. This means that the different shock events can be classified based on the number of "counts". In order to test the reliability of this method, a series of tests are performed on the shock sensor. With the sensor mounted on the bicycles, 10 measurements were taken of a series of example scenarios. The scenarios ranged from minor bumps and drops to entire bicycle thefts. These reliability tests are summarized in the table below.

	Test Scenario				
Test #	**Bump**	**Drop**	**Seat Theft**	**Wheel Theft**	**Bicycle Theft**
1	4	12	15	10	30
2	5	10	14	13	28
3	5	12	14	14	27
4	6	13	15	13	26
5	4	12	14	14	24
6	4	9	13	14	31
7	6	11	16	12	27
8	5	15	16	19	22
9	5	10	13	19	23
10	4	9	13	20	29
Mean	4.8	11.3	14.3	14.8	26.7
Std Dev	0.8	1.9	1.2	3.4	3.0
-3σ Value	2.43	5.63	10.82	4.72	17.75
$+3\sigma$ Value	7.17	16.97	17.78	24.88	35.65

Table 5: Shock Sensor Reliability Test Results

The two objectives of the above testing are to evaluate the risk that the threshold could trigger a false positive/negative. In other words, the device alerts the user of a theft when there is no one, or the device does not alert of a theft when there is. Bumps or drops are events that we would like to trigger an alarm for, however they are not events where we want to send a notification. Therefore, the alarm threshold will be set at 3. This nearly covers the -3 sigma level for bumps. We want the notification threshold to protect against component and bicycle theft. Therefore, this value is driven by the -3 sigma value for seat theft. Thus, a value of 9 is used. In other words, after 3 consecutive alarms, a notification will be sent.

Once the threshold is set, testing is done to verify that everything is working properly. The above scenarios were repeated 10 times each. During every test, the device functioned as expected and no false or missed reporting were made. During the bump and drop tests, only alarms were sent. During tampering/theft events, alarm and notification was sent with 100% reliability.

For calibration and testing of IMU sensor, please refer to Appendix 2.

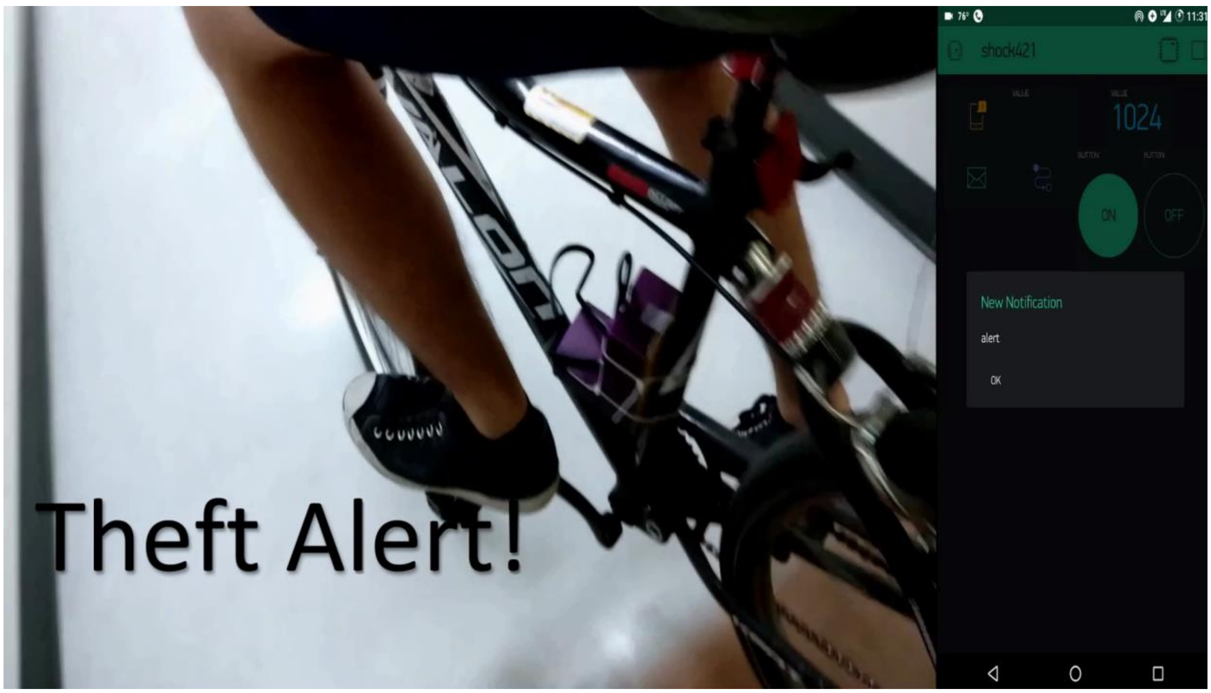

Figure 10: Notification on Blynk app

Appendix 1

DESIGN OF EXPERIMENTS

As the thickness of the housing is the only design parameter, DOE with ten design points has been conducted. Optimal Space-Filling Design method is selected as it can distribute the design parameters equally throughout the design space with the objective of gaining the maximum insight into the design with the fewest number of points.

CONSTRAINTS

a) Minimizing the Mass of the housing
b) Equivalent stress maximum is less than the yield stress of housing material (PLA). A factor of safety of 1.5 was included resulting in a value of 18 MPa.
c) First resonance frequency is greater than or equal to 600 Hz. The random response spectrum from cycling ranges from 10 to 300 Hz. This is due to imperfections in roads that cause the bicycles and cyclist to vibrate. 600 Hz was chosen because we wanted to maintain at least 1 octave distance between the chassis resonance and the random response spectrum.

RESPONSE SURFACE MODEL

A generic aggregation response surface model was chosen for this analysis. This is a generic model that is ideal for straight-forward, highly linear analyses. The predicted vs. observed values are plotted below for the equivalent stresses, geometry mass, and natural frequency.

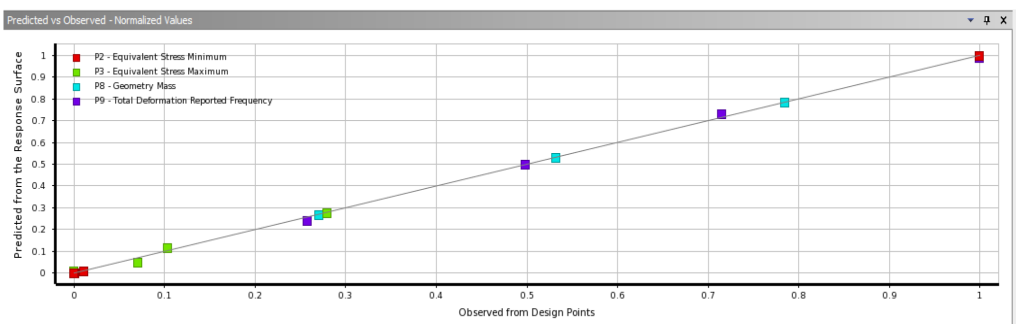

Figure 11: Graph of predicted vs observed values

The relative absolute error for the parameters varied from 0% to 3% (0% being the best). This shows that our response surface model accurately predicts our desired parameters within 3% of the correct value. Similarly, our R^2 value, or the coefficient of determination was very close to 1. Coefficients of determination are tabulated below:

Equivalent Stress Min	Equivalent Stress Max	Geometry Mass	Frequency
1	0.99882	1	0.99873

Table 6: Coefficients of determination of output parameters

SENSITIVITY ANALYSIS

The output parameters proved to be very sensitive to the DOE analysis. All 4 parameters showed 100% local sensitivity to material thickness. This confirms that our initial assumption was correct, since all 4 parameters vary to some degree with the material thickness.

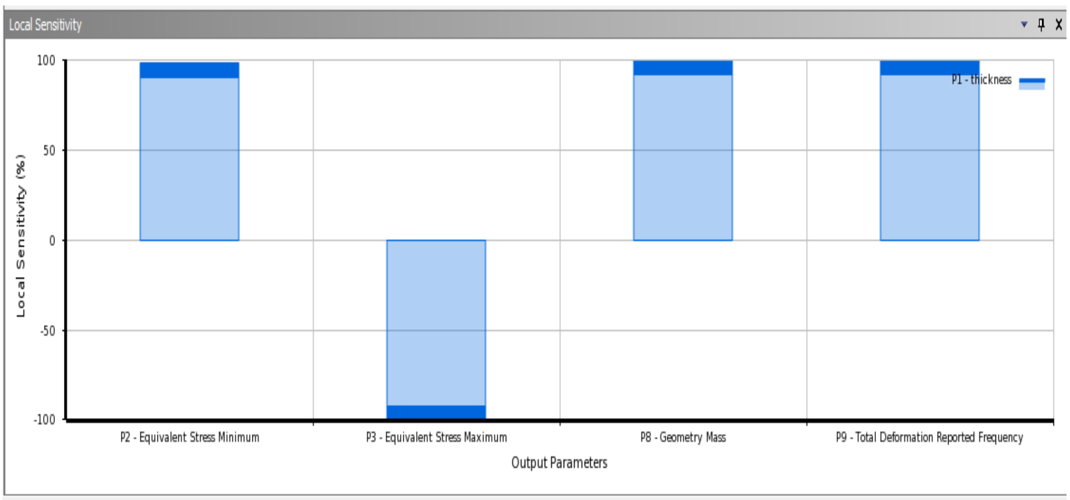

Figure 12: Sensitivity analysis

Geometry mass is directly related to the material volume which is directly related to the material thickness. The equivalent stress is directly related to the area moment of inertia which is also dependent on thickness. Finally, the resonance frequency is directly related to the material stiffness which is a function of the material's modulus of elasticity, cross sectional area and length.

SENSITIVITY ANALYSIS AFTER OPTIMIZATION

Initially screening method is used to get an idea of how the parameters of the system would behave. Since the system only had one objective (minimize mass), NLPQL was chosen. Other parameters were set as constraints. The results of the screening and NLPQL were identical, but the NLPQL method converged after 20 evaluations while the screening method converged after 1000 evaluations.

	A	B	C	D	E	F	G
	Table of Schematic C4: Optimization						
1	Name	Parameter	Objective		Constraint		
2			Type	Target	Type	Lower Bound	Upper Bound
3	Minimize P8	P8 - Geometry Mass	Minimize		No Constraint		
4	P9 >= 600 Hz	P9 - Total Deformation Reported Frequency	No Objective		Values >= Lower Bound	600	
5	P3 <= 1.8E+07 Pa	P3 - Equivalent Stress Maximum	No Objective		Values <= Upper Bound		1.8E+07
*		Select a Parameter					

Figure 13 Constraints in optimization

DISCUSSION OF OPTIMIZATION RESULTS

The results of the optimization are summarized in the figure given below.

	A	B	C	D	E	F
	Table of Schematic C4: Optimization					
5	Optimization Method					
6	NLPQL	The NLPQL method (Nonlinear Programming by Quadratic Lagrangian) is a gradient-based algorithm to provide a refined, local, optimization result . It supports a single output parameter objective, multiple constraints and is limited to continuous parameters. The starting point must be specified to determine the region of the design space to explore.				
7	Configuration	Approximate derivatives by Central difference and find 50 candidates in a maximum of 20 iterations.				
8	Status	Converged after 20 evaluations.				
9	Candidate Points					
10		Starting Point	Starting Point (verified)	Candidate Point 1	Candidate Point 2	Candidate Point 2 (verified)
11	P1 - thickness (cm)	0.35		0.16681	0.35	
12	P3 - Equivalent Stress Maximum (Pa)	4.7434E+06	4.4516E+06	1.8E+07	4.7434E+06	4.4516E+06
13	P8 - Geometry Mass (kg)	0.58092	0.58092	0.28452	0.58092	0.58092
14	P9 - Total Deformation Reported Frequency (Hz)	2915.6	2916.8	1519.5	2915.6	2916.8

Figure 14 Optimization results in ANSYS

Candidate point 1 was the optimal design scoring the best in all categories. A device thickness of 0.16681 cm keeps the maximum stress values below our threshold of 18 MPa. It also has a resonant frequency far beyond our constraint of 600 Hz. This is illustrated in the figure below.

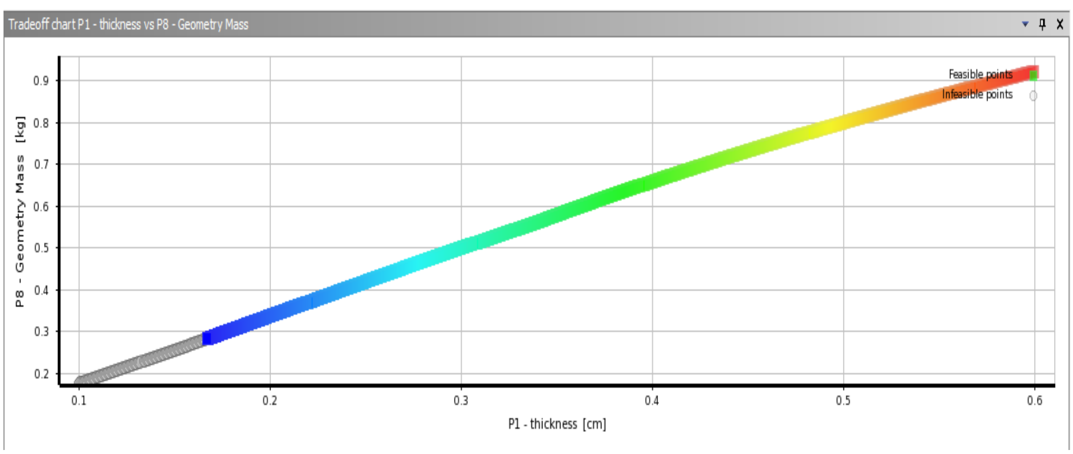

Figure 15 Tradeoff chart in ANSYS

This figure outlines the results of the initial optimization using the screening method. This was the first method implemented to get an idea of the behavior of our system. You can see the feasible points (colored) and the infeasible points (grey). Since geometry mass and thickness are linearly related, the furthest left feasible point is the “optimal” material thickness.

This design results in a geometry mass of 0.29 kg. This is over a 50% change from the starting point of 0.58 kg and will ultimately result in a design that accomplishes our goal of minimizing the weight while maintaining survivability.

Appendix 2

ELECTRICAL ANALYSIS OF IMU

The first step to address the electrical challenges was to get the IMU sensor working with our Arduino control board. Once the Arduino code was set up, the device could continuously monitor by utilizing the features of the IMU sensor. However, continuous monitoring only solves part of the challenge. Calibrating the sensors to detect when a notification/alarm needs to be sent was the real challenge.

To calibrate the sensors accurately, a large amount of data was needed. Below is a picture of our test setup. Several different scenarios were simulated ranging from minor tampering to bicycle riding.

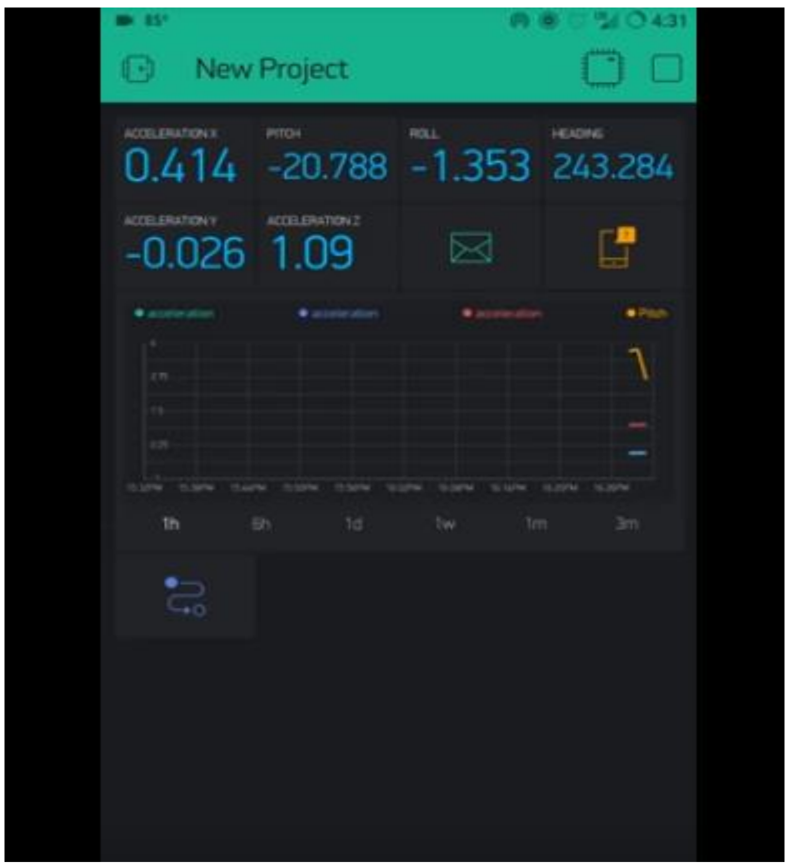

Figure 16: Blynk app reading when bike is being tampered

Figure 17: Bike being tampered when stationary

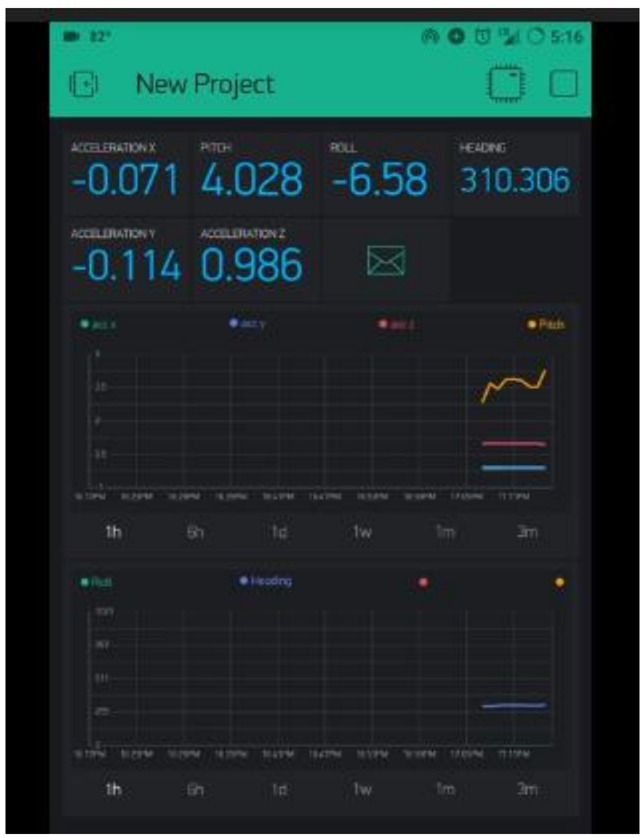

Figure 18: Blynk app reading when the bike is in motion

Figure 19: Bike in motion

The readings of the Spark fun IMU sensors were observed with the help of the Blynk app. It was seen that the readings of the Spark fun IMU sensors were fluctuating and quite inconsistent. The data was exported to excel sheet and it was observed that these data could not be used to predict the motion or activity associated with the bike.

A more reliable sensor MPU 6050 was used. It was seen that this IMU sensor gave a more stable reading compared to Spark fun IMU sensor i.e. there were lesser fluctuations compared to the previous sensor. The accuracy of the sensor was checked using the software processing. This software helped in visualizing the sensitivity and accuracy of the MPU sensors.

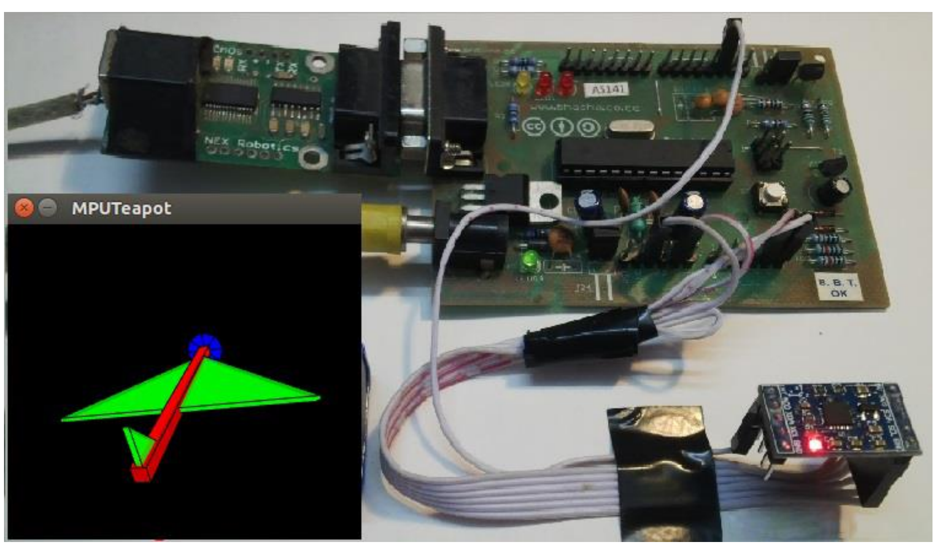

Figure 20: MPU sensors with processing

However, to record or observe the data from MPU sensors, an external software for storing data i.e. cool term was used. The data was exported into excel file for processing the data. It was seen that these data were more reliable and it could be used to determine the direction of acceleration of the bicycle.

Even though the MPU sensors were more reliable, it could be used to determine only the direction of the acceleration of the bike. It was tough to predict the magnitude of these acceleration values in specific cases like bike theft, lock tampering and accidental knocking of the bike. Moreover, these values if acceleration could change for each bike since their inertia can change thus affecting the magnitude. Hence, a fixed limit of the threshold value could not be determined after numerous trial and error methods. Also, it would require manual changes in the coding which would impact the cost of the product because of the need for customization.

The shock sensors were more dependable since the alarm set off was based on the vibrations picked up by the shock sensors. This does not depend on the inertia of the bike whatsoever.

Appendix 3

DESIGN ATTRIBUTES AND LEVELS

Design attributes used in the survey include:

a) **Price**: The selling price of the product that the consumer will pay. It was classified into $0 to $25, $25 to $50, $50 to $75.
b) **Deterrence method**: The method that the anti-theft device uses to prevent bicycle theft. Levels for this include: GPS, siren, notification, and immobilization technique.
c) **Size**: The physical size of the device. Categorized into small, medium, and large.
d) **Battery type**: Levels for this are rechargeable and non-rechargeable.
e) **Battery life**: The length of time the consumer can go without replacing/recharging the devices batteries.
f) **Material**: The physical material of the device. Material types include plastic, carbon fibre, ceramic, and stainless steel

Design Attribute	Levels
Price	< $25, $25-$50, $50-$75
Method	GPS, Siren, Notification, Immobilization Technique
Size	Small, Medium, Large
Battery	Rechargeable, Non-rechargeable
Battery Life	1 week, 2 weeks, 3 weeks
Material	Plastic, Carbon Fiber, Ceramic, Stainless Steel

Table 7: Summary of attributes and levels

DATA AND RESULTS OBTAINED FROM SURVEY

The survey was conducted among students of Arizona State University. Over 118 responses were recorded. However, among these responses, 28 participants did not own a bicycle. The responses were recorded over a 2-day period.

Several precautions were implemented in the survey to validate the data. To start, the survey was primarily distributed among university students who are our target consumer group. Furthermore, several questions were added in the survey as a way of checking for "candid or arbitrary" responses. The first question on the survey is: Which type of bike do you own currently, if the user selects "I don't own a bike" then survey ends and further survey data is not recorded. The survey also includes a variety of question that are mandatory to ensure the participants remain active in their selections.

DISCRETE CHOICE ANALYSIS

Pre-processing the survey data

Once the responses are recorded, the survey raw data is downloaded as a .csv file. The downloaded file contains responses to all the questions and hence it is important to remove all other unnecessary information from the file. In this analysis, the responses to the 10 scenario questions are retained with the corresponding discrete levels. The resulting file looks like this.

Response to question 1	Candidate 1 Attribute level - 1	Candidate 1 Attribute level - 2	….	Candidate 2 Attribute level - 1	Candidate 2 Attribute level - 2

Table 8: Survey Format

There were 118 responses to the questions after removing the 'invalid' responses i.e. responses which failed our validation question). So, there are 118 rows and 130 columns in the .csv file now.

Model setup

The MATLAB code attached at the end of this report was used for setting up the mixed logit model and conducting analysis. The Attributes and levels in the code is made consistent with the survey. The code also uses Dr. Kenneth Train mixed logit code.

In the model, it is assumed that only Price has a linear impact on the human choice making. Other attributes such as Method, Size, Battery, Battery life, Material are assumed as non-linear since it is not sure how it affects the decision-making process. Price for example has a negative impact i.e. the higher the price, the lower is the chance a person would buy a product. This sensitivity of one's preference to attribute known as Part-worth's is included only for the Price attribute per Train's code.

The MATLAB code is as follows,

```
X =
[x(:,1:3)*[25,50,75]',x(:,4:6),x(:,7:9),x(:,10:11),x(:,12:14),x(:,15
:18)];
number_features = size(x,2);
```

Following line assigns a tag to the part-worth. The tag for linear attribute Price is the attribute name Price itself. For other nonlinear ones, the tags are the discrete levels of their respective attributes.

```
NAMES =
{'Price';'Alarm';'Immobilize';'GPS';'Small';'Medium';'Large';'Rechar
ge';'Non-re';'1 week';'2 weeks';'3 weeks';'Steel';'Plastic';
'Ceramic' ;'C fiber'};
```

Results from Analysis

		Mean	StdDev	Share<0	Share=0
Price	normal	-6.3425	12.2767	0.6995	0.0000
Alarm	normal	0.3374	0.8480	0.3450	0.0000
Immobilize	normal	1.1603	1.4497	0.2070	0.0000
GPS	normal	0.9084	1.1693	0.2140	0.0000
Small	normal	-0.1017	0.7866	0.5520	0.0000
Medium	normal	-0.2968	0.7569	0.6595	0.0000
Large	normal	-0.9054	0.8849	0.8495	0.0000
Recharge	normal	-1.9323	1.1628	0.9510	0.0000
Non-re	normal	-2.9682	1.2158	0.9910	0.0000
1 week	normal	-1.9334	0.8019	0.9920	0.0000
2 weeks	normal	-1.3958	0.6582	0.9805	0.0000
3 weeks	normal	-1.5367	0.8040	0.9730	0.0000
S Steel	normal	-0.5095	0.7896	0.7340	0.0000
Plastic	normal	-1.0653	1.3682	0.7840	0.0000
Ceramic	normal	-0.4356	1.1547	0.6415	0.0000
C fiber	normal	-0.0727	0.7555	0.5300	0.0000

Figure 21: Results of discrete choice analysis

Interpreting analysis results

From the results, it is evident that Price, which is assumed as a linear attribute has the highest magnitude with a negative part worth. It suggests that people are less likely to buy a product if it is expensive.

In case of Method (Alarm, GPS, Immobilize), Immobilize is the most preferred method followed by GPS. Similarly, it can be inferred that, people are more likely to buy our product if its size is small.

With respect to the Battery life attribute, there is an interesting case, where people preferred our product with battery life 2 weeks than 3 weeks. However, this does not make sense as a battery life of 3 weeks would be the preferred one. This can be attributed to noise in our data or people are indifferent to battery life when it's beyond 1 week.

Since we have now learned some of the customer preferences, the survey could be further improved by refining certain attributes and discrete levels (e.g. battery life levels) and the mixed logit model could better capture the preferences.

CODE AND RAW DATA

The code used for this analysis and Dr. Train's mixed logit script can be found here.

The .csv file where the responses are stored can be downloaded here.

The code used for launching the survey is included here