# Modified Bicycle Motion Capstone

# Mid-Point Report

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# 1 BACKGROUND

## 1.1 Introduction

This project is about modifying a bicycle to limit range of motion in the knee joint. The project was presented by our client Dr. Scot Raab, an assistant professor of Athletic Training at Northern Arizona University. Dr. Raab had suffered a knee injury that resulted in his meniscus being removed. This severely limits his range of motion in his knee making it difficult to ride a bicycle. Although there are products that accomplish this, they tend to limit torque output, making it difficult for the rider to go uphill and attain high speeds. The objective of this project is to design a device for a standard bicycle that will limit range of motion in the knee with minimal torque loss.

## 1.2 Project Description

Following is the original project description provided by the sponsor:

> "Modified Bicycle Motion"
>
> Problem: Cyclist (recreational or competitive) that suffer knee injuries limiting ROM (Range of Motion) must give up cycling because the top of the pedal stroke causes extreme flexion of the knee. This results in abnormal forces across the knee joint and the patellar femoral articulation causing discomfort.
>
> Current attempted solutions:
>
> 1. Raise seat height but to go to high prevents appropriate alignment at the bottom of the pedal stroke and may result in rocking left and right on the saddle resulting in low back issues or soft tissue damage to the Perineum (area of soft tissue between what cyclist refer to as the sit bones or the ischium's)
> 2. Shorten the crank arm of the pedal but this decreases torque and speed available to the cyclist or ability to climb inclines.
>
> Objective: Protect ROM (limit it) and allow cyclist to produce maximal torque using current gears available to cyclist via front or rear chain rings
>
> That last part almost allows the team to invent a new set of gears but that requires thinner, thicker, longer, or shorter chains, etc. As you add rings to the gears your chain must be thinner to fit between the gears or the hub needs to get wider and that create s wider bike, etc. The objective of this project is to limit the amount of drastic modifications to existing bikes, but provide a smaller ROM for the rider.
>
> Create a modification that can be applied to (one size, multiple sizes?) standard bikes to modify the motion of the cyclist so their knees do not bend beyond 90 degrees."

## 1.3 Original System

This project involved the modified design of a standard two-wheel bicycle design. A standard bicycle is composed of a frame, fork, wheels, drivetrain, handlebars, brakes, and a saddle.

### 1.3.1 Original System Structure

A standard bicycle frame design consists of a double diamond design and features a fork that is placed in the head tube of the frame. Bicycles can be made from steel, aluminum, titanium, or carbon fiber. Most bicycle components are made of either aluminum or carbon fiber depending on the price level of the build. The Figure below is of a standard road bike and has all of the components labeled.


*Figure 1: Bicycle Diagram*

### 1.3.2 Original System Operation

A standard bicycle converts mechanical energy from the user into translational motion. This is performed via the drivetrain system containing a set of chain-driven gears. This set of gears is put in motion by the user through the pedals. The bicycle's drivetrain contains a set of adjustable gears, allowing the user to shift to a different gear ratio depending on terrain. This system is cable-operated, and adjusted manually by the user via a switch on the handlebars. This same handlebar system contains the controls for the cable-operated brakes and steering functionality [1].

### 1.3.3 Original System Performance

The weight of our client's road bicycle is 19 lb. and the general modern mid-range road bike weighs around 17-18 lbs. Our client generally averages about 15-16 mph on his bike rides, but can fluctuate due to head or tail winds and the amount of climbing or descent included in the ride.

### 1.3.4 Original System Deficiencies

The original system forced the user to bend their knee at an angle less than 90 degrees at the top of the pedal stroke, causing pain for a rider with flexural knee issues. It had been determined that a combination of the pedal crank arm length and seat height were the primary cause of this issue. Table 1 tabulates a list of commonly manufactured crank arm lengths.

*Table 1: Commonly Manufactured Lengths of Crank Arms*

| Crank Arm Length (mm) |
|---|
| 165 |
| 170 |
| 172.5 |
| 175 |

# 2 REQUIREMENTS

## 2.1 Customer Requirements (CRs)

Our customer requirements were rated on a scale of 1 to 5, 1 being the least important. Our customer requirements are durability (4), retrofittability (5), low weight (3), maximum torque (5), low cost (3), safety (5), and aesthetics (2).

We rated retrofittablity as a 5 because our client wanted a device that he can attach to his own bicycle instead of having to replace his entire bicycle. We rated maximum torque as a 5 because it was one of our main objectives and what has distinguished our design from existing designs. We rated safety as a 5 due to the engineering code of ethics. We rated durability as a 4 because we desire for our design to not break in a crash and for it to withstand uneven terrain. We rated low weight as a 3 because low weight is desirable and convenient, but was not necessary. We rated low cost as a 3 because we liked our product to be accessible to more cyclists. Finally, we rated aesthetics as a 2 because we valued function over form.

## 2.2 Engineering Requirements

Engineering Requirements were created from our customer requirements and are listed in Table 2. The first requirement for the modified design is added weight. Since our design to have the ability to be retrofitted onto different bicycles, the added weight should not exceed 300 grams. The second requirement for the modified design is the effect of cost. The cost should be less than $250 per design. All the design requirement should be met within this cost. The third engineering requirement for the design is falling weight. The design should be able to sustain a falling weight of more than 50 lbs. at a height of 0.6 ft. which is the criteria bicycles are typically designed and tested for. The fourth aspect considered is the effect of modified design on power generation. The design required that the maximum difference in power generation of modified design with reference to the standard crank should be less than 5%. The fifth requirement for the design is its effect on the knee. The knee angle should always be greater than 90°.

*Table 2: Engineering Requirements*

| Sr. no | Requirement | Condition |
|---|---|---|
| 1 | Added Weight | < 300g |
| 2 | Cost | < $250 |
| 3 | Sustain Falling weight | 50 lb. at height of 0.6ft |
| 4 | Power generation as compared to standard cranks | Difference < 5% |
| 5 | Knee Angle | > 90° |

## 2.3 Testing Procedures (TPs)

The following list outlined the testing procedures to be performed. Most were derived from the engineering requirements.

1) Knee angle testing – taking pictures of knee angle at key locations during a pedal stroke
2) Torque test – 3D print test platform, using belts to test the torque
3) Falling weight test – outlined in the engineering requirements
4) Seat height test – to see how much higher the seat must be in order for the knee angle to be less than 90 degrees throughout pedal stroke

5) Gear test – testing the force/time it takes for a foot to reach the bottom of the pedal stroke after applying pressure
6) Weight test – weighing the design using a tabletop scale

## 2.4 Design Links (DLs)

Our selected design met the engineering requirements previously stated. Each design link correlated to number to the engineering requirements.

1) Added weight is less than 300g since the only weight being added is a spring and rail added to the crank arm.
2) The crank arm and the spring has cost less than $250 meeting our cost requirement. Per Section 6.3 the estimated cost was $230 which meets the requirement.
3) After machining the part, it will be tested (number 3 of testing procedures) to ensure that it meets the requirements.
4) Our calculations showed a shortened crank arm has a 10% difference in torque generation. Our design will lessen that difference, making it a less than 5% difference.
5) The knee angle will remain less than 90 degrees with our design because the design involved the crank arm shortening to ensure a larger knee angle.

## 2.5 House of Quality (HoQ)

A House of Quality was used to determine our most important engineering requirements for this project. In the table, the customer requirements were listed on the left and weighted in terms of importance on a scale of 1 to 5, 5 being the most important and 1 being the least important. The customer requirements were rated 0, 1, 3, or 9 depending upon their correlation with the engineering requirements. A 0 was no correlation, 1 was a weak correlation, 3 was a medium correlation, and 9 was a strong correlation to the engineering requirements. The weight factor was multiplied by the correlation value and summed up at the bottom calculating the absolute technical importance (ATI). The engineering requirement largest ATI number was first in Relative Technical Importance (RTI) and RTI continued down until the lowest ATI and that was the last in RTI.

[See Appendix A for House of Quality]

Our teams most import engineering requirement was the sustained falling weight. This engineering requirement won since our design can sustain a falling weight of 50 lbs. it is safe and durable by being able to sustain damage from a crash. Power generation and knee angle were also important engineering requirements to consider when we designed our product.

# 3 EXISTING DESIGNS

## 3.1 Design Research

We researched many different existing designs that claimed to help reduce forces on the knee joint and/or reduce the knee's range of motion, or the knee angle. We conducted web searches and wrote literature reviews on the existing designs we found, whether in the form of an article, a patent, or a product's website. The existing designs found are outlined and compared to customer requirements in Section 3.2.

## 3.2 System Level

The following section describes existing designs found and compares it to customer requirements and to the other existing designs.

### 3.2.1 Existing Design #1: Shortened Crank Arm (Orthopedal)

This design was a product available on the market, called the Orthopedal. The Orthopedal is a small metal device that is attached onto a bicycle crank arm illustrated in Figure 2. It has four different slots along the crank arm to insert the pedal, thus adjusting the crank arm length. The shortened crank arm length results in a limited range of motion, causing reduced forces on the knee joint. However, it reduces torque capacity causing increased difficulty in biking uphill and reduced maximum speed. [2]


*Figure 2: Orthopedal Crank Arm*

### 3.2.2 Existing Design #2: Retractable/Extendable Crank Arm Patent

This design was a US patented retractable crank set for a bicycle. This crank set, illustrated in Figure 3, has a crank arm that extends and retracts depending on position. The crank shaft will be in the retracted phase at the top of the pedal stroke which will reduce the effects of patellar femoral articulation. Then the crank shaft will extend along the front side of the stroke which results in more produced torque. The crank path is illustrated in Figure 4 in orbital L. This design is similar, but is more desirable in terms of torque than the Orthopedal design described in 3.2.1. However, this design cannot be easily retrofitted onto different bicycles, like the Orthopedal. [3]

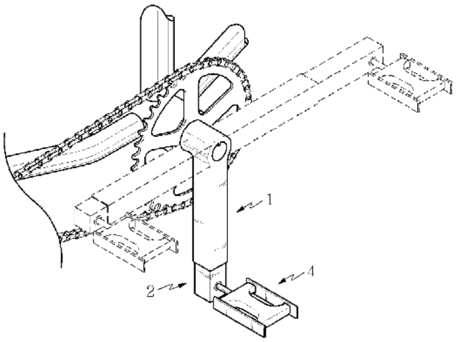


*Figure 3: Extendable/Retractable Crank Arm*

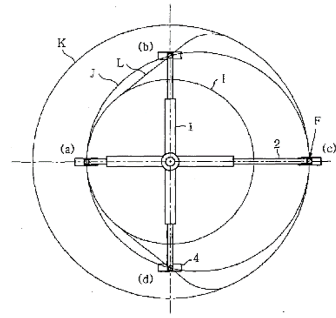


*Figure 4: Pedal Path for Extendable/Retractable Crank Arm*

### 3.2.3 Existing Design #3: CrankTip Pedal

This design is a device that is currently available on the market and is attached onto the pedal of a standard bicycle. The device has a dual swing-arm mechanism that moves the pedal in front of the end of the crank arm along the front of the pedal stroke causing increased torque. The crank arm shortens along the back of the stroke to reduce range of motion experienced by the knee at the top of the stroke. The path of the pedal for a CrankTip Pedal is compared to the pedal path of a standard pedal in Figure 5. This design can be easily retrofitted onto any bicycle and has a more desirable torque than the plain shortened crank arm design. However, it's high in cost. [4]

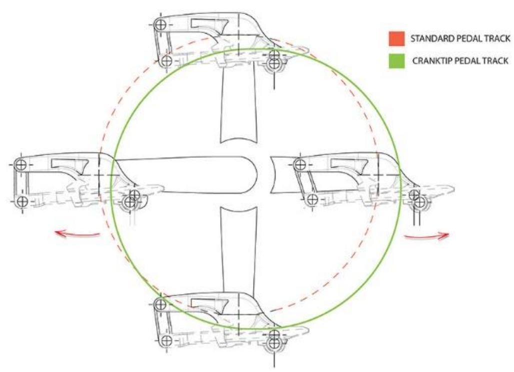


*Figure 5: CrankTip Pedal Path vs. Standard Pedal Path*

### 3.2.4 Existing Design #4: Kneesavers

This design is a small device that is currently on the market, called Kneesavers. It extends the pedals outward from the bicycle, as seen in Figure 6, reducing forces on the knee joint. This design changes the forces acting on the knee, however it does not affect the knee angle throughout the pedal stroke. [5]


*Figure 6: Pedal without Kneesavers vs. Pedal with Kneesaver*

### 3.2.5 Existing Design #5: Pivoting Crank Arm (Duke University)

This design was created by a group of students at Duke University. They were tasked with modifying a bicycle so that their client, who has limited range of motion in her left knee, can continue to bike as a hobby. Their design consists of a pivoting crank arm that pivots to shorten the crank arm, reducing the range of motion in the knee and making it more comfortable for the injured rider. This design is pictured in Figure 7 below. This design is limited due to its poor torque output which produces the same problem as the Orthopedal and the shortened crank arm. It reduces the maximum speed attainable and the ability to go uphill comfortably. [6]

*Figure 7: Pivoting Crank Arm*

### 3.2.6 Existing Design #6: Rotor Q-Rings

This design is of chain rings that are applied to standard cranks. The chain rings are elliptical in shape, shown in Figure 8, and reduce the patellar force on the knee at the top of the pedal stroke by making the chain ring size smaller. The chain ring becomes bigger along the front of the pedal stroke where the most power is produced, thus creating more torque. Although this does not directly affect the range of motion in the knee, it can be combined with a shortened crank arm to limit range of motion and increase torque output. [7]


*Figure 8: Elliptical Rotor Q-Ring Chain Ring*

## *3.3 Functional Decomposition*

The final product works by using the user’s legs to compress and relax a spring to generate translational motion. This is accomplished by pedaling the crank arm apparatus to generate motion. The springs allow the user to bend the knees as little as possible during the power stroke of the pedal stroke. Removing the user’s legs from the system exits the continuous loop of spring compression and relaxation. The functional decomposition is illustrated in Figure 9.

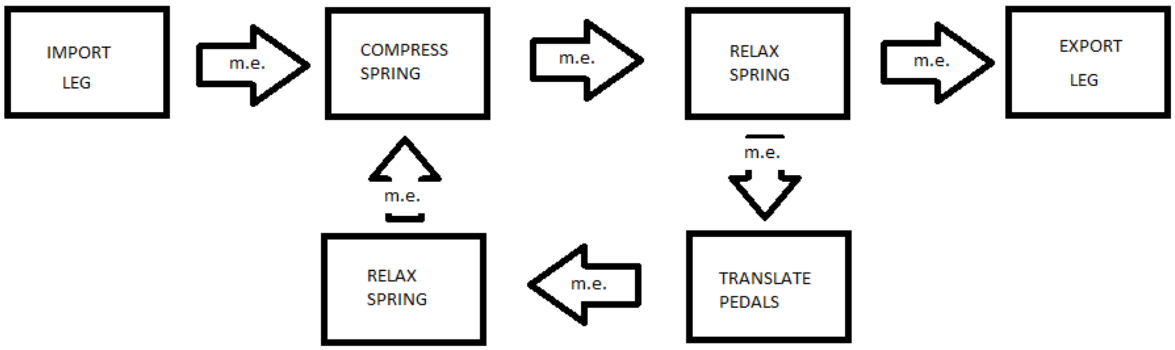


*Figure 9: Functional Decomposition*

## *3.4 Subsystem Level*

The main function of this project is to propel the rider of the bicycle forward through the drivetrain of the bicycle. First, the user applies force through the legs on to the pedals, which are attached to the end of crankset. The force from the crankset is applied to chain rings that causes them to rotate in a clockwise motion, the teeth on the chain ring pull the chain in the same direction. The chain will pull rotate the cassette (gear set located at the back of the bicycle) and the rear wheel in the clockwise direction. The content of the section below will be discussing the existing designs for (1) cranksets, (2) chains, and (3) cassettes.

### 3.4.1 Subsystem #1: Crankset

Force is applied through the pedals on the crank arms make them act as a lever. The chain rings are fixed to the crankset and rotate with the cranks in a clockwise motion.

#### 3.4.1.1 *Existing Design #1:* Shimano Ultegra Crankset

The Shimano Ultegra road bicycle crankset features a four arm spider design for mounting two chain rings, capable of handling a variety of different chain ring sets, chain guide on chain rings to reduce chain dropping, made of aluminum, and works for 11 speed group sets. This product relates to our customer requirements by having optimal stiffness for power/torque transfer, durable, aesthetics, low weight (765g), and reasonably priced. [8]


*Figure 10: Shimano Ultegra Crankset*

#### 3.4.1.2 *Existing Design #2:* Shimano XTR Trail Crankset

The Shimano XTR mountain bicycle crankset features three different four arm spider designs for mounting 1-3 chain rings (1X, 2X, or 3X), made for 11 speed group sets, and made of aluminum. This product relates to our customer requirements by providing optimal power transfer through the cranks, low weight (1X – 583g, 2X – 630g, and 3X – 656g), durable, aesthetics, and safe. [9]


*Figure 11: Shimano XTR Trail Crankset (2X)*

#### 3.4.1.3 *Existing Design #3:* Campagnolo Super Record Crankset

The Campagnolo Super Record road bicycle crankset features a four arm spider design for mounting the two chain rings, step-up system on chain rings to enhance shifting performance, carbon construction, compatible with 11 speed group sets, and a simple assembly for ease of maintenance. This crankset relates the following customer requirements durable, aesthetics, no torque/power loss, and low weight (603g). [10]

*Figure 12: Campagnolo Super Record Crankset*

### 3.4.2 Subsystem #2: Chains

The chains are held in place by the toothed gears that are the chain rings and cassettes. The chain will carry the clockwise rotation of the crankset which will move the cassette and rear wheel.

#### 3.4.2.1 *Existing Design #1:* Sram XX1 Eagle Chain

This Sram XX1 mountain bicycle chain features quiet operation, no interior square edges, increased wear resistance over previous iterations, hollow pins, and compatible with 12 speed group sets. This chain relates to the following customer requirements of being durable, low weight from the hollow pins, and aesthetics (gold colored). [11]

*Figure 13: Sram XX1 Eagle Chain*

#### 3.4.2.2 *Existing Design #2:* Shimano Dura-Ace Chain

The Shimano Dura-Ace chain features hollow pins, a PTFE coating to help increase the wear resistance of the chain, and is compatible with 11 speed group sets.  This product relates to our customer requirements by being low weight (243g) and having increased durability. [12]

*Figure 14: Shimano Dura-Ace Chain*

#### 3.4.2.3 *Existing Design #3:* Muc-Off Nano Chain

The Nano Chain is a chain is not made by a bicycle component company, however it is made by company that makes chain lubricants. A chain can be chosen for the drivetrain of the purchaser's choice. The chain is hand treated and has a special lubricant applied to it to reduce drivetrain resistance and improve the chain's weatherproof capabilities. This chain meets the customer requirements of durability and improves the torque output efficiency of the drivetrain. [13]

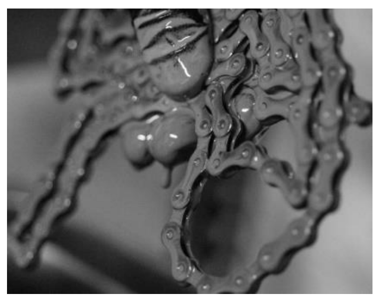

*Figure 15: Muc-Off Nano Chain*

### 3.4.3 Subsystem #3: Cassettes

The cassette the group of gears located at the rear of a bicycle and is attached to the rear wheel. The motion transferred from the chain causes the cassette to rotate clockwise and rotate the rear wheel.

#### 3.4.3.1 *Existing Design #1:* Sram XX1 Eagle Cassette

Sram's XX1 Eagle Cassette is one of the only commercially available cassettes that has 12 cogs or gears on it, has a wide range of gears that are optimal for mountain biking (10-50 teeth), one of the strongest cassettes available, and has the smallest tooth available which has 10 teeth in it. This product meets the customer requirements of durability, maximum torque output from the 10 tooth cog, and aesthetics (gold colored). [14]

*Figure 16: Sram XX1 Eagle Cassette*

#### *3.4.3.2 Existing Design #2:* Campagnolo Super Record Cassette

The Campagnolo Super Record cassette features six titanium sprockets, has a nickel-chrome surface treatment to increase the life of the cassette, and the teeth are designed to provide maximum power transmission to the rear wheel. This design meets the customer requirements of maximum torque, durability, and lightweight (177g). [15]

*Figure 17: Campagnolo Super Record Cassette*

#### *3.4.3.3 Existing Design #3:* Shimano Ultegra Cassette

The Shimano Ultegra cassette features the availability to have a wide range of gears available for road cycling ranging from 11 to 32 teeth, which is better for climbing. This cassette aligns with the torque because an 11 is the general industry standard for the smallest number of cassette teeth and this design is reasonably priced. [16]

*Figure 18: Shimano Ultegra Cassette*

# 4 DESIGNS CONSIDERED

## 4.1 Crankset Slider

The crankset slider was a crank based concept that consisted of a crank with a channel machined out of it. A tension spring was attached at the top of the channel and to the pedal holder, which is the drawing on the right side of Figure 19 below. In the 3 to 6 o'clock position of the pedal stroke the spring elongates, thus increasing the length of the crank. The crank length is shortened at the top of the pedal stroke, which will allow the knee angle to open up and ease the pain in the knee. Advantages of this design is that it maximizes torque in the pedal stroke, low weight, keeps the knee at an angle greater than 90º, and is retrofittable. Disadvantages of this design is that this design was difficult to manufacture, due to the possibility of welding aluminum.

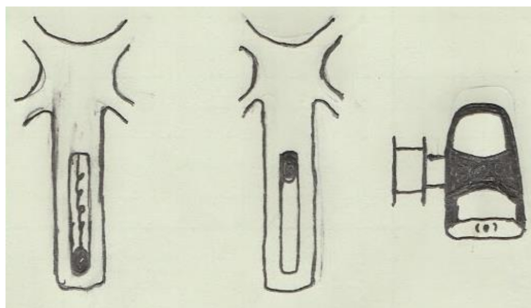

*Figure 19: Crankset Slider Concept*

## 4.2 Pedal Slider

The pedal slider design was like the crankset slider except that it is mounted to a standard set of cranks. The design was a hollow rectangular box with an open side. A tension spring was attached to the top of the inside of the box and to the top of the pedal holder. This design screws into normally where the pedal would go and the straps on the top of it will wrap around the cranks to hold the pedal slider in place. Same as the crankset slider, the pedal slider's spring in the 3 to 6 o'clock position of the pedal stroke elongates and in the 12 o'clock position the spring will be retracted thus making the crank arm feel shorter and increasing the knee angle. Advantages of this design is that it is low weight, can be placed on any crankset with the same threading, and keeps the knee angle greater than 90º. Disadvantages of this design is there is a safety and durability issue with the spring and widens the rider's stance on the bicycle.

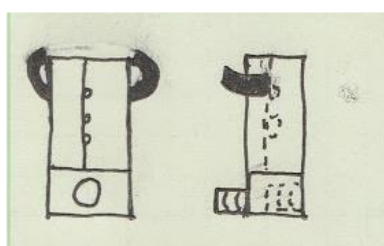

*Figure 20: Pedal Slider Concept*

## 4.3 Translating Cranks

The translating cranks was a crank based design. The design used two vertical parallel bars that attached to the crank arms and to the pedal bar which can be seen above the crank arm in Figure 21 below. The two bars could move freely in either the left or right direction. In the lower half or 3 to 9 o'clock position of the pedal stroke the cranks would be in the extended position, illustrated by the drawing on top in the Figure. This position would extend the crank length through part of the downward stroke, increasing the torque output. In the upper half of the pedal stroke or 9 to 3 o'clock position of the cranks, the cranks would be in the lower position shown in the Figure. This would shorten the crank length at the top of the pedal stroke allowing a greater knee angle. Advantages of this design were that it was retrofittable, able to maximize torque output in the pedal stroke, and kept the knee angle greater than 90°. The disadvantages of this design were that the pedal bar moving freely may be difficult to adjust to and the vertical bars could break from impact forces of a crash.

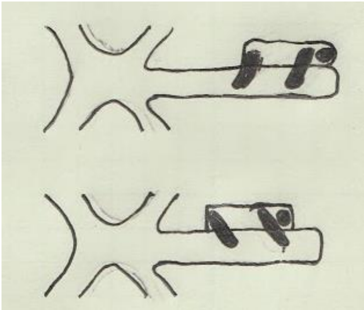

*Figure 21: Translating Crankset Concept*

## 4.4 Four Chainrings

The four chainrings design was the concept of creating a greater range of gears available to the rider. The gears would range from an extremely tall gear (55T or 54T) that can be used for fast descents or sprint finishes in a race to a small gear (30T or 32T) for steep or long climbs. The team recommended that this design is paired with short crank arms to keep the knee angle greater than 90°. The advantages of this design were that the largest chairing would maximize torque output, increase the range of gears usable by the rider, and the design is durable. The disadvantages of the four chainrings were that there are currently no commercially available cranksets, shifters, or front derailleurs that are designed to accommodate four chainrings on a bicycle.

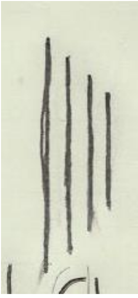

*Figure 22: Four Chainrings Concept*

## 4.5 Q-Rings / Elliptical Chainrings

Q-rings are commercially available elliptical chainrings, they were mentioned previously in section 3.2.6 of this report. The team recommended that this design was paired with short crank arms in order to keep the knee angle greater than 90°. These chainrings allowed the user to produce more torque through the power phase of the pedal stroke and Q-rings reduce the force on the knee in the dead spots of the pedal, which is located at the top and bottom of the pedal stroke. The advantages of this design were that it was lightweight, durable, safe, retrofittable, and helped to produce maximal torque. The disadvantages of this design were that Q-rings drop chains more frequently than standard round chainrings, crank arm lengths were nonadjustable, and elliptical chainrings may take time to get accustomed to.

## 4.6 Gear Ratios

Adjusting the gear ratios on the client's bicycle was the simplest solution. This design involved making the chainrings larger and/or making the cassette teeth smaller to produce more toque through the drivetrain of the bicycle. The advantages of this design were that it was safe, durable, retrofittable, low weight, inexpensive, and simple. The disadvantages of this design were that the knee angle might be less that 90° and the torque increase in the system may be marginal.

## 4.7 Manually Adjustable Pedals

An issue with the current design of a shorter crank arm length was that it limits torque. This limited torque created a designed disadvantage when in competitive applications. As a modification of this design, the user could adjust the crank arm length on an as-needed basis. By releasing a locking mechanism connecting the pedal to the crank arm, the user could move the pedal to several positions along the crank arm while riding. This resulted in a shorter effective crank arm length. In application, the rider can shorten the effective crank arm length while at cruising speeds, and lengthen it when extra torque was needed for added acceleration.

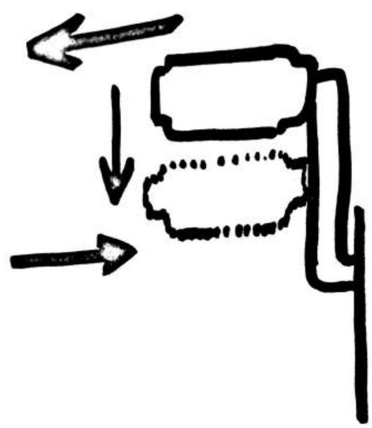

*Figure 23: Manually Adjustable Pedals*

## 4.8 CVT (Continuously Variable Transmission)

As currently designed, a CVT transmission maximizes the torque transferred from an engine to the wheels. This is done by having a large number of gear sets that seamlessly change gearing based on the input torque and rpm. These transmissions are frequently used in small (under 50cc) scooter applications. To explore the maximization of the available torque a user can utilize, the implementation of a CVT transmission may be advantageous. In application the user would not need to shift the bicycle, the gearing ratio delivering maximum torque would already be selected. This coupled with a shorter crank arm would provide the user with the maximum torque with minimal bending of the knee.

*Figure 24: CVT Concept*

## 4.9 Translating Seat

While current designs raise the seat to minimize knee bending, this caused discomfort and possible injury for the user. This approach translated the seat horizontally. This would change the angle the knees would bend without adding the unwanted discomfort. This design would be achieved by adding a horizontal post onto the base of the seat. A metal pin would be inserted to lock the seat into the horizontal post.

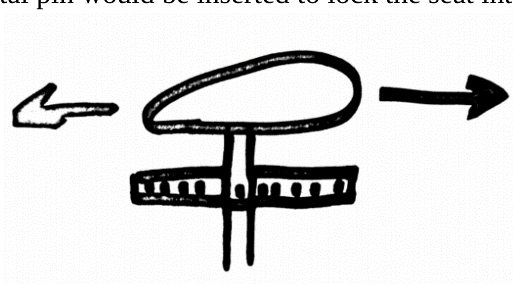

*Figure 25: Translating Seat Concept*

## 4.10 Modified Pedal Shape

In an attempt to create an adjustable crank arm length, a modification of the pedal can be utilized. In this design, the pedal would be modified to have multiple "steps" of height along its width. While this would significantly increase the width of the pedal, this would achieve an inexpensive and effective way to adjust the angle of the users' knees.

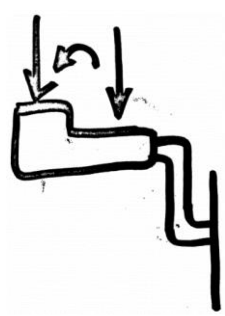

*Figure 26: Modified Pedal Shape Concept*

# 5 DESIGN SELECTED

## 5.1 Rationale for Design Selected

A decision matrix was used in order to decide which designs to pursue and is shown in Table 3. In the table, the customer requirements were listed on the left and weighted in terms of importance on a scale of 1 to 5, 5 being the most important. Each design was rated on a scale of 1 to 5, 5 being the design completely fulfills the customer requirement and 1 being the design did not satisfy the customer requirement. Each rating was multiplied by the customer requirement weighting and added together to create the total score.

*Table 3: Decision Matrix*

| Customer Requirements: | Weightings: | Designs: | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Crankset Slider | Translating Cranks | Pedal Slider | 4 Chain Rings | Q-Rings | Adjustable Pedals | Translating Seat | CVT | Pedal Shape | Gear Ratios |
| Durable | 4 | 3 | 4 | 3 | 5 | 5 | 4 | 4 | 3 | 4 | 5 |
| Retrofittable | 5 | 5 | 5 | 5 | 2 | 4 | 4 | 3 | 3 | 4 | 5 |
| Low weight | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 4 | 4 |
| Max torque | 5 | 4 | 3 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 3 |
| Low cost | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 4 |
| Safe | 5 | 4 | 3 | 2 | 4 | 4 | 3 | 4 | 4 | 3.5 | 4 |
| Aesthetics | 2 | 4 | 3 | 2 | 4 | 3 | 3 | 3 | 3 | 2 | 4 |
| Knee angle | 4 | 4 | 3 | 4 | 3 | 3 | 4 | 2 | 3 | 4 | 1 |
| | Total Score: | 122 | 107 | 108 | 105 | 119 | 111 | 93 | 100 | 114.5 | 116 |

As illustrated in Table 3, the crankset slider design, Q-rings, and improved gear ratios were the three designs that received the highest score. Due to the patented design of the Q-rings, we decided not to pursue that, but potentially add it to another design. So, the pursued designs were the crankset slider and the gear ratios.

The crankset slider could easily be retrofitted to any bicycle, it would greatly improve torque as opposed to a standard shortened crank arm, would help the knee angle, and was safe for the rider. These benefits caused this design's high score and our selection of this design to pursue.

The improvement of gear ratios is very durable, has increased torque capacity, and could easily be retrofitted. These benefits caused its high score and our selection of this design to pursue. The design did receive a 1 in terms of knee angle, because the knee angle is unaffected. However, when paired with a shortened crank arm, it met this requirement and increases its score.

## 5.2 Design Description

The crankset slider was a crank based concept that consisted of a crank with a channel machined out of it. A tension spring was attached at the top of the channel and to the pedal holder. In the 3 to 6 o'clock position of the pedal stroke the spring elongates, thus increasing the length of the crank. The crank length would be shortened at the top of the pedal stroke, which allowed the knee angle to open up and ease the pain in the knee.

### 5.2.1 Modeled Drawing

In this section the initial 3-D design of our crankset slider design was included in Figures 27 and 28. Figure 27 illustrated our design without the tension spring and pedal holder in it and in Figure 28 illustrated the crankset slider with the pedal holder attached to spring. The channel extended for most of the crankset, which would make the extension in the power stroke equivalent to a standard sized crank length and at the top of the stroke the crankarms will be shorter to allow for a greater knee angle.

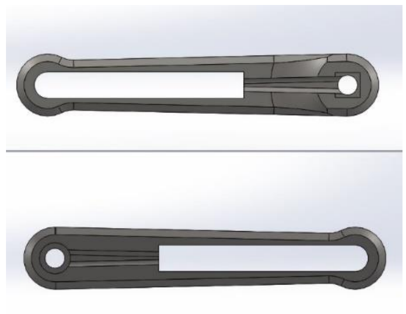

*Figure 27: Crankset Slider without Spring and Pedal Holder*

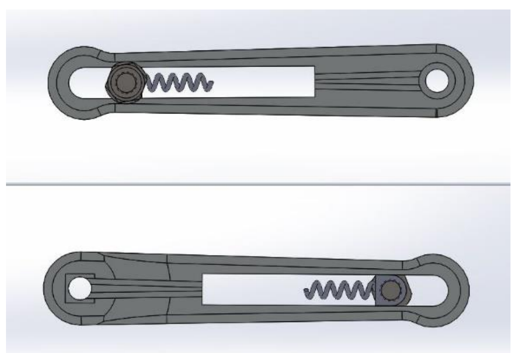

*Figure 28: Crankset Slider with Spring and Pedal Holder*

Figure 29 illustrated how the crankset slider design appears when attached to a bicycle. The crankset is shown at the bottom of the pedal stroke to display how the crankset behaves at that part of the stroke.

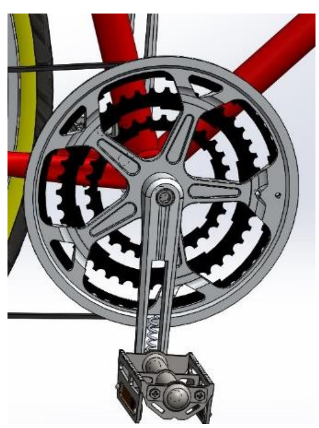

*Figure 29: Crankset Slider attached to bicycle*

# 6 PROPOSED DESIGN

## 6.1 Intended Design Construction

Our slider crankset design was a modified commercially available crankset. The crankset is a Bontrager Select Triple crankset to keep the same crankset that our client has on our bike. From the center of where the threading is on the crankset a 40 mm vertical slot towards the top of the crank arms will be drilled out at the NAU Machine Shop.

The pedal holder was a small square piece made of steel or aluminum with a rounded top and bottom, in the center of the pedal holder a 9/16 inch x 20 tpi threading is tapped for the pedals. On the right-side pedal holder, the threading is a standard threading direction and the left side pedal holder will be reverse threaded because all left side bicycle crank arms have reverse threading. The tension spring will be attached to the top of the channel in the crankset and the pedal holder by fasteners or by welding.

After the pedal holder is placed inside the channel of the cranks a washer or small piece of sheet metal with a hole in in the center is welded or pressed on the pedal holder to prevent lateral movement of the pedal slider.

## 6.2 Material Selection for Components

For our project it was necessary to choose the right material for the crankset, chain, and the cassette. For bicycle components it is important that the chosen material is strong, light, and durable. The chosen material needs to be strong in order to be capable of handling the force a rider outputs. Lightweight is an important factor in bikes because the lighter the bike is, the less effort it takes to ride the bike. Durable is important because it will need to be capable of handling thousands of cycles and possibly impact damage from a crash.

### 6.2.1 Crankset – Aluminum

Carbon fiber is common place material used in most modern bicycle frames and components because of its exceptional strength to weight ratio. The best material for this case would be carbon fiber, however it costs significantly more than aluminum. The benefits of aluminum over carbon fiber are that it can be machined in many different types of ways and that it will be much easier and cheaper to manufacture a part of aluminum. The strength and durability of the crankset are important factors to consider while making the bicycle component. Aluminum is optimal material to build our design out of because of its machinability and has a strength to weight ratio that is better than most metals.

### 6.2.2 Chain – Stainless Steel

The chain is stainless steel, this a common material used in bicycle chains. Stainless steel has excellent wear capability, high strength, and after a wet ride the chain will not rust.
Properties of stainless steel:

i. High density –Stainless Steel has density of 500 lb./$ft^3$
ii. High strength – about 325 ksi.
iii. Cost – $1.06/lb.

### 6.2.3 Cassette – Nickel Stainless Steel Alloy

Nickel and stainless steel are strong metals, when the two metals combine because it increases the strength and wear capabilities of either of the metals. A nickel and steel alloy was an ideal combination for a cassette. Below are properties of the alloy.

Properties of Nickel-Stainless steel

i. Density – about 546 lb./$ft^3$
ii. High strength – approximately 630 ksi.
iii. Cost– $17.20/lb.

The cassette transfers the torque from the crankset to the rear wheel. The cassette handles the constant changing of gears, which leads to a lot of wear on the teeth. The teeth of the cassette therefore needed to be strong enough to withstand the effects that are produced through the crankset. The best choice for a cassette was a Nickel-Stainless Steel alloy.

#### 6.2.4 Bill of Materials

The bill of materials in Appendix B was made based on the materials that were chosen. We have purchased the components and will machine it from there. The prices that have been quoted in this report are the relative prices that are currently in the market.

## *6.3 Cost and Budget*

The client budget allotted for this project of $1500. This amount was set to cover the expenses for analysis, prototyping, and the final product. Prototype manufacturing is currently in progress, expecting a finished prototype available to display at the Hardware Review Two. Although assembly and manufacturing are not scheduled yet, a budget of estimated manufacturing and material costs are seen in Appendix B. From this analysis, the cost is $302.97 meaning we will be under our budget by $1197.33. Based on this information, it would be beneficial to allocate some of these additional resources into research, development, and manufacturing of the highest quality product. We will discuss this financial plan in our next team and staff meeting.

# 7 IMPLEMENTATION

To ensure our team met our project deadlines, our team set up a Gantt chart. This helps to organize the team on important milestones and deadlines. All the tasks are completed up to March 3, 2017 including this report. See Appendix C for Gantt Chart.

## *7.1 Manufacturing Processes*

Currently, the manufacturing of the crank arm assembly is in progress. Contained within this section, is an outline of the processes required to manufacture our final product. The manufacturing processes required for each subassembly are in their respective sections below. These subassemblies include the crank arm, spring assembly, pedal assembly, and linear rail assembly.

#### 7.1.1 Crankarm Assembly

The crank arm assembly will be machined to accommodate each of the other sub-assemblies. Seen below in Figure 30, the manufacturing print specifies each of the following features to be machined into the crank arm. Note the 5/8” slot milled into the crank arm. This slot will serve to allow the pedal assembly to smoothly move as it is acted on while riding. At the bottom of this slot is a ¼”-20 tapped hole. This hole will serve to allow the bottom half of the spring assembly to be firmly mounted to the crank arm. Above and below the slot are a set of 2 additional ¼”-20 tapped holes. These will allow the linear rail to be bolted to the crank arm.

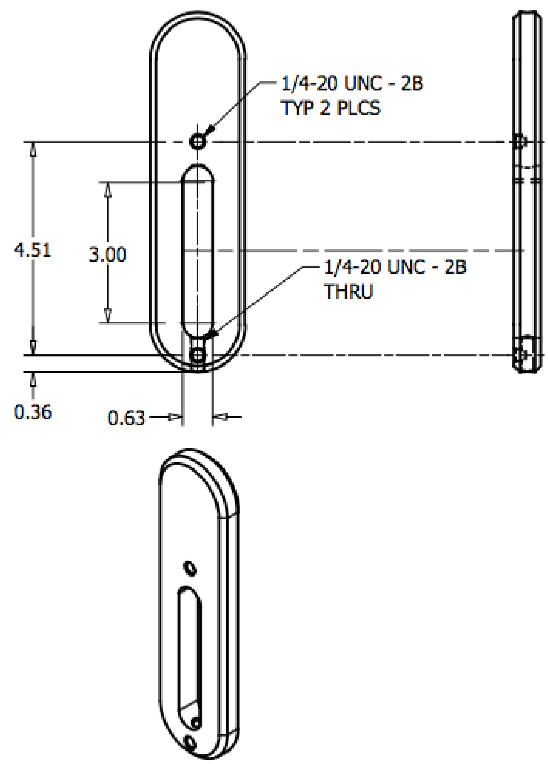


*Figure 30: Crankarm Assembly Drawing*

### 7.1.2 Modified Washer

The spring assembly is made up of a spring, 2 ¼"-20 Philips head machine screws, 4 nuts, 2 washers, and 2 modified washers. The washers serve to hold the spring in place while the compression cycles elapse. Because of this design, the outward facing washers must have a slot machined into them to allow the spring up through this clamping mechanism. Below in Figure 31, the washer is displayed with this offset 1/16" slot machined into it.

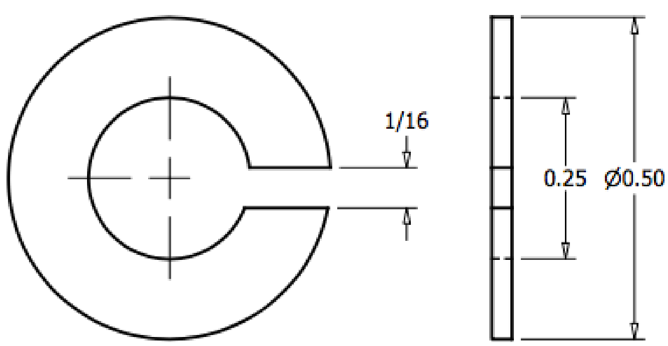


*Figure 31: Modified Washer Assembly Drawing*

### 7.1.3 Linear Rail Assembly

Allowing the pedal to translate linearly with minimum friction, the linear rail assembly is mounted to the crank arm and pedal assembly. As seen below in Figure 32, the linear rail has (2) countersunk ¼"-20 tapped holes. These threaded holes line up with the ¼"-20 holes displayed in Figure 32. A carriage containing roller bearings slides on this rail. To this carriage, the pedal assembly will be mounted.

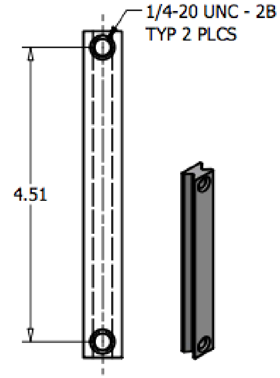


*Figure 32: Linear Rail Assembly Drawing*

### 7.1.4 Pedal Assembly

The pedal assembly attaches the pedal, spring assembly, and linear rail carriage into one unit. As seen below in Figure 33, a 9/16"-20 tapped hole serves to thread the clients' pedals into the crank arm assembly. This tap is currently being shipped because it is a non-standard size. A smaller, 7/16-14 threaded shank on the back will allow this to be threaded into the carriage of the linear rail. This shank also has the bottom milled flat, with a ¼"-20 thru-hole tapped through the shank. This thru-hole serves to mount the top half of the spring assembly.

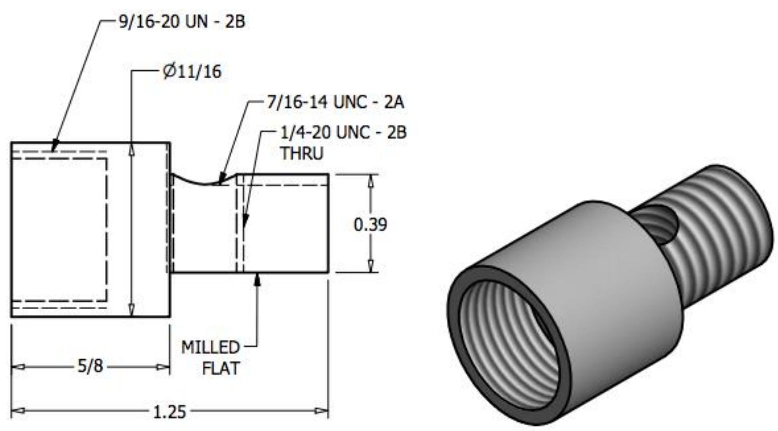


*Figure 33: Pedal Holder Drawing and Model*

## 7.2 Building Functional Prototype

It is slated that by next week, all the materials will have arrived allowing manufacturing and assembly of the entire assembly. After this is completed, extensive experimental analysis will be performed to gather data. Manufacturing will take place at Valley Forge and Bolt company in Phoenix, AZ. This facility was chosen due to the amount of threading and fastening equipment that will be utilized. They have offered to manufacture our product at no cost.

## 7.3 Design of Experiments

To find the best iteration of our final design, the variables that will be tested is two different spring rates and lengths. Trials will be performed by placing one of the two springs into the crankset for each part of the trial and each spring will be tested at an easy to moderate effort and a hard effort too. The easy to moderate effort will be used for replicating a training ride and the hard effort is used to replicate efforts like those in a bicycle race. The trials are to be done on a bicycle resistance trainer to keep the bicycle stationary to allow for videotaping and picture taking of the design in use, which will allow the team to analyze the tested variables. For the stiffness trial the two springs used will have different spring rates, but each spring will be of similar length. In the spring length trial will use two springs will have different lengths, but both springs will have the same spring rate.

The first objective of the spring rate and length trials is to compare the knee angle at the top of the stroke to distinguish which spring from each trial provides the user with the optimal knee angle that is greater than $90^o$. The second objective of the spring stiffness and length trial is to compare the torque outputs of the different spring rates and lengths, the results from each trial will be compared to determine which spring allows the pedals to extend the furthest down the crank in the power stroke.

## 7.4 Testing

As of the due date of this report, March 3, 2017, the design has not been fully constructed, which means the design has not been tested yet. Once tests are performed and the results are analyzed, the team will be able to choose the optimal spring for the design and make any design alterations if necessary.

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# Appendices

## *Appendix A: House of Quality*

| | | Engineering Requirements | | | | |
|---|---|---|---|---|---|---|
| Customer Req. | Weight Factor | Added Weight <300 g | Design Cost <$250 | Sustain Falling Weight ≥50 lbs At .6 ft | Power Generation <5% Difference Vs. Stnd. Cranks | Knee Angle > 90° |
| Durable | 4 | 0 | 0 | 9 | 0 | 0 |
| Retrofittable | 5 | 1 | 0 | 0 | 0 | 0 |
| Low weight | 3 | 9 | 3 | 0 | 0 | 0 |
| Max Torque | 5 | 0 | 0 | 0 | 9 | 1 |
| Low cost | 3 | 1 | 9 | 0 | 0 | 0 |
| Safe | 5 | 0 | 0 | 3 | 0 | 0 |
| Aesthetics | 2 | 0 | 0 | 0 | 0 | 0 |
| Knee Angle | 4 | 0 | 0 | 0 | 1 | 9 |
| Target (w/ tol.) | | 200 (<300) g | $160 (<$250) | 55 (>50) lb. at .6 ft | 3 (<5) % | 93°-141° (>90) |
| ATI | | 35 | 36 | 51 | 49 | 41 |
| RTI | | 5 | 4 | 1 | 2 | 3 |
| TP# | | 6 | N/A | 3 | 2,5 | 1,4 |
| DL# | | 1 | 2 | 3 | 4 | 5 |

## *Appendix B: Bill of Materials*

| Part # | Part Name | Quantity | Cost ($) |
|---|---|---|---|
| 1.1 | **Cranksets** | 3 (2: ISIS Bottom Bracket (BB), 1: Square Taper BB) | 91.93 |
| 1.2 | **Fasteners** (A set of fasteners is comprised of: 2 bolts, 4 washers, and 2 nuts.) | 2 Sets | 7.00 |
| 1.3 | **Springs** (Spring 1: k=10 lb./in and Spring 2: k=30 lb./in) | 4 (Two pairs of each spring) | 3.84 |
| 1.4 | **Thomson Linear Rail** | 2 | 199.90 |
| | **Total** | **11** | **302.67** |

## *Appendix C: Gantt Chart*

| | | Name | Duration | Start | Finish | Predecessors | Resources |
|---|---|---|---|---|---|---|---|
| 1 | | Modified Bicycle Motion Capstone | 174d | 09/06/2016 | 05/05/2017 | | |
| 2 | | Client Meeting 1 | 1d | 09/13/2016 | 09/13/2016 | | Fahad Alajmi[50% |
| 3 | | Team Meeting | 1d | 09/14/2016 | 09/14/2016 | | Fahad Alajmi[50% |
| 4 | | Perform Background Research | 6d | 09/14/2016 | 09/21/2016 | 2 | Fahad Alajmi[50% |
| 5 | | Staff Meeting 1 | 1d | 09/20/2016 | 09/20/2016 | | Fahad Alajmi[50% |
| 6 | | Team Meeting | 1d | 09/21/2016 | 09/21/2016 | | Fahad Alajmi[50% |
| 7 | | Presentation 1 | 1d | 09/27/2016 | 09/27/2016 | | Fahad Alajmi[50% |
| 8 | | Team Meeting | 1d | 09/28/2016 | 09/28/2016 | | Fahad Alajmi[50% |
| 9 | | Background Report | 7d | 09/22/2016 | 09/30/2016 | 4 | Fahad Alajmi[50% |
| 10 | | Team Meeting | 1d | 10/05/2016 | 10/05/2016 | | Fahad Alajmi[50% |
| 11 | | Concept Generation | 10d | 10/05/2016 | 10/18/2016 | | Fahad Alajmi[50% |
| 12 | | Client Meeting 2 | 1d | 10/13/2016 | 10/13/2016 | | Fahad Alajmi[50% |
| 13 | | Staff Meeting 2 | 1d | 10/18/2016 | 10/18/2016 | 11 | Fahad Alajmi[50% |
| 14 | | Presentation 2 | 1d | 10/25/2016 | 10/25/2016 | 11 | Fahad Alajmi[50% |
| 15 | | Team Meeting | 1d | 10/26/2016 | 10/26/2016 | | Fahad Alajmi[50% |
| 16 | | Preliminary Report | 1d | 10/28/2016 | 10/28/2016 | 11 | Fahad Alajmi[50% |
| 17 | | Team Meeting | 1d | 10/19/2016 | 10/19/2016 | | Fahad Alajmi[50% |
| 18 | | Team Meeting | 1d | 11/02/2016 | 11/02/2016 | | Fahad Alajmi[50% |
| 19 | | Team Meeting | 1d | 11/09/2016 | 11/09/2016 | | Fahad Alajmi[50% |
| 20 | | Staff Meeting 3 | 1d | 11/15/2016 | 11/15/2016 | | Fahad Alajmi[50% |
| 21 | | Team Meeting | 1d | 11/16/2016 | 11/16/2016 | | Fahad Alajmi[50% |
| 22 | | Individual Analytical Report | 1d | 11/18/2016 | 11/18/2016 | | Fahad Alajmi[50% |
| 23 | | Final Proposal Report | 1d | 11/23/2016 | 11/23/2016 | 22 | Fahad Alajmi[50% |
| 24 | | Presentation 3 | 1d | 11/22/2016 | 11/22/2016 | | Fahad Alajmi[50% |
| 25 | | Team Meeting | 1d | 11/30/2016 | 11/30/2016 | | Fahad Alajmi[50% |