Flux Electric Bicycle

Alec Korver, Bryan Hanenberg, Christopher Slice

Mentor: Professor Doug De Boer

Dordt College

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***Executive summary***

Transportation options in Northwest Iowa have common shortcomings that can be solved with an electric bicycle. This provides a stewardly, enjoyable, and aesthetically pleasing alternative. The final design did not fulfill each criterion and constraint fully, but as a whole was a success. Using a freewheeling crank set and operating the mid-drive motor at 750W with a built in controller allowed for intuitive, practical use while maintaining affordability. The bike can be driven under electric power alone, but our design also allowed for an electric pedal-assist mode. Our design adhered to the local laws and regulations, which allows the bike to be ridden without any certification. Our bicycle’s self-contained battery box uses a keyed switch for additional security. The battery capacity that was chosen allowed for up to 20 miles of pedal free operation, which exceeded our initial design constraint. Although the controller programming did not allow for the immediate display of certain information to the rider, all of this information was provided by the inclusion of a web-based riding simulation. The battery is removable but requires tooling and is labor intensive. We deemed our prototype a success because it ultimately met each of our initial criteria and constraints.

***Introduction***

The goal for our senior design team was to design, simulate, and build an electric bicycle that has been optimized for use in northwest Iowa. Our project seeks to address the shortcomings of commonly used travel options by offering a stewardly, enjoyable, and aesthetically pleasing alternative solution. We do not wish to reinvent the wheel, but to present an existing technology in a new way that meshes better with our societal values. Our project seeks to create an electric bicycle that improves people's everyday commute, whether that is a leisurely ride to the post office, a daily commute to work, or a trip to the grocery store, in ways that prioritize project development driven by Christian shalom seeking principles.

Design constraints and criteria were identified by discussing what the average commuter of northwest Iowa values. Professor Schuurman, who did his masters research on simulating electric scooters, took the role as our customer to help identify some of these criteria. From our discussions we concluded that the bike would need to be able to ride on gravel roads, but will be primarily used on paved surfaces. It should have good hill climbing capabilities and be comfortable to ride. The riding range under electric power alone should be at least 10 miles with a fully charged battery and an ideal top speed of between 15mph – 20mph.

***Problem Description***

According to the United States Department of Transportation the average driver travels 29 miles per day or a total time of 55 minutes spent behind the wheel. 87% of these daily trips are taken in personal motor vehicles (1).

For many drivers, personal comfort, time, and convenience are among the most important criteria used for determining how they make their daily commutes. With the ever-growing concern for our environmental impact, it is becoming increasingly important that we pursue ecologically friendly and healthy travel alternatives. Bicycles may be a suitable alternative for many individuals with short commutes, but they inadequately address the importance of time and convenience for many potential users. Our project seeks to address these shortcomings by offering an attractive alternative travel solution. We do not wish to reinvent the wheel, but to present an existing technology in a way that meshes better with our local societal values by focusing on speed, reliability, quality, convenience, and aesthetics. Our goal is to design an electric bicycle that is an improvement to the everyday drive by overcoming the shortcomings of highly individualistic modes of transportation in ways that prioritize Christian normative principles. By focusing on design characteristics in a holistic manner we can ensure that our electric bicycle can better fulfill its flourishing potential. An electric bike is more than the sum of its parts, and by recognizing the importance of looking at the design as a whole we will create a product that is environmentally friendly, promotes clear and open communication with ones neighbor, and increases public interest in using more energy efficient means of transportation.

***Project Context***

***Historical Context***

As human civilization develops, the need for transportation of individuals and goods grows. The wheel enabled efficient utilization of energy, so that humans could move heavier loads with less exertion, i.e. wheelbarrows. In 1817, Charles of Sauerbrun invented a device, which allowed for the driving of a wheel with pedals, along with the ability to steer. This was the forerunner of the bicycle (2). Driven to make life easier, the steam engine was soon applied to the bicycle by the Frenchman Pierre Michaux in the 1860's (3). With the introduction of the internal combustion engine and its ensuing popularity, the motorbike was also invented and put into mass production in Germany already by 1894 (4). During this time, electric motors competed with the internal combustion engine for market share throughout the world (5). However, due to the gas biased infrastructure and superior power that gas engines could provide, electric bicycles faded to the background. Despite the limitations of gas powered devices during the oil crises of the later 20th century, the lack of affordable, low weight, and high-density batteries meant that electric bicycles would remain a luxury and not become widespread in use. However, by the turn of the 21st century, issues have arisen that give electric bicycles another chance at popularity. Climate change, erratic prices of oil, and advances in battery technology have combined to produce a political and economic environment that is ready for the adoption of electric bicycle technology (6).

The history of electric bicycles provides valuable insight into what a successful design must employ. Governmental regulation has been indirect in this realm, as only recently electric bikes have been able to compete with motorbikes, and begin to fall under more restriction. In order to still be classified as a motorcycle and avoid licensure and the annual fees that accompany it, the bike must only be able to reach 20 MPH on electric power alone (7). Socioeconomic factors have much to do with a successful design as well. Previously, electric bikes have been prohibitively expensive for the average consumer. Distances that potential consumers commute have also been problematic, as the range of electric bikes is considerably less than a similar motorbike. Perpetual obesity rates and unhealthy lifestyles have opened Western society up to options that consider the personal health of the commuter, instead of simply time saved and convenience. If lessons are not learned from the failure of electric bikes in the past, they are doomed to fade into obscurity again.

The E-bike design acknowledges the shift in societal thinking away from "bigger is better" and toward environmentally friendly and economically sensible solutions. This design provides the range required for people in rural communities such as Northwest Iowa, while not exceeding it. This allows the bike to be affordable. Including the ability for pedal assist or entirely pedal driven allows for a health conscience use, serving the needs of those that wish to add regular exercise to their daily life. Specifically for rural communities that are experiencing increasing urbanization, this design is ideal. As smaller towns become a rarity, people are traveling further during their daily lives. Because of this, human-powered bicycles are becoming a less viable alternative.

***Social/Cultural context***

There are several societal benefits of widespread adoption of lightweight, efficient, and environmentally friendly vehicles. First, a vast amount of energy can be saved simply because electric bikes are much lighter than traditional cars. The typical commuter vehicle weighs around 3,000lbs and is made from a combination of glass, metals, and petrol products. An electric bicycle weighs around 35lbs and requires significantly less natural resources to be produced. Every day millions of drivers are needlessly transported to and from work or school in their 3,000lbs personal vehicles in an effort to move 180lbs of biological mass a few short miles. Energy dense fossil fuels are carelessly used and are ultimately converted into low quality and unrecoverable energy. Additionally, energy is further wasted in the production of these steel vehicles. Cars require significantly more energy to be produced and are often made from a combination of products, many of which are difficult to recycle. The electric bicycle requires less infrastructure, energy, and raw materials to be produced. A reduction of energy used in production as is essential to reducing air pollution, and could potentially play a large roll in slowing global warming. An increased adoption of electric bikes could lead to increased demand for more renewable energy sources. This could greatly impact culture by changing norms for transportation in many places.

Our project assumes that the world values convenience over sustainability, and that most people need to be coaxed or persuaded to use more sustainable practices. That, or there is such a small emphasis on sustainable transportation in our culture, that most people do not even know that there is a need for it. If there were a greater emphasis on sustainability in our culture today, this or other modes of transportation similar to it would likely be commonplace. Instead, there is a large number of fossil fuel powered internal combustion vehicles in service. In addition, people are unwilling to compromise what they already have to be more sustainable. For example, for electric cars to be deemed viable in our society they are expected to be able go as far on a single charge as an internal combustion engine can on a single tank of gasoline, even though there are very few people who use a whole tank of gas every day. This emphasis shows that our society should be more contentious of our impact on the earth, and need to change our expectations on standards of energy usage in order to maintain the health of our planet.

A good quality and relatively inexpensive electric bicycle may open the door for many more efficient and environmentally friendly vehicles, particularly for short distances. However, there is also development of highly efficient human powered vehicles by several groups. These vehicles are at their heart bicycles, but with highly efficient bearings and aerodynamic bodies that greatly reduce rolling friction and wind resistance. If an electrical system similar to the one in our project is used on an aerodynamic vehicle such as this, it would greatly increase the range and efficiency of an electric bicycle. This improvement could make it practical for long distance commuters to use electric bicycles as well. So these two emerging designs complement each other and really enable practical uses of both.

An electric bicycle is a culturally appropriate solution for personal transportation that reduces our environmental impact. In our culture a good product needs to be very easy to use, secure, and safe. Electric bikes are easy to use and even easier to maintain than their motorcycle counterparts. The bike will never need an oil change, and has far fewer moving parts that can fail and necessitate repairs. It works just like any other bicycle, and can be ridden just like any other whether or not you want to use the motor on it. It is also much lighter than other two-wheeled personal vehicles, which makes handling it much simpler for the user as well. In order to turn it on, all you need to do is turn a key and it connects the battery and motor automatically, unlike motorcycles where a kick-start is sometimes necessary and possibly difficult to use.

Electric bicycle adoption serves society by reducing the impact of modern transportation on the environment in a variety of ways. Most notably in the reduction of burning of fossil fuels for transportation, as well as fabrication costs in terms of materials used, and energy spent to manufacture the vehicle. This could be done without a technological solution if people were more willing to give up comforts and conveniences and simply use regular bicycles. However, that is not a popular idea in the culture we live in. As a result a technological compromise is made, that is not only much more efficient, but also allows the user some of the previously had conveniences. It also allows people who previously were required to use an automobile, mostly due to distance and time considerations, to use a more environmentally friendly method of commuting.

Our project is focused on providing a vehicle for a commuter who lives in the Sioux Center area of northwestern Iowa. This mandated a number of different design choices being made due to geography, weather, and local laws. The geography of the landscape had an effect on the size of the battery in order to get places, as well as gear ratios to ensure that the bike would be able to get up steep terrain. The weather of the area played an effect on protecting the battery, and picking waterproof connectors and such in order to protect the bike. Local laws also require things such as lights or reflectors, as well as limited the size of the motor on the bike and top speed.

There is a cultural trend towards more sustainable or “green” alternatives to almost everything. This trend could boost demand for a personal electric vehicle such as our bike. Public transportation is also “greener” than cars, but people also want independence from bus and train schedules, so it would likely create a higher demand for both public transportation as well as personal electric vehicles. Other things such as the Internet of Things, could allow for more security features and information tracking for the project. For example, a password from a phone could potentially be used to turn on the bike in addition to or instead of a physical key that can be stolen. Or an RFID key with the user’s phone could be used to unlock it as well, since a phone is easier to keep track of, and will be noticed more quickly if it is lost or stolen.

***Contemporary Technological Context***

An electric bicycle consists of 4 major components: motor, batteries, controller, and the bicycle. Bicycles come prebuilt intended for different applications, which include: road, hybrid, and mountain. The type of bike needs to be carefully determined based on the rider’s primary intended use and geographical location. Duvine.com gives a summary of the differences between these bikes which is outlined below (8):

Road Bikes

These lightweight bicycles are built for speed and long distances. Drop handlebars, skinny tires and a minimal saddle are their most distinguishing characteristics. Road bikes are built for speed and smooth riding. They are nimble, fast handling, precision machines best suited to more experienced riders and avid cyclists. However, many guests find that a road bike is actually more enjoyable than other bicycle types as they make the cycling a bit less difficult. The riding position is aerodynamic with the rider bent over the dropped handlebars. They are designed for well-paved roads and cannot be used for off road riding.

Mountain Bikes

If you want to get off the road and ride in rugged terrain, the mountain bike is the one for you. Mountain bikes put you in an upright riding position for better visibility, and have flat handlebars for good steering control. They are equipped with fat, knobby, shock absorbing tires. A typical mountain bike also has a shock absorbing suspension system. Hill climbing is a lot easier on a mountain bike because they have a wider gear range than a typical road bike. They are heavier than road bikes, but are more comfortable to ride.

Hybrid Bikes

The hybrid or cross bike combines the comfort and upright riding position of a mountain bike with the lighter weight and responsive features of a road machine. Tires are narrower than a mountain bike’s but wider and more robust than a road bike. A hybrid shares the same wide range gearing as a mountain bike, which makes hill climbing a snap. They also handle well on less than perfect roads. You can use one for trail riding, but a hybrid won’t be able to stand up to the roughest of terrain.

**E-bike Technology**

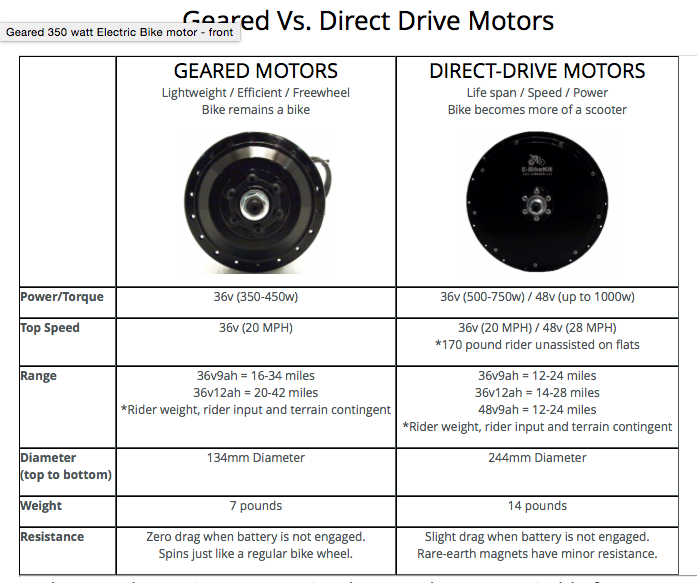
The 3 main types of motors used in electric vehicles include: induction, brushless dc (BLDC) and brushed dc. Induction motors are a tried and true technology. They have been around for nearly a century and have proven themselves to be useful for many different applications. Tesla motors, a high performance electric vehicle manufacturer, uses induction motors as the mainstay for all their vehicles, but induction motors are rarely seen in the electric bike market for a few reasons:

“One of the main differences is that much less rotor heat is generated with the DC brushless drive. Rotor cooling is easier and peak point efficiency is generally higher for this drive. The DC brushless drive can also operate at unity power factor, whereas the best power factor for the induction drive is about 85 percent. This means that the peak point energy efficiency for a DC brushless drive will typically be a few percentage points higher than for an induction drive” (9)

In brushless motors, as the size of the motor and the load grows the magnetic losses of the motor increases proportionately and part load efficiency drops. With induction motors, as the size of the motor and the load grows, the losses do not necessarily grow. (9) Because of this scaling relationship for efficiency BLDC motors tend to be better suited for smaller size and load applications, such as an electric bicycle. Induction motors are difficult to find for low power applications (<500W) because of the low power efficiency losses. Because of these limitations BLDC and brushed motors are more commonly implemented in the electric bike market. The motors mounting location is as equally important as choosing what type of motor to be used.

The three most common mounting configurations for the motor include direct drive hub, geared hub, and mid drive. Direct drive hub motors are commonly used because they are more simple, quieter, and faster. However they tend to have less torque than a geared hub or a mid drive motor, weigh more, and resistively drag when unpowered. Geared hub motors tend to be smaller, lighter and offer more torque than their direct drive counterparts, but they make more noise, have a lower top speed and are more complex. The chart below gives a good summary of the two types of hub motors.

(10)

 Figure 1.1, Geared Hub vs Direct Drive

The direct drive and geared hub motors are mounted in the hub of the front or rear bicycle wheel. A hub-mounted motor usually comes preinstalled in a wheel, which makes it easy to install. Hub mounted motors tend to change the way a bike handles because they add 7 lbs. – 14 lbs. of mass to the center of a wheel. A common complaint is that the bike handles poorly because of how this changes the location of the center of mass and increases the inertia of the wheel. Electric bike hub motors are typically brushed or brushless dc (BLDC) motor. In contrast to the hub mounted motor is the mid drive motor.

A mid drive motor is typically mounted off of the bottom bracket of the bicycle and drives the rear wheel through the bicycles gears. Mid drive motors reposition the mass of the motor towards the bottom center of the bike frame, which keeps the center of mass nearer the rider. Unlike hub motors, mid drives do not alter the inertial characteristics of the wheel. This gives them more normal handling characteristics. Mid drives are more complex to install and cost more than hub drive motors. Mid drive motor configurations typically use a BLDC motor but there are a few companies producing brushed mid drive motors. The type of motor that is used dictates what type of controller is needed.

BLDC motors require a more complex controller than a brushed motor. There are two standard types of BLDC controllers: The first controller is referred to as sensor less because it does not use Hall effect sensors to determine motor position. Instead a sensor-less controller uses the back-EMF, which is a function of the rotor’s position and speed, to determine the rotor position. The problem with this type of controller is that detection of position using back-EMF at zero and very low speeds is not possible. For an electric bike this is a significant problem because there are many times that the bike will be not moving or moving at very low speeds. Many of the cheap Chinese e-bikes that are being sold with brushless hub motors often use these sensor-less controllers because they are generally lower cost and can be used for multiple e-bike models. So while these electric bike controllers are inexpensive and often marketed as a “one size fits all” type controller, a sensored controller will provide a better overall performance and longer life.

A sensored controller uses Hall effect sensors positioned around the mounted rotor to detect the rotors position and speed. While a motor and controller that use Hall effect sensors is more complex and more expensive, it has the ability to sense position and speed while stopped or at low speeds. These types of controllers are used with the more expensive electric bike kits that typically utilize mid drive motors. They provide a smoother torque response because they sense actual position instead of relying on the back-EMF, which is unreliable in low speeds applications. The motor and controller specifications help establish constraints and criteria for choosing a battery pack.

**Batteries**

The battery is usually one of the most expensive parts of an electric vehicle and one mistake many consumers make is focusing on price instead of the quality of the battery. The main problem with getting an inexpensive and low quality battery is the likelihood of potential defects. When most things have defects, they simply break and are no longer useable anymore. However, in the case of lithium ion batteries, these potential defects can be hazardous to the electronics using them and the people nearby as well. Failures of bad batteries often include fires, explosions, or just leaking of battery acid. Getting a legitimate name brand (not a Chinese copy with a name brand printed on it) greatly reduces the chances of injury for consumers, and should be used in any consumer application. It is also common to find that low quality brands from Asia often do not supply what they say that they do. The picture at right is an example of a common find. The customer bought "18650" batteries, and found that they were actually much smaller batteries put into the 18650 size case.

http://www.rzbiker.com/20120527\_184518.jpg

There are other ways to save money on a good battery for an electric bike. Most prominently is the ability to make your own battery pack. Individual lithium ion cells can be purchased from companies in bulk, these are the same cells that are often used in battery packs for electric bikes. The main problem with this is making very secure connections between the batteries. This is difficult because pressure connections allow sliding of the connections, and can allow corrosion over time that reduces the effectiveness of the battery. Soldering would be the next easiest option, but these battery cells are sensitive to high temperatures, and getting the connections hot enough to solder could cause fire, acid leakage, or just a reduction in capacity. When battery packs are manufactured, they are often spot welded together with nickel tabs for ease of manufacturing, and a lower chance of overheating the battery. However, battery spot welders are much less common than soldering irons and clamps, and most people wouldn’t know how to use it. Another potential problem with creating a battery pack is the lack of a Battery Monitoring System (BMS). These monitor the current output and voltage of the battery pack and makes sure that the pack does not reach dangerous conditions. However, these conditions change depending on what type of cell is used, and great care is needed to ensure that the correct BMS is used and that it is installed correctly. Otherwise it could result in the batteries starting on fire or leaking as was mentioned previously.

Another possible option would have been to purchase smaller battery packs with leads already connected. This would be an easy way to create a larger battery pack, however there are a few drawbacks. First, it would likely be more expensive than a single large battery pack, even though it would be more flexible. Second, there would be a lot more resistance introduced into the battery due to wire lengths and imperfect connections between the different small battery packs. Third, the conglomeration of small battery packs would be much more prone to failure. The extra connections have a greater chance to come loose unless secured very well. There is also an increased chance to get foreign objects/material between connections that could cause shorts and become dangerous. Fourth and last, finding a battery monitoring system for protection can be extremely difficult as they are usually made to be compatible for very specific combinations of battery cells, and types of cells

**E-bike Commerce**

Electric bicycles have been sold for a number of years and generally fall under 3 price/performance categories: Low Cost/Low Performance: ($100 - $700), Mid Cost/Standard Performance: ($700 - $2000), and High Cost/High Performance: ($2000+).

Low Cost/Low Performance bikes are generally produced and distributed as way to test the electric bicycle market in a new area. They generally utilize low quality bicycle components, motors, and SLA batteries. While there is nothing inherently wrong with these types of bicycles they are not well suited for an individual who intends on using their bike more than occasionally. These bicycles will typically suffer from rough shifting, poor braking and minimal electronic management. These categories of electric bikes should be avoided because according to Court Rye, founder of electricbikereview.com, which has reviewed 300+ electric bikes since 2012,

“My feeling is that $1,500 is the lowest level worth exploring right now. I've seen too many unhappy customers who purchased online and are now struggling to fix a throttle mechanism or find a replacement battery pack because the cells they got were of very low quality. There have even been some fires when cheap batteries were damaged and didn't have an electronic management system in place to prevent overload.” (11)

The adage “you get what you pay for” holds true for the electric bicycle market. It is important to be a well-informed consumer when researching electric bikes because of the many different variations available. We have the technology to produce e-bikes that are quiet, reliable, efficient, and overall a joy to ride; but without demand for electric bicycles these technologies are often overlooked in order to meet the insatiable appetite for cheaply made goods. Customers are unhappy with their purchases of electric bikes partly because of the lack of good quality and reasonably priced electric bikes available in the U.S. market. The demands of the well-informed consumer are unmet because of how small the U.S. e-bike market is. According to The Smithsonian

“Last year, about 25 million e-bikes were sold in China; in the U.S. the number was under 100,000. According to [Pike Research](http://www.pikeresearch.com/newsroom/annual-sales-of-electric-bicycles-will-surpass-47-million-by-2018-2), U.S. sales might climb over 100,000 this year and could reach as high as 350,000 in 2018. But that would still be a sliver of projected global sales in 2018, just under 50 million. And it would not only be dwarfed by the market in China–which will still account for almost 90 percent of worldwide sales–but also will fall well below e-bike purchases in India, Europe and Japan.” (12)

The U.S. is the largest consumer nation in the world but yet we lag behind the rest of the developed world in terms of adopting ecofriendly forms of transportation. People are often reluctant to give up their automobiles for other forms of transportation because of the “convenience factor” of owning and driving your own vehicle. This is clearly shown in the graphic below that compares e-bike sales around the world.

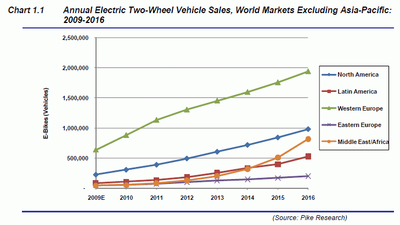


Figure 1.2, Annual Electric Two-Wheel Vehicle Sales

Electric bicycles have come a long way in terms of technology and offer a convenient and quick form of transportation. Boris Mordkovich, a green tech entrepreneur from New York who’s in the middle of a cross-country odyssey to promote e-bikes in the U.S. points out that this may be due to misconceptions people have of electric bikes.

“Most of the people in the U.S. either aren’t familiar with electric bikes or have misconceptions about them, confusing them with scooters, motorcycles and everything in between. As long as that’s the case, they fail to see the benefits in them. However, as soon as they are explained what an electric bike is and how it actually works, or better yet, take their first ride on it, the perception changes drastically.” (13)

***Design Norms, project requirements (criteria and Constraints)***

The design norms and project requirements have stemmed from the social, economic, pistic, ethical, juridical, and aesthetic normative principles. As a whole the design seeks shalom for consumers and creation. Our team's ability to fulfill these principles through a concrete design are framed within the constraint of time, therefore a perfect design can only be sought after, not obtained. Our team has focused on building a holistic electric bicycle. We understand that an electric bicycle is more than the sum of its parts and, that just like the Dooyweerdian norms, cannot be reduced and separated from the other bicycle components. Aesthetics, the bike must clearly communicate how it ought to be used. It should be designed such that it is intuitive and easy to use. We were able to adhere to these norms by designing a bike that is durable, low maintenance, long lived, and comfortable. Another important aspect of our design process was the judicial norm. The judicial norm requires that the cost of the bike must reflect the amount of services it provides to the user. Much of our design process has been spent on optimizing the design, so that the user is able to have a bike, which delivers the highest return in usefulness for their money. As per the judicial norm, the design's constraints also serve to ensure safe and legal operation for the user. The customer requested that no additional certification be required for operation. If the bike goes faster than 20 mph on motor power alone or operates above 750W, law classifies it as a motorcycle; as such these were added as constraints. To further comply with Iowan law and allow for night riding, front and rear lights were also required. In order to travel between Orange City and Sioux Center, the customer also required that the bike be able to go a minimum of 10 miles on motor power alone. Along with justice for the customer in particular, this is the minimum that the bike can travel in order to be economically useful and judicial to any user in a city or rural environment.

Constraints

1 Bike must provide at least 10 miles of operation on electric motor power alone

2. Bike must not go faster than 20 mph on electric power alone on flat ground (See Appendix B)

3. Bike must not operate over 750W

4. Bike will have front and rear lights for riding after sundown per Iowa law

Our design criteria arose from a desire for an optimized experience characterized by balance between ease of maintenance, aesthetic beauty, usefulness, and safety for all users. Essentially, the Social, judicial, economical, and pistic norms cooperate with each other in the design. The Bike must be able to be ridden in most weather conditions, seasons, and times of day therefore being waterproof and operable in a wide range of temperatures with LED headlights and taillights. The safety of the rider must not be put in jeopardy. A kill switch on the brake allows for an immediate stoppage of the chain in case of an accident. The motor's heat sink shouldn't provide an opportunity of danger by way of burning the rider's legs. Upon acceleration, it is unacceptable for inexperienced riders to be at risk of flipping the bike over due to excessive torque, therefore the creep must be kept at minimum. A proper design must be an extension of the user, and able to be normally maintained by the user at low cost without requiring extensive knowledge. The battery must be able to be charged and removed by the average person, provide only relevant and vital information to the user as to the state of the bike (such as remaining battery charge, current speed, etc.). History and our personal experience with electric bicycles show they have failed aesthetically, in that they are not enjoyable to operate or seem out of step with how a bicycle ought to look in a cultural context. This design sought also to appear modern, being minimalistic and not easily distinguishable from a regular bicycle. Distinguishable

Criteria

1. Bike operation will be simple enough for a teenager's use.

2. Bike will have a temperature sensor for motor and battery, relative, only supplying immediate temps

3. Bike's heat sink will not danger rider through poking or burning

4. Bike will be able to be operated in ambient temperatures ranging from 32 to 100 °F, as well as in rain.

5. Bike's battery will be removable and chargeable via 120V 15A house outlet.

6. Bike will have kill switch to prevent revving of engine in case of a crash

7. Bike will appear modern: minimalist, sleek, and easily identifiable as a bicycle.

8. Bike will display information to the rider in the form of remaining charge, current speed, distance ridden, and projected remaining mileage,

9. Bike will feature a key lock to deter battery and motor theft

10. Battery containment unit (BCU) will be rigid, water proof, and lockable, lasting for at least two years

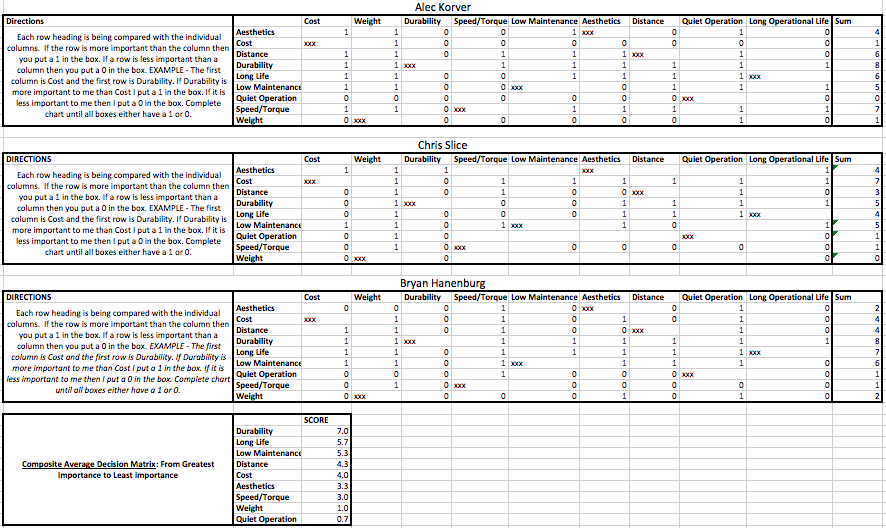
11. Must use metric bolts

12. Bike will have a creep so that users of all ages are not perturbed upon acceleration

13. Bike will feature LED lights for night riding

***Design alternatives & Evaluation of those alternatives***

Table 1.1, Decision Matrix



From Table 1.1 it can be seen that durability, long life, low maintenance, and riding distance were among the most important criteria for the project. Both the customer and project mentor also consistently mentioned these criteria as being important. Because of their importance we decided that off the shelf components and kits would be our primary source for parts. Off the shelf components will be better suited towards larger scale bike production applications in the future post prototype phase. Bicycle companies have spent a lot of time, money, and energy developing products that have good durability, long life, and low maintenance.

**Early Simulation**

In order to make early design decisions, an Excel Spreadsheet was made to act as a general model for electric bicycles performance. The design process necessitated that we had an efficient way to compare different electric motors, gearing ratios, and bicycle configurations. The simulation modeled the different configurations against a riding profile mapped out using GPS data. A GUI prompted the user to enter the rider/bike weight, gearing ratios, and electric motor parameters such as the torque constant, internal resistance, peak power, and operating voltage. Tables and graphs were produced for the torque-speed power band curves for bicycles gearing ratios and the motor efficiency at different power input levels. This data was then used to solve a cubic velocity equation for each section of the riding profile to find the ride time and “mpg” Watt Hours/ Kilometers for the bicycle configuration. The early simulation was used to provide simple quantitative comparisons between the different bicycle configurations. It was soon determined that for the design choices be better understood we would need to characterize our own electric motor and use those parameters for more accurate comparisons.

**Electric motors**

We decided upon using a brushless mid-drive electric motor because of the distinct advantages they have over other alternatives as covered in the current e-bike technology section. Three brushless motor systems were considered for project implementation: Cyclone Motors 650W, Astro Motors 3210 2KW, and the 750W Bafang BBSO2. Each of these motors has distinct advantages for implementation and was compared accordingly. Because of the importance of determining the motor characteristics for use in simulation modeling, we contacted Groschopp, an electric motor manufacturer in Sioux Center Iowa, to see determine whether they could assist us in bench testing any of our motors. By having the ability to bench test any motors, the project no longer necessitated that we purchase a well-documented electric motor, which gave us more freedom in our selection.

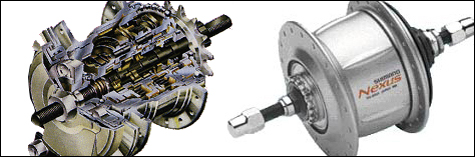
The Cyclone motors 650W system is an all in one mid-drive electric bike conversion kit being produced and sold from Taiwan. This kit is the lowest cost option at $370. The kit includes the gear reduction system, mounting brackets for the motor, the motor, throttle, and controller. The motor mounts to the down tube of the bicycle frame and uses a gear reducer directly attached to the motor shaft and another external gear that is chained to the primary bicycle gear to step down the shaft speed. The manufacturers website includes hand drawn plots of the motor characteristics but lacked specific motor specification details. We attempted to email the manufacturer and two distributors to help determine if this kit would meet our needs, but did not receive any responses. The concerns about this kit include the lack of motor specifications, the unknown shipping time from Taiwan to USA, no manufacturer warranty, and no programmable controller. Professor De Boer recommended that we do not purchase an electric motor and controller kit from without a warranty and from outside the USA incase there were any problems with the kit.

The Astro Motors 3210 is a 2KW brushless motor being produced and sold in the USA. This is sold as a motor only and does not include a gear reduction system, mounting system, throttle, or controller. The motor is $470 and their recommended controller is $1000, making this option the most expensive on the list. Astro Motors manufacturers and sells motors for hobbyist RC aircraft. Because the motor is intended for use with RC aircraft, the motor operates at 9000RPM. To be able to use this motor on an electric bike the shaft speed would have to be stepped down to 150 RPM. This motor also uses a controller that senses motor position by using the motor back EMF. There are no hall effect sensors installed on this motor and the controller available cannot use hall effect sensors for position sensing. We contacted the company asking whether or not they would be able to install hall effect sensors and whether they had any controllers that would be compatible with the 3210. The company responded saying they did not sell sensored motors and did not have a controller available for a sensored motor. The 3210 is the most well documented motor under consideration and comes with a limited warranty. Professor De Boer recommended that we do not purchase a motor without a paired controller because of the likelihood of recurring problems, and the amount of time and energy it would take to reliably interface a 3rd party controller with a motor.

The Bafang BBSO2 is an all in one 750W mid-drive electric bike conversion kit being produced in China, but available for purchase in the USA. The total price for this kit is $544.95, which includes the motor with a built in/upgraded controller with 3077 MOSFETs, helical gear reduction system, bottom bracket mounting hardware, throttle, pedals, crank set, primary bike gear, and onboard bike computer. This kit was available for purchase from Lunacycle.com, whom we contacted about the motor specifications. They did not have any motor specifications available beyond operating voltage, peak current, gear ratio, and peak power output. Our primary hesitation with this motor is this lack of documentation. The primary benefits of this kit are: it is sold via a US distributor, the motor, controller, and gear reduction systems are built into a single unit which mounts to the bottom bracket of the bicycle, the controller has upgraded FETs to allow higher continuous current during operation, and very little customization would be necessary to implement this kit.

Our group selected the Bafang BBSO2 conversion kit. This kit was selected for a few reasons. The kit includes almost all of the necessary parts to convert a typical bicycle into an electric bicycle. It uses a bottom bracket mounting system, which allows it to be installed on almost any bike frame. The distributor was easy to contact and offered a 90-day warranty. The controller configurations can be customized to allow for either a throttle or pedal speed sensor controlled motor. The pedal speed sensor works with the pedal assist system (PAS), which has 9 different levels of assist. These levels are each individually configurable to adjust the percentage of motor response relative to pedaling speed. The motor and controller use Hall effect sensors for absolute position sensing. The controller can be programmed to limit different amounts of current allowing the bike to be configured to street legal levels in any state. For Iowa this legal limit is 750W. The system has a good performance to cost ratio; it is a good value. The distributor was willing to give us a 10% discount off our entire order, including the purchase of a battery, if we sent them the bench testing results for the motor. These attributes made this selection the ideal choice for our project.

**Internally Geared Hubs and Derailleurs**

Most bicycles come equipped with a derailleur and chain tensioner. Derailleurs are typically 98% efficient. Gear ratio for gear ratio these transmission systems tend to be among the least expensive options for use with a bike, but they are more prone to failures than an internally geared hub and require more regular maintenance. These systems are not closed and are easily exposed to the water, salt, and sand that is typically encountered in the wintry months of northwest Iowa. Derailleurs are also more prone to the chain slipping, chain links breaking, and the chain can fall off of the gears due to bumps. Because of these shortcomings, derailleurs can be risky to use for very long bike rides (50 miles or more) or for areas with very steep hills.

An internally geared hub is a closed system that does not require routine maintenance or care. Bicycles that use this type of transmission do not need chain tensioners. The internally geared hub uses planetary gears and is able to be shifted under load without having to rotate the pedals. This is important because when using a mid drive electric motor, it is important that you select the appropriate gear or you run the risk of burning up your motor and controller. This scenario can easily happen if you come to a stop on a hill, are in too high of a gear, and have difficulty even getting started. The high current in the bike produces more heat, and more heat on a stationary bike means more risk of burning up the components. A bike with an internally geared hub can be down shifted from the highest gear to the lowest gear without pedaling. This allows you to select the appropriate gear quickly and efficiently. One draw back of the internally geared hub is that they are less efficient than a derailleur. Internally geared hubs tend to be around 92% efficient. These systems tend to cost more than a derailleur, and they typically come in 3, 5, 7, 8, 9, and 13 speed options. We decided upon using an internally geared hub because of the distinct advantages associated with being able to shift without pedaling or while under load as well as the durability and lack of required maintenance.

We primarily considered 4 different internally geared hubs. The Shimano Nexus 3 speed hub, Shimano Nexus 7 speed hub, Shimano Nexus 8 speed hub, and the Shimano Alfine 8 speed hub. When it comes to picking a hub, one of the most important things to consider is the overall gear ratio. The gear ratio is important because it helps decide whether you are pushing your bike or riding your bike. Figure 1.02 is a graphical representation of their overall gear ratios for the four different hubs considered.

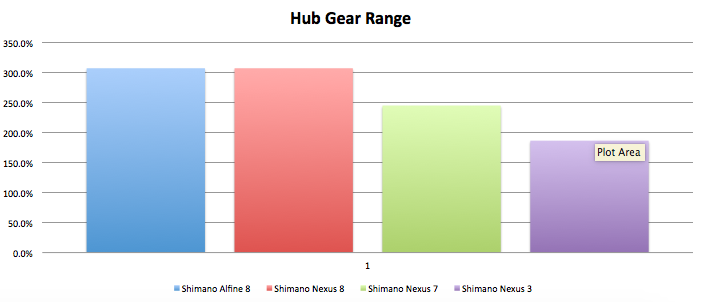


Fig 1.3, Hub Gear Range

The percentage values represent difference between the highest and lowest gears. For example the Shimano 8 speed hubs have a gear ratio % of 306%. This means that in the highest gear the bike will travel 306% further per pedal revolution. Bikes with lower gear ratios (GR< 200%) will be less expensive, simple to build, rugged, and are ideal for flat riding locations. Bikes with gear ratios (200%< GR < 300%) will be more expensive but better suited for riding in areas with some hills or little wind. Bikes with gear ratios (300% < GR) are better suited for areas with steep hills or high winds. The internal hubs in the last category will be the most expensive, but will be better suited for a wider range of conditions. The hubs with the largest gear ratios will also allow the motor to be operating in its peak efficiency areas more consistently than hubs with the smallest gear ratios. The best value hubs will be the ones that provide the largest overall % gear ratio/cost. This analysis can be seen in Table 1.2.

Table 1.2, Geared Hub Comparison

|  |  |  |  |
| --- | --- | --- | --- |
|  | Shift Range % | Price | % Range/$ |
| Shimano Alfine 8 | 306.5% | $243.99 | 1.26 |
|  |  |  |  |
| Shimano Nexus 8 | 306.5% | $189.00 | 1.62 |
|  |  |  |  |
| Shimano Nexus 7 | 244.5% | $170.12 | 1.44 |
|  |  |  |  |
| Shimano Nexus 3 | 186.1% | $49.85 | 3.73 |

From Table 1.2 it can be seen that the best value hub is the Nexus 3. However for hubs with higher total gear ratios the Shimano Nexus 8 is the better value. It can also be seen that the Shimano Nexus 8 and the Shimano Alfine 8 have the same overall shift range. That is because they use the same gear ratios and steps with the only difference between the two being the Shimano Alfine 8 coming equipped for disc brakes. For a bike that will use disc brakes the Shimano Alfine series would be the preferred hub. our project intends for the user to have a wide range of usability in northwest Iowa, it is necessary for the bike to have the highest gear ratio available. For our project we ended up selecting the Shimano Nexus 8 because it was a better value than the Nexus 7 with a wider overall gear ratio.

**Primary and Secondary Gear Ratios**

It is also important to carefully consider the number of teeth on the primary and secondary sprockets on the bike. It is important to select sprockets that will maximize the usability of the bicycles gearing. By running different primary to secondary gear ratios through our excel simulation, we determined that the primary gear should have 52 teeth instead of the 48 or 50 tooth options. The 52 tooth primary gear will take better advantage of the gearing ratios of the internally geared hub because the limitations of the other gears meant we were unable to maximize our speed. The excel simulation verified that we would have enough power to make it up the hills of NW Iowa with this selection.

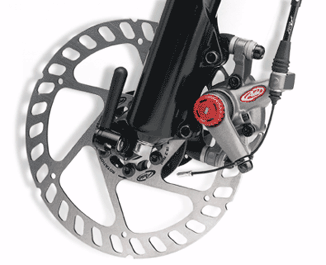
**Bike Frames**

Four frame styles were initially considered for the project: Hybrid, Track, Mountain, and Road. As discussed in the contemporary technological context section there are advantages and disadvantages to each frame style. Because we decided on using an internally geared hub, we had to use a track bike (fixie bike) frame. This style of frame has rear wheel drop outs that open towards the end of the bike. This style of dropout allows for the bike chain to be manually tensioned by setting the rear wheel and tightening the drop out bolts. Other bike frames do not allow for manual chain tensioning which is a necessary provision for use with an internally geared hub. Other bike frame variations would have to undergo custom modification to accommodate the appropriate rear drop out brackets. For the bike frame three materials were considered: steel, aluminum, and carbon fiber.

Steel bike frames are the most commonly found. Steel is a very durable material for building a bike frame. They can be scratched, dinged, and even bent, and they can still retain their structural integrity. Steel frames tend to be somewhat flexible and offer a softer ride. Steel frames typically weigh more than their aluminum and carbon fiber counterparts but this is reflected in their reduced cost. A steel frame can start out as cheap as $50 or cost significantly more for the more advanced chromoly steel versions.

Aluminum bike frames have been becoming very popular the past few years. These frames have become significantly less expensive than they used to be and as such are becoming more widely used. Frames made from aluminum tend to be light, strong, and stiff. A properly designed aluminum frame will make a bike feel very responsive especially in tight handling situations. One drawback of aluminum frames is that their stiffness transmits rode vibrations to the rider more easily. These frames typically start price around $150 and can cost almost as much as their carbon fiber counterparts.

Track bike and road bike frames are typically suspension less, as such it is important to reduce the road vibrations felt by the rider. Carbon fiber is an excellent material for reducing this road vibration. Carbon fiber is a lightweight woven fabric material commonly used in the bike frame industry, but these frames are typically cost prohibitive. A full carbon fiber track bike frame starts in price around $500 and can easily exceed $2000. Because this bike is intended for the typical northwest Iowa commuter is was determined that these frames would not fit within our budget. For our project we ended up purchasing a Keirin Pro 6061 aluminum track bike frame. This frame was chosen because of its lightweight, durability, and overall build quality.

  
**Rim and Disc brakes**

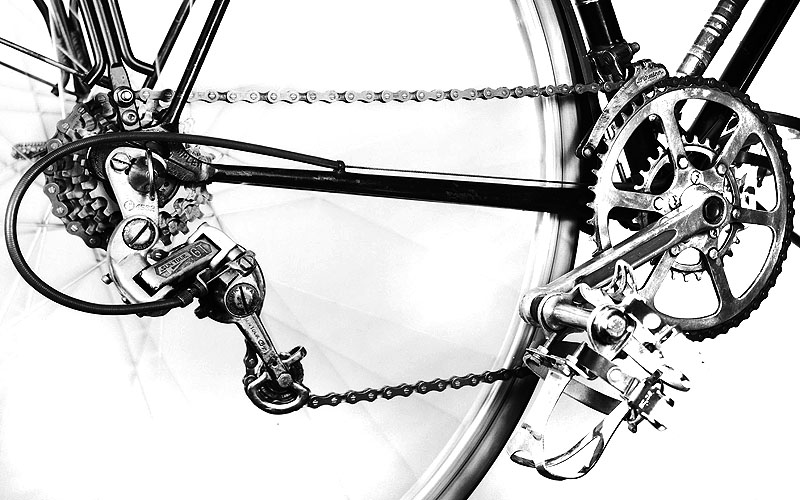
Disc brakes can apply a much better braking force, and have increased reliability, but are significantly more expensive and require it to be built into the wheel. Disc brakes are typically used on bikes that are made for riding in the mountains or areas with large and steep hills. This is because they can maintain their braking force for a long time without breaking down like rim brakes do.

Rim brakes are significantly less expensive than disc brakes, provide a decent braking force, are much more common. Since Iowa does not have a mountainous terrain, use of rim brakes would be overkill. We were also limited in our selection because the selected internally geared hub is incompatible with disc brakes. Our choice of rim brakes was also limited because our frame/forks is designed for 28"/700cc racing wheels. Because our bike uses 26" wheels it became necessary for us to use extended reach rim brakes. The necessary brake extension also prevented us from adding a second brake to the front wheel.

**Battery voltage/Amp-hour rating**

Per the design constraints, enough energy was needed to go at least 10 miles. When running this through the initial Excel simulation, we found out that at least 13 Ah was needed with a 48v battery. To ensure that the bike would be able to go this full distance over the entire life of the battery, we needed to account for about a 20% reduction in capacity over approximately 300 cycles. This means we would need at least a 16.25 Ah battery. By rounding up to the next possible size, we came to the conclusion that a 20 Ah battery would be the right size. We considered trying to find two smaller batteries that were closer to give a longer range, however the price of batteries does not scale proportionally with the size. As a result it was much more cost effective to simply use a large capacity battery pack, especially if a higher voltage was used. There are many vendors that sell battery packs like these, though most of them are Chinese. These Chinese suppliers, though inexpensive, there are a lot of quality risks associated with Chinese battery packs as well as a lack of warranty. Thus it was chosen to buy from an American supplier. A 52 volt 20.8 amp-hour battery from Lunacycle was chosen due to good reviews, relatively low cost, and because they guaranteed that the pack was made with genuine Samsung cells.

**Chain/Belt drive**



Chains are much more common and less expensive than belts, plus there is less friction between the sprockets and the chain than there is between a belt and their gears. However, belts are known to last a significant length longer than chain drives due to a lack of sliding parts and corrosion.

**External monitors**

We ensured that there was a monitor in order to read and display battery charge and speed to ensure that the rider can be knowledgeable of a potential lack of power, and that they can obey local road laws as well.

**Battery Case**

To ensure the battery, the most expensive piece of the bicycle, is kept safe, a good case is needed. Most of the cases available at the moment are one of two different styles. The highest quality ones is mounted above the rear wheel on a rack that keeps them directly behind the seat. The other types are soft cases, either leather or another fabric that can be mounted inside the frame of the bicycle. We initially opted for a free cloth bag that fit inside the frame of the bicycle because it kept the center of gravity low and in the center of the bicycle, as well as because it came free with the motor and battery that we purchased. However it became apparent that this was not going to work very well. Due to the size of the battery, the straps attaching the bag to the bicycle began to rip. In addition, the bag was not completely waterproof, did not provide a good location for an ignition, and was not impervious to theft. A rear-mounted solution was considered, as it could provide all of these things. But a centrally mounted unit was preferred due to the better center of gravity, and the customer did not like the way rear-mounted cases looked.

Since there is such variability in the shape and size of bicycle frames, commercially available hard cases meant to fit in the center of the frame are very hard to find. Thus it was decided to fabricate one specific to the bike frame that we have. Several different options were shown to the customer and the team and the best looking design was chosen from those. We chose to make the case from 0.05-inch thick 5051 H32 aluminum sheet due to its corrosion resistance, bendability, strength, and lightweight.

We bought a standard 52v battery from an American supplier, so that if there are ever any complications with the battery, there is a possibility of a warranty to replace the part. If that is not possible, it is not a custom solution, so a new pack just needs to be purchased and replaced.

An keyed switch is a significant requirement in our design criteria. It's important in the prevention of theft and increasing safety by allowing a physical connection to be broken when it is turned off, which ensures that no more current is flowing.

Temperature sensors are directly built into the battery to ensure safe operation, and will disconnect the battery from the load in the case that the temperature gets too high. Separate temperature sensors are available, but are for testing purposes only, and don’t really have a purpose besides giving us information.

***Final Design Description***

Our final design is an optimized electric bike solution for a northwestern Iowa resident. As such, it is primarily composed of high quality, off the shelf components instead of customized solutions. This not only ensures that the final product is durable, but that it is low maintenance, and it is easily fixed and has readily obtainable replacement parts. This was only strayed from in the case of the battery containment unit, simply because it is extremely difficult to find a mass produced solution that will fit inside a bike frame, and that fits our requirements.

The main piece of the bicycle, the frame, is a 61cm Keirin Pro 6061 aluminum alloy track bike frame. To match the frame we bought Taylor Wheels front and rear wheels, with the rear wheel containing a Shimano Nexus 8 speed internally geared hub. For power, a Lunacycle modified Bafang BBS02 750 watt motor and controller kit was used. To power the motor a Lunacycle 52V, 20.8 Ah battery pack was used. To contain and protect the battery, a custom fabricated box was made from 0.05" 5051 H32 aluminum sheet metal. This also housed other electronics such as two automotive relays for the charging port and for disconnecting the motor from the battery. The case also serves as a mount for the ignition key that operates the relays. Many other accessories and components were also needed to make the bike functional, such as a seat, handlebars, brakes, pedals, front and rear lights, and more. A full list of purchased parts and their costs can be found in Appendix A.

Construction of the bike is fairly straightforward with the exception of soldering a few wires, and construction of the battery case. The battery case was made from a single sheet of aluminum that was measured out cut into four separate pieces with a shear, and bent into shape. The resulting pieces were then clamped together and holes were drilled and tapped so that bolts could easily hold them together. The case was affixed to the bike by bending strips of aluminum around the frame and flattening out the ends to they could be bolted to the top and back of the box. A circular hole was drilled in the top front of the battery for the ignition, and then widened into a D shape so the ignition wouldn’t slip in the box when turned. Three other holes were cut into the box in the top front and back, and the bottom. These were for the motor cables going to the battery (in the bottom back), the display cable going down to the motor controller (in the top front), and the port for charging the battery (in the top back). The box was held together by a number of bolts that have been threaded into the aluminum that give it both structural strength and makes it more secure.

The bike can be operated by turning the keyed switch, and then holding the power button until the display turns on. Then the throttle can be used to adjust the amount of torque applied to the rear wheel. As an alternative, the pedal assist mode can be used by pressing the + or – buttons to choose a pedal assist level. Once a pedal assist level has been chosen, one must simply begin pedaling, and the motor will automatically apply torque to assist. To turn off, turn the keyed switch back to the starting position and remove the key.

***Testing and Design Validation***

***Groschopp Testing Info & Motor Discussion***

We purchased the Bafang BBS02 750W mid-drive electric motor system from LunaCycle.com. The manufacturer and distributor both lacked specifications necessary for accurate simulation according to our specifications. Knowing this prior to purchase we contacted Groschopp in Sioux Center to help us determine the missing specifications. In order to perform the speed torque tests on the motor we needed to measure the axle torque and speed. Paul Ross, John Kleyer, Tyler Gengler, and Jim Oosterhuis, engineers at Groschopp recommended that we perform the tests on the entire mid-drive system, including the gear reduction components, and model the system as a single motor. The recommendation was made for two reasons. First with the housing of the motor removed there was no bearing to keep the rotor aligned for a test. Secondly it would reduce the complexity of the simulation by modeling the motor and gear reduction system as a single unit.

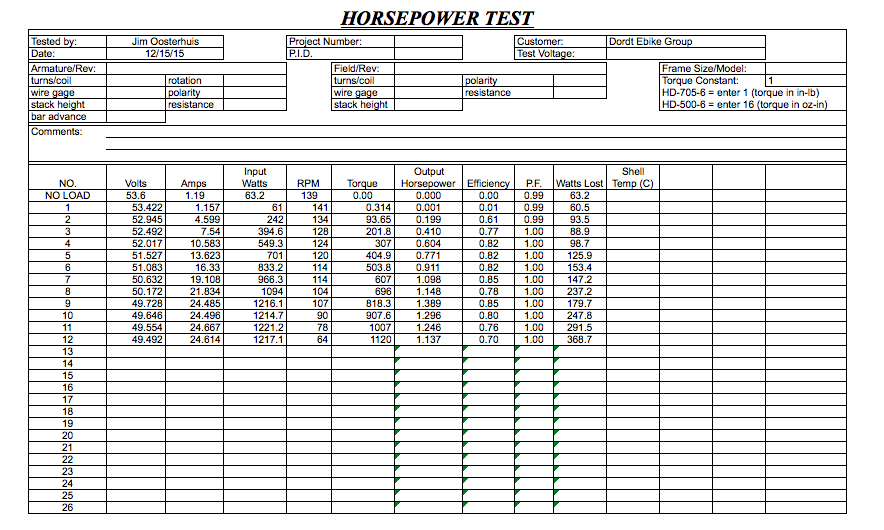
We determined that the brushless dc motor has 16 magnets, 8 poles, 18 slots (additional for a specific back-EMF shape). The primary motor shaft is a 9 tooth steel helix, the second stage mating gear has 23 teeth and the 1st stage gear is 1 inch tall**.** The controller is built into the motor housing and uses (3) hall-effect sensors positioned around the windings to sense the rotor position. The controller was “waterproofed” by the manufacturer by completely covering it in silicon RV sealant. The controller has two modes of operation. The first mode uses the thumb throttle to control the output torque of the motor. The second mode of operation is known as pedal assist system (PAS). Which uses a speed sensor at the crank to control the torque output of the motor. At lower speeds the motor applies more torque and at higher speeds it applies less torque. The controller has (0 – 9) PAS modes, each of which are independently configurable. The PAS system response rate is customizable and can be configured connecting the controller to a computer and opening the controller programming GUI.

A temperature probe was installed into the motor/controller housing in order to monitor the internal temperature during operation. The motor and controller temperature is important to monitor because as the temperature rises the resistance of a conductor also rises, which means more current will be turned into heat, which will increase the resistance even further. This has a cyclical effect until the motor and/or the controller fails. The temperature information will help determine the ideal current limitation and ramp response settings for us to program into the controller. The consumer model will not come with the temperature probe installed.

The motor gear reduction system has a 21.9:1 reduction that uses a helical primary gear in order to decrease the amount of noise during operation.

Oosterhuis an electrical engineer at Groschopp who assisted us in taking apart the motor said the motor was well-built and good quality. He also assisted us with performing a motor characterization test. This test monitored the battery voltage, current, motor speed, and torque at the rotor. The load of the motor was gradually increased until we reached a predetermined output current from the battery (24.5 Amps). The results of these tests can be seen in Table 1.3 and Figure 1.4.

TABLE 1.3, Groschopp Test Data



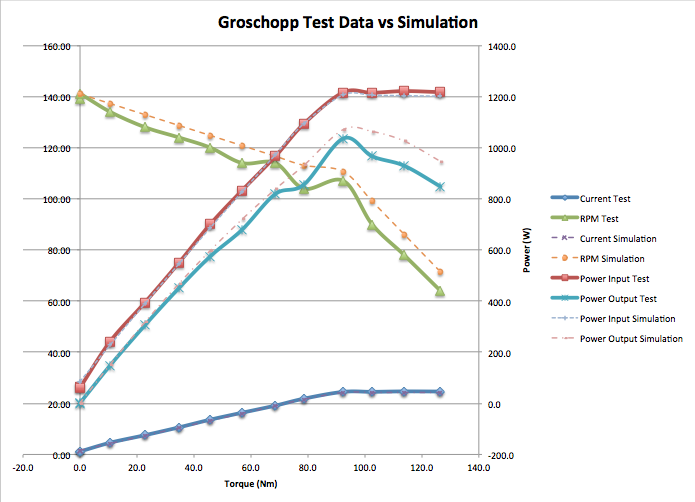


Figure 1.4, Groschopp Test Data vs Simulation

From this information we were able to revise the early excel simulation to more accurately model our specific motor. Figure 1.4 shows the excel simulation values (dashed lines) in comparison to the Groschopp testing values (solid lines). One observation is that the "RPM Test" line changes slope after the "Current Test" line levels off. This flexion point produces a non-linearity of the "RPM Test" line. In an ideal world the "RPM Test" line would be completely linear. The comparison of the real world test vs the excel simulation validated the performance of our simulation. This validation gave us the necessary groundwork for implementation our final web based simulation.

**Final Simulation**

Once a higher degree of modeling precision had been achieved for the bicycle's variables, the limiting factor of our simulation's integrity as a whole was the precision of the variables, which represented the elevation change. The previous resolution of 1km meant that in areas such as northwest Iowa, which exhibits flat landscape on average but has many rolling hills, the simulation results would not hold true on smaller trips. In order to develop a simulation with enough elevation points a Google Elevation API was implemented. By sending requests to Google's servers through a JavaScript program, elevation changes on the scale of one meter or less are possible, allowing for a highly precise modeling simulation to be made. While JavaScript allows for automated importing of this elevation data into our previous excel spreadsheet, this provided an opportunity for an all-inclusive, web based simulation. Publishing our simulation on the Web allowed for a lightweight, easily accessible simulation that could be ran on any computer or device connected to the Internet. As an added benefit, the Google Roads API also allowed for the customer to choose any self-determined path on earth at whim, and generate an elevation profile with our simulation's model of the bikes performance on that path. By abstracting the number of primary and secondary sprocket teeth, along with motor parameters (such as efficiency, kc & kt values, etc.) into the code, we produced web based simulation that allows the simulation of a e-bike's performance of any user inputted route based only 6 variables – Radius of the wheel, mass of the bike and rider, average power input, battery voltage and battery capacity. This code can be seen in appendix C.

This simulation, in order to provide an informative and aesthetic user experience, was giving the capability of being quickly and intuitively performed, the results easily interpreted, and easily tested with control variables. The simulation provides default specification numbers that can be changed by the user. Instructions are kept to a minimum, widely familiar Google map controls are implemented, and symmetry is maintained throughout the page. Results are displayed in a different tab, which holds the results for all simulations ran in a session. The results themselves are kept to relevant and useful details: the distance traveled, time it took, % of the battery remaining, and equivalent gas mileage. The latter gives the customer an appreciation for the efficiency of electric vehicles, allowing for routes and designs, which reinforce economic and judicial normative choices regardless of technical know-how. Finally, in order to be able to quickly replicate a path's simulation with control variables allows for the user to determine the optimal Wattage to run through the motor and the size of a battery needed for their specific purposes. Both of these choices further encourage and allow users to be judicious and economic with their money and energy usage.

**Battery Cold Charge Test**

A test was performed to determine if the battery pack had cold temperature shut off protection. We placed the battery in a 0 °F freezer for approximately 24 hours to ensure that the entire battery was below normal operating temperatures. Then a kill-a-watt meter was plugged into a wall outlet in order to monitor current so that it could be determined if the battery was being charged or not. Then the charger was plugged the charger into the kill-a-watt meter. After the current settled from initially plugging in the charger, the charger was connected to the battery. There was an initial jump in current to about 4 amps as the charger kicked in and fans started spinning. A few seconds later the current had gone down to approximately 3 amperes and stopped falling. The battery was then immediately disconnected to prevent permanent damage due to cold charging. This test showed that the battery BMS does not have a feature that prevents charging while the battery is too cold.

***Conclusions and Recommendations***

|  |  |  |
| --- | --- | --- |
|  | Total Cost | MSRP(130% Cost) |
| Deluxe Model | $1,949.44 | $2,631.74 |
| 20 AH Battery |  |  |
| 8 Speed Internally Geared Hub |  |  |
| Aluminum Track Bike Frame |  |  |
|  |  |  |
| Standard Model | $1,496.67 | $2,020.50 |
| 10 AH Battery |  |  |
| Fixie Frame |  |  |
| 3 Speed Internally Geared Hub |  |  |
|  |  |  |
| Base Model | $1,209 | $1,632.15 |
| Fixie Bike - Complete |  |  |
| 3 Speed Internally Geared Hub |  |  |
| 10 AH Battery |  |  |
|  |  |  |
| Eco-Model | $1,092.01 | $1,474.21 |
| Fixie Bike - Complete |  |  |
| Single Speed |  |  |
| 10 AH Battery |  |  |

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***Appendix A: Itemized list of parts purchases***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PART | PRICE | QUANTITY | TOTAL | URL |
| XLC Dual Grips | $8.49 | 1 | $8.49 | <https://www.amazon.com/gp/product/B001BN6V6C/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1> |
| HDE 2 Pack LCD Thermometer | $10.99 | 1 | $10.99 | <https://www.amazon.com/gp/product/B00W3YB2VW/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1> |
| LED Lights for Bikes | $29.99 | 1 | $29.99 | <https://www.amazon.com/gp/product/B00RX6LW2O/ref=oh_aui_detailpage_o00_s01?ie=UTF8&psc=1> |
| 8FUN Bafang right throttle | $21.99 | 1 | $21.99 | <https://www.amazon.com/gp/product/B010ELRR3M/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1> |
| XLC Alloy MTB Pedal | $11.49 | 1 | $11.49 | <https://www.amazon.com/gp/product/B000YRU4NM/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1> |
| Sunlite recessed brake nut | $4.09 | 2 | $8.18 | <https://www.amazon.com/gp/product/B004TN34WA/ref=oh_aui_detailpage_o05_s00?ie=UTF8&psc=1> |
| Key Switch | $11.23 | 1 | $11.23 | <https://www.amazon.com/gp/product/B0002BA3PE/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1> |
| KMC Master Link | $9.99 | 1 | $9.99 | <https://www.amazon.com/gp/product/B00K7YIVGE/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1> |
| Universal Chain tool | $12.95 | 1 | $12.95 | <https://www.amazon.com/gp/product/B005EP95ZC/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1> |
| KMC X8.99 Bike Chain | $18.56 | 1 | $18.56 | <https://www.amazon.com/gp/product/B0013BV540/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1> |
| Tektro extended reach brake | $23.99 | 2 | $47.98 | <https://www.amazon.com/gp/product/B00BLM4EJY/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1> |
| Seat post shim | $10.06 | 1 | $10.06 | <https://www.amazon.com/gp/product/B0011W87FQ/ref=oh_aui_detailpage_o04_s00?ie=UTF8&psc=1> |
| Brake cable and housing | $12.55 | 1 | $12.55 | <https://www.amazon.com/gp/product/B0050LUBZ8/ref=oh_aui_detailpage_o05_s00?ie=UTF8&psc=1> |
| Low profile 7" zip ties (100) | $10.99 | 1 | $10.99 | <https://www.amazon.com/gp/product/B009VJZS0I/ref=oh_aui_detailpage_o05_s00?ie=UTF8&psc=1> |
| Plastic cable clips (6) | $8.31 | 2 | $16.62 | <https://www.amazon.com/gp/product/B00KYSULDE/ref=oh_aui_detailpage_o06_s00?ie=UTF8&psc=1> |
| XLC brake levers | $12.95 | 1 | $12.95 | <https://www.amazon.com/gp/product/B000NUIHV6/ref=oh_aui_detailpage_o08_s00?ie=UTF8&psc=1> |
| Riser bar | $39.99 | 1 | $39.99 | <https://www.amazon.com/gp/product/B001C4SB36/ref=oh_aui_detailpage_o08_s01?ie=UTF8&psc=1> |
| Bike seat | $13.99 | 1 | $13.99 | <https://www.amazon.com/gp/product/B00858T8MU/ref=oh_aui_detailpage_o08_s03?ie=UTF8&psc=1> |
| Bike stem | $16.88 | 1 | $16.88 | <https://www.amazon.com/gp/product/B008PNUEF0/ref=oh_aui_detailpage_o08_s03?ie=UTF8&psc=1> |
| 26 x 1.50 tubes | $8.74 | 2 | $17.48 | <https://www.amazon.com/gp/product/B00165PA1W/ref=oh_aui_detailpage_o08_s03?ie=UTF8&psc=1> |
| Headset spacer | $10.09 | 1 | $10.09 | <https://www.amazon.com/gp/product/B003UWFFNW/ref=oh_aui_detailpage_o08_s03?ie=UTF8&psc=1> |
| Seat post | $9.95 | 1 | $9.95 | <https://www.amazon.com/gp/product/B00DMHLRIM/ref=oh_aui_detailpage_o09_s00?ie=UTF8&psc=1> |
| Bottom Bracket 68x110.5mm | $15 | 1 | $15.00 | <https://www.amazon.com/gp/product/B00B58QJBU/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1> |
| Kenda K-193 Commuter tire 26" x 1.5" | $24.65 | 2 | $49.30 | <https://www.amazon.com/gp/product/B006GEZQX0/ref=oh_aui_detailpage_o00_s01?ie=UTF8&psc=1> |
| Taylor Wheels rear wheel w/ nexus inter 8 | $208.99 | 1 | $208.99 | <https://www.amazon.com/gp/product/B00AA8SMV6/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1> |
| Taylor Wheels 26" front wheel | $86.99 | 1 | $86.99 | <https://www.amazon.com/gp/product/B00AA8SXJW/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1> |
| Pure Fix Keiring 6061 61cm Frame | $203.21 | 1 | $203.21 | <https://www.amazon.com/gp/product/B012CAYY0M/ref=oh_aui_detailpage_o03_s02?ie=UTF8&psc=1> |
| Adjustable bike kickstand | $12.70 | 1 | $12.70 | <https://www.amazon.com/gp/product/B00FIKIK7C/ref=oh_aui_detailpage_o03_s03?ie=UTF8&psc=1> |
| Lunacycle bbso2 750W kit - Upgraded 3077 Fet | $542.95 | 1 | $542.95 | <http://lunacycle.com/motors/bafang-mid-drive-and-parts/bafang-bbs02-750w-mid-drive-with-upgraded-3077-controller/> |
| Lunacycle 52v 20.8 ah Samsung 18650 battery | $582.95 | 1 | $582.95 | <http://lunacycle.com/batteries/packs/52v-samsung-18650-20-8-ah/> |
| Lunacycle Triangle Bag | $0 | 1 | $0.00 |  |
| Lunacycle Smart Fast Charger | $55 | 1 | $55.00 |  |
| Lunacycle watt meter | $0 | 1 | $0.00 |  |
| Lunacycle order discount | -$112.60 | 1 | -$112.60 |  |
| Lunacycle shipping and handling | $80 | 1 | $80.00 |  |
| .050" 5052-H32 ALUMINUM SHEET 24 inches x 36 inches | $44 | 1 | $43.85 | <https://www.onlinemetals.com/merchant.cfm?pid=7127&step=4&showunits=inches&id=240&top_cat=60> |
| Luna Cycle Watt Meter | $35 | 1 | $34.96 | <http://lunacycle.com/batteries/guages/luna-cycle-watt-meter/> |
|  |  |  |  |  |
|  |  |  |  |  |
| Unnecessary Parts total | $73 | Grand Total | $2,166.69 |  |

***Appendix B: Local Laws & Regulations***

Iowa Code 321.1, Iowan Law pertaining to Electronically Assisted Vehicles

20B. *"Electric personal assistive mobility device"* means a self-balancing, nontandem two-wheeled device powered by an electric propulsion system that averages seven hundred fifty watts and is designed to transport one person, with a maximum speed on a paved level surface of less than twenty miles per hour. The maximum speed shall be calculated based on operation of the device by a person who weighs one hundred seventy pounds when the device is powered solely by the electric propulsion system. For purposes of this chapter, *"electric personal assistive mobility device"* does not include an assistive device as defined in section 216E.1.

***Appendix C:***  ***JavaScript Code for Web Simulation***

<!DOCTYPE html>

<!--EBike Simulator version 1.3, 03/30/16, 8:06 pm-->

<html>

<head>

<meta charset="utf-8">

<title>E-Bike Simulation v1.3</title>

<style>

html, #body {

height: 100%;

width: 100%;

margin: 0px;

padding: 0px;

}

#map {

position:fixed;

width: 100%;

height: 98vh;

padding: 0px;

margin: 0px;

}

#panel {

position: absolute;

top: 5px;

left: 50%;

margin-left: -180px;

z-index: 5;

background-color: #fff;

padding: 5px;

border: 1px solid #999;

}

#bar {

width: 240px;

background-color: rgba(255, 255, 255, 0.75);

margin: 8px;

padding: 4px;

border-radius: 4px;

}

#autoc {

width: 100%;

box-sizing: border-box;

}

</style>

<!--allows for use of the elevation chart-->

<script src="https://www.google.com/jsapi"></script>

<!--these are necessary for the Snap Example-->

<script src="https://ajax.googleapis.com/ajax/libs/jquery/1.9.1/jquery.min.js"></script>

<script src="https://maps.googleapis.com/maps/api/js?libraries=drawing,places"></script>

<!--For cubic equations-->

<!-- Latest compiled and minified CSS -->

<link rel="stylesheet" href="https://maxcdn.bootstrapcdn.com/bootstrap/3.3.6/css/bootstrap.min.css" integrity="sha384-1q8mTJOASx8j1Au+a5WDVnPi2lkFfwwEAa8hDDdjZlpLegxhjVME1fgjWPGmkzs7" crossorigin="anonymous">

<!-- Optional theme -->

<link rel="stylesheet" href="https://maxcdn.bootstrapcdn.com/bootstrap/3.3.6/css/bootstrap-theme.min.css" integrity="sha384-fLW2N01lMqjakBkx3l/M9EahuwpSfeNvV63J5ezn3uZzapT0u7EYsXMjQV+0En5r" crossorigin="anonymous">

<!-- Latest compiled and minified JavaScript -->

<script src="https://maxcdn.bootstrapcdn.com/bootstrap/3.3.6/js/bootstrap.min.js" integrity="sha384-0mSbJDEHialfmuBBQP6A4Qrprq5OVfW37PRR3j5ELqxss1yVqOtnepnHVP9aJ7xS" crossorigin="anonymous"></script>

</head>

<body>

<div class ="row">

<div class = "col-xs-8 col-sm-6">

<div id = "title">

<label><font size = "10">Dordt EBike Simulator v1.3 </font></label>

</div>

<div class = "row" outline = "1px solid black">

<div class = "col-xs-8 col-sm-6">

<label id ="textBoxLabel"><font size = "5">Step 1: Name this instance of your Simulation:</font></label>

</div>

<div class = "col-xs-8 col-sm-6">

<input class = "form-control" id="nameOfSim" type="text" value = " " enabled>

</div>

</div>

<br>

<br>

<div class = "row">

<div class = "col-xs-8 col-sm-6">

<label id ="instructions"><font size = "5">Step 2: Specify Simulation variables:</font></label>

</div>

<div class = "col-xs-8 col-sm-6">

<input class = "form-control" id="defaultButton" type="button" value="Reset Values to Default" enabled>

</div>

</div>

<div class = "row">

<div class="col-xs-8 col-sm-6">

<label id ="textBoxLabel">Mass Rider (kg)</label>

<input class = "form-control" id="massRider" type="number" value=85 enabled>

<br>

<label id ="textBoxLabel">Mass Bike (kg)</label>

<input class = "form-control" id="massBike" type="number" value=25 enabled>

<br>

<label id ="textBoxLabel">Radius Wheel (m)</label>

<input class = "form-control" id="radiusWheel" type="number" value=0.335 enabled>

</div>

<div class="col-xs-8 col-sm-6">

<label id ="textBoxLabel">Average Throttle Input</label>

<select id = "inputPowerAverage" class = "form-control" name ="Types of Motors">

<option value ="1000">1300W Low</option>

<option value ="1150">1300W Med</option>

<option value ="1300">1300W High</option>

<option value ="450">750W Low</option>

<option value ="600">750W Med</option>

<option value ="750">750W High</option>

</select>

<!--

<label id ="textBoxLabel">Average Power Input (W)</label>

<input class = "form-control" id="inputPowerAverage" type="number" value=1100 enabled>

-->

<br>

<label id ="textBoxLabel">Battery Voltage (V)</label>

<input class = "form-control" id="voltageBattery" type="number" value=53.5 enabled>

<br>

<label id ="textBoxLabel">Battery Capacity (Ah)</label>

<input class = "form-control" id="ampHourBattery" type="number" value=20 enabled>

</div>

</div>

<br>

<br>

<div>

<!--step2-->

<label id="instructions"><font size = "5">Step 3: Click and drag to move the map. Specify the path you would like to simulate by

<br>&nbsp;&nbsp;&nbsp;&nbsp;(1) Click your starting point,

<br>&nbsp;&nbsp;&nbsp;&nbsp;(2) Click once at every intersection you will turn (also click once every half mile for best results), and

<br>&nbsp;&nbsp;&nbsp;&nbsp;(3) double click your destination. <br>Click "Simulation Start" when complete. To erase a previous path, select "click here" at the top right of your screen.

</font></label>

</div>

<br>

<div>

<input class = "form-control" id="simulationButton" type="button" value="Simulation Start" disabled>

</div>

<div id="elevation\_chart"></div>

<p id ="output"></p>

</div>

<div class = "col-xs-4 col-sm-6">

<div id="map"></div>

<div id="bar">

<p class="auto"><input type="text" id="autoc" /></p>

<p><a id="clear" href="#">Click here</a> to clear map.</p>

</div>

</div>

</div>

<p style = "position: fixed; bottom: 0px;">Christopher Slice (C) Feb 2016. Portions of this page are modifications based on work created and shared

by Google and used according to terms described in the Creative Commons

3.0 Attribution License.</p>

<div>

<script>

var apiKey = 'AIzaSyBYDBcKNSQyXIiZNmgFGb0ECdNBykf9g3Y';

var maxNumberOfSamples = 256;

//prompt("Enter the total number of elevation samples you would like to use");

var actualNumberOfSamples = 0;

var totalDistance = 0;

var resolution = 0;

var placeIdArray = [];

var polylines = [];

var snappedCoordinates = [];

var path;

var globalElevations = [];

var map;

var drawingManager;

var elevator;

var outputString = "";

var tab1 = null;

var simulationCounter = 0;

//remember, if you want to change default values, ensure you do it here and

//at the textbox html.

var massRider = 85; //rider's mass (kg) b1

var massBike = 25; //bike's mass (kg) b2

var radiusWheel = .335; //Wheel radius b3

var inputPowerAverage = document.getElementById("inputPowerAverage"); //average input power (dictated by throttle and current limit settings) b7

var voltageBattery = 53.5; // battery voltage (constant for battery) b8

var ampHourBattery = 20; //battery capacity (Ah) b24

//default Sim values to be saved to change the values back later.

var massRiderDef = massRider; //rider's mass (kg) b1

var massBikeDef = massBike; //bike's mass (kg) b2

var radiusWheelDef = radiusWheel; //Wheel radius b3

var inputPowerAverageDef = inputPowerAverage; //average input power (dictated by throttle and current limit settings) b7

var voltageBatteryDef = voltageBattery; // battery voltage (constant for battery) b8

var ampHourBatteryDef = ampHourBattery; //battery capacity (Ah) b24

// Load the Visualization API and the columnchart package.

google.load('visualization', '1', { packages: ['columnchart'] });

//calls initialize upon launch

$(window).load(initialize);

//Sets up the map, Drawing Manager, sets up the clear/search functions,

//sets up the button click event, and upon the finishing of drawing,

//calls snaptoroad(path)

function initialize() {

var mapOptions = {

zoom: 17,

center: {lat: 43.0833, lng: -96.1671}

};

map = new google.maps.Map(document.getElementById('map'), mapOptions);

elevator = new google.maps.ElevationService;

// Adds a Places search box. Searching for a place will center the map on that

// location.

map.controls[google.maps.ControlPosition.RIGHT\_TOP].push(

document.getElementById('bar'));

var autocomplete = new google.maps.places.Autocomplete(

document.getElementById('autoc'));

autocomplete.bindTo('bounds', map);

autocomplete.addListener('place\_changed', function() {

var place = autocomplete.getPlace();

if (place.geometry.viewport) {

map.fitBounds(place.geometry.viewport);

} else {

map.setCenter(place.geometry.location);

map.setZoom(17);

}

});

// Enables the polyline drawing control. Click on the map to start drawing a

// polyline. Each click will add a new vertice. Double-click to stop drawing.

drawingManager = new google.maps.drawing.DrawingManager({

drawingMode: google.maps.drawing.OverlayType.POLYLINE,

drawingControl: true,

drawingControlOptions: {

position: google.maps.ControlPosition.TOP\_CENTER,

drawingModes: [

google.maps.drawing.OverlayType.POLYLINE

]

},

polylineOptions: {

strokeColor: '#696969',

strokeWeight: 2

}

});

drawingManager.setMap(map);

// Snap-to-road when the polyline is completed.

drawingManager.addListener('polylinecomplete', function(poly) {

path = poly.getPath();

polylines.push(poly);

placeIdArray = [];

runSnapToRoad(path);

});

// Clear button. Click to remove all polylines.

$('#clear').click(function(ev) {

for (var i = 0; i < polylines.length; ++i) {

polylines[i].setMap(null);

}

polylines = [];

ev.preventDefault();

outputString = "";

document.getElementById("simulationButton").disabled = true;

return false;

});

//generate graph button

document.getElementById('simulationButton').addEventListener('click', function () {

displayPathElevation(elevator, map);

setTimeout(function(){generateSimulation();}, 2000);

});

document.getElementById('defaultButton').addEventListener('click', function () {

resetToDefault()

});

}

function resetToDefault(){

massRider = massRiderDef;

massBike = massBikeDef;

radiusWheel = radiusWheelDef;

inputPowerAverage = inputPowerAverageDef;

voltageBattery = voltageBatteryDef;

ampHourBattery = ampHourBatteryDef;

document.getElementById("massRider").value = massRider; //b1

document.getElementById("massBike").value = massBike; //b2

document.getElementById("radiusWheel").value = radiusWheel; //b3

document.getElementById("inputPowerAverage").value = inputPowerAverage; //b7

document.getElementById("voltageBattery").value = voltageBattery; //b8

document.getElementById("ampHourBattery").value = ampHourBattery; //b24

}

function isNumber(n) {

return !isNaN(parseFloat(n)) && isFinite(n);

}

function bold(id, number) {

if (number == 1) {

//document.getElementById(id).style.fontWeight = 'bold';

}

else if (number == 0) {

//document.getElementById(id).style.fontWeight = 'normal';

}

}

// Snap a user-created polyline to roads and draw the snapped path

//called by initialize upon polylinecomplete event

function runSnapToRoad(path) {

var pathValues = [];

//Grabs the URL value of each latlng along the polyline

for (var i = 0; i < path.getLength(); i++) {

pathValues.push(path.getAt(i).toUrlValue());

}

//Performs the actual snaptoraod function

//when it is done, the new latlngs are sent to procecsssnaptoRoadResponse(data)

//drawSnappedPolyline is also called

$.get('https://roads.googleapis.com/v1/snapToRoads', {

interpolate: true,

key: apiKey,

path: pathValues.join('|')

}, function(data) {

processSnapToRoadResponse(data);

drawSnappedPolyline();

});

}

// Store snapped polyline returned by the snap-to-road method.

function processSnapToRoadResponse(data) {

snappedCoordinates = [];

placeIdArray = [];

//generates latlng objects for each of the new snappedpoints and is stored

for (var i = 0; i < data.snappedPoints.length; i++) {

var latlng = new google.maps.LatLng(

data.snappedPoints[i].location.latitude,

data.snappedPoints[i].location.longitude);

snappedCoordinates.push(latlng);

placeIdArray.push(data.snappedPoints[i].placeId);

}

}

// Draws the snapped polyline (after processing snap-to-road response).

function drawSnappedPolyline() {

var snappedPolyline = new google.maps.Polyline({

path: snappedCoordinates,

strokeColor: 'black',

strokeWeight: 3

});

snappedPolyline.setMap(map);

polylines.push(snappedPolyline);

//now that the polyline is complete, the path is finished, the button is enabled

document.getElementById("simulationButton").disabled = false;

}

//calls and receives the callback from getelevationalongpath

//calls plotelevation

function displayPathElevation(elevator, map) {

//Create a pathElevation request object using this array

//ask for 256 samples along that path

//initiate the path request

elevator.getElevationAlongPath({

'path': snappedCoordinates,

'samples': maxNumberOfSamples

}, plotElevation);

}

//takes an array of elevationResult object, draws the path on the map

//and plots the elevation profile on a visualization API columchart

function plotElevation(elevations, status) {

//open a new tab and write the elevation chart to it

if (tab1 == null){

tab1 = open('graphTab.html');

}

simulationCounter++;

//tab1.document.write("<div id = elevation\_chart></div>");

if (status !== google.maps.ElevationStatus.OK) {

//show the error code inside the chartDiv

chartDiv.innerHTML = 'Cannot show elevation: request failed because ' +

status;

return;

}

actualNumberOfSamples = elevations.length;

//call findTotalDistance

totalDistance = 0;

findTotalDistance();

//create a new charty in the elevation\_chart DIV

var chart = new google.visualization.ColumnChart(chartDiv);

//Extract the data from which to ppoulate the chart.

//Because the samplesa re equidistant, the 'Sample'

//column here does double duty as distance along the X axis

var data = new google.visualization.DataTable();

data.addColumn('string', 'Sample');

data.addColumn('number', 'Elevation');

//updates google chart and writes to file

for (var i = 0; i < elevations.length; i++) {

data.addRow(['', elevations[i].elevation]);

globalElevations[i]= elevations[i].elevation;

}

//Draw the chart using the data within its DIV

chart.draw(data, {

height: 150,

legend: 'none',

titleY: 'Elevation (m)',

titleX: 'Distance (m)'

});

}

//finds total distance between snappedCoordinates

function findTotalDistance() {

for (var i = 0; i < snappedCoordinates.length-2; i++) {

totalDistance += getDistance(snappedCoordinates[i], snappedCoordinates[i + 1]);

}

resolution = totalDistance / (actualNumberOfSamples - 1);

var counterOrName;

if (document.getElementById('nameOfSim').value == " "){

counterOrName = simulationCounter;

}

else{

counterOrName = document.getElementById('nameOfSim').value;

}

tab1.document.write("<title>E-Bike Sim Results</title> <table style = 'width:30%'>" +

"<tr>" +

"<td>Sim Name</td>" +

"<td>" + counterOrName + "</td>" +

"</tr>" +

"<tr>" +

"<td>distance(mi)</td>" +

"<td>" + round100((totalDistance/1000\*.621371)) + "</td>" +

"</tr>" +

"<tr>"+

"<td>resolution (ft)</td>" +

"<td>" + round100((totalDistance/(actualNumberOfSamples-1))\*3.28084) + "</td>" +

"</tr>");

outputString += "number of elevation points: " + actualNumberOfSamples +

", total distance (km) = " + totalDistance/1000 +

", distance between each elevation point (m) = " +

totalDistance/(actualNumberOfSamples-1) + " ";

}

function rad(x) {

return x \* Math.PI / 180;

};

function round100(x){

return Math.round(100\*x)/100;

};

//takes two latlngs and returns the distance between them (figuring in curvature of the earth)

function getDistance(p1, p2) {

var R = 6378137; // Earth?s mean radius in meter

var dLat = rad(p2.lat() - p1.lat());

var dLong = rad(p2.lng() - p1.lng());

var a = Math.sin(dLat / 2) \* Math.sin(dLat / 2) +

Math.cos(rad(p1.lat())) \* Math.cos(rad(p2.lat())) \*

Math.sin(dLong / 2) \* Math.sin(dLong / 2);

var c = 2 \* Math.atan2(Math.sqrt(a), Math.sqrt(1 - a));

var d = R \* c;

return d; // returns the distance in meter

};

function generateSimulation() {

var massRider = document.getElementById("massRider").value; //b1

if (isNumber(massRider) != true){

alert(massRider + "massRider is not a number!");

}

var massBike = document.getElementById("massBike").value; //b2

if (isNumber(massBike) != true){

alert(massBike + "massBike is not a number!");

}

var radiusWheel = document.getElementById("radiusWheel").value; //b3

if (isNumber(radiusWheel) != true){

alert(radiusWheel + "radiusWheel is not a number!");

}

var inputPowerAverage = document.getElementById("inputPowerAverage").value; //b7

if (isNumber(inputPowerAverage) != true){

alert(inputPowerAverage + "inputPowerAverage is not a number!");

}

var voltageBattery = document.getElementById("voltageBattery").value; //b8

if (isNumber(voltageBattery) != true){

alert(voltageBattery + "voltageBattery is not a number!");

}

var ampHourBattery = document.getElementById("ampHourBattery").value; //b24

if (isNumber(ampHourBattery) != true){

alert(ampHourBattery + "ampHourBattery is not a number!");

}

//simulation variables

var rpmPerVolt = 57; //RPM/V b9

var radPerVoltSec = 5.97; //rad/(V\*s) b14

var maxCurrent = inputPowerAverage / voltageBattery; //Max Currnet, inputPowerAverage/voltageBattery b15

var rpmNoLoad = 141; //RPM no Load speed b20

var areaOfRider = 0.75; //m^2 area of rider b21

var airDensity = 1.184; //kg/m^3 air density b23

var dragCoeff = 1; //coefficient of drag b22

var wattHourBattery = ampHourBattery \*voltageBattery; //battery capacity (Wh) b25

var actualWattHourBattery = wattHourBattery \* .85; //usable battery capacity b26

var fudgeFactor = .63; //10% for internally geared hub, 18% for ....

var powerAtWheel = inputPowerAverage\*fudgeFactor; //power realized at the wheel, incorporates a fudge factor

var torqueAtPoint = [globalElevations.length-1];

var velocityAtPoint = [globalElevations.length - 1];

var timeAtPoint = [globalElevations.length - 1];

var torqueDragAtPoint = [globalElevations.length - 1];

var sumOfTorqueAtPoint = [globalElevations.length - 1];

var totalTimeSeconds = 0;

var totalTimeMinutes = 0;

var totalTimeHours = 0;

var totalPowerUsed = 0;

var gasMileage = 0;

//globalElevations[i] has my array

//resolution has my resolution

findTorqueAtPoints(torqueAtPoint, globalElevations, massRider, massBike, radiusWheel, resolution);

//find velcoity at points

//.5\*dragCoeff\*airDensity\*areaOfRider\*x^3+x\*torqueAtPoint[i]-power

var totalVelocity = 0;

for (var i = 0; i < globalElevations.length-2; i++) {

velocityAtPoint[i] = solveCubic(.5 \* dragCoeff \* airDensity \* areaOfRider, 0, torqueAtPoint[i], powerAtWheel \* -1);

}

//sum up all the times for total ride time

//find the time it takes to get to get ot each point

//divide an array of distances by velocity

for (var i = 0; i < globalElevations.length-2; i++){

timeAtPoint[i] = resolution / velocityAtPoint[i];

totalTimeSeconds += timeAtPoint[i];

}

totalTimeMinutes = totalTimeSeconds/60;

totalTimeHours = totalTimeMinutes/60;

outputString += "The total time is (m) " + totalTimeMinutes + " ";

//use total ride time and power input to find Wh used. Divide this number by km to find gas mileages

totalPowerUsed = inputPowerAverage \* totalTimeHours;

//gasMileage = ((inputPowerAverage/3600)\*totalTimeSeconds)/0.07587

gasMileage = totalPowerUsed/(totalDistance/1000\*.621371);

outputString += "Final Data: totalPowerUsed = " + totalPowerUsed + " gasMileage = " + gasMileage + " ";

//print time it took to take path (max quickness), battery left, wh/km (mpg), (estimated distance you can travel)

//writes the output to the current tab

//document.getElementById("output").innerHTML = outputString;

var batteryPercentage = 0;

if (round100(100\*(ampHourBattery\*.85-(totalPowerUsed/voltageBattery))/(ampHourBattery\*.85))< 0){

batteryPercentage = 0;

}

else{

batteryPercentage = round100(100\*(ampHourBattery\*.85-(totalPowerUsed/voltageBattery))/(ampHourBattery\*.85));

}

//writes the output to the next tab

tab1.document.write(

"<tr>" +

"<td>Time(mins)</td>" +

"<td>" + round100(totalTimeMinutes) + "</td>" +

"</tr>" +

"<tr>"+

"<td>Wh Used</td>" +

"<td>" + round100(totalPowerUsed) + "</td>" +

"</tr>" +

"<tr>"+

"<td>% battery remaining</td>" +

"<td>" + round100(100\*(ampHourBattery\*.85-(totalPowerUsed/voltageBattery))/(ampHourBattery\*.85)) + "</td>" +

"</tr>" +

"<tr>"+

"<td>Ah Used</td>" +

"<td>" + round100(totalPowerUsed/voltageBattery) + "</td>" +

"</tr>" +

"<tr>"+

"<td>Wh/mile</td>" +

"<td>" + round100(gasMileage) + "</td>" +

"</tr>" +

"<tr>"+

"<td>Joule Equivalent MPG</td>" +

"<td>" + round100((1/gasMileage)\*33400) + "</td>" +

"</tr>" +

"<tr>" +

"<td>" + " " + "</td>" +

"</tr>");

if (batteryPercentage == 0){

alert("Simulation Complete, v1.3. Your results are in the new tab. WARNING: Your Bicycle cannot make this distance on only battery power.");

}

else{

alert("Simulation Complete, v1.3. Your results are in the new tab");

}

}

//takes torqueAtPoints, globalElevation, massRider, massBike, radiusWheel and fills the torqueAtPoint[] array

function findTorqueAtPoints(torqueAtPoint, globalElevations, massRider, massBike, radiusWheel, resolution) {

/\*

for (var i = 0; i < globalElevations.length - 2; i++) {

var temp = globalElevations[i + 1] - globalElevations[i];

var angle = Math.atan(temp / resolution);

var forceGravity = (Math.sin(angle) \* 9.81 \* (massRider + massBike)) + 4.41;

torqueAtPoint[i] = radiusWheel \* forceGravity;

// torqueAtPoint[i] = radiusWheel\*(Math.sin(Math.atan((globalElevations[i+1]-globalElevations[i])/resolution))\*9.81\*(massRider+massBike))

}

\*/

var totalTorque = 0;

for (var i = 0; i < globalElevations.length - 2; i++) {

var temp = globalElevations[i + 1] - globalElevations[i];

var angle = Math.atan(temp / resolution);

var forceGravity = Math.sin(angle);

forceGravity\*=9.81;

forceGravity =(massRider \* forceGravity) + (massBike \* forceGravity);

forceGravity+=4.41;

torqueAtPoint[i] = radiusWheel \* forceGravity;

if (torqueAtPoint[i]<0){

torqueAtPoint[i]=0;

}

}

}

function cuberoot(x) {

var y = Math.pow(Math.abs(x), 1/3);

return x < 0 ? -y : y;

}

function solveCubic(a, b, c, d) {

if (Math.abs(a) < 1e-8) { // Quadratic case, ax^2+bx+c=0

a = b; b = c; c = d;

if (Math.abs(a) < 1e-8) { // Linear case, ax+b=0

a = b; b = c;

if (Math.abs(a) < 1e-8) // Degenerate case

return [];

return [-b/a];

}

var D = b\*b - 4\*a\*c;

if (Math.abs(D) < 1e-8)

return [-b/(2\*a)];

else if (D > 0)

return [(-b+Math.sqrt(D))/(2\*a), (-b-Math.sqrt(D))/(2\*a)];

return [];

}

// Convert to depressed cubic t^3+pt+q = 0 (subst x = t - b/3a)

var p = (3\*a\*c - b\*b)/(3\*a\*a);

var q = (2\*b\*b\*b - 9\*a\*b\*c + 27\*a\*a\*d)/(27\*a\*a\*a);

var roots;

if (Math.abs(p) < 1e-8) { // p = 0 -> t^3 = -q -> t = -q^1/3

roots = [cuberoot(-q)];

} else if (Math.abs(q) < 1e-8) { // q = 0 -> t^3 + pt = 0 -> t(t^2+p)=0

roots = [0].concat(p < 0 ? [Math.sqrt(-p), -Math.sqrt(-p)] : []);

} else {

var D = q\*q/4 + p\*p\*p/27;

if (Math.abs(D) < 1e-8) { // D = 0 -> two roots

roots = [-1.5\*q/p, 3\*q/p];

} else if (D > 0) { // Only one real root

var u = cuberoot(-q/2 - Math.sqrt(D));

roots = [u - p/(3\*u)];

} else { // D < 0, three roots, but needs to use complex numbers/trigonometric solution

var u = 2\*Math.sqrt(-p/3);

var t = Math.acos(3\*q/p/u)/3; // D < 0 implies p < 0 and acos argument in [-1..1]

var k = 2\*Math.PI/3;

roots = [u\*Math.cos(t), u\*Math.cos(t-k), u\*Math.cos(t-2\*k)];

}

}

// Convert back from depressed cubic

for (var i = 0; i < roots.length; i++)

roots[i] -= b/(3\*a);

return roots;

}

</script>

</div>

</body>

</html>

***Appendix D:*** - Web Based Simulation Screenshot

