SAMPLE APPLICATION SUBMISSION:

The following offers part of a potential application submission which includes not only potential answers but comments on the answers to provide insight as to why certain parts work (or don’t work). Do not treat this as a perfect answer but an answer with many good elements to it. Comments are made both in the margin and are also presented in italics sections throughout.

The danger in providing such an example is that some teams may try to match the topic chosen in the sample thinking that that is the kind of idea that “we are looking for”. This couldn’t be farther from the truth as we truly encourage a wide range of ideas to be submitted. To make this point even clearer, we chose a sample idea that clearly could not be created: a Perpetual Motion Bicycle. However if any of you are able to create a realistic perpetual motion machine we would be very interested in learning more about it.

All of the numbers and references in this sample are “made up” and just placeholders for the purposes of this being a representative sample of a part of a potential application submission. Comments have also been made throughout the sample to highlight both the submission’s strengths and a few potential weaknesses as well to help point out common mistakes made in performing the kind of analysis the application asks for. It is highly encouraged that you read through the entire sample.

**WHAT IF I STILL HAVE QUESTIONS:**

First we encourage you to please take a list at our FAQ page to see if the question has already been asked. Before you submit your application you are strongly encouraged to review the FAQ as well.

Second, please attend one of the open on-line conferences where you can ask questions live to members of the judging committee. These conferences are limited to the first 99 attendees who sign on, but any number of people are welcome to watch from the same terminal. A list of the times for these on-line conferences and protocol for asking questions during the conferences can be found at Cornell Cup’s Website on the Team Info, Timeline & On-line Q&As Page.

In order to be fair, no one on the judging committee is allowed to review any part of your application before your final submission and they reserve the right not to answer any questions that would be deemed as giving your team an unfair advantage.

It’s okay for your final entry to go beyond the scope/scale of the solution you propose in your application, however you do not want to have to reduce the scope of your final entry’s solution. If you do have to reduce the scope of your final entry’s solution, it needs to be well justified.

**APPLICATION FORM:**

More than providing a means for selecting the Cornell Cup’s final competing teams, this application is designed to help teams formally think about their projects and develop plans in the critical first steps of the design process. Ultimately, this will serve as both an excellent educational exercise for you to gain experience in initializing a new project and to help increase your chance of success in the projects you are creating for the competition. We greatly hope that even those teams that do not get selected for the finals, that they will continue to follow the competition’s entry development process for its educational value and to help them gain experience to create even better entries for next year’s event. Additionally, even if you are not selected but you continue the competition process, the Cornell Cup Competition Committee would love to hear about any great achievements you have made and may even be interested in featuring them on our website.

**Project Abstract (200 words):**

Describe your project, the challenge it is trying to be a solution to, and why your solution is unique and exciting in 200 words or less. This abstract will be displayed publically on the competition website.

*Potential Answer Excerpt:*

Transportation is a major concern in today’s society. The common use and perceived need for resource-heavy and polluting automobiles is taxing our energy resources and environmental quality, as well as being a strain on the economy. As a partial solution to these issues, this team proposes the creation of a Perpetual Motion Bicycle or “PMB” that is capable of carrying significant loads with minimal effort from the rider.

The PMB will offer this functionality through a unique circuit design and controls system such that once sufficient energy has been input into the PMB, the PMB will be able to output greater effective energy than the rider has put into the system. The PMB will also utilize a team designed sensor system that estimates the effort the bike is currently exerting and a team created “cruise control” algorithm to combine the sensor information with the rider’s desired speed to estimate the energy demand on the overall system. Ultimately the PMB will be tested in both urban streets and hilly rural areas as a viable alternative for local errand runs or commutes.

**Challenge Definition:**

What is the challenge you are trying to accomplish? Why is this a worthwhile challenge to undertake? What will a good solution to this challenge be able to do?

*In this section we are looking to see that you understand the challenge you are trying to solve. Part of defining a challenge is to first think about and formalize what a solution needs to be able to do. Clearly stating what are these needs and why the challenge needs them helps both the reader and the writer understand what is important to this challenge and why. Challenges should be described in a very* ***functional*** *manner, meaning that any solution that could perform the challenge’s required functions would be a valid solution. It is the “how the various valid solutions would rank according to your performance metrics”, described later on that determine whether a valid solution is a good solution to a challenge. Having a good idea of what the exact challenge is that you are trying to solve is more important than trying to develop a solution quickly.*

*Potential Answer Excerpt: (Please note this is only a piece of an acceptable answer)*

Transportation is a major concern in today society. The common use and perceived need for resource-heavy and polluting automobiles is taxing our energy resources and environmental quality, as well as being a strain on the economy. As a partial solution to these issues, this team proposes the creation of a Perpetual Motion Bicycle or “PMB” that is capable of carrying significant loads with minimal effort from the rider.

The challenge that must be solved in order to make this a reality is that a device must be created that can store the energy from the available energy inputs, either human pedaling or coasting down hills, and then be able to utilize that stored energy to drive the working components of the bicycle, mainly the wheels. It is critical that this utilization of stored energy be available and sufficient in both its duration and its peak output, especially during times of high energy demand, such as when going up hills or needing to accelerate from a stop.

Furthermore, the PMB will be required to recognize the current energy demand and be able to make a decision as to what is the proper energy output for the device in order to meet that demand. This recognition of demand must also occur in a very timely fashion. Likewise, the device must also be able to respond/adjust its response to this recognized demand to produce an overall reasonable system response time. As will be discussed in the Performance Metrics section, the appropriateness of the response time for this challenge will be determined largely based on human perception as to what is acceptable.

This also emphasizes the need for a user interface device that can allow the rider to set the desired speed. Additionally, the device must also communicate to the rider an indication of the available stored energy and its current usage rate. Similarly the device should also communicate if additional rider input, i.e. peddling, is needed at any point.

Overall the subsystem detecting the demand must be able to effectively sense and communicate the information about the operating conditions that can be translated into a desired wheel output. The sensor system of a valid solution must therefore be able to convert the force being exerted on the tires combined with the measure the number of wheel rotations compared against the desired speed, into a measure of the required demand. Once achieved, the remaining challenge of the sensor system is to provide this information to the main processor, or decision making system, to determine the proper outputs. However, in order for the device to still be considered a bicycle and not a motorized vehicle the power of the motors however cannot exceed 1.21 Jigawatts.

*Additional paragraphs that detail additional requirements, particularly any technical specifics, would be included after this. The number of paragraphs required may vary considerably for various challenges. The key is to be able to convey how well do you understand the needs of the challenge you are trying to solve.*

The real puzzle to solve in this challenge is the perpetual motion characteristic. This requires that a valid solution must at some point in its operation be able to continually output energy greater than the energy input, despite any inefficiencies that exist within the power output components of system as well as the power demand from running any of the sensor, processor, or user interface components. This requires that the power inputted by the user is somehow increased in the transfer, storage, or usage process without additional outside inputs. This requirement is particularly challenging and is addressed in detail in both the Proposed Solution and the Feasibility sections.

Although the focus of the challenge is on making sure the bicycle can continue to move as a perpetual motion machine, the bicycle must also be able to stop. This may require the rider to have to input energy to initialize the system again but it may be possible to disengage the perpetual motion device during breaking periods and then re-engage it. This potential need for some energy input during the use of the PMB is considered acceptable for any solution to this overall challenge.

The bicycle itself must also be able to support the needed equipment for this functionality while at the same time meeting the ergonomic concerns of the rider and still allowing for room the additional loading of the bicycle. As will be discussed in the Performance Measures section however this part of the challenge will be considered to be largely outside the scope of the solution although some performance constraints will be included in order to ensure the design is realistic with regards to this larger challenge need.

*Additional paragraphs would most likely be necessary to continue to describe the challenge. Again this is only a sample of part of what an acceptable answer for this section may include. Potential additional challenge needs to specify might also include how the device has to handle outside factors. An example of an outside factor might be environmental conditions such as inclement weather and mud. There might also be challenge needs with respect to the robustness of the device as many bike riders are not known for being gentle to their bikes. We could also include something to say that these challenge needs are understood but are outside of the scope of this proposal, and that would be acceptable too. However the more complete the solution you create, the more impressive it might be, provided that you can achieve it. Where to draw that line of what will be inside or outside of the scope of your challenge is up to you and what you believe you can accomplish.*

*This process of defining the challenge’s needs is a key part of becoming a professional engineer and is sometime also referred to as “Problem Identification” or “Making sure you are solving the right challenge”, i.e. you don’t want to go to all the effort of creating something cool only to realize that it really doesn’t meet the needs of your original challenge. Regardless of what you call it, making sure that your challenge is well defined and understood is crucial to the start of a successful and efficient project creation.*

**Proposed Solution:**

What is your proposed solution approach to this challenge? Why will this be a good solution? What is the scope of the solution? (What will it be able to do when you’re done?, What won’t it be able to do? and/or, What new knowledge will you have?) What do you plan to be able to demonstrate at the Cornell Cup Expo?

*In this section we are looking to learn about what makes your solution unique and worthwhile to investigate as a valid approach to meeting the need you described in the Challenge Definition section. This is not a sales pitch, but a realistic description of what your product will be able to do, and given the challenge you have defined, why it is important that your solution does this.*

*You may think that the world’s greatest engineers are the ones who can dream up the most fantastic solution to a problem but this is not always the case. The greatest engineers can dream up fantastic solutions but they also are able to recognize how the spirit of their dreams can be best realized to fit the specific needs of the challenge and the resources available.*

*Potential Answer Excerpt: (Please note this is only a piece of an acceptable answer)*

As a solution to the challenge defined in the section above, this team’s entry will be the creation of a mechanism that can attached to most modern bicycles and enable those bicycles to function as a perpetual motion bicycle, or PMB. This approach will allow this team’s entry solution to be more widely applicable as the cost to users would be only for the device and not the need to buy an entirely new bike as well. This was considered a key aspect to the design as the challenge description makes reference to economic aspects of the transportation challenges at large.

Worldwide, bicycles remain an important mode of cheap, clean, transportation. However, some of the larger deterrents to increasing their use are the speed and cargo capacity of the bike as largely limited by the physical capabilities of the bicycle rider. Hence through the creation of a Perpetual Motion Bicycle (PMB), which can output more energy than is put in by the user there lies the potential to improve both of these characteristics, speed and cargo capacity, with minimal effort from the rider. Furthermore, creating a faster and higher capacity PMB would thereby reduce the demand for other forms of transportation, which in return reduces the environmental and energy strain mentioned in the forefront of the challenge definition.

The scope of the presented PMB solution for this competition will be focused on the creation of the hardware for the PMB as well as the control system. Taken as a whole, these components will be referred to throughout this application as the PMB engine. The feasibility of the attachment of the PMB engine to a bicycle will also be considered but the focus of the entry design will be on the PMB engine itself as it is considered the larger challenge and within the spirit of this competition.

Overall, the current design approach can be broken into 7 major subsystems whose main interactions are highlighted below in Figure 1. The seven subsystems to be created are a sensor system to read in the needed data, a system to filter that sensor data, an algorithm to convert the filtered sensor data into more meaningful information for the purposes of the PMB device (i.e. energy demand), a controller to regulate the available energy while trying to meet the energy demands and enables the perpetual motion energy return, motor outputs to drive the bicycle wheels, an energy storage system, and finally a user interface system.

Sensor

System

Sensor

Filters

Demand

Algorithm

PMB

Controller

Motor

Actuation

System

Energy

Storage

System

User Interface

Device

Standard

Bicycle

*Wheel Rotation*

*Wheel Force*

*Filtered*

*Wheel Rotation*

*Wheel Force*

*Desired Speed*

*Rider & Cargo Weight*

*Available Energy*

*Actual Speed*

*Est. Travel Distance*

*User Input Need*

*Energy Input*

*(via rider)*

*Energy*

*Demand*

*Preset Bicycle Characteristics*

*(Attaches to)*

*Desired Motor*

*Output*

*Actual Motor*

 *Output*

*Supplied Energy*

*Breaking Detection*

*(Attaches to)*

Figure 1 : Key Sub-Systems Interfaces and Information & Energy Transfers

The process can be thought of as starting at the sensor system which will be responsible for collecting information such as the current speed and the human effort. In determining the human effort required, this sensor system will have to use information from the wheel rotations as specified in the challenge definition. This is anticipated to be performed using a combination of strain gauges on the wheels and a low range IR receiver/detector pair to act as a kind of wheel encoder. An IR encoder is planned at this stage because it is anticipated to be cheaper than most off the shelf encoders for the kind of accuracy that is anticipated to be needed.

The raw data from the sensors will be fed into the microprocessor at a high frequency rate, presumably at 30 Hz or faster. The first responsibility of the microprocessor will be to manage the application of a filter, potentially in both in hardware and in software, to this incoming data to help ensure its accuracy. This may also include some sensor fusion elements should both bicycle wheels be wired with sensors for increased accuracy and to deal with any wheel slippage or loss of contact with the road. Out this analysis, the microprocessor will feed the results to both the rider’s display and to the demand interpretation algorithm.

The demand interpretation algorithm will also be carried out by the microprocessor. From a high level, this algorithm will take in the results from the sensor interpretation section as well as the desired speed set by the user via the rider’s display unit. It will also take into consideration the mechanics of the bicycle and the standard bicycle equations of motion. It is anticipated that these mechanical aspects will be established for the PMB engine through a set-up and calibration step, however, the scope of this entry will assume those mechanical aspects of a single 10-speed road bicycle. As an output to this subsystem, a conversion algorithm will be developed for being able to translate this information into desired force and power requirements for the PMB engine to deliver to the bicycle wheels.

Ultimately, the greatest challenge lies in the development of the controller that regulates the power to wheels while enabling the perpetual motion energy generation effect. This control system will take in all of the above information as inputs as well as information regarding the performance characteristics of the motor system as well as an update of current energy available in the storage system. The control system will be based upon the work of [1,2] which as will be described further in the Feasibility section, has shown that the PMB engine is possible. However, the work in [2] also suggests that in order to initiate the PMB engine, some initial threshold of energy must first be obtained and made available in storage and the proposed solution intends to handle this through the rider pedaling the bicycle. Due to the challenge requirement that the bicycle must also be able to stop the proposed solution will also require the rider to occasionally reinitialize the system by pedaling.

In order to reduce the need for pedaling however, the PMB engine will also be designed to recapture some of the energy during periods when the bicycle is coasting, while going down a hill for example, as well as through regenerative breaking. As an output, the controller will determine the amount of energy from the storage system that should be applied to the motor drive system and also report these values to the rider’s user interface system, which is currently planned on being a small GUI device similar to many bicycle “trip-tracker” computers.

The GUI system will be created to report information commonly provided such as time of day, trip time, and current speed. The challenge also requires that the GUI provide information to the user on the amount of energy available and hence the GUI will display the percent charged and an estimate on the time and distance that can be covered with the available stored energy. The GUI will also provide information as to current efficiency of the system as the inclusion of similar information in cars like the Prius has been shown to significantly influence the way that drivers prefer to drive their cars [3].

(*Additional paragraphs would need to be provided for all of the blocks in Figure #1. In some cases, details can be provided as to the implementation, especially if they provide insight into the capabilities of what the final product is aiming to achieve. Ultimately emphasis on the functionality of the team’s entry with regards to several subsystems and the subsystems’ interfaces helps provide the reader with a better understanding of what your entry will be capable of doing and more confidence that you can achieve it.)*

The end solution entry will also provide a partial simulation as to the effectiveness of the system. In this partial simulation the entire PMB engine will be physically created but the appropriate amount of energy required by for the PMB to supply to the motors will be simulated. The simulation will also include a mechanism for removing the appropriate amount of stored energy as from the physical device system. It is believed that the creation of this simulation will also be valuable for testing purposes and for developing a calibration procedure for future PMB devices to be created.

The simulation of the demand allows the team to focus on the creation of the PMB engine itself. As mentioned earlier, attachment to a physical bicycle and general ergonomic concerns are important but will most likely remain beyond the scope of this project. As a means for justifying the practicality of the PMB engine as being able to meet the attachment problem needs, the PMB engine’s microcontroller, energy storage system, and motor drive system will all be required to fit within two 12” by 12” by 6” boxes that could potentially fit on either side of the back wheel of the bicycle. The solution entry will also not include the designing of a storage area for additional “cargo” but rather the effect of the cargo will be simulated by on the bike by increases in the estimated mass of the bike to account for the cargo’s weight.

The one development area that the simulated system will not be able to test is the accuracy of the developed sensor system. This element will developed and tested via connection to a real bicycle with optional dense weights placed on the bike to represent the potential inclusion of extra cargo. However it is anticipated that a fixed position exercise bike will be used for in-lab testing and for demonstration of the PMB engine, in conjunction with the simulator, at the final competition event in May.

*Please also remember that you are not bound to using the specific implementation you provide in the proposal. You may change what your final implementation will be as new information is discovered through the design process. However, you must provide a good explanation as to why a change was made.*

*From a functional standpoint, i.e. what your entry can ultimately do, you need to be more careful in your proposal not to promise more than what you are confident you can deliver on. If you promise something truly groundbreaking and you are only able to do something good, it most likely would have been better to promise something good and meet what you have promised or even exceed what you have promised.*

*As with any proposal you submit throughout your professional career, there will always be a competitive element. The key is not to overextend yourself but proudly state what you are confident you can achieve. As this is a student competition, however, some leniency will be granted as we do want you to test your own personal boundaries to help you grow and realize your potential*.

**Performance Measures:**

How will you know you have achieved your goals / met the challenge’s need? How will you measure your entry’s performance? What are some of the specific metrics that will be used? What are some existing (even partial) solutions that you could measure your solution against?

*Include as many as possible at this phase, ordering the most important or critical ones first.*

*When describing your metrics be sure to include what metrics are most important or a ranking system to the best of your ability at this phase. You will be welcomed to change these values and/or include more metrics in your final solution. However any departure from what is presented in your application should be justified in your final report.*

*Not all performance measures will be able to be discussed in detail with regards to the test equipment and data obtainment as there is not enough room in the application, nor is it typically worthwhile. However, for those performance measures that will require "special" or “unusual” equipment or test conditions an explanation should be given. The means for obtaining information or test equipment needs can also be addressed in Feasibility, Potential Concerns, or even Timeline sections if you feel it is easier to address them there. When in doubt, however, as to whether or not something needs to be explained, it is best for the author to include information. It is also better that a feasible estimation method of an ideal performance measure be used rather than rely on obtaining the “ideal” data that simply cannot be achieved within this project. Additionally, deciding what information to go into more detail on and what information to leave out is part of the challenge of writing any technical document and this application is just one example.*

*Potential Answer Excerpt: (Please note this is only a piece of an acceptable answer)*

The following is a list of the performance measures the PMB engine design will be judged on. Target values are provided for some performance measures already. However, as it is uncertain what specific components will be utilized, some of the target values will have to be determined and/or modified throughout the design process.

Most of the target or comparison values will be determined via utilizing existing vehicles and technology when applicable to the specific performance measures, as each existing technologies may only be able to be judged along a subset of the performance measures that the PMB will be judged on. Modern bicycles and cargo bikes such as the Cervelo P4 and Sanitov trike allowed on city bicycle paths will be used to determine target baselines especially with regards to the amount of human effort and perceived effort required on today’s most cutting edge bicycles. A motorized scooter and a Honda Prius will also be used to establish comparisons at least in terms of energy efficiencies, cost, trip times, and cargo capacity performance measures. Finally a standard 10 speed road bicycle will also be used in establishing as an “average” baseline for most of these performance measures. The testing for the PMB engine will also consider its performance when attached to the same 10 speed road bicycle.

With regards to components of the overall PMB engine, such as the sensors, the effectiveness may have to be measured against the “best known true value” which is represented generically as *S\**. The best known true value, as it is used in the measures below may have to be obtained, using either well-controlled laboratory setups and/or with more expensive sensors that will not actually be included within the final PMB engine design.

Many of the tests, particularly those using existing vehicles, will also be conducted over defined “Test Trips”. It is planned that 2 “Test Trips” will be considered: the first in a fairly level downtown urban area and the second in a more rural “hilly” area. The length of the trips will attempt to approximate the average errand run or commute of people living in both areas. Weights will also be included to represent roughly 2 full bags of groceries and it is anticipated that a light, medium, and heavy weight rider will be considered.

Performance measures that are currently being considered are described in the tables below, where a definition of each variable is provided in the description column at least the first time that variable is used. Table 1 focuses on the sensor and sensor fusion subsystem performance measures and includes not only accuracy measures but as the overall PMB challenge is heavily focused on efficient energy usage, the sensors energy usage is also taken into account with the Sensor Power Consumption Measure.

|  |  |  |
| --- | --- | --- |
| **Measure** | **Equation** | **Description** |
| **Accuracy of Sensors** | $$\frac{S-S^{\*}}{S^{\*}}=PE\_{S}$$ | Ave. % error of raw sensor data, *PES*, using the best known true value, *S\**, where *S* generically represents the sensor’s raw value |
| **Sensor Filtering** | $$\left(\frac{S-S^{\*}}{S^{\*}}\right)-\left(\frac{S\_{f}-S^{\*}}{S^{\*}}\right)= \frac{S-S\_{f}}{S^{\*}}$$ | Ave. % error difference of filtered sensor data, *Sf*, compared to the unfiltered sensor data, *S* |
| **Sensor Fusion** | $$\left(\frac{S\_{f}-S^{\*}}{S^{\*}}\right)-\left(\frac{S\_{fus}-S^{\*}}{S^{\*}}\right)= \frac{S-S\_{f}}{S^{\*}}$$ | Ave. % error difference of sensor fusion data, *Sfus*, compared to the filtered sensor data, *Sf* |
| **Sensors Power Consumption** | $$\frac{E\_{S}}{E\_{PMB}}$$ | Ave. and Maximum energy required to power sensors, *ES*, energy required to power PMB engine, *EPMB* |

Table 1: Initial Key Sensor and Sensor Subsystem Performance Measures

Table 2 below looks at the performance measures for the mechanical aspects. The motor response will be determined using the kind for performance tools mentioned in the description below in order to create a very smooth response. The exact evaluation of the “smoothness” of the motor response however will have to be determined during the development.

|  |  |  |
| --- | --- | --- |
| **Measure** | **Equation** | **Description** |
| **Motor Response** | $$TBD$$ | Will be measured in terms of Rise time, Settling Time, and Maximum Percentage Overshoot |
| **User Effort** | $$\frac{R\_{input,PMB}}{R\_{input}}$$ | The (average, total, maximum) amount of energy inputted by a rider using a bicycle with the PBM engine, *Rinput, PMB* The (average, total, maximum) amount of energy inputted by a rider using a bicycle without the PBM engine, *Rinput* |
| **Space Requirements** | $$V\_{PMB}, D\_{PMB}$$ | Total volume of the PMB engine, *VPMB*, and maximum dimension of the PMB engine, *DPMB*, both compared against the PMB engine “box” defined in the proposed solution section as a baseline |
| **Weight of Device** | $W\_{PMB, }\frac{W\_{PMB,1}}{W\_{PMB,2}}$  | Total weight of the PMB engine, *WPMB*, Maximum weight of either half of the PMB engine, *WPMB, 1* for side 1, and *WPMB, 2* for side 2. Ratio of weight between the 2 sides of the PMB engine. |

Table 2: Initial Key Mechanical and User Interface Performance Measures

A “Human Perception” performance measure will also be included to address the innate challenge need that if this device is to be successful, users have to believe that it is significantly helping them. The measure of the perception of effort required will be determined by observing the amount of power exerted by a rider on a PMB bicycle under various test scenarios. These tests might be done in junction with User Effort performance measure tests with the addition that the rider is asked to adjust an “effort” meter as they are riding. As human perception is a difficult quantity to measure, the actual performance measure technique will be determined once some of the other performance measure testing has begun.

Table 3 below focuses largely on efficient energy usage of the PMB engine as that is a primary motivator for this challenge.

|  |  |  |
| --- | --- | --- |
| **Measure** | **Equation** | **Description** |
| **Efficiency of Energy Storage** | $$\frac{E\_{output}}{E\_{input}}$$ | Energy output from storage, *Eoutput*, Energy inputted into storage, *Einput* |
| **Capacity of Energy Storage** | $$E\_{max}$$ | Maximum amount energy can be stored, Emax |
| **Energy Output from PMB Engine** | $$E\_{output,PMB}$$ | (Average, Total, Maximum) amount of energy supplied by the PMB engine to the bicycle.  |
| **PMB Engine Energy Output Duration**  | $\frac{E\_{output,PMB}}{t}$  | (Average, Total, Maximum) amount of energy supplied by the PMB engine to the bicycle over a fixed length of time, *t*.  |
| **Threshold of Energy Storage for PMB Effect to Occur** | $$E\_{T}$$ | Amount of energy stored required after which the PMB Engine could indefinitely power the bicycle, *ET* |

Table 3: Initial Key Mechanical and User Interface Performance Measures

Ultimately through the measures of the 3 tables above, a statement will be able to be made as to how well the PMB engine itself works. The measures of Table 4 below and the Human Perception measure however reach out to the broader challenge goals of is the Perpetual Motion Bicycle even a good idea in the first place and it is anticipated that the comparison vehicles mentioned earlier in this section will be heavily utilized in testing these measures as well.

|  |  |  |
| --- | --- | --- |
| **Measure** | **Equation** | **Description** |
| **Additional Cost** | $$\frac{C\_{PMB}}{C\_{10}}$$ | Cost of PMB components & assembly, *CPMB*, Cost of the 10 Speed road bicycle, *C10* |
| **Trip Time** | $$t\_{trip,vehicle}$$ | Time taken for average test trip by test vehicle, *ttrip, vehicle* |
| **Cost of Additional Travel Time** | $$\frac{G\_{\$}G\_{Prius}}{t\_{trip,vehicle}-t\_{trip,Prius}}$$ | Price of Gas, *G$*, Gas used in average test trip by Prius, *GPrius*, Time taken for average test trip by Prius, *ttrip,Prius* |
| **Cost of Maintenance** | $$C\_{M1}, C\_{M2}, C\_{M5}$$ | Anticipated costs of maintenance over a 1 yr., 2 yr. and 5 yr. time period, *CM1*, *CM2*, *CM5*.  |
| **Cost of Repair** | $C\_{R1}, C\_{R2}, C\_{R5}$  | Anticipated costs of repair over a 1 yr., 2 yr. and 5 yr. time period, *CR1*, *CR2*, *CR5*.  |
| **Robustness** |  | Delta in all performance measures after 50, 100, 150, 200, and 250 hours of operation. |

Table 4: Test Trip, Cost, and Robustness Performance Measures

*Ask yourself, given the need that was defined in the Challenge Definition and if you were given two different designs for the PMB would you feel confident in using these performance measures to 1) say that they were able to meet all of the challenges needs and 2) could you confidently say which one is better? You might be able to come up with a few more measures than what is presented here but this kind of reflective review is a helpful exercise for evaluating your own application performance measures.*

**Timeline & Milestones:**

Provide a timeline for the creation of your competition entry. This timeline should include major milestones, and the deliverables that must be achieved in order to declare the milestone has been reached. It is imperative that time for testing, documentation, and review sessions be included within your timeline.

*In this section we are looking to see that there exists a reasonable plan to achieve your proposed solution. Explanation of the reasoning behind the timeline can be left to the “Feasibility & Resources Available” Section as well as the “Potential Concerns & Alternative Plans” section if desired.*

***All that is required for your application are the milestones and their deliverable summary.*** *In your final report however, a more complete timeline will be required that includes estimates on the relative effort for each deliverable as well as any interdependencies of deliverables. We recommend actually beginning to develop this timeline* ***as soon as possible*** *as it will greatly help with the success of your project. Recommended forms of presenting your timeline can be in the form of a Gantt or PERT chart or a spreadsheet.* *A spreadsheet is given as an example only to demonstrate that the format of the submission is not as important as it being able to convey the information clearly.*

*Especially if this is your first time, taking the time to stop and think about a timeline can be almost painful at times to do because you have a passion inside that wants to begin physically creating your ideas as soon as possible and it can be very hard to see the value in this step if you haven’t done a schedule to this detail or never even used a schedule to this detail. Consider this a core training exercise, it will push you in ways you may not at first want to be pushed but in the end, and perhaps not even until the end of the project, you will realize you have become stronger.*

*To make it easier and to guide you as to how to create an effective schedule we have provided a sample schedule which you may copy, edit, add, & remove parts from. The level of detail will depend upon the size of the project and your role in the project but the important thing is to get in the mode of thinking about all of the things that need to occur in order to achieve a larger goal. The planning processes and tools used may vary from company to company and even from project to project but the ability to decompose an idea into a working plan that make that idea a reality will serve you well for your entire career.*

*Plan for the creation of your detailed timeline to occur over 1 to 2 Weeks, depending on the team’s experience and the complexity of the project. For parts that are unknown in the future, provide as much information as you can but try to show what earlier tasks will help to inform the unknown parts.*

**Feasibility & Resources Available:**

Please comment on the feasibility of the proposed solution, and the timeline you have developed to create that solution. What evidence can you give that your proposed solution to the challenge will work? (References to journal papers, past projects, or similar sources are recommended when possible but are not required) Please also explain any special resources required and their availability to your team for this project.

*Projects that are testing the boundaries of what is possible are highly encouraged but should include a convincing description as to how you will be able to achieve it. Additionally, in the “Potential Concerns & Alternative Plans” section, description should be given on what will happen if you aren’t able to achieve the desired outcome; i.e. what will you still be able to achieve and showcase if something falls through. Projects that are also ingeniously simplistic solutions to complex challenges are also highly encouraged and it is recognized that these may not require as in-depth descriptions in this section.*

*What resources do you have already or will you be able to obtain that will help provide a convincing argument that you can carry out your proposed solution? (Listing equipment, construction and testing facilities, advisory expertise, and team experience can all be included to answer this question)*

*Potential Answer Excerpt: (Please note this is only a piece of an acceptable answer)*

The largest concern that obviously stands out is the proposal of any kind of perpetual motion machine, i.e. a machine that can output greater effective energy than is put into the system. The paper “Perpetual Motion Machines for Beginners” by Dr. Ima Nginary recently published in IEE however demonstrates a control system where once a certain threshold of stored energy is obtained, the overall system can transform this stored energy output into a greater output energy. The threshold that is required is dependent upon both the maximum energy output for the system and the efficiency of the rest of the system. The results that were shown in the paper indicated that a highly efficient motor was used in their tests. Hence, it will be a goal to make the system as efficient as possible in order to keep the PMB engine’s energy threshold low. It is believed that this goal will be achievable but that there may be a trade-off regarding the cost of the overall system.

This trade-off will be measured through the 3 performance metrics “Additional Cost” versus “Energy Output from PMB Engine” and “Efficiency of Energy Storage”. The metrics “PMB Engine Energy Output Duration” and “Threshold of Energy Storage for PMB Effect to Occur” will be used as a significant measure as well for quantifying how well the solution energy is at recreating the PMB effect and be an indicator as to how much of an aid the PMB engine is to the cyclist rider. However this later concept of aiding the rider will be more directly measured using the “User Effort” and “Human Perception” metrics.

The paper [2] also showed that the maximum amount of energy that was currently found to be possible from a perpetual motion machine was rather small to be practical to replace current traditional energy generation sources. However, from the data presented in [3] the energy generated should be sufficient for driving a heavily-loaded bicycle up a reasonable incline. Appendix B, offers some initial calculations that determine the energy needs of heavily-loaded bicycle and compared to the data in [3] it appears that a perpetual motion machine can be created with a energy output that is 20~25% in excess of what is required for this bicycle application

To pursue this project, the lab equipment currently held by the advisor will be more than adequate regarding the sensitivity and other capabilities required for this kind of work. However, in order to ensure everything will be done in a timely fashion, it has been determined that if selected the team will utilize the voucher towards the purchase of another oscilloscope. The most expensive equipment is perhaps the other vehicles needed for testing and the team had received assurances from colleagues that they can be borrowed for the purposes of this project. This should allow the majority of the allowed funding to be used for the purchase of a the PMB engine components, a single 10 speed bike to be dismantled and utilized in the lab, and for travel to the final competition. The team is also planning on applying for student team funding through our college, applications for conference travel funding, and through alumni and other companies who commonly fund student projects at our university. A rough estimate on the budget is provided in Appendix C, however the budget does not provide absolute constraints on the amount spent in each category. Furthermore, in order to ensure that the equipment purchased will be well cared for and last the duration of the project an emphasis on the creation of safety circuits and proper operation guides have been included within the project timeline and the budget planning.

The filtering of the sensor system will use classical techniques but the algorithm for calculating an estimate of demand from this data will need to be created by the team. The team will base this algorithm not only the on the mechanical equations of the bicycle system but those used by automobile cruise control systems and as well as tests used by physical therapists in order to determine the strength of a patient’s muscles.

Although a final selection has not been made yet, from the specifications of the several potential Arm based embedded systems boards including the Arm5000, the StrongArm, and the ArmorSuiteAlpha, we should be able to more than adequately handle the computation and the majority of the sensor and mechatronic I/O. The one exception to this is that one of the sensors being considered requires a proprietary “black box” connection with documentation only for a proprietary companion board, and it could not be determined whether this board is based on Arm technology. However, the proprietary companion board is being used as a kind of “helper board” for the sensors I/O and the proprietary companion board will be interfaced with the Arm based board. In the unlikely event that the control algorithms become far more computationally intensive than expected, there is a possibility to parallelize some of the work preferably using the second Arm based board. However this is unlikely and in order to keep within the embedded systems spirit of the project, efforts will be focused on keeping the design “small” in terms of physical space and power concerns.

The control system for the system is perhaps one of the most complex aspects, as it requires the implementation of many of the concepts from the papers described earlier. Fortunately, the team’s advisor has significant experience in control systems. Additionally one member of the team has already taken a standard feedback controls course and another member is currently taking a similar course. Furthermore, an advanced controls course is being offered in the Spring which at least one of the team members will be taking. As a combined group, the members of the team have also already taken classes in sensor filtering & fusion techniques and will be taking classes in processor design during this academic year. A couple of the team members are also avid cyclists and are very familiar with the mechanics of a bicycle and one of them has already received “green apron” machinist status, the second highest level of machining certification available at our college. The team overall is also highly devoted to this project and are excited to hopefully demonstrate their PMB at the Cornell Cup USA Competition Expo.

**Potential Concerns & Alternative Plans:**

What are some of the potentially most impactful concerns and how likely are they to occur? What are steps you plan to take to mitigate these concerns? What are some of the ways you will handle these concerns should they arise? What are some of the alternatives you are considering should these concerns prevent the solution you proposed in the “Proposed Solution” section earlier. How will this affect your timeline and at what point in your timeline will you have to decide whether or not to proceed with an alternative plan?

*It can be helpful to sometimes write this section before completing the Feasibility section as it may make you aware of additional concerns that you should be able to address in the Feasibility section. We want you to challenge yourselves in what you can accomplish but it’s important to have a strong fallback position. There’s nothing wrong with questioning your own ideas or the way you originally thought about doing things. It’s okay, even good, to question this and to re-evaluate your proposed solution or implementation approaches as you will almost assuredly arrive at a stronger overall project in the end.*

*Potential Answer Excerpt: (Please note this is only a piece of an acceptable answer)*

Although a number of convincing arguments have been made in the feasibility section, the most outstanding potential concern in the design is the required stored energy threshold that must be achieved in order for the PMB to function as a perpetual motion machine. As discussed in [2], this threshold can vary depending on the application and there is potential concern that this threshold may be too high, causing either the rider to have to work too hard to achieve that threshold or causing a need for such large batteries that the PMB engine would be too expensive or the bicycle would become too large to be useful. The data presented in [3] helps to alleviate these concerns but even if the perpetual motion effect is never realized, the proposed PMB bicycle will still provide away to store energy that might have normally been wasted during typical bicycle use and then utilize that energy to assist the rider later in their trip. Additionally should the energy return/storage not be as effective as there is room in the schedule during the middle of the second semester to investigate other forms of energy recovery. This would still allow the PMB engine to potentially offer a significant benefit as compared to an unassisted rider.

The next largest concern is most likely the development of the demand algorithm. This will assuredly rely upon an experimental process in order to determine the proper fusion of the sensor data so that the output mirrors an intuitive measure of the demand. It is also possible that there may exist variations in test conditions that could affect which sensors should be more trusted than other. Due to this need to discover the best utilization of the sensors’ data, the timeline has also included the initial use of a COTS encoder as compared to the team built, cheaper, IR encoder system. This will allow the algorithm work to begin earlier by initially using the data from the more robust encoder at a reasonable additional cost. Furthermore, the COTS encoder will also provide a means for testing the accuracy of the IR encoder and the COTS encoder can acts as a back-up should the IR encoder design not meet the process needs.

As mentioned earlier, the scope of the proposed solution is for the creation of the PMB engine and not the final ergonomic means for fixing it to the bike. However, the potential for a bicycle crash should be considered even in the PMB engine design. One of the components that offers the largest potential risk in a crash is the energy storage system, particularly as batteries are a likely option for energy storage. However, the weight of the batteries is also related to the system performance and the threshold concern. Lower density batteries are more common and will be considered, but higher power density batteries can offer lower weight but are typically more dangerous, i.e. more flammable and require well monitored charging. In order to ensure this issue is given proper attention, an additional battery investigation step to outline the characteristics of potential options was added early on in timeline. This will not only leave room for adjustment, should significant concerns be found, but will allow for quicker final selection to be made in conjunction with the motor selection by date xx/yy/zzzz. In addition to providing the team’s decision as to what was the best trade-off storage solution, the end report will include a matrix listing benefits and risks associated with the considered energy storage options.

The human user element is an important concern and although the PMB’s operation will be simulated, the measurement of test trip demand may require a human to ride a bike along the test trips. Although this is not believed to be of any significant risk to the rider, the university’s office that handles all human testing will be involved to review the test plans and the team will go through whatever training that university office requires. In the timeline, there have been included dates for the testing plans review as well as back-up dates should the university office require any changes to the test plans.

Another important concern to consider is that the bicycle must function just as well with the PMB disengaged as it does engaged. This is an important safety concern not only for standard braking but should something go wrong with the PMB engine. A complete mechanical disengage switch is included in the design and an error/warning system will also be included within the PMB engine’s user display. Only one member of the team has taken a course in mechatronics but this is certainly better than none. The team has already spoken with the professor from that course as well and she has volunteered to have her PhD student be available for questions. However, of course, all of the work will be completely and solely done by the team’s registered members only.

Finally, in order to help address any additional concerns that might arise during the project’s development, the team has established regular weekly meetings with their advisor and tentative project review dates with the team’s faculty reviewers. The advisor has also offered time during her normal office hours. The team itself has also developed its own work check policy where all of the work performed by one member will be reviewed by at least one other member.

*The* *potential concerns listed here are pretty good, but there are some that were not included. For example, the author forgot to mention other common operation errors or what about mud or dirt on the IR sensor. Driving through mud, loose gravel, etc. may also affect the demand and control algorithms. These are operation conditions that are very likely for the given application and therefore should probably be included, if there is room in the report. However as there is a page limit, as there commonly is in the real world, you have to decide what are the most important (i.e. the most likely and most impactful) concerns to discuss.*

*The “mud” concern is also a good example of how it is very important to think about how your product could be used outside of the “lab” conditions. Usually it is a very good idea to think about these concerns in your design right away so that they can help with your challenge definition scope. Sometimes these scope issues are also dealt with splitting your project into different phases, i.e. deal with the concerns that only affect the main or “expected” or more ideal uses first, and then have later phase(s) that address more complicated versions of the challenge. Each phase however should really start out with its own “challenge definition”, “proposed solution” and so forth, to make sure it addressed professionally.*

*There are pros and cons to this multi-phase approach however. A potential con is that although it can make things easier in the earlier phases, it can cause more re-work in the later phases as later phase challenge needs can make earlier phase solution approaches suddenly invalid. However a potential pro is if you do not have enough information yet about the needs of the later phases, you can use the earlier phases to help identify those needs. In this second case, the potential for re-work may be treated as an acceptable risk since you have no other way to define those later phase challenge needs accurately at the start. Even if potentially important issues like the “mud” are not going to be dealt with it at all during the project, it would be better to state that these are outside of the scope of this competition entry. Then the judges will at least know that these concerns were thought about.*

*The judges will still have to decide whether the entry will be selected. If by chance another Perpetual Motion Bicycle entry was offered that year that did everything else that this one did but also handled these additional situations, the one that handled these additional situations would be selected (assuming that their application was convincing that they could accomplish everything they said they could.*) *Where* *to draw the line as to what to include and what not to include within your project’s scope can be part of every design engineer’s daily tasks and when thinking about larger design decisions it is important to discuss them with your team and your advisor. And defining the scope brings us back to the importance of making sure you have well defined the challenge that you and your team intend to create a solution for.*

*The dependencies of all of the elements of starting up any new project can lead to a very iterative nature, where you define part of the project, work though another, which helps you to learn more about the project, which in turn helps you to refine your earlier work. This process can continue on and on but at some point you decide you have reach a diminished return on your iterations and/or you have achieved a level of comfort with your defined challenge and solution approach. The key is to do your best to truly understand and communicate what it is you are trying to do and how you intend to approach it. This process which is reinforced through this application is so important to helping make sure your amazing ideas can be heard and realized that we are offering over hundreds of thousands of dollars in awards, as listed on the website, to reward our finalists with the opportunity to take their ideas even further. We can’t wait to see what you will create!*

**REFERNCES**

*Giving credit where credit is due is an important part of not only being a professional but providing good references also helps others understand the basis of your work. It is recommended that you follow the IEEE journal standards or similar standards for listing all references. At the very least, references should follow something similar to the general form below:*

[ref. #] 1st Author Last Name, 1st Author First Initial(s), 2nd Author Last Name, 2nd Author First Initial(s),

 “Title of Reference”, *Source of Reference,* Date of Publication

*If you do not have any references for your application, that is perfectly acceptable as well and you may leave this section out of your final application. Remember, the pages used for the references section do not count towards the total number of main application pages.*

*Potential Answer Excerpt:*

[1] Nginary, I.M. “Perpetual Motion Machines for Beginners” *Journal of Wishful Thinking*, 2009

[2] Maidupp, N.T. “Threshold Performance Measures for Perpetual Motion Machines” *Journal of Wishful*

 *Thinking but not Quite as Wishful Thinking as the Journal of Wishful Thinking Journal*, Jan. 2010

[3] Phantescee, M.Y. “Survey of Capabilities and Limitations of Current Perpetual Motion Machines”

 *Experimental Journal of Things Yet to Come*, 2010