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Team T521: Sprinter Data

Cedeño I. Dylan; Marc R. Griffiths; Noyes M. Jordan; Pierre A. Handy; Ulysse R. M. Edwin

FAMU-FSU College of Engineering 2525 Pottsdamer St. Tallahassee, FL. 32310

Abstract

Every athlete wants to reach their full potential, whether that is by reacting faster or finishing stronger. Everyone has room for improvement, including sprinters. A product that can be used to improve a sprinter's performance would be extremely helpful. The goal of our project is to create a desirable product that will objectively measure and predict a sprinter's performance. Eventually, all athletes will have access to our product – sprinters at any level and athletes in any sport. But for our project, collegiate track teams are our main focus. Since every athlete is different, we will personalize our measurements and predictions to each sprinter. There are many ways to try to improve a runner's performance, but we decided the best approach was the wholistic one. Since this is an entrepreneurial project, we will make sure this product is desirable for purchase by making it cost-effective, self-contained, and have low hinderance to performance. Our selected design is the Launch Monitor Pro, a base station on the track that will interact with the sprinter and their coach. Using a high-speed camera and sensors, we will measure the sprinter's takeoff form at the beginning of the race and their average speed throughout the race. The Launch Monitor Pro will look at the images closely and analyze the data. We will then find correlations between the sprinter's measurements and times. Finally, we will use innovative technology to help the coach and sprinter identify how the sprinter can improve. This new technology will enhance performance and maximize potential.

Keywords: sprinting, performance, prediction, measurement, sports

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Notation

BMC	Business Model Canvas
VDR	Virtual Design Review
HOQ	House of Quality
AHP	Analytical Hierarchy Process
IR	Infrared
ANOVA	Analysis of Variance

Chapter One: EML 4551C

1.1 Project Scope

1.1.1 Project Description

The objective of this project is to create a desirable product that will objectively measure and predict a sprinter's performance.

1.1.2 Key Goals

To achieve our objective, we have developed three key goals, based on information collected in customer background. The first goal of this project is to develop a method to objectively measure a sprinter's performance by focusing on their takeoff form, as well as their average velocity throughout the race. When observing takeoff form, we want to focus on the runner's line of attack, second step and associated stride length, starter gun reaction time, and impulse out of the block. These components of takeoff form addressed in the video given with the project brief. The second key goal is to predict a sprinter's performance by creating individualized trends based on data from personalized inputs and start measurements. Finally, the last goal is to create a product that is desirable for purchase by making it cost effective, self-contained, and have minimal hinderance to performance.

1.1.3 Market

There are several markets that will be targeted during this project. The primary market is college track teams, including sprinters, coaches, and recruiters. Customers in this market were interviewed to help us decide on our project objective and key goals. Secondary markets are:

fans and parents of the sprinters, professional running teams, high school track teams, and other sports.

1.1.4 Assumptions

Before beginning the project, assumptions must be declared to control the scope. The first assumption made was that the technology will be used on a range of sprinter heights from 5-foot-3 to 6-foot-4. It also must be assumed that the sprinter/coach/recruiter has prior knowledge and experience about running form. It is assumed that the user has access to a smartphone or laptop. Another assumption is that the sprinter is starting out of a standard starting block. It is also assumed that the technology will be used in fair weather. Another assumption is that the technology will be used on a collegiate approved track. Finally, it is assumed that the consumer is more concerned about performance accuracy than about the product price.

1.1.5 Stakeholders

There are several stakeholders in this project. While there is not a specified sponsor, some stakeholders that provided prior knowledge of the project are Dr. Devine, Michael Ormsbee, and Ricardo Argro. Another stakeholder is the advisor of this project, Dr. Clark. Some professors involved as stakeholders are Dr. McConomy, Ms. Gray, and Dr. Hooker. Other stakeholders of this project include the FAMU-FSU College of Engineering and investors in the InNOLEvation challenge. Many of these stakeholders provided much of the prior knowledge necessary to develop the project description and key goals mentioned before. Others will provide guidance throughout the project.

1.2 Customer Needs

To begin research about the customers, it was decided that the personas who will be the end users of this technology are sprinters, track coaches, and recruiters. So, several questions were created to interview these consumers. Research was also done to answer questions that could not be answered with the limited time and resources. While there was simply not enough time to receive as many interviews as desired, interpreted needs were formed based off what was collected. Explanation of these results can be found below.

Sprinters

Question: What aspects do you focus on most in your sprinting form?

Answer: “Takeoff and stride”

Interpreted Need: The tool aids in improving/ strengthening the user’s takeoff form and stride.

Explanation: This need gives more guidance on what should be focused on about the running form. It was already known that form is important to perform well in running, but now there are more specifics on what aspects of the form should be focused on.

Question: Do you feel like your form and personal record are correlated?”

Answer: “Somewhat. some of my best runs have been back when my form wasn’t as refined as now, but vice versa is also true”

Interpreted Need: The tool provides the ability to store both sprinter data related to form, and recorded race times.

Explanation: This statement proves that form and performance are somewhat correlated. It gives the need that the technology not only provides data related to a runner's form, but also provides old race times for comparison in training.

Question: If there was a tool that could help improve your sprinting speed would you be more concerned about your start or the overall race?

Answer: "Every runner is different because some lack explosiveness in their start and others have trouble with the rest of the race. I personally was an explosive runner; I had a lot of strength and an amazing start. But after the first 10 meters I would have a problem maintaining the same speed throughout the rest of race so for me personally I would like a tool that would help me with that"

Answer: "That's a tough one. A good start can put you ahead of the pack, but it won't guarantee you a win. I think I'd still choose the start though."

Interpreted Need: The technology can track performance at both the start time, and throughout the race to satisfy all types of runners.

Explanation: This statement proves that the start, as well as the progress throughout the race, is what runners focus on. It gives the need that the technology tracks the entire race instead of just one section.

Question: Would you rather have an app where you can capture images or a wearable that is tracked through an app?

Answer: "Something I can wear would be ideal"

Answer: “Well I know the belt to monitor your stride pattern exists already I think so I will say the app because track athletes watch a lot of film especially in college and we analyze frame by frame our race”

Interpreted Need: The technology could have both a wearable and an app to satisfy all different types of runners.

Explanation: Since the two customers interviewed provided opposing answers, it was decided that a need for the project would be that the technology could involve both a wearable and an app. Since every runner prefers different methods, this would be ideal; realistically, as more interviews are gathered, there will be a better idea for the preferred method.

Question: Would you be interested in comparing your ability to professionals'?

Answer: “I already do that. Their records are what I strive for”

Interpreted Need: The tool incorporates professional sprinters and eases the effort required for sprinter comparisons.

Explanation: Since it is desired to compare results with another person, a shadow runner feature would be ideal for the project.

Question: Would you be willing to incorporate technology in your analysis of performance?

Answer: “Yes”

Interpreted Need: The product provides technology for sprinters to improve their performance.

Explanation: This question was just to make sure that the product will be desired. It is good to know that sprinters would want to incorporate technology into their training.

Question: Do you think there is room for improvement in your performance? If so, where do you think you can improve most? Do you know how to improve it?

Answer: "There's always room for improvement. I think that I need to work on my pace the most and practice is the way I am trying to improve it."

Interpreted Needs: The analysis from the product exposes users' fundamental weaknesses.

Explanation: Since sprinters typically see room for improvement in their performance, it would be ideal for the technology to identify sprinters' current weaknesses so they can know where they could improve.

Question: Would you feel comfortable using a wearable to track your performance? What would be required of the wearable so that it does not hinder performance?

Answer: "Yea I would have no problem with it. It just needs to be lightweight and feel like I am not wearing it."

Interpreted Need: In order to not hinder performance, the wearable is lightweight, and the user will not feel extra weight.

Explanation: This statement allows for a wearable option in the concept generation. It also gives a better idea of what the wearable needs to be like, in order to not hinder performance.

Question: Do you think that your form affects your running?

Answer: "Yes of course. Form is one of the most important things"

Interpreted Needs: The product analyzes users form to improve performance

Explanation: This statement solidifies the fact that form does, indeed, affect running performance. The need explains that the product analysis will incorporate the runner's form when improving performance.

Coaches

Question: What element(s) do you believe is most important for a sprinter to have good performance?

Answer: Running posture, leg action, and arm action are the most important elements for a sprinter's performance.

Interpreted Needs: The tool considers the user's running posture, leg action, and arm action.

Explanation: Since time did not allow for coach interviews (yet), research was done to get a better understanding of what a coach focuses on in a good runner. Two videos were watched, and the information was transformed into an answer for one of the pre-developed questions. The answer was then translated to a need, giving more information about which aspects of a runner's form should be focused on.

Question: What are some of the aspects you notice most in a good sprinter's form (specifically at the start of the race)?

Answer: Line of attack is most important. I look at the angle coming out of the blocks and decide whether that is the best angle for each sprinter. This angle will be different for every sprinter. I then look at the technique within that angle of acceleration. Every person has alignment issues; I try to find the issue with every runner immediately, so that I can decide the best form for prevention of injury.

Interpreted Need: Make sure the technology is able to visualize the line of attack.

Explanation: From the customer statement, it is evident that the line of attack is the most important element of form for this coach. Therefore, this needs to be incorporated in the technology. It has already been discussed that the technology should be customized for different types of runners, so this is not necessary to re-iterate in this need.

Question: Would you be willing to incorporate technology in your analysis of the sprinters' performance?

Answer: I would like to have a video of the runners.

Interpreted Need: The technology needs to be able to capture videos of the sprinters.

Explanation: This coach mentioned several times in the interview that he would like to have a video of the runners. So, the need is that the technology needs to be able to do this.

Question: Would you want to use a wearable to track sprinters' performance or would that get in the way?

Answer: I wouldn't mind that as long as its light enough to not affect running ability. Maybe they could wear something that connects to checkpoints at every 5 meters and it can tell the velocity at each checkpoint. This can check where the runner reaches top speed and how speed can be maximized. We could decide from there if they are reaching top speed too early or too late and we can fix accordingly.

Interpreted Need: The technology will be able to measure instantaneous velocity.

Explanation: The coach mentions many times that he wants to be able to look at the speed of his runners throughout the race. If the technology could track the instantaneous velocity throughout the race, then that would fulfill this want.

Question: Who do you compare your sprinters to?

Answer: I try to find a model athlete that fits every particular person. I have a guy right now that is about 5'5 or 5'6; I cannot model him off of Bolt because he is 6'7. I try to find an athlete around the same stature and body type.

Interpreted Need: Technology needs to have data of several different athletes for comparison based on body shape/size.

Explanation: It has already been discussed that the technology needs to be able to compare data to professional athletes. But, with this customer statement, it is now known that the technology needs to have data of several different types of athletes in order to compare sprinters with professionals of similar body types.

Question: Do you employ a specific training about how fast they are getting out of the blocks?

Answer: Not necessarily. I want something that could measure the amount of force off the blocks. I do not get too caught up in how fast the runner gets out of the blocks, which is different than other coaches. I want to maximize the ability to accelerate as fast as possible so that the runner can reach the best end speed.

Interpreted Need: Technology has to measure the force out of the blocks.

Explanation: While some coaches like to measure the time it takes for a runner to get out of the starting blocks, this is not the case for this coach. He would prefer to measure the force out of the blocks. Although this was something we were already considering, it is good to know that force is more important than time to some coaches. Therefore, it is definitely necessary to incorporate this into the technology.

Question: Do you train all body types the same?

Answer: Nope, all different.

Interpreted Need: The technology needs to be personalized based on different athlete's bodies.

Explanation: This is a very important need, so is re-iterated here. Every runner is different, so the technology needs to be customizable to many different body types.

Question: How long can you allow for setup and how often would you use the product?

Answer: Fairly quick setup during or before warmup would be ideal. It will be used twice a week during pre-season and potentially five days a week during season.

Interpreted Need: The technology needs to be able to be used daily for about two hours at a time. Needs to be durable and water resistant.

Explanation: While this technology will not be used during a downpour, it needs to be able to be used daily, even through light showers. It has to be able to withstand a full practice and be used multiple times a week.

General

Question: What is a reasonable price point for the product cost?

Answer: Well, I can give you the price of existing technology to give you an idea. The Whoop system is about $400 per user. But track teams typically buy a subscription to the technology

Answer: Personally $5,000 of my own money. If its like the 1080 sprint - $20,000 because it is only made in Sweden. The 1080 offers resistance and assistance. This allows the body to adjust to a particular speed. With Covid, $5,000 sounds doable.

Interpreted Need: The technology will have varying price models for different markets. It will need to be sold for no more than $5000.

Explanation: This question was asked to someone who has knowledge about technology used in sports. He was able to provide insight on existing technology, so that there is a better idea about a realistic product price in this industry. This question was also asked to a track coach who looked into purchasing a technology like this one before. He was able to provide insight about how much he is willing to pay, considering Covid. This allows for better understanding concerning budget, as well as desire for the end user.

1.3 Functional Decomposition

1.3.1 Introduction

After the project scope was formulated and the customer needs were explored, a functional decomposition was able to be developed. Based off the key goals for the project, major functions were formed in order to break down what the product has to do. From these major functions, minor functions were then produced for further breakdown of the specific components the technology must include. These major and minor functions were categorized using a hierarchy flow chart and a cross-reference table.

1.3.2 Data Generation

To determine what functions the product must have, research was performed on existing technology and interviews were conducted with consumers fitting the ideal personas. As discussed in the project scope, it was decided that the consumers would be sprinters, coaches, and recruiters. So, several interviews have been conducted, and continue to be performed, to gather more information. Based on what is known from research thus far, key goals were decided upon in the project scope and functions were created in this functional decomposition.

1.3.3 Explanation of Results

As stated in the project scope, the key goals for this project are to measure aspects of a sprinter's start and their instantaneous velocity, to predict their performance based on the data collected, and to create a desirable product for purchase. From these pre-determined goals, major functions were created to describe what the technology must do. Minor functions were then generated to further break down the functions that the product must have. These major and minor functions were broken down and categorized using the visualization of a hierarchy flow chart and a cross-reference table. These tables will be further discussed below.

1.3.4 Hierarchy Flow Chart

To begin the functional decomposition, it was decided that the functions can be formed most clearly through a hierarchy flow chart. Key goals were turned into functions and minor functions were built off from there. These major functions and minor functions can be visualized in the hierarchy flow chart below.

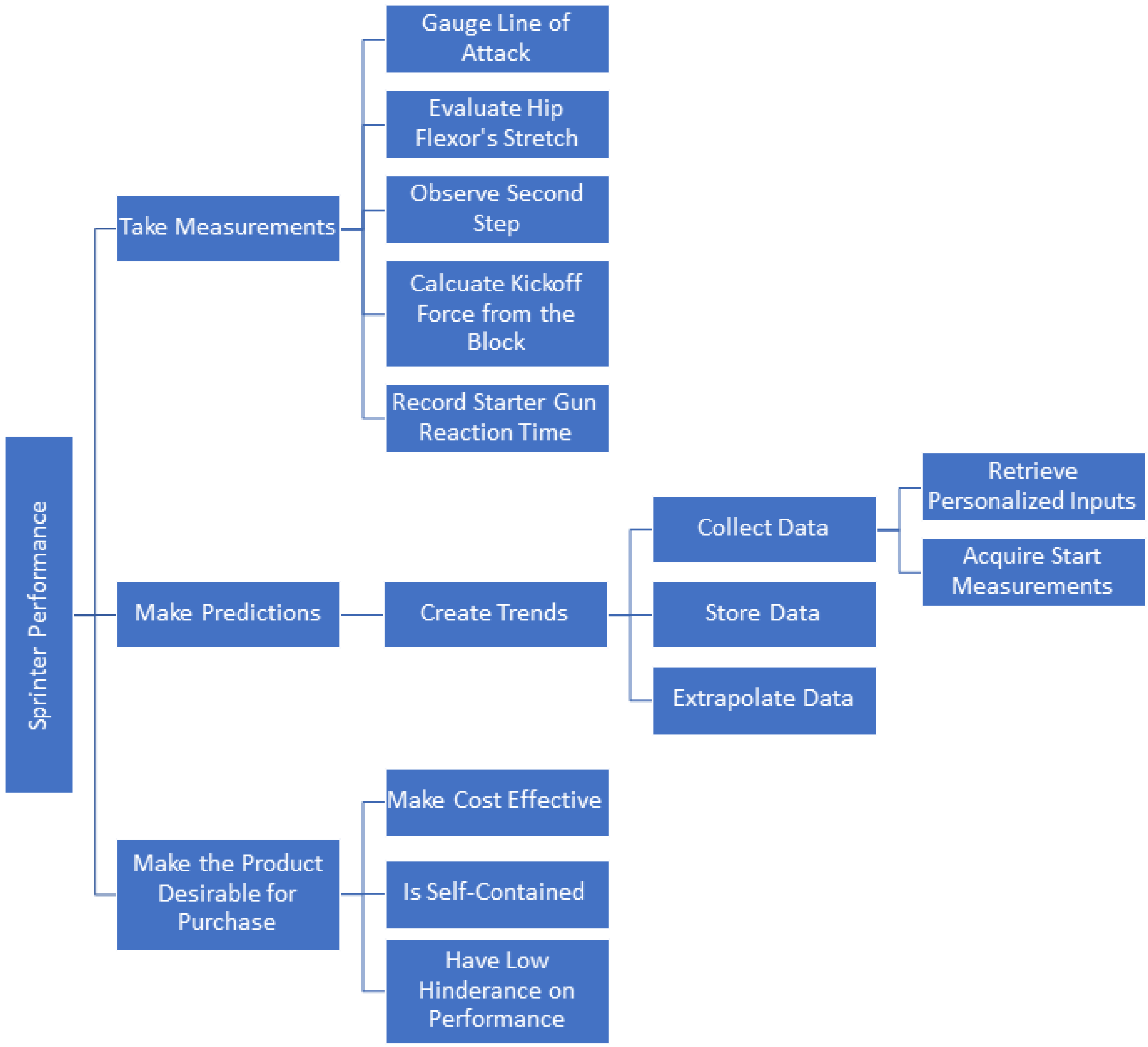


Figure 1: Original Hierarchy Flow Chart

1.3.5 Cross-Reference Table

From the hierarchy flow chart, a cross-reference table was developed. In this table, minor functions were categorized by major functions. While most of these minor functions fall under one specific major function, some can fall under more than one. This idea of smart integration will be further discussed below. These categorizations and cross references can be observed in Table 1:

Table 1: Cross Reference Table

	Take Measurements	**Make Predictions**	**Make the Product Desirable for Purchase**
Gauge Line of Attack	**X**		
Evaluate Hip Flexor's Stretch	**X**		
Observe Second Step	**X**		
Calculate Kickoff Force from the Block	**X**		
Record Starter Gun Reaction Time	**X**		
Track Instantaneous Velocity	**X**	**X**	**X**
Create Trends		**X**	**X**
Collect Data	**X**	**X**	**X**
Store Data		**X**	**X**
Extrapolate Data		**X**	**X**

Retrieve Personalized Inputs		X	X
Acquire Start Measurements	X	X	
Make Cost Effective			X
Is Self-Contained			X
Have Low Hinderance on Performance			X

1.3.6 Connection to Systems

As the hierarchy flow chart was created, the idea was to communicate how each major and minor function relates to each other. When breaking down a sprinter performance tracking system, there were three system priorities considered to reach the objective.

The first priority is that the system must take measurements. This is imperative as the device cannot complete its objective without this function. From here, the different types of measurements needed were considered and broken into minor functions. These measurements include the line of attack, the hip flexor's stretch, the stride length of the second step, kick off force from the starting blocks, the starting gun reaction time, and the instantaneous velocity. All these measurements are necessary as they will provide feedback to the customer of the monitored performance and allow them to make minute adjustments to their form, while seeing how it affects their performance for each run.

The second major function is that the system must make predictions. This is necessary as the system will be designed to help the customer improve their performance. When making these predictions, the customer will be able to gauge how changes in their form will affect their overall time. In order to make predictions, the system must create data trends. These trends will allow for the system to comprehend the data and make the aforementioned predictions. For the trends to be created, the system will need previous data to work off of, which is why the system must collect, store, and extrapolate data. If the data is not collected, it cannot be stored, and if it is not stored it cannot be extrapolated. Furthermore, if it is not extrapolated it cannot create trends. For the collected data to be relevant to each individual user, the inputs must be personalized. If the inputs are not personalized, the trends cannot be made specific for individual sprinters, which is a need for this project. Finally, the data collected must also be relevant, which is why it needs to collect the start measurements of the sprinters. These specific start measurements, mentioned in the first major function, were also created based off of customer needs.

The final priority is for the system to be desirable for purchase. If everything previously stated is available, but no one wants to purchase the product, there is no point to the product existing. The product can be made desirable for purchase by making the system cost effective, self-contained, and having little impact on sprinter performance. The product needs to have little impact on performance during testing, otherwise it will collect inaccurate data. With inaccurate data, the product is useless and no one would want to use it. The product being self-contained is also a large selling point, as this way users can buy the product alone and not need any other major purchases for setup or use. The average user will not know what sensors to buy, or what cables are needed to connect them, so when everything needed is included, it opens up the user base and allows for more consumers. Being cost effective is necessary, as there are competitors to the product with high price points. Consumers are more likely to purchase a product that is cheaper, as long as it still has all the necessities.

All of these systems integrate with each other. The product will measure and predict a sprinter's performance while being desirable for purchase. In order to predict a sprinter's performance, the system will measure a sprinter's data. To make the predictions, it will use this measured data. Since the product does these things, it will be desirable for purchase. To make the product more desirable, features of easy use are added to create a larger market. With all of these systems working together, this product will be marketable, which is the main objective for this entrepreneurial project.

1.3.7 Smart Integration

The major functions, visualized and discussed above, encapsulate the main objective of the project. Although minor functions mostly fall under one major function, the relationships tend to overlap as they all originate from a single need, to improve a sprinter's performance. These overlaps are depicted in the cross-reference table shown above. While tracking instantaneous velocity mainly falls under the major function of taking measurements, it also leads to making predictions and making the product desirable for purchase. Collecting data, storing data, creating trends, and extrapolating data are mainly needed to make predictions, though also greatly aid in creating a product that is desirable for purchase. This is because the consumer needs a way to visualize and understand data in a simple form. In addition to making predictions and increasing consumer interests, collecting data is a byproduct of taking measurements. Without the data collected from acquiring start measurements, predictions cannot be made. Finally, retrieving personalized inputs, such as body type, height, weight, etc., is a user-controlled method of taking measurements. This information will be used to make personalized predictions for the given user, also making the product desirable for purchase.

In order to integrate these systems and make sure all of the functions work together to provide a common goal of improving sprinters' performance, innovation will be necessary. This product will use inventions that already exist in our world today, to innovate a holistic system in order to improve sprinters' performance through a marketable technology.

1.3.8 Action and Outcome

The tool that is being created during this project will include several actions in order to reach all of the customer needs and key goals. The first action is that it will use a camera to capture the start of a sprinter. The aspects that the technology will measure are the line of attack, hip flexor's stretch, and observing the second step of the sprinter. With the aid of this technology, the user will also be able to measure the force exerted from the starting block, the starter gun reaction time. Along with capturing the start of the sprinter, the technology will be able to track the instantaneous velocity of the sprinter throughout the race.

Along with capturing the start measurements, the technology will create trends, collect data, store data, and extrapolate the data to make predictions. The product will retrieve personalized inputs, so that the start measurements can be altered for different types of runners. It will then utilize the personalized inputs and collected data to make predictions through a machine learning model. The product will acquire the start measurements to predict the best start times. For customer satisfaction, the product will be made cost effective, and have low hindrance on sprinters performance. All of these actions will make the product desirable for purchase.

The outcome for this project is that a marketable technology is created in order to improve the overall performance of track athletes, personalized to their specific body types.

1.3.9 Function Resolution

While there are many key goals for this project, there are a few things that absolutely must be achieved. Such things include making our product affordable. This goal is arguably the most important aspect of this project because if it is not achieved, the project is essentially a failure. Having a product that satisfies all the customer needs but cannot be afforded by said customer is useless.

Another essential goal is making a product with settings that can be customized to every type of runner. This is necessary because no two runners are the same. Not only will it make the product more marketable, it will greatly increase its desirability.

1.4 Target Summary

After finalizing the functional decomposition, it was time to formulate targets and metrics for each function and other needs. To begin, it was decided that the hierarchy flow chart needed to be modified and some assumptions needed to be added. Below is the updated hierarchy flow chart:

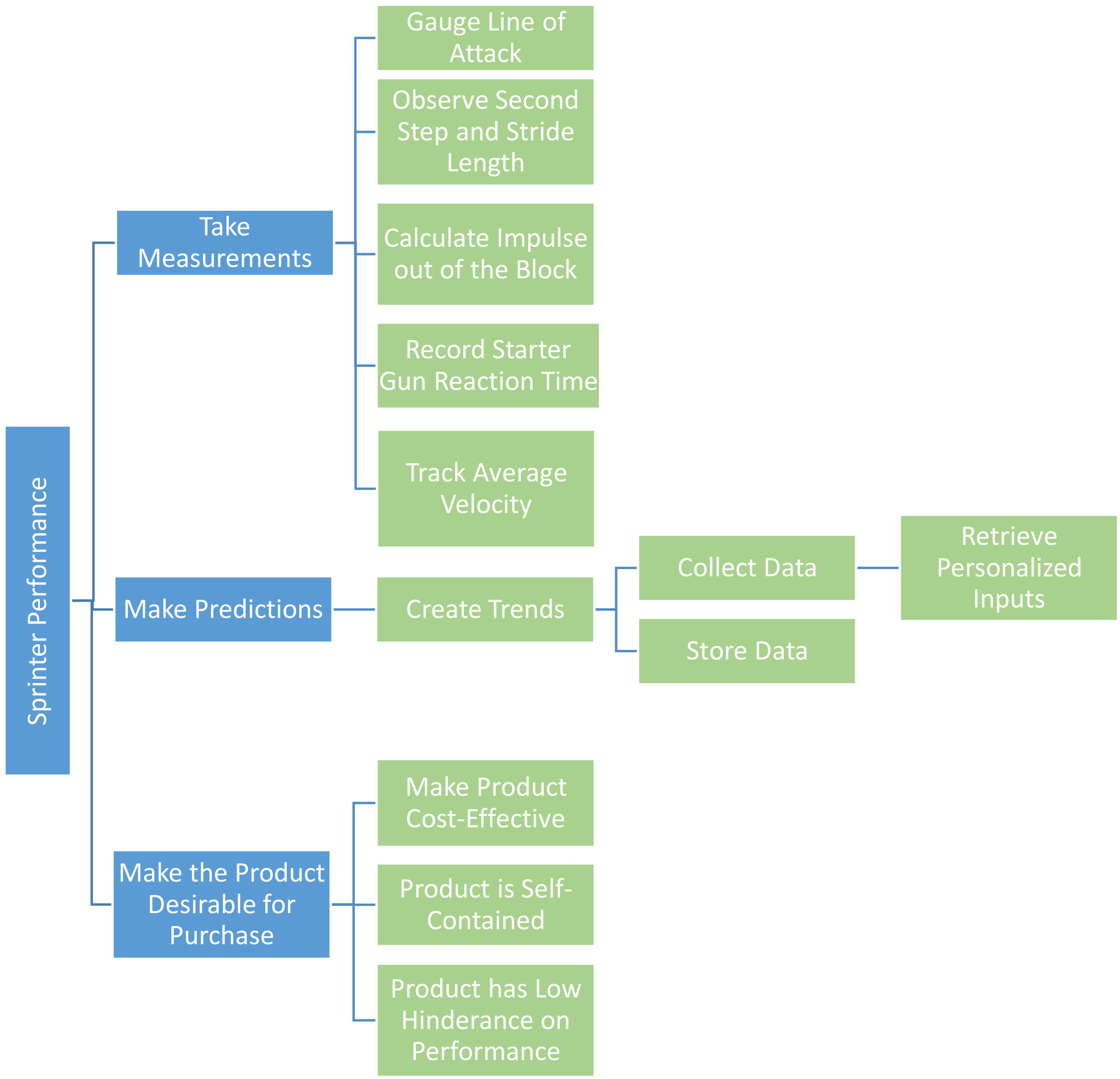


Figure 2: Updated Hierarchy Flow Chart

From this flow chart, targets and metrics were created for each minor function, which are visualized in green boxes. After starting to think about targets for each function, it was also decided that some new assumptions should be made. Below is an updated list of assumptions for the project:

- The sprinter/coach/scout has prior knowledge and experience about running form
- The sprinter is starting out of a standard starting block
- The technology will be used in fair weather
- The technology will not have access to a power outlet during use
- The technology will be used on a collegiate approved track
- The consumer is more concerned about performance accuracy than about the product price
- The user has reasonable data connection or Wi-Fi
- The 100-meter race is the only distance to be considered for now; longer races will be considered in future work
- The technology will not be used for hurdlers
- The technology only measures one sprinter at a time
- The product will be bought for a team, not an individual; this will be modified for secondary markets in future work

After making these assumptions, targets and metrics were finally able to be assigned to each function and other needs. Along with the minor functions shown above, targets and metrics were made for three other needs. The three interpreted needs that were considered are listed below:

- The tool incorporates professional sprinters and eases the effort required for sprinter comparisons
- The analysis from the product exposes users' fundamental weaknesses
- The technology needs to be able to be used daily for about two hours at a time

All of these targets and metrics, along with the tools and methods of validation for each, will be discussed in detail below.

For the major function of taking measurements, the target was chosen to be competitive with one of the competitors, 1080 Motion's, level of accuracy of 1%-2% [1]. It was decided that this would be the case for all the measurements. First, the first minor function of gauging the line of attack was considered. Forming four constant points on the user's body as a reference to the main areas measuring the line of attack, allowing the formulation of the line of attack to be consistent with each user. The angles from the line of attack will be formed from a generally ideal 180-degree angle from the foot to the knee and the knee to the hip. In testing, a still image with a known line of attack will be presented, the desired accuracy will need to be met on this image as well as on a moving sprinter. The units of degrees were chosen to accurately portray the measurements in a commonly used format.

Next, observing the second step was considered. Using the point at the foot as a reference to the user's foot, the highest point during the second step would be used in relation to the ground to determine the height. In testing, a still image with a known second step (blurry and clear) will be presented, the desired accuracy will need to be met on this image as well as on a moving sprinter. The units of millimeters (mm) were chosen to accurately portray the measurements in a commonly used format.

Measuring stride length was considered next. Using the points at the feet as a reference, the furthest distance from the each during the third step would be the measure of the stride length. In testing, a still image with a known stride length (blurry and clear) will be presented, the desired accuracy will need to be met on this image as well as on a moving sprinter. The units of millimeters (mm) were chosen to accurately portray the measurements in a commonly used format.

Then, calculating the impulse off the block was considered. Application of sensors reading the force output with respect to time would give the impulse, testing of the sensor with a set load generating a desired impulse (maximum) would be used in determining the accuracy of the sensor and its calibration initially. The units of Newton seconds (N·s) were chosen to accurately portray the measurements in a commonly used format.

Next, recording the starter gun reaction time was considered. Using the time at which the gun fires and relating it to the rise time from the impulse would be how this area of the product would function. Testing the impulse with the video of the known load would be how accuracy of the sensor would be tested. The units of seconds (s) were chosen to accurately portray the measurements in a commonly used format.

The last measurement function was tracking the instantaneous velocity. Using a motor with an encoder, the velocity of a moving object from rest will be determined, having a known velocity. A video will also be used to get the distance of an object relative to its time required to get to the position to determine its instantaneous velocity. For both tools, units of meters per second (m/s) were chosen to accurately portray the measurements in a commonly used format.

Having a product create trends is a useful way of collecting data that end users can utilize. If processing takes a significant amount of time to for the data to outputted, then the user will be less likely to use the product. This can be seen when users complain about poor optimization regarding apps on their computers and phones, as in today's market everybody wants everything to be fast. Fast is a subjective term, but for most people, they would not enjoy waiting more than 15 seconds for something to load. This number also comes from the amount of time track coaches would have for each trial. If for some reason our trials came back as taking more than fifteen seconds, we would use optimizations in the code to allow the data to read in and process faster. This can be done through different functions, pre-filling arrays, and other small ease-of-life improvements.

The product needs to store data as users will want to reference both their own previous trials as well as the data comparing themselves to the top athletes. Since there will be a lot of different trials stored, the data needs to be compressed so that a single practice session does not take up all the space on someone's storage disk. 10 MB of data is a reasonable expectation for each trial, as the text data will not take up much space (at most 2MB) and the video data will be compressed to 720p at 60 fps, which takes up around 5MB for a 60 second video [2]. 10MB per trial will not take up an unreasonable amount of space for a whole session, as that allows 100 different trials at max video length per 1GB of storage space. If the data per trial was found to be over 10MB, we would investigate different compression ratios for the video to see what the lowest resolution and frame rate can be while still being useable for clear playback.

In order to retrieve personalized inputs, the technology needs to provide a range of heights and weights within a reasonable interval to reduce the amount of specificity of each professional athlete to the user, doing so in a reasonable interval. Testing the ability to store the data by inputting the information, to then search for and find it by looking for a user's name and timing the duration, with a software. For the metric of height in meters and weight in kilograms, with respect to user preference when entering the measurements, and the time in seconds was chosen to accurately portray the measurements in a commonly used format.

For this product to be desirable, it is necessary that it be reasonably priced. After looking at similar products and interviewing customers in the primary market, it was concluded that the product needs to be below $15,000. For this to come to fruition, the bill of materials must be compiled, and production costs must be determined. If the result falls above the target price, alternative materials must be searched for, that are cheaper but do not take a toll on the efficiency. Finally, if the price still falls above the target, cheaper manufacturing will need to be investigated.

When purchasing a product, it is more desirable for it to include everything necessary for it to operate. The product created for this project should not be a "batteries not included" type package. To ensure this, the product must be tested in every scenario possible. Covering all bases will allow for confirmation that no other technology is needed in order to operate it.

Having a product that has a low hinderance on performance will increase its desirability. When it comes to running gear, one of the main focuses is to make it lightweight. Therefore, if a wearable is utilized for this product, making sure it weighs less than a kilogram is a significant goal. After assembling the wearable portion of the product, it will be weighed on a scale. If the target is not met, alternative materials will be researched. Materials that offer similar characteristics but weigh less will be looked into for consideration.

Along with considering all of the functions, targets and metrics were also created for other needs. The first need that was considered was the need to incorporate professional sprinters into the technology. Incorporating data from professional sprinters will allow users to see the value of the product and ease the effort required for them to make comparisons. Athletes are looking to perform their best and the way that they can do this is by trying to be like the best, which are professional athletes. With the use of a data analysis software, the product will utilize the public data from a minimum of five professional athletes. These measurements will include the average heights, weights, etc. This data will be stored in the technology to streamline the process for users when comparing their performance.

Another need is for the technology to expose users' weaknesses. The analysis of this product will do this, so the users can know what to focus on in order to improve their performance. With the use of a statistical analysis software, the technology will have a margin of error of 5% for each of the measurements [3]. This margin will be in reference to the statistics of the professional runner they are being compared to. Having a percent difference outside of this margin will not necessarily mean that a sprinter has a weakness in this area, but it will make users aware of potential weaknesses compared to professional athletes. These metrics will be obtained from start measurements, and if users are higher than the margin of error, they will have an idea about what they might need to improve. This will allow them to push themselves to obtain a specific target.

The last need considered was that the technology needs to be able to be used daily for about two hours at a time. This time range was obtained from interviewing coaches and gaining knowledge about how long their practices typically are. To give the user some slack, this technology's battery life will last at least three hours. With the use of a battery life analysis software, this battery life will be validated by measuring the amount of power the technology's power bank can hold. If the battery capacity is three hundred milliampere-hours (mAh) and the device consumption is one hundred milliamperes (mA), then the technology will have a battery life of three hours [4].

While all of these targets and metrics are important to meet throughout the project, some are absolutely critical for the product to be successful. The first critical target is that all of the measurements taken need to be accurate within 2%. If the measurements are not taken accurately, then it defeats the purpose of this technology. Therefore, it would lead to an unsuccessful project. Another target that is critical to meet is that the wearable weighs less than 1 kilogram. If the wearable weighs too much, it can hinder performance, and therefore invalidate the measurements. Finally, the last critical target is that the technology has a battery life of at least three hours. It is assumed that the technology will not have access to a power outlet during use, so the technology must last the entire training time or else it will be essentially useless.

Table 2 shows a full list of the targets and metrics for each function and need:

Table 2: Target Catalog

Function/Need	Metric	Target
*Gauge Line of Attack	Accuracy of measuring the angle at the ankle, knee, hip, shoulder	Accurate within 2%
*Observe Second Step	Accuracy of measuring the height off the ground from the blocks	Accurate within 2%
*Measure Stride Length	Accuracy of measuring the length from the second step to the third step	Accurate within 2%
*Calculate Impulse from the Block	Accuracy of calculating the force off the block, with respect to time	Accurate within 2%
*Record Starter Gun Reaction Time	Accuracy of recording the time from the starter gun sound to impulse rise	Accurate within 2%
*Track Instantaneous Velocity	Accuracy of tracking the velocity at every 5 meters	Accurate within 2%
Create Trends	Time it takes to output relationships between measurements	Within 15 seconds of request time
Store Data	Compression and frame rate of videos recorded	720 pixels at 60 frames per second
	Amount of storage taken by data collected	Maximum of 10 megabytes per trial
Retrieve Personalized Inputs	Time it takes to store the inputs of the athlete being measured, given by the athlete	Inputs stored in under 5 seconds

Make Product Cost Effective	Desired cost to keep the purchase price under	Keep purchase price under $15,000
Product Is Self-Contained	Additional purchase necessary outside of product	$0.00 spent outside of product purchase
*Product has Low Hinderance on Performance	If a wearable is used, the weight it must stay under	Wearable must weigh less than 1 kilogram (~2 pounds)
The tool incorporates professional sprinters and eases the effort required for sprinter comparisons	Number of professional athletes the technology needs to store statistics for	At least 5 different professionals
The analysis from the product exposes users' fundamental weaknesses	Percent difference between measurements of the user and the compared professional that is pointed out as a potential weakness	A measurement greater than 5% difference from professional is a potential weakness
*The technology needs to be able to be used daily for about two hours at a time	The battery life needed for the technology to hold between charges	A battery life of at least 3 hours

1.5 Concept Generation

1.5.1 Generation Tools

Once the targets and metrics were created, the concepts could be generated. To do this, one hundred concepts were generated. In order to maximize the potential concepts, concept generation tools were utilized. First, categories were created for a crap shoot. A table of these categories is shown below:

Table 3: Crap Shoot

People	Common Activities	Potential Resources
Sprinters	Sprinting	Video
Coach	Competing	Sensors

Scout	Training	Stopwatch
Parents	Performing	Sprinter blocks
Fans	Exercising	Wearable
Athletes	Supporting	Software/ application

From this table, about 30 concepts were generated. This method led to concepts related to other people, rather than just the primary users of athletes and coaches. It also allowed for interesting concepts that were not necessarily considered before. The issue with this method was that some concepts came out vaguer than the project is planned for.

Another tool that was used for concept generation was biomimicry, where uses in nature was considered for potential concepts. This tool allowed for much more imagination. While most of these concepts did not lead to fidelity concepts, they did open our minds to approximately fifteen ideas we did not consider before.

Along with the crap shoot and biomimicry, a morphological chart was created to generate several concepts based on the functions of this project. This morphological chart can be visualized in the table below:

Table 4: Morphological Chart

Functions	**Potential Solutions**				
Gauge Line of Attack	Record a video	Take a picture	Have dots on the sprinter as a reference	Have a line on the sprinter as a reference	
Observe Second Step	Sprinter has a tape measure on their foot	Recording a video	Sprinter runs next to a ruler	Having a laser sensor on the sprinter's foot	Having a string temporarily attached to the sprinter's foot
Calculate Kickoff Force from the Block	Place a force sensor on block	Incorporating a scale under blocks	Using a variation of the individual's body to determine the impulse	Using a spring that would retain compression form force	
Record Starter Gun Reaction Time	Using the starting of the gun with respect to the impulse	Record the audio of the starter gun	Using a high-speed camera to determine when the gun is fired	Using a timer	Slowing down video
Track instantaneous Velocity	Using a video	Having a laser sensor on the sprinter's foot	Using a string attached to a motor and encoder	Using a infrared sensor on the track	Using a radar gun
Retrieve Personalized Inputs	User input	Measured	Creation of a user interface		
Collect Data	Researching sprinter's record	Accepting user input			
Store Data	Placed in a compressed folder	Store in a spreadsheet	Writing the information down	Using a server	Placing in a third-party application?
Create Trends	Makes a line graph	Creates a pivot table	Uses error bars	Creates a bar graph	Make comparisons

					to other athletes
Make Product Cost Effective	Comparable to markets	Using cheaper parts	Has a lay-away system	Having a subscription option	Having a renting option
Product is Self-Contained	Within one app/ software	Comes with all parts included	Use of default applications	Able to fit in a trunk	
Product has Low Hinderance on Performance	Embedded in uniform	Does not use a wearable	Technology in the shoe(s)	Lightweight	

Approximately fifty concepts were generated using this chart. This was the most beneficial method, since it considered each function and allowed for a breakdown of what the product can do to meet each function. These concepts came out much more detailed and led to most of the fidelity concepts.

After creating the one hundred concepts, the best eight fidelity concepts were chosen. These concepts were then broken up into five medium fidelity concepts and three high fidelity concepts. These fidelity concepts will be discussed below.

1.5.2 Medium Fidelities

The medium fidelities are some of the best concepts that were generated from the one hundred concepts. These concepts are detailed and have solutions to many of our functions. Most of them come from the While we are not positive that they are our top three concepts, they will still be further considered in the selection process. Below, these medium fidelities are listed in detail.

Concept 1: User Based System.

A technology that is as user based as possible. The technology will utilize a video to measure track form and a chord/motor system to measure instantaneous velocity. One end of the chord will be attached to the sprinter, while the other end is attached to a motor and decoder. The user will input their own measurements, such as height and weight, as well as the statistics of the professional they want to compare themselves to. This will all be incorporated into a user-friendly application for analysis of performance and trends.

Concept 2: Dots and Infrared.

Use an infrared sensor on the track to measure instantaneous velocity at ten-meter intervals. Camera checks when gun is fired are placed on the sprinter so that the starting measurements can be gauged while a video is recorded from a base station. Use impulse sensors on the blocks, and marker for measurement laid out at the beginning of the track. User inputs through a user interface in application available on phone or computer. Create data using bar graph. Include a subscription model. No wearable is used, other than dots. Record audio of starting gun.

Concept 3: Lasers, Springs, and Radar Guns.

Have a laser sensor on the sprinter's foot to observe the second step. Use a spring that would retain compression from force to calculate the kickoff force from the block. Use a radar gun to track instantaneous velocity. Measure the runner at the start of the training session to retrieve personalized inputs. Implement a lay-away option to make the product cost efficient.

Concept 4: Lasers, Dots, and Sensors with Professionals.

Use a laser sensor on the sprinter to track the instantaneous velocity. Have dots on the sprinter as a reference to gauge the line of attack and to observe the second step through video.

Place a force sensor on the block to calculate the impulse from the block. Use the sensor on the block to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time. Create a user interface to retrieve personalized inputs. Research the sprinter's records to collect data, in addition to accepting users' inputs for professional sprinters they have details on. Use a server to store the data. Have our visuals make comparisons to other athletes to create trends. Use cheaper parts to make the product more cost effective. Have the product come with all parts included to make a product that is self-contained. If there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

Concept 5: Machine Learning Prediction.

The use of machine learning will be implemented to predict sprinters performance and compare it to data that is inputted from professional sprinters. Using professional sprinters data and the user's data, the machine learning model will get stronger and stronger.

1.5.3 High Fidelities

The high fidelities are, what we believe, the three best concepts out of the one hundred generated. These all came from the morphological chart and are written in much detail. These will be heavily considered in the selection process. These three concepts are listed below.

Concept 6: Tension Cord Training Mechanism.

By utilizing a video to measure a sprinter's form at the start, as well as a tension cord and encoder to measure instantaneous velocity, this will collect all measurements in a self-contained product. One end of the tension cord will be attached to the athlete, while the other end is attached to a motor and decoder. This cord/motor mechanism will offer assistance and resistance. The tension cord will be weightless in order to not hinder performance, unless desired.

Personalized inputs will be measured at the start of the training session for later comparison. To create trends, these measurements will be stored using a server and trends will be created using line graphs. The product price will be comparable to other markets and lay away will be offered.

Concept 7: All Inclusive Technology.

Use a laser sensor on the sprinter to track the instantaneous velocity. Have dots on the sprinter as a reference to gauge the line of attack. Observe the second step through video. Place a force sensor on the block to calculate the impulse from the block. Use this sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time Create a user interface to retrieve personalized inputs. Research sprinter's records to collect data, in addition to accepting users' inputs for sprinters they have details on. Place information into a compressed folder to store the data. Have our visuals make comparisons to other athletes to create trends. Use cheaper parts and a renting option to make the product more cost effective. Have the product come with all parts included and keep the technology within one application or software to make a product that is self-contained. If there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

Concept 8: Launch Monitor Pro.

Use infrared sensors on the track to measure instantaneous velocity at ten-meter intervals. Dots are placed on the sprinter so that the starting measurements can be gauged while a video is recorded from a base station. Use impulse sensors on the blocks, and a marker (possibly measuring tape) laid out at the beginning of the track for accurate measurements. User inputs will be placed and accessed through a user interface in an application that is available on a phone or computer. The product will be a complete purchase model. No wearable other than dots will be utilized. Audio of starting gun will be recorded. All measurements and trends will be outputted to the same application as the user interface. Data is stored on the user's device. Trends will be created from the stored data using line graphs. Machine learning will be used to interpret the line of attack and measurements for output to device. The base station will have high speed camera, so data is consistent.

1.6 Concept Selection

After one hundred concepts were generated and eight fidelity concepts were chosen, it was time to start the selection process. Involved in the selection process is a House of Quality, Pugh charts, and the Analytical Hierarchy Process. These three elements will be discussed in great detail below.

1.6 1 House of Quality

The first step of the selection process is the House of Quality. The House of Quality is a functional deployment tool used to translate customer requirements into engineering characteristics. It is important to understand which engineering characteristics will contribute the most to satisfy the customer's needs so that a successful product is created. Customer requirements are listed in column one, which were determined from the previously found customer needs. Each customer need has an importance weight factor that was determined using a binary comparison matrix. The next seven columns contain the engineering characteristics with their units, if applicable, listed above them. Every customer need was then compared to each engineering characteristic to determine if there was a relationship between them. The House of Quality can be observed in Table 5:

Table 5: House of Quality

		Engineering Characteristics						
	Units	N/A	Seconds	Megabytes	$	Pounds	Hours	N/A
Customer Requirements	**Importance Weight Factor**	**Accurate within 2%**	**Processing Time**	**Data Size**	**Price**	**Low Weight**	**Battery Life**	**No additional Purchase Required**
Gauge Line of Attack	3	5						
Observe Second Step	3	5						
Measure Stride Length	3	5						
Calculate Impulse from the block	3	5						
Record Starter Gun Reaction Time	3	5						
Track Instantaneous Velocity	3	5						
Create Trends	2		5					
Store Data	2		1	7				
Retrieve Personalized Inputs	2		5					
Cost Effective	3				9			
Self-Contained	1							7
Low Hinderance on Performance	5					7		
Daily use without	3						9	

external power								
Raw Score	222	90	22	14	27	35	27	7
Relative Weight		0.4054	0.0991	0.0631	0.1216	0.1577	0.1216	0.0315
Rank Order		1	4	5	3	2	3	6

If a relationship was found, a value was assigned dependent upon how much the engineering characteristic will contribute to the customer requirement. According to Table 1, the values assigned were 1, 3, 5, 7, and 9; with higher values correlating to larger contributions from the engineering requirement. Once the values were assigned, a sum-product analysis was performed to determine a raw score for each engineering characteristic. Each raw score was then divided by the total raw score to determine the relative weight for each characteristic. Accuracy had the highest raw score and ended up with a 0.4054 relative weight out of 1, therefore it is the highest priority engineering characteristic. Low weight was the second highest priority, price and battery life tied for third, and the rest were in the following order: processing time, data size, no additional purchase required.

1.6.2 Pugh Charts

After the House of Quality was finalized, the Pugh charts were able to be created. The Pugh charts were created based off the twelve functions and the eight fidelity concepts. These functions became the selected criterion for the Pugh charts and the eight fidelity concepts were narrowed down to four concepts for the analytical hierarchy process. The results of the Pugh chart process were obtained by eliminating all the concepts with high minuses to filter the best possible concepts. This process will be further discussed below.

A total of three Pugh charts was created. In the first one, the datum was a pre-existing product called the 1080 Sprint. This product has been considered throughout the design process as comparison for what our product should include, so we felt it appropriate to be used as the first datum in the Pugh chart process. In Table 6, below, this first Pugh chart can be visualized:

Table 6: Pugh Chart 1

Selection Criteria	**1080 Sprint**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gauge Line of Attack	DATUM	+	+	+	+	+	S	+	+
Observe Second Step		S	-	+	S	+	S	+	+
Calculate Kickoff Force from the Block		S	+	+	+	+	S	+	S
Record Starter Gun Reaction Time		+	+	+	+	+	+	+	+
Track Instantaneous Velocity		S	-	S	+	-	S	+	-
Retrieve Personalized Inputs		+	S	+	+	+	+	+	+
Collect Data		S	-	-	-	+	S	+	+
Store Data		+	+	+	+	+	S	+	+
Create Trends		+	+	+	+	+	S	+	+
Make Product Cost Effective		+	-	-	-	+	S	+	-
Product is Self-Contained		+	-	-	-	+	S	-	-
Product has Low Hinderance on Performance		+	+	+	+	+	S	+	-
# of pluses		8	6	8	8	11	2	11	7
# of Minuses		0	5	3	3	2	0	1	4

The concept that was eliminated from this first chart was concept two, highlighted red. This was due to the fact that it had the highest number of minuses. Concept eight, highlighted in yellow, was chosen as the datum for the second Pugh chart, since it was the most neutral concept according to pluses and minuses. Table 7 shows the second Pugh Chart:

Table 7: Pugh Chart 2

Selection Criteria	8	1	3	4	5	6	7
Gauge Line of Attack	DATUM	S	-	S	S	-	S
Observe Second Step		S	-	-	S	-	S
Calculate Kickoff Force from the Block		S	-	S	-	-	S
Record Starter Gun Reaction Time		S	-	S	-	-	S
Track Instantaneous Velocity		-	-	-	-	-	-
Retrieve Personalized Inputs		S	-	-	-	+	S
Collect Data		S	S	S	S	S	S
Store Data		S	-	+	S	+	S
Create Trends		-	-	+	S	S	+
Make Product Cost Effective		+	+	S	S	S	+
Product is Self-Contained		S	S	S	S	S	S
Product has Low Hinderance on Performance		-	-	S	S	-	S
# of pluses		1	1	2	0	2	2
# of Minuses		2	9	3	4	6	1

From the second chart, concepts three and five were eliminated due to the high volume of minuses. Finally, one last chart was created with concept four as the datum. This Pugh chart can be observed in Table 8:

Table 8: Pugh Chart 3

Selection Criteria	4	6	7	8
Gauge Line of Attack	DATUM	-	S	S
Observe Second Step		S	S	S
Calculate Kickoff Force from the Block		S	S	S
Record Starter Gun Reaction Time		S	+	+
Track Instantaneous Velocity		-	S	S
Retrieve Personalized Inputs		+	S	S
Collect Data		S	S	S
Store Data		S	-	-
Create Trends		-	S	-
Make Product Cost Effective		+	+	-
Product is Self-Contained		S	S	S
Product has Low Hinderance on Performance		-	S	S
# of pluses		2	2	1
# of Minuses		4	1	3

From this Pugh chart, we got a better idea about how the final four concepts compare in the criterion. In the end, concepts four, six, seven, and eight were kept for comparison in the Analytical Hierarchy Process since we were not ready to eliminate any of them yet. It seems that the biggest difference in comparison comes from the cost criteria, so this will be looked at in more detail in the AHP, below.

1.6.3 Analytical Hierarchy Process

The Analytical Hierarchy Process was begun by using the functions generated in the functional decomposition. The functions that involve taking start measurements were all grouped into once criteria called "Accuracy of Measurements", since they will all be included in every concept and solely depend on accuracy. Similar to the accuracy criteria, "Collect Data", "Store

Data", and "Create Trends" were all grouped into one criterion called "Data Management", since they will also all be included in every concept and are solely dependent upon processing time. The remaining criterion were kept individual due to being significant and unique. The start of the AHP process, with these criteria, can be visualized in Table 9 below:

Table 9: AHP Criteria [C]

AHP Criteria							
	Accuracy of Measurements	Track instantaneous Velocity	Retrieve Personalized Inputs	Data Management	Make Product Cost Effective	Product is Self-Contained	Product has Low Hinderance on Performance
Accuracy of Measurements	1	3	5	1	3	5	0.2
Track instantaneous Velocity	0.333333333	1	1	1	1	3	0.2
Retrieve Personalized Inputs	0.20	1.00	1	1	3	3	0.2
Data Management	1.00	1.00	1.00	1	1	3	0.2
Make Product Cost Effective	0.33	1.00	0.33	1.00	1	3	0.2
Product is Self-Contained	0.20	0.33	0.33	0.33	0.33	1	0.2
Product has Low Hinderance on Performance	5.00	5.00	5.00	*5*	5.00	5.00	1
SUM	8.066666667	12.33333333	13.66666667	10.33333333	14.33333333	23	2.2

Form this table, one can see that tracking the instantaneous velocity is slightly less important than having accurate measurements; having accurate measurements would be expected when using the product. If accurate start measurements are not provided but a capability of inaccurately tracking the instantaneous velocity was offered, consumers would reduce their interest in the technology.

Similar to tracking the instantaneous velocity, the retrieval of personalized inputs, making the product cost effective, or having the product be self-contained are all much less important than having accurate measurements. Tracking the instantaneous velocity seemed to have equal importance with the retrieval of personalized inputs and making the product cost effective. The product being self-contained has lower importance than tracking the instantaneous velocity due to not being obviously desired by multiple customers. Retrieval of the Personalized Inputs and data management would work closely together causing their importance to be equal, though is slightly more important than making the product cost effective or self-contained due to the expectation of having personalized information. Data management and making the product cost effective both would equally influence the demand for the technology; yet slightly more important than the product being self-contained because the data management is the aspect which provides visual representations of data collected and data stored. Making the product cost effective was more important than having the product be self-contained due to the interest in having a desirable monetary value being of likely interest to a larger number of customers that may not travel as often.

The largest concern for the product was having low hinderance on performance. This criterion has the highest importance, compared to all aspects of the technology due to the goal of the customers to improve the sprinter's performance. If the technology hinders an athlete's performance, then the product is useless.

After this first step of the AHP, the second step was to normalize the criterion. This normalization can be observed in Table 10:

Table 10: Normalized Criteria [N]

Normalization															
	Accuracy of Measurements	Track instantaneous Velocity	Retrieve Personalized Inputs	Data Management	Make Product Cost Effective	Product is Self-Contained	Product has Low Hinderance on Performance	Average	Weighted Sum	Criteria	Consistency	λ	RI	CI	CR
Accuracy of Measurements	0.12397	0.24324	0.36585	0.09677	0.2093	0.21739	0.09091	0.19249	1.5442852	0.19249	8.02261	7.60174	1.35	0.10029	0.07429
Track instantaneous Velocity	0.04132	0.08108	0.07317	0.09677	0.06977	0.13043	0.09091	0.08335	0.6167627	0.08335	7.39955				
Retrieve Personalized Inputs	0.02479	0.08108	0.07317	0.09677	0.2093	0.13043	0.09091	0.10092	0.7438626	0.10092	7.37055				
Data Management	0.12397	0.08108	0.07317	0.09677	0.06977	0.13043	0.09091	0.09516	0.7450904	0.09516	7.83005				
Make Product Cost Effective	0.04132	0.08108	0.02439	0.09677	0.06977	0.13043	0.09091	0.07638	0.5494803	0.07638	7.19378				
Product is Self-Contained	0.02479	0.02703	0.02439	0.03226	0.02326	0.04348	0.09091	0.03802	0.2778549	0.03802	7.3089				
Product has Low Hinderance on Performance	0.61983	0.40541	0.36585	0.48387	0.34884	0.21739	0.45455	0.41368	3.3452922	0.41368	8.08673				

In this table, one can see that the criteria values were normalized and averaged. A weighted sum was developed, along with a consistency value, lambda value, RI value, CI value, and CR value. These values can be seen in the figure above.

After that was completed, two design alternatives were chosen: accuracy and cost. Accuracy was chosen since its criteria weight was the highest among all the factors. The second highest weight was less than half the weight that accuracy has. This fact strengthened the decision to choose accuracy. On the other hand, cost was chosen as alternative because it is the biggest deciding factor being as this is an entrepreneurship project. Once the factors were chosen, they were compared against the concepts in the first matrices. The same steps of comparing, normalizing, and determining the consistency were done in this matrix. In the end, another set of consistency, lambda, RI, CI, and CR values were found. The tables below can be used to visualize this process:

Table 11: Accuracy Comparison

Accuracy Comparison				
	Concept 4: Lasers, Dots, and Sensors with Professionals	Concept 6: Tension Cord Training Mechanism	Concept 7: All Inclusive Technology	Concept 8: Launch Monitor Pro
Concept 4: Lasers, Dots, and Sensors with Professionals	1	0.333333333	1	3
Concept 6: Tension Cord Training Mechanism	3.00	1	0.333333333	3
Concept 7: All Inclusive Technology	1	3.00	1	0.333333333
Concept 8: Launch Monitor Pro	0.333333333	0.333333333	3	1
Sum	5.333333333	4.666666667	5.333333333	7.333333333

Table 12: Accuracy Comparison Normalized

Normalized Accuracy Comparison												
	Concept 4: Lasers, Dots, and Sensors with Professionals	Concept 6: Tension Cord Training Mechanism	Concept 7: All Inclusive Technology	Concept 8: Launch Monitor Pro	Average	Weighted Sum	Criteria	Consistency	Lambda	RI	CI	CR
Concept 4: Lasers, Dots, and Sensors with Professionals	0.1875	0.071428571	0.1875	0.409090909	0.21387987	1.208333333	0.21388	5.649588868	5.562756	0.89	0.520919	0.585302
Concept 6: Tension Cord Training Mechanism	0.56	0.214285714	0.0625	0.409090909	0.31	1.666937229	0.312094	5.341135674				
Concept 7: All Inclusive Technology	0.1875	0.64	0.1875	0.045454545	0.265827922	1.48538961	0.265828	5.58778626				
Concept 8: Launch Monitor Pro	0.0625	0.071428571	0.5625	0.136363636	0.208198052	1.181006494	0.208198	5.67251462				

Table 13: Cost Comparison

Cost Comparison				
	Concept 4: Lasers, Dots, and Sensors with Professionals	**Concept 6: Tension Cord Training Mechanism**	**Concept 7: All Inclusive Technology**	**Concept 8: Launch Monitor Pro**
Concept 4: Lasers, Dots, and Sensors with Professionals	1	0.33	0.33	3
Concept 6: Tension Cord Training Mechanism	3	1	3	1
Concept 7: All Inclusive Technology	1	0.33	1	3
Concept 8: Launch Monitor Pro	0.33	1	0.33	1
Sum	5.33	2.66	4.66	8

Table 14: Cost Comparison Normalized

Normalized Cost Comparison												
	Concept 4: Lasers, Dots, and Sensors with Professionals	**Concept 6: Tension Cord Training Mechanism**	**Concept 7: All Inclusive Technology**	**Concept 8: Launch Monitor Pro**	**Average**	**Weighted Sum**	**Criteria**	**Consistency**	**Lambda**	**RI**	**CI**	**CR**
Concept 4: Lasers, Dots, and Sensors with Professionals	0.187617261	0.12406015	0.070815451	0.375	0.189373215	0.879854109	0.18937	4.64613809	4.51625	0.89	0.17208	0.19335
Concept 6: Tension Cord Training Mechanism	0.562851782	0.37593985	0.643776824	0.125	0.426892114	1.829381274	0.42689	4.28534802				
Concept 7: All Inclusive Technology	0.187617261	0.12406015	0.214592275	0.375	0.225317421	1.030816782	0.22532	4.57495375				
Concept 8: Launch Monitor Pro	0.061913696	0.37593985	0.070815451	0.125	0.158417249	0.722157273	0.15842	4.55857729				

The last step was to find the alternative value using the final rating matrix and the Pi values calculated. In the end, it was found that accuracy had the largest alternative value. Since concept 8 has the greatest accuracy, according to Figure 5, this concept will be chosen for final selection.

1.6.4 Final Selection

According to the selection process, concept 8 is the best concept to meet our functions and targets. Throughout the process, we had a few realizations that could make the final concept even better. So, we decided to make a few alterations to the final concept. Below gives a detailed description of our final concept.

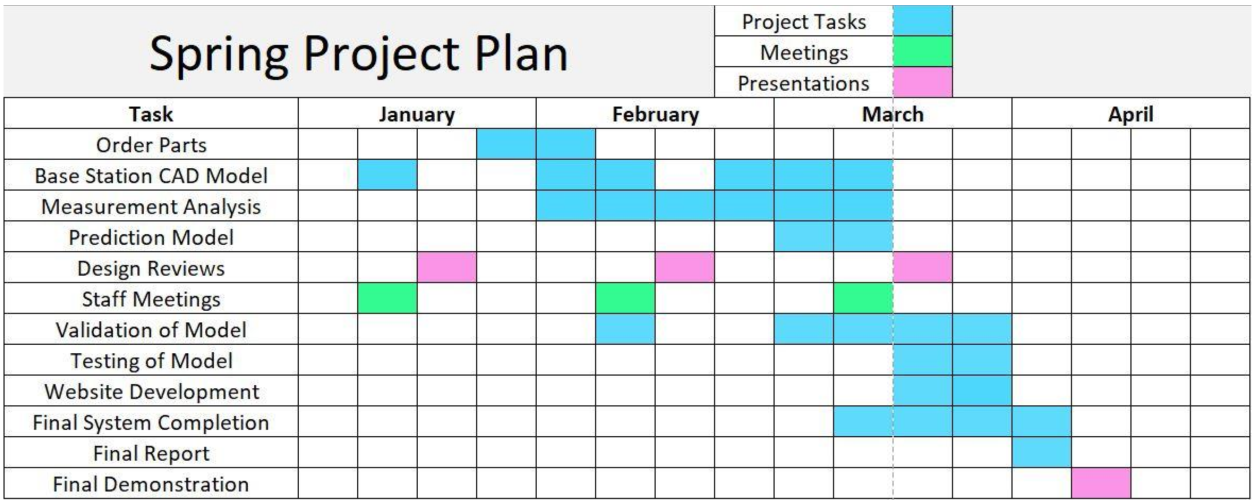
Launch Monitor Pro:

Use infrared sensors on the track to measure instantaneous velocity at ten-meter intervals. Dots are placed on the sprinter so that the starting measurements can be gauged while a video is recorded from a base station. Use impulse sensors on the blocks, and a marker (possibly measuring tape) laid out at the beginning of the track for accurate measurements. User inputs will be placed and accessed through a user interface in an application that is available on a phone or computer. The product will be a complete purchase model. No wearable other than dots will be utilized. Audio of starting gun will be recorded. All measurements and trends will be outputted to the same application as the user interface. Data is stored in the same application as the user interface. Trends will be created from the stored data, using line graphs. Machine learning will be used to interpret the line of attack and measurements for output to device. The base station will have high speed camera, so data is consistent.

1.8 Spring Project Plan

Now that we have wrapped up the planning phase of the design process, we will begin the Validation phase. The table below shows a visualization for our Spring Project Plan:

Table 15: Spring Project Plan



We will begin by finalizing the parts that will be ordered. We will then create a CAD model of our base station in Creo Parametric to be 3D printed. Once all of our parts come in, we will begin the process of the measurements analysis and prediction model. We will then finalize the validation and testing of our product and prepare for final reports and demonstrations. Throughout the semester, we will conduct design reviews and participate in staff meetings to be sure that we are on schedule with our timeline.

Chapter Two: EML 4552C

2.1 Restated Project Definition and Scope.

1.1.1 Project Description

The objective of this project is to create a desirable product that will objectively measure and predict a sprinter's performance.

1.1.2 Key Goals

To achieve our objective, we have developed three key goals, based on information collected in customer background. The first goal of this project is to develop a method to objectively measure a sprinter's performance by focusing on their takeoff form, as well as their average velocity throughout the race. When observing takeoff form, we want to focus on the runner's line of attack, second step and associated stride length, starter gun reaction time, and impulse out of the block. These components of takeoff form addressed in the video given with the project brief. The second key goal is to predict a sprinter's performance by creating individualized trends based on data from personalized inputs and start measurements. Finally, the last goal is to create a product that is desirable for purchase by making it cost effective, self-contained, and have minimal hinderance to performance.

1.1.3 Market

There are several markets that will be targeted during this project. The primary market is college track teams, including sprinters, coaches, and recruiters. Customers in this market were interviewed to help us decide on our project objective and key goals. Secondary markets are:

fans and parents of the sprinters, professional running teams, high school track teams, and other sports.

1.1.4 Assumptions

Before beginning the project, assumptions must be declared to control the scope. The first assumption made was that the technology will be used on a range of sprinter heights from 5-foot-3 to 6-foot-4. It also must be assumed that the sprinter/coach/recruiter has prior knowledge and experience about running form. It is assumed that the user has access to a smartphone or laptop. Another assumption is that the sprinter is starting out of a standard starting block. It is also assumed that the technology will be used in fair weather. Another assumption is that the technology will be used on a collegiate approved track. Finally, it is assumed that the consumer is more concerned about performance accuracy than about the product price.

1.1.5 Stakeholders

There are several stakeholders in this project. While there is not a specified sponsor, some stakeholders that provided prior knowledge of the project are Dr. Devine, Michael Ormsbee, and Ricardo Argro. Another stakeholder is the advisor of this project, Dr. Clark. Some professors involved as stakeholders are Dr. McConomy, Ms. Gray, and Dr. Hooker. Other stakeholders of this project include the FAMU-FSU College of Engineering and investors in the InNOLEvation challenge. Many of these stakeholders provided much of the prior knowledge necessary to develop the project description and key goals mentioned before. Others will provide guidance throughout the project.

2.2 Results and Discussion

Throughout this project, there were many successes and notable findings. They were also several failures and shortcomings. The following subsections will discuss all of these results, as well as what would be done in future work.

2.2.1 Software and Hardware Components

The actual implementation of the hardware went quite well. Everything fit as expected and the overall functionality of the Launch Monitor Pro was achieved. There were some issues, however, sourcing parts as the requested power supply and camera never came in. This was fixed by using spare parts found around the senior design lab. There was also a hiccup as the wrong IR sensors were ordered, so for final assembly and proof of concept there is only one IR sensor installed down the track. Below, a graphic of the Launch Monitor Pro prototype on the track can be observed:

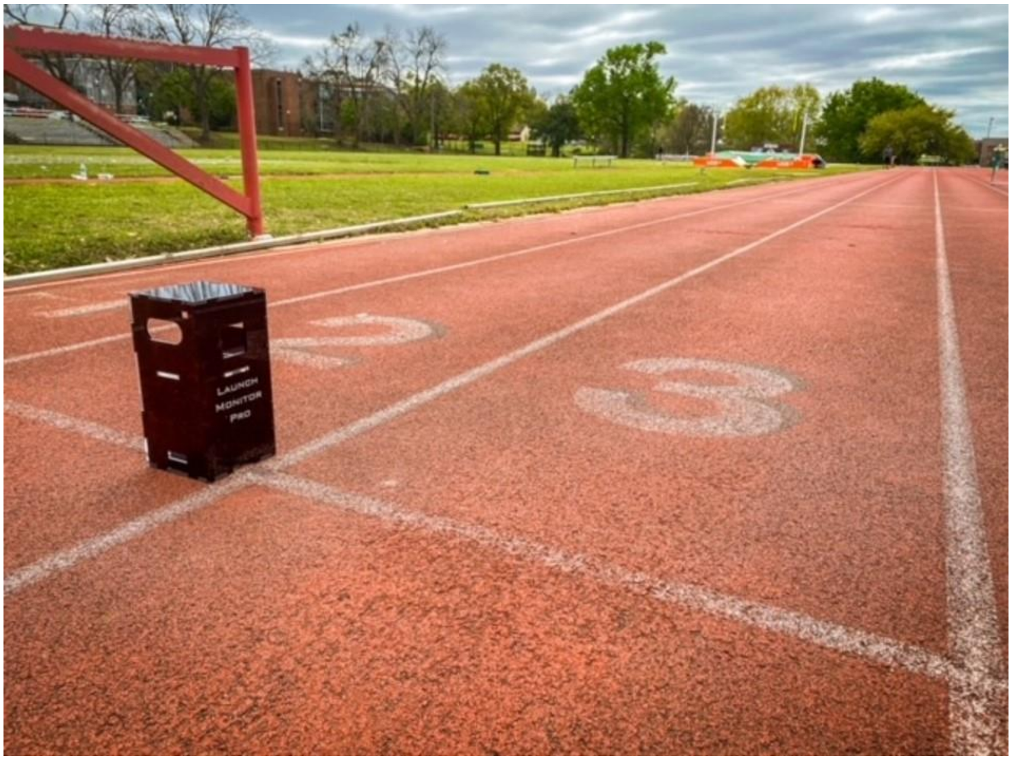


Figure 3: Launch Monitor Pro

As for software, the proof of concept was achieved but overall, the product cannot function in its current state. This is due to issues with the data being read in from the sensors, as well as issues with the image processing. Currently, the sensors are feeding in usable data, however it needs to be “cleaned,” as it is impossible to directly import into analytical software. There are random spikes in readings as well as a couple of garbage data outliers, but once cleaned they account for the needed measurements adequately. On the image processing side, OpenCV was able to read in the images from the camera, however only the object identification was utilized. Essentially the camera could pick up the dots and tell what they were but could not relate them to each other. The fix is not impossible, just difficult with the current knowledge base of OpenCV. A barrier for this was completing the processing directly on the Raspberry Pi itself, as the processing time is notably slower than a typical compute of today's standards. If this project were taken further, it would be a better workflow to get the OpenCV processing working on a typical computer for a more efficient us of time, and then transfer it over to the Raspberry Pi.

2.2.2 Statistical Analysis Component

For the statistical analysis, there were four main statistical values that were focused on. First the multiple R, which is the correlation coefficient that measures the strength of a linear relationship between two variables. When dissecting the data for the multiple R 3 numbers were very important 1,0, and -1. The closer the value was to 1 that means there was a strong positive relationship. The closer the value was to 0 that means there is a strong negative relationship. The closer to -1 that means there is no relationship at all. Next, was R-squared, which means the coefficient of determination which is an indicator of goodness of fit. It shows us how many points fall in the regression line. Generally, R^2 of 95% or more is considered a good fit. Another statistical value was the residual sum of squares, which means the smaller the residual SS compared to the total SS the better the model fits the data. Finally, one of the most important values is the significance F. This tells us how reliable the data is. If the value is less than 0.05 the model is okay, if it is greater than 0.05 a different variable should be chosen.

Unfortunately, the measurements needed to run the statistical analysis were not able to be fully gathered. So, to test the statistical analysis, pseudo measurements were used. From these pseudo measurements, there were significant results and insignificant results. The most significant relationship and most successful implementation of linear regression was the line of attack and time. These results can be visualized below:

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.41529809							
R Square	0.1724725							
Adjusted R Square	0.14488825							
Standard Error	0.57915113							
Observations	32							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	2.09721279	2.09721279	6.25257176	0.018094			
Residual	30	10.0624809	0.33541603					
Total	31	12.1596936						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	10.3149909	0.19341522	53.3308135	2.7607E-31	9.91998436	10.7099975	9.91998436	10.7099975
line of attack(angle)	-0.022717	0.00908493	-2.5005143	0.018094	-0.0412709	-0.0041631	-0.0412709	-0.0041631

Figure 4: Line of Attack Linear Regression

The results were a multiple R of 0.41, a R^2 of 17%, a residual ss (sum of square) of 10 compared to a total ss of 12.1, and a significance F value of 0.018.

The most insignificant relationship and most unsuccessful implementation of the linear regression that was found was impulse and time. These results can be seen below:

Regression Statistics								
Multiple R	0.01981335							
R Square	0.00039257							
Adjusted R Square	-0.0340767							
Standard Error	0.61409925							
Observations	31							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	0.00429498	0.00429498	0.01138897	0.91574667			
Residual	29	10.9364189	0.37711789					
Total	30	10.9407139						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	10.3060086	3.52873665	2.92059442	0.00669742	3.08893177	17.5230854	3.08893177	17.5230854
Impulse (N)	-0.0021089	0.01976096	-0.1067191	0.91574667	-0.0425246	0.03830683	-0.0425246	0.03830683

Figure 5: Impulse Linear Regression

The results were a multiple R of 0.019, a R^2 of 0.00039, a residual ss (sum of square) of 10.93 compared to a total ss of 10.94, and a significance F value of 0.91. There were 32 different trials that were ran to ensure that this data could be as accurate as possible, but these trials were not based on real measurements. The data could have been unsuccessful due to that.

2.2.3 Notable Findings

Throughout Senior Design I and Senior Design II, many discoveries surfaced. Some were revealed through hardships, but nonetheless, they were all notable findings. One such finding was that the lack of products in this market. While researching competing products, it was found that there were none like the Launch Monitor Pro. This would allow for a completed Launch Monitor Pro to take over the market.

Discussing with collegiate track coaches also led to discovering the budget that typical track teams have, i.e., how much a program is willing to pay for this piece of equipment. This gave us a better idea about how much we should spend on developing and the product, as well as how much we should market it for.

Another notable finding was that the line of attack measurement proved to have a significant relationship with time in our pseudo trial. After running ANOVA and linear regression tests for all the variables, line of attack was the only variable in our data sampling that had a nearly ideal significant F value. While this may differ from sprinter to sprinter, it was surprising that this was the only significant measurement in our pseudo trial.

In the beginning of this project, it was believed that only mechanical engineering knowledge would be necessary. But, as the project developed further, it was found that software engineering and computer programming knowledge would be required to fully complete this project.

2.3 Conclusions

In conclusion, this project was the start to a revolutionary product to be used in the sprinting market. Although some knowledge limitations and time constraints led to an unfinished product, this project is set up to be easily finished by another team. After code refinements, linear regression tests, and application development, this product will be a complete success.

2.4 Future Work

All in all, the proof of concept of this project was collected. This product will work and can be utilized as a tool for athletes to improve themselves, it just needs major refinement. Below shows an outline of what is planned for future work of this project:

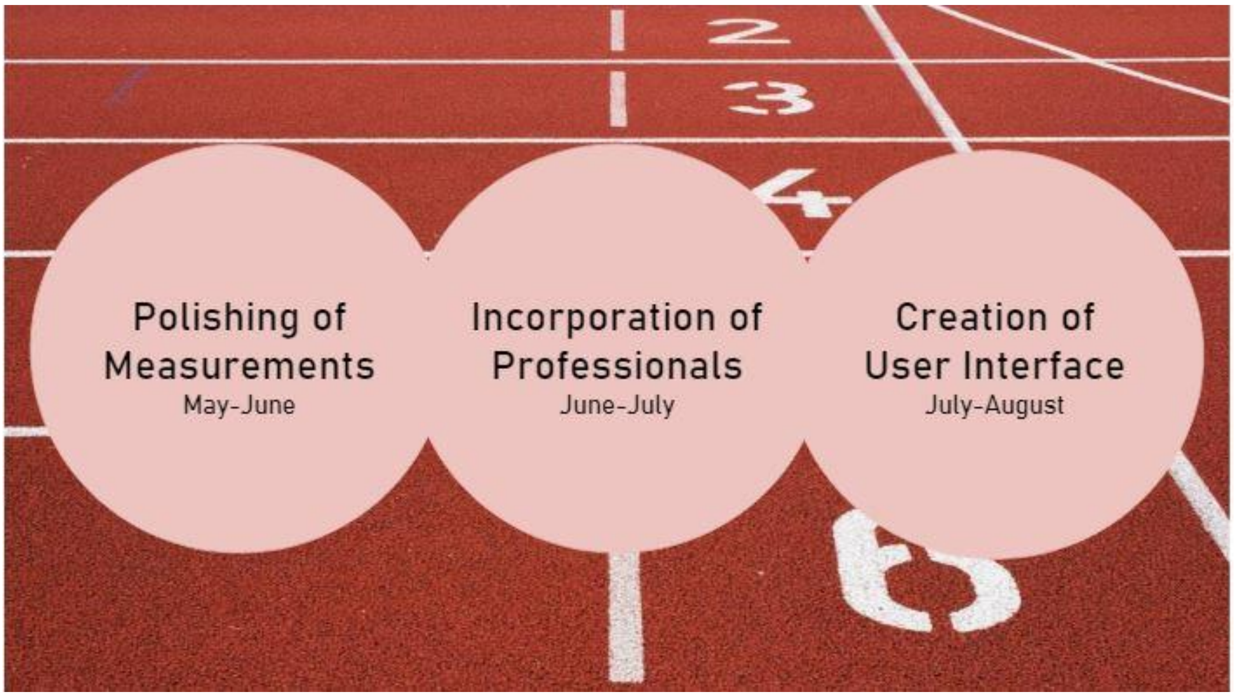


Figure 6: Future Work

The data needs to be cleaned and be able to be directly imported to analytical software. The processing needs to be taken further to get true utilization, and overall, the measurements taken need to be packaged in a more user-friendly way. The hardware itself needs no major refinement. Once the data is cleaned and usable, the ANOVA and Linear Regression models can be used with real data. This will provide a true correlation based on real world tests.

In the future, the hope is to also incorporate professional sprinters for measurement comparison and better prediction. After all measurements and predictions are refined, this addition will create an even more successful product.

After all this is accomplished, the user interface, such as an application on a mobile device or computer would need to be created to present the data in streamlined user-friendly way. Once all of this is accomplished, this product would be viable for daily use by athletes and coaches.

References

[1] Rakovic, Elvir & Paulsen, Gøran & Helland, Christian & Haugen, Thomas & Eriksrud, Ola. (2020). Validity and reliability of a robotic sprint resistance device. The Journal of Strength and Conditioning Research. Retrieved October 29, 2020, from https://www.researchgate.net/publication/343999790_Validity_and_reliability_of_a_robotic_sprint_resistance_device

[2] How to Accurately Calculate Video File Size (Plus: Bonus Glossary). (2019, November 13). Retrieved October 29, 2020, from https://www.circlehd.com/blog/how-to-calculate-video-file-size

[3] Track and Field Scholarship and Recruiting Standards. (n.d.). Retrieved October 27, 2020, from https://athleticsrecruiting.com/trackandfieldrecruitingstandards.html

[4] Battery Life Calculator. (n.d.). Retrieved October 29, 2020, from https://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-battery-life

Appendices

Appendix A: Code of Conduct

1.2.1 Mission Statement

Team 521 is dedicated to meeting the needs of their stakeholders, to the best of their abilities, in an efficient and effective manner. Our mission is to utilize technology to enhance the performance of athletes and help them maximize their full potential.

1.2.2 Team Roles

In order to uphold our mission, every team member is responsible for doing their part to meet weekly deadlines. Below are details of the responsibilities for each of these members:

Dylan Cedeño – Project Manager

- Delegates tasks to other team members
- Sets deadlines for things that need to be done
- Updates Basecamp with tasks and deadlines after each meeting
- Acts as the main point of contact for stakeholders

Marc Griffiths – Design Engineer

- Makes sure PowerPoints are prepared for every presentation
- Includes graphics/animations and makes sure slides flow smoothly
- Keeps a running PowerPoint of project updates, in case of an unexpected presentation

Jordan Noyes - Quality Engineer

- Makes sure all assignments flow nicely and are free of grammatical errors
- Puts assignments in proper format, making them look pleasant and professional
- Takes attendance at every formal meeting
- Uploads minutes to Basecamp after each formal meeting
- Submits assignments to canvas with the proper file name and format

Handy A Pierre – Research Engineer

- Does research for existing products relating to the project
- Defines methods for how our goals will be accomplished

- Translates qualitative data to quantitative data
- Interprets data into simple terms and understandable formats

Edwin Ulysse – Data Engineer

- Gathers data from trial runs and prototypes
- Analyzes the gathered data
- Initiates competition and market research
- Prepares entrepreneurship pitches
- Main point of contact for Dr. Devine
- Informs the team of all InNOLEvation deadlines

Other Duties

- Will be discussed as a team during formal meetings
- Will be agreed upon by all members
- Will be acknowledged and posted on Basecamp by Dylan

1.2.3 Methods of Communication

To ensure that each team member is fulfilling their responsibilities, we will have more than one method of communication. Basecamp will be the formal method of communication. Each team member is required to check Basecamp once every twenty-four hours. Basecamp is where all important documents will be posted and tasks will be assigned. All tasks will be posted by Dylan, all files will be uploaded by Jordan, and discussion can be posted by any team member. GroupMe will be the informal method of communication, where team members can have unofficial discussion about meeting times and assignments. Team members are expected to check the GroupMe more than twice a day. Email will be used for formal communication with stakeholders.

Meeting minutes will be taken at every formal meeting by Jordan. There is a file uploaded on Basecamp that will be updated after every meeting. If a team member misses a meeting, they are expected to review these minutes within twelve hours.

Class time will be the primary meeting time. This time is mandatory for all members and will be used effectively. When necessary, we will extend meeting time to after class and weekends. Alternate meeting times will be finalized at least two days in advance. If a meeting is scheduled with less notice, then absence of a teammate is acceptable with reason.

In Basecamp, there is a spreadsheet which includes the overlap of every teammate's availability. It also includes blocked off times that are unavailable. This spreadsheet will be used when an alternate meeting time is necessary. The spreadsheet is based off of a joint Outlook calendar, which will be updated by individual team members when there is a change in their schedule.

All messages posted in Basecamp or GroupMe should be acknowledged, never ignored. These messages should be responded to as soon as possible, within a maximum of 12 hours. Emails should be responded to within 24 hours. These delays are lenient and expected to be strictly followed. If there is a time that a team member knows that he/she will be out of service for longer than the allowable time, then they must let the team know ahead of time.

1.2.4 Dress Code

It is expected that all team members should dress accordingly for meetings and presentations. For meetings including only team members, everyone may wear whatever they feel comfortable in. For meetings with the advisor or sponsor, team members should wear semi-professional clothing. Semi-professional includes a collared shirt, such as a polo or a button-down. For presentations, team members must wear professional clothing. Professional dress includes a button-down with a tie or blazer.

1.2.5 Attendance Policy

Attendance is mandatory for formal meetings. Formal meetings include class time, as well as pre-planned meetings with at least two days' notice. There is a running attendance spreadsheet uploaded to Basecamp. Jordan will take attendance at every formal meeting, including the reason for absence.

If a team member misses more than three meetings without an adequate excuse, the team will involve Dr. McConomy.

1.2.6 Statement of Understanding

Every member of Senior Design group 521 has read and understands these codes of conduct. By signing below, all members agree to follow these codes.

Name	**Signature**	**Date**
Dylan Cedeno	Dylan Cedeno	01/12/21
Marc Griffiths	Marc Griffiths	01/12/21
Jordan Noyes	Jordan Noyes	01/12/21
Handy A Pierre	Handy A Pierre	01/12/21
Edwin Ulysse	Edwin Ulysse	01/12/21

Appendix B: Customer Background

The table below shows all of the interviews that were conducted to achieve our customer background.

Table B1: Customer Interviews

Question/Prompt	Customer Statement	Interpreted Need
Sprinters		
What aspects do you focus on most in your sprinting form?	"Takeoff and stride"	The tool aids in improving/ strengthening the user's takeoff form and stride.
Do you feel like your form and personal record are correlated?	"Somewhat. some of my best runs have been back when my form wasn't as refined as now, but vice versa is also true"	The tool provides the ability to store sprinter data related to form and recorded times.
If there was a tool that could help improve your sprinting speed would you be more concerned about your start or the overall race?	"Every runner is different because some lack explosiveness in their start and others have trouble with the rest of the race. I personally was an explosive runner; I had a lot of strength and an amazing start. But after the first 10 meters I would have a problem maintaining the same speed throughout the rest of race so for me personally I would like a tool that would help me with that" "That's a tough one. A good start can put you ahead of the pack, but it won't guarantee you a win. I think I'd still choose the start though. "	The technology can track performance at both the start time, and throughout the race to satisfy all types of runners.
Would you rather have an app where you can capture images or a wearable that is tracked through an app?	"Something I can wear would be ideal " "Well I know the belt to monitor your stride pattern exists already I think so I will	The technology could have both a wearable and an app to satisfy all different types of runners.

	say the app because track athletes watch a lot of film especially in college and we analyze frame by frame our race “	
Would you be interested in comparing your ability to professionals'?	“I already do that. Their records are what I strive for “	The tool incorporates professional sprinters and eases the effort required for sprinter comparisons.
Would you be willing to incorporate technology in your analysis of performance?	“Yes”	The product provides technology for sprinters to improve their performance
Do you think there is room for improvement in your performance? If so, where do you think you can improve most? Do you know how to improve it?	“There’s always room for improvement. I think that I need to work on my pace the most and practice is the way I am trying to improve it. “	The analysis from the product exposes users' fundamental weaknesses
Would you feel comfortable using a wearable to track your performance? What would be required of the wearable so that it does not hinder performance?	“Yea I would have no problem with it. It just needs to be lightweight and feel like I am not wearing it. “	In order to not hinder performance, the wearable is lightweight, and the user will not feel extra weight
Do you think that your form affects your running?	“Yes of course. Form is one of the most important things “	The product analysis users form to improve performance
Coaches		
What element(s) do you believe is most important for a sprinter to have good performance?	Running posture, leg action, and arm action are the most important elements for a sprinter’s performance.	The tool considers the user’s running posture, leg action, and arm action.
What are some of the aspects you notice most in a good sprinter’s form (specifically at the start of the race)?	Line of attack is most important. I look at the angle coming out of the blocks and decide whether that is the best angle for each sprinter. This angle will be different for every sprinter. I then look at the technique within that angle of acceleration. Every person has alignment issues; I try to	Make sure the technology is able to visualize the line of attack

	find the issue with every runner immediately, so that I can decide the best form for prevention of injury.	
Would you be willing to incorporate technology in your analysis of the sprinters' performance?	I would like to have a video of the runners.	The technology needs to be able to capture videos of the sprinters
Would you want to use a wearable to track sprinters' performance or would that get in the way?	I wouldn’t mind that as long as its light enough to not affect running ability. Maybe they could wear something that connects to checkpoints at every 5 meters and it can tell the velocity at each checkpoint. This can check where the runner reaches top speed and how speed can be maximized. We could decide from there if they are reaching top speed too early or too late and we can fix accordingly.	The technology will be able to measure instantaneous velocity
Who do you compare your sprinters to?	I try to find a model athlete that fits every particular person. I have a guy right now that is about 5'5 or 5'6; I cannot model him off of Bolt because he is 6'7. I try to find an athlete around the same stature and body type.	Technology needs to have data of several different athletes for comparison based on body shape/size
Do you employ a specific training about how fast they are getting out of the blocks?	Not necessarily. I want something that could measure the amount of force off the blocks. I do not get too caught up in how fast the runner gets out of the blocks, which is different than other coaches. I want to maximize the ability to accelerate as fast as possible so that the runner can reach the best end speed	Technology has to measure the force out of the blocks

Do you train all body types the same?	Nope, all different.	The technology needs to be personalized based on different athlete's bodies
How long can you allow for setup and how often would you use the product?	Fairly quick setup during or before warmup would be ideal. It will be used twice a week during pre-season and potentially five days a week during season.	The technology needs to be able to be used daily for about two hours at a time. Needs to be durable and water resistant.
General		
What is a reasonable price point for the product cost?	Well, I can give you the price of existing technology to give you an idea. The Whoop system is about $400 per user. But track teams typically buy a subscription to the technology	The technology will have varying price models for different markets. It will need to be sold for no more than $5000.
	Personally $5,000 of my own money. If its like the 1080 sprint - $20,000 because it is only made in Sweden. The 1080 offers resistance and assistance. This allows the body to adjust to a particular speed. With Covid, $5,000 sounds doable.	

Note: Since contact was not made with any coaches yet, these customer needs are subject to change. Once more interviews are carried out with coaches and sprinters, more needs will be developed.

Appendix C: Functional Decomposition

The figure and chart below show the elements that were gathered for our functional decomposition.

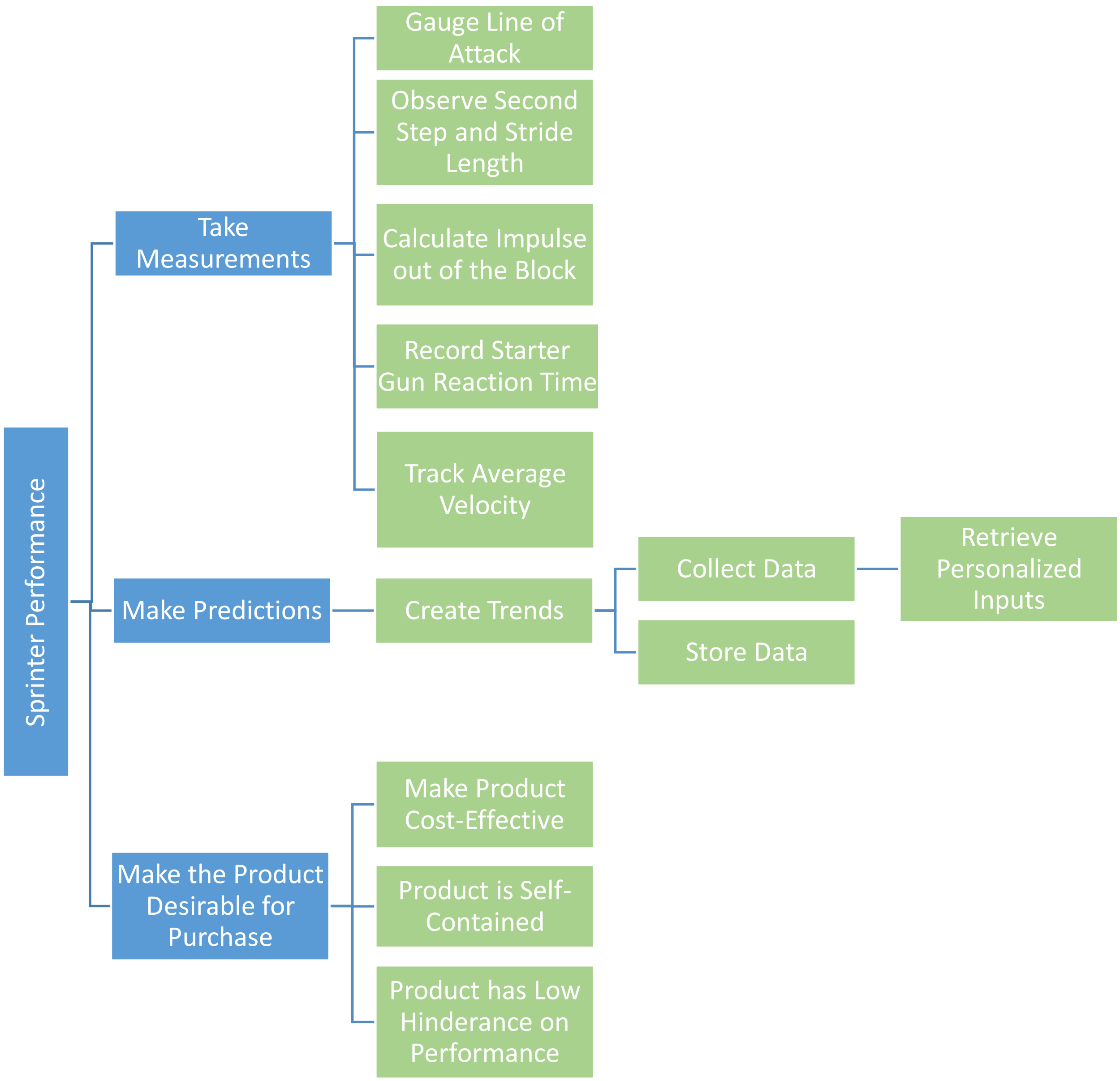


Figure C1: Hierarchy Flow Chart

Table C1: Cross Reference Table

	Take Measurements	**Make Predictions**	**Make the Product Desirable for Purchase**
Gauge Line of Attack	X		
Observe Second Step and Stride Length	X		
Calculate Impulse out of the Block	X		
Record Starter Gun Reaction Time	X		
Track Average Velocity	X	X	X
Create Trends		X	X
Collect Data	X	X	X
Store Data		X	X
Retrieve Personalized Inputs		X	X
Make Product Cost Effective			X
Product is Self-Contained			X
Have Low Hinderance on Performance			X

Appendix D: Target Catalog

Below, shows the target catalog for each of our targets and metrics. An asterisk signifies a critical target.

Table D1: Target Catalog

Function/Need	Metric	Target
*Gauge Line of Attack	Accuracy of measuring the angle at the ankle, knee, hip, shoulder	Accurate within 2%
*Observe Second Step	Accuracy of measuring the height off the ground from the blocks	Accurate within 2%
*Measure Stride Length	Accuracy of measuring the length from the second step to the third step	Accurate within 2%
*Calculate Impulse from the Block	Accuracy of calculating the force off the block, with respect to time	Accurate within 2%
*Record Starter Gun Reaction Time	Accuracy of recording the time from the starter gun sound to impulse rise	Accurate within 2%
*Track Instantaneous Velocity	Accuracy of tracking the velocity at every 5 meters	Accurate within 2%
Create Trends	Time it takes to output relationships between measurements	Within 15 seconds of request time
Store Data	Compression and frame rate of videos recorded	720 pixels at 60 frames per second
	Amount of storage taken by data collected	Maximum of 10 megabytes per trial
Retrieve Personalized Inputs	Time it takes to store the inputs of the athlete being measured, given by the athlete	Inputs stored in under 5 seconds
Make Product Cost Effective	Desired cost to keep the purchase price under	Keep purchase price under $15,000
Product Is Self-Contained	Additional purchase necessary outside of product	$0.00 spent outside of product purchase
*Product has Low Hinderance on Performance	If a wearable is used, the weight it must stay under	Wearable must weigh less than 1 kilogram (~2 pounds)

The tool incorporates professional sprinters and eases the effort required for sprinter comparisons	Number of professional athletes the technology needs to store statistics for	At least 5 different professionals
The analysis from the product exposes users' fundamental weaknesses	Percent difference between measurements of the user and the compared professional that is pointed out as a potential weakness	A measurement greater than 5% difference from professional is a potential weakness
*The technology needs to be able to be used daily for about two hours at a time	The battery life needed for the technology to hold between charges	A battery life of at least 3 hours

Note: An asterisk next to a function/need implies a critical target/metric

Appendix E: 100 Concepts

The list below shows all 100 concepts that were generated during our concept generation phase.

General Ideas Throughout Design Process:

1. A "reinvented" ankle weight. focuses on the take-off from the blocks. Attaches to the ankle and the base of the foot. Essentially an elastic band that "makes" the user use muscles to walk (ie ankle weights). When they take it off, they will be able to shoot out of the blocks even faster.

2. A break-away training block that has either a parachute or elastic cables that have magnets that breakaway when enough force is applied. After repetition, the runner will feel "free" when the mechanism is detached.

3. Wearables – could be too heavy; expensive

4. Augmented reality goggles – ghost best race

5. Rower machine for assistance/resistance

6. Have the ideal line of attack be shown with the individual's line of attack.

7. Better 1080 Sprint

Biomimicry:

8. Using an unmanned vehicle to move at the sprinter's velocity using a tracking software to move at the athlete's speed, simulating a predatory flying creature hunting.

9. Using a parachute that could open at variable percentages causing the amount of drag to be varied, similar to a flying squirrel using its skin to glad at variable rates.

10. Using an unmanned vehicle on the track to move at the sprinter's velocity using a tracking software to move at the athlete's speed, simulating a carnivore tracking its prey.

11. Development a device that could attach to a sprinter's body and shoe to measure the velocity second step and force off the blocks.

12. Technology which facilitates a training experience, fancy tread mill.

13. Using video of a sprinter to measure their performance.

14. Using the aglet as a tracking device to measure the sprinter's performance.

15. Using a small fan to generate a signal to track the instantaneous velocity and cools the sprinter.

16. Motors and encoders attached to the sprinter.

17. Nanofiber material with embedded sensors.

18. Utilize skills from the fastest animals to help sprinters improve their skills; I.e. do not run at full capacity until necessary (big race)

i. https://academic.oup.com/icb/article/55/6/1125/2363919

19. Utilize animal speed prediction to help predict human speed

i. https://www.smithsonianmag.com/smart-news/formula-explains-why-mid-sized-animals-are-fastest-180964090/

20. Observe the form of cheetahs and incorporate this into the technology

21. Observe the form of ostriches and incorporate this into the technology

22. Observe the form of handicap dogs and incorporate this into the technology

Crap Shoot:

23. Scout using video to track performance of sprinters from the start of the race to analyze later – creation of a video recording device

24. Fan desiring videos of sprinters performance

25. Track athletes' performance by using video, sensors, and a stopwatch to gather data

26. Incorporate a wearable, as well as a software to measure an athlete's speed

27. Aid coaches in observing runners' performance off the blocks by creating an application

28. Improve the experience for fans and supporters of athletes by making an application that compares sprinters to each other and to professionals

29. Improve training for athletes by incorporating advanced technology

30. Aid the scouting process by creating a portable tracking device to observe potential athletes

31. Create a technology that allows collegiate athletes to virtually compete against professionals

32. By placing sensors on starting blocks, the track, and in a wearable on the athlete, we can accurately measure several aspects of the runner's performance

33. Aid athletes by incorporating tracking technology into their uniform that will collect and store data from every part of the race.

34. Using a wristband as a tracker to record the athlete's performance.

35. Using a drone with tracking and recording capabilities to capture and analyze the athlete across the entire race.

36. Having an R/C car drive parallel to the runner in order to track their instantaneous velocity

37. Using a spring attached to the sprinters shoe that snaps off when a inputted velocity is reached

38. Using a robotic bunny (like dog races) to encourage the user to run faster

39. Using a google glasses type goggles to have the runner run against times of inputted professionals

40. Using special technology integrated shoes that will track the second step and stride length

41. Using a morph suit to track every aspect of the runners form during the race

42. Have bands that offer resistance for coaches to hold while athlete runs. Track force using an impulse sensor. Output data to phone.

43. Smart timer. Have it start and stop once athlete begins/ends race. Have time data export to smart phone. Sensors at end of track to monitor exact finish line cross, Timing starts with audio of starting pistol.

44. Ankle weights that time the runners. Can load different weights.

45. Smart blocks that read the impulse force and starting data of the runner.

46. Launch monitor that only tracks the start of the race while recording high speed video. Records video and force off blocks. Exports video to smart phone.

47. Sensors for instant velocity down the track. Exports graphical data of speed at different points during the run.

48. Smart mat that athletes run on. Can track individual steps and force of each step. Custom length can be 10m to track the start or 100m to track whole race. May link multiple mats together.

49. Elastic smart strap that allows faster runner to pull slower runner. Reads in different measurements to interpret the force difference between the two athletes.

50. App that allows coaches and runners to track their data compared to themselves or other sprinters. Can only input times, basically a social media with a sprinting focus. Can only be entered by confirmed coaches.

Morphological Chart:

51. Using a string attached to a motor and encoder, as well as sensors on the blocks, to track the velocity at the start and throughout the race.

52. Attach a tension cord to the sprinter to provide assistance and resistance in order to aid in training

53. By utilizing a video to measure a sprinter's form at the start, as well as a tension cord and encoder to measure instantaneous velocity, this will collect all measurements in a self-contained product. The tension cord will be weightless, not hindering performance unless desired. Personalized inputs will be measured at the start of the training session for later comparison. To create trends, these measurements will be stored using a server and trends will be created using line graphs. The product price will be comparable to other markets and lay away will be offered.

54. By using a tension cord attached to a motor and encoder, a user interface will be created specifically for each user to track and analyze their performance. This profile will be personalized for each user, and their performance product will be compared to other athletes, collegiate and professional.

55. Using pre-existing iPhone and apple watch applications to help track performance, dots to track start form, and a tension cord and motor to track instantaneous velocity. This will be a full wearable to accurately track measurements, basically a suit. This suit will need to be adjustable according to the size/shape of the runner. Personalized inputs will be inputted to the technology and a suit can be rented for training.

56. By using a spring under the blocks that retains compression in order to track the start impulse, as well as a chord to measure instantaneous velocity, and photos to gauge the line of attack, we can gather appropriate measurements. We can then use personalized inputs to compare these measurements to professional runners, in order to create trends and predict potential weaknesses. All of these aspects would be incorporated into a single application

57. Make a technology that is as user based as possible. The technology will utilize a video to measure track form and a chord/motor system to measure instantaneous velocity. The user will input their own input measurements and the statistics of the professional they want to compare themselves to. This will all be incorporated into a user-friendly application for analysis of performance and trends.

58. By utilizing a video to measure a sprinter's form at the start, as well as a tension cord and encoder to measure instantaneous velocity, this will collect all measurements in a self-contained

product. The tension cord will be weightless, not hindering performance unless desired. Personalized inputs will be inputted by the user at the start of the training session for later comparison. To create trends, these measurements will be stored using a spreadsheet and trends will be created using error bars. The product price will be comparable to other markets and rentals will be available.

59. A subscription process for an application that can collect start measurements of an athlete to compare to professional runners in order to create trends and predict their performance.

60. By using a radar gun to track the user's instantaneous velocity, as well as having a laser sensor on the user's foot, this will ensure that the product is lightweight.

61. Having the sprinter run next to a ruler, as well as using a radar gun to track their instantaneous velocity, and having the data stored in a compressed folder will create a use friendly interface.

62. Having dots on the sprinter to gauge the line of attack can also be used to pick up on the runner's instantaneous velocity using a laser gun.

63. Having a line on the sprinter as a reference of a correct line of attack is a cheaper part that can be used to ensure that the product is cost efficient.

64. By using cheaper parts and comparing the pricing to the markets, recording the audio of the starter gun to record starter gun reaction time, placing a force sensor on the block to calculate kickoff force from the block, measuring the users body characteristics to use as personalized inputs, and embedding the technology into the uniform to ensure that it has low hinderance on performance.

65. Having the ability to use default applications will reduce cost as well as further ensure that the product is self-contained,

66. Using a high speed camera to determine when the starter gun is fired and when the user reacts to it, having the sprinter wear a tape measure on their foot to observe the second step, and placing all data into a compressed folder.

67. Record a video to gauge the line of attack, as well as use a radar gun to track velocity, and write the information down to store the data.

68. Incorporating a scale under blocks to calculate kickoff force, using a timer to record starter gun reaction, as well as researching sprinters to collect data

69. Having a laser sensor on the sprinter's foot to observe the second step, use a spring that would retain compression from force to calculate the kickoff force from the block, use a radar gun to track instantaneous velocity, measure the runner to retrieve personalized inputs, and implement a lay-away option to make the product cost efficient.

70. Using a laser sensor on the sprinter to track the instantaneous velocity and to observe the second step, Having dots on the sprinter as a reference to gauge the line of attack, Placing a force sensor on the block to calculate the impulse from the block, using a timed starter gun and a video to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data, using a server to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

71. Using a laser sensor on the sprinter to track the instantaneous velocity and to observe the second step, Having dots on the sprinter as a reference to gauge the line of attack, Incorporating a scale under blocks to calculate the impulse from the block, using a timed starter gun and a video to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data, using a server to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

72. Using a laser sensor on the sprinter to track the instantaneous velocity and to observe the second step, Having dots on the sprinter as a reference to gauge the line of attack, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data, using a server to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

73. Using a laser sensor on the sprinter to track the instantaneous velocity and to observe the second step, Having dots on the sprinter as a reference to gauge the line of attack, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, using a server to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

74. Using a laser sensor on the sprinter to track the instantaneous velocity, Having dots on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, using a server to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

75. Using a laser sensor on the sprinter to track the instantaneous velocity, Having dots on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Incorporating a scale under blocks to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, using a server to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

76. Using a laser sensor on the sprinter to track the instantaneous velocity, Having dots on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, using a server to store the data, having our visuals make comparisons to other athletes to create trends, having a subscription option to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

77. Using a laser sensor on the sprinter to track the instantaneous velocity, Having dots on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, Placing information into a compressed folder to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts and a subscription option to make the product more cost effective, coming with all parts included to make a product which is Self-Contained,

and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

78. Using a laser sensor on the sprinter to track the instantaneous velocity, Having a line on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, Placing information into a compressed folder to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts and a subscription option to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

79. Using a laser sensor on the sprinter to track the instantaneous velocity, Having dots on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, Placing information into a compressed folder to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts and a renting option to make the product more cost effective, coming with all parts included and being within one app/ software to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

80. Using a laser sensor on the sprinter to track the instantaneous velocity, Having a line on the sprinter as a reference to gauge the line of attack and to observe the second step through video, Placing a force sensor on the block to calculate the impulse from the block, Using a sensor to assess the starting of the gun with respect to the impulse to determine the starter gun reaction time, creation of a user interface to retrieve personalized inputs, researching sprinter's record to collect data in addition to accepting users inputs for sprinters they have details on, Placing information into sever to store the data, having our visuals make comparisons to other athletes to create trends, using cheaper parts and a subscription option to make the product more cost effective, coming with all parts included to make a product which is Self-Contained, and if there are wearables, they will be lightweight to ensure that the product has low hinderance on performance.

81. Using a video to measure a user line of attack and form this data will be inputted into the users' personal file.

82. Using a video once the user confirms their recording the tool will store their data into a compressed folder

83. Using a video, the data will be compiled into a pivot table to create visualizations for the user

84. Having the ability to use video from a cellular device will allow the company to have less parts and to make our product cost effective

85. The use of the videos will be imbedded into the software like snapchat a user will be able to record anytime they want, and it will automatically save this will allow the product to be self-contained

86. The user will have a sensor on their foot that will be Bluetooth compatible this sensor will connect with the software to time when the user takes off and to also be able to see how the user takes off.

87. The user will have access to data from a multitude of professional runners and they will be able to use their life video with augmented reality to compare side by side performance.

88. A video recording will take place at the starter guns deployment. This video will be compared to professional sprinters at the start of their race to ensure that the user is implementing the best practices.

89. A video will be recorded on the sprinter and with the use of image recognition a line will be placed on the sprinter throughout the whole race as an interface. This line will also be available in the playback.

90. A high-speed camera will be used to determine exactly when the gun is fired.

91. Using infrared sensors on the track, instantaneous velocity is measured at 10m intervals. Dots are placed on the sprinter so that the starting measurements can be gauged while a video is recoded from a base station. Uses impulse sensors on the blocks, and marker (possibly measuring tape) for accurate measurement laid out at the beginning of the track. User inputs through a user interface in application available on phone or computer. Creates data using line graph. Complete purchase model. No wearable other than dots. Records audio of starting gun. Outputs everything to app, can create trends from stored data. Data is stored on user’s device. Processing from user’s device. Machine learning necessary to interpret line of attack and measurements for output to device. Base station has high speed camera, so data is consistent.

92. Using an infrared sensor on the track, instantaneous velocity is measured at 10m intervals. Dots are placed on the sprinter so that the starting measurements can be gauged while a video is recoded from a base station. Uses a spring on the blocks, and marker for measurement laid out at the beginning of the track. User inputs through a user interface in application available

on phone or computer. Creates data using line graph. Subscription model. Runners wear pennies to make sensors track more reliably. Records audio of starting gun.

93. Using an infrared sensor on the track, instantaneous velocity is measured at 10m intervals. Camera checks when gun is fired are placed on the sprinter so that the starting measurements can be gauged while a video is recoded from a base station. Uses impulse sensors on the blocks, and marker for measurement laid out at the beginning of the track. User inputs through a user interface in application available on phone or computer. Creates data using bar graph. Subscription model. No wearable other than dots. Records audio of starting gun. \

94. Using an infrared sensor on the track, instantaneous velocity is measured at 10m intervals. Camera checks when gun is fired are placed on the sprinter so that the starting measurements can be gauged while a video is recoded from a base station. Uses impulse sensors on the blocks, and marker for measurement laid out at the beginning of the track. User inputs through a user interface in application available on phone or computer. Creates data using bar graph. Subscription model. No wearable other than dots. Records audio of starting gun.

95. Using a camera deep learning algorithm will help compare the stride lengths of runners throughout the race ensuring that the runners.

Random:

96. IOT will be used with chips on the users' shoe or clothing to quickly retrieve data while the user is sprinting.

97. The use machine learning will be implemented to predict sprinters performance compared to the data that is collected from professional sprinters. Using professional sprinters data, the machine learning model will get stronger and stronger

98. A user interface will be created to allow users you easily navigate through the screen. This will be done either with AWS or react native

99. Augmented reality will be used to have side by side comparisons of user's old performance VS. new performance

100. Light wearable technology will be in users' shoes to track the amount of force that is exerted

101. Arm sleeve or leg sleeve will have a wearable that tracks bending and extensions for the users form

102. IOT will be used to connect the user's wearable and an electric starting block to measure the force that the user is utilizing

103. Coaches will be able to have live data while the user is sprinting because the wearable will be connected to the software and the user interface.

Appendix F: Work Breakdown Structure

Below outlines our complete Work Breakdown Structure for the two semesters.

Task	**Assigned to:**
1. Project Scope	
1.1 Project Description	Handy
1.2 Key Goals	Dylan
1.3 Market	Edwin
1.4 Assumptions	Marc
1.5 Stakeholders	Jordan
1.6 Integrate Voices	Jordan
1.7 Submit Assignment	Jordan
2. Customer Needs	
2.1 Customer Statements	Edwin
2.2 Interpreted Needs	Dylan
2.3 Integrate Voices	Jordan
2.4 Submit Assignments	Jordan
3. Functional Decomposition	
3.1 Cross-Reference Table	Dylan
3.2 Hierarchy Chart	Marc
3.3 Task Analysis	Edwin
3.4 Integrate Voices	Jordan
3.5 Submit Assignment	Jordan
4. Target Metrics	
4.1 Every Function Gets Target	Edwin
4.2 Method of Validation	Handy

4.3 Tools Needed to Validate	Handy
4.4 Integrate Voices	Jordan
4.5 Submit Assignment	Jordan

5. Concept Generation

5.1 Create 100 Concepts	Edwin
5.2 Medium Fidelity Concepts	Handy
5.3 High Fidelity Concepts	Handy
5.4 Methodical Tools	Dylan
5.5 Integrate Voices	Jordan
5.6 Submit Assignment	Jordan

6. Concept Selection

6.1 House of Quality	Edwin
6.2 Pugh Chart	Dylan
6.3 AHP	Handy
6.4 Integrate Voices	Jordan
6.5 Submit Assignment	Jordan

7. Virtual Prototype

7.1 CAD	Marc
7.2 Power BI	Edwin

8. Physical Prototype

8.1 Fabrication	Dylan
8.2 Testing	Jordan

9. InNOLEvation

9.1 Workshops	Edwin

9.2 Application Deadline: Nov 6	Dylan
9.3 Submission Deadline (Business Model Canvas): Jan 11	Edwin
9.4 Submission Deadline (Complete & Final BMC): Feb 2	Edwin
9.5 Submission Deadline (Executive Summary): Mar 1	Marc
9.6 Final Judging & Awards Ceremony: Mar 5	Dylan

10. Virtual Design Review 1

10.1 Project Brief	Dylan
10.2 Project Scope	Dylan
10.3 Customer Background	Edwin
10.4 Customer Needs	Edwin
10.5 Future Work	Handy
10.6 Make PowerPoint Professional	Marc
10.7 Submit Assignment	Jordan

11. Virtual Design Review 2

11.1 Summarize VDR1	Edwin
11.2 Functional Decomposition	Marc
11.3 Targets and Metrics	Handy
11.4 Concept Generation	Jordan
11.5 Concept Selection	Dylan
11.6 Future Work	Edwin
11.7 Make PowerPoint Professional	Marc
11.8 Submit Assignment	Jordan

12. Virtual Design Review 3

12.1 Summarize VDR2	Handy
12.2 Discuss Progress Since	Marc
12.3 Future Work	Dylan

12.4 Make PowerPoint Professional	Marc
12.5 Submit Assignment	Jordan

13. Virtual Design Review 4

13.1 Summarize VDR3	Edwin
13.2 Discuss Progress Since	Jordan
13.3 Future Work	Dylan
13.4 Make PowerPoint Professional	Marc
13.5 Submit Assignment	Jordan

14. Virtual Design Review 5

14.1 Summarize VDR4	Dylan
14.2 Discuss Progress Since	Handy
14.3 Future Work	Edwin
14.4 Make PowerPoint Professional	Marc
14.5 Submit Assignment	Jordan

15. Completion

15.1 This Project Has Been Completed	Dylan

Appendix G: Operations Manual

Given the limited time and resources available, The Sprinter Data project can be considered a success. Unfortunately, due to limited knowledge about electrical and computer engineering, some aspects of the design were not able to be validated fully. On the other hand, our mechanical and industrial engineering knowledge allowed us to get as far as we did. We do believe that the project can be finished in its entirety with more time and expertise.

For future work, the project could be more successful with an electrical engineer and a computer engineer on the team. Future work would include more in-depth validation of measurements, analysis of average velocity, polishing of the user interface, incorporation of professionals, and integration of machine learning.

Detailed Concept

The final concept selected consists of a base station housing with a camera and on board processor, infrared (IR) sensors located along the track, force sensors on the starting blocks, and measuring tape along the start of the track. This setup allows for the most accurate measurements to be taken.

Base Station

The base station is a 6” x 6” x 12” enclosure that houses a high-speed camera, Raspberry Pi 4b, and power supply. The camera allows for the user to capture the starting form of a sprinter in slow motion, allowing for visualization of line of attack, and the measuring of stride length and second step. The raspberry pi is there to process data from the camera and the external sensors. The power supply is used to prevent power drain when a user’s laptop is connected.

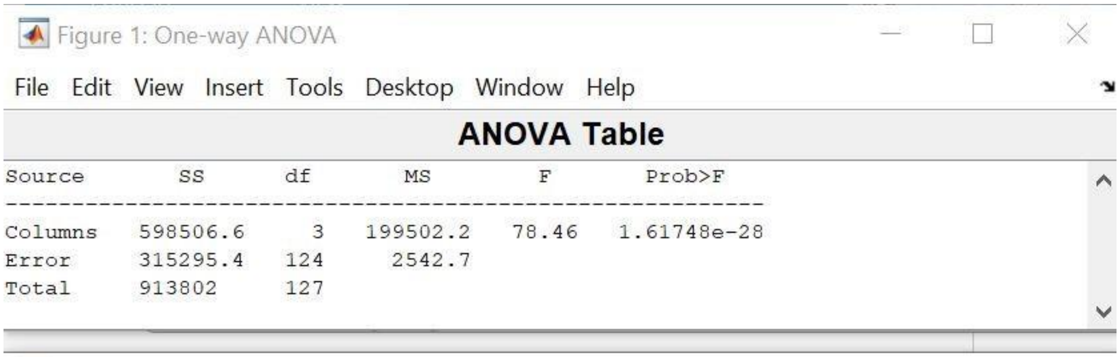
Track Overview

Infrared sensors are placed along the track in 10-meter intervals, allowing for the average velocity of the sprinter to be taken throughout ten different intervals. Force sensors are placed on the starting blocks to measure impulse out of the blocks, as well as the starter gun reaction time. All the sensors are connected to the raspberry pi located within the base station. The base station itself sits on the starting line to capture the starting form as previously stated.

Prediction Model

In order to predict sprinters' performance, we used ANOVA to recognize which measurements had the most significance depending on the sprinter. ANOVA, or Analysis of Variance, is an analysis tool used in statistics that splits an observed aggregate variability found inside a data set into two parts: systematic factors and random factors. The systematic factors in our project have a statistical influence on our given data set. The random factors do not have an influence on our given data set.

For this project, ANOVA is utilized to determine the influence that the independent variables have on the dependent variable. In our case, the independent variables are our starting measurements: line of attack, second step, stride length, force from the block, and starter gun reaction time; and our dependent variable is race time. Below shows a sample of the data that is outputted in an ANOVA test.



Source	SS	df	MS	F	Prob>F
Columns	598506.6	3	199502.2	78.46	1.61748e-28
Error	315295.4	124	2542.7		
Total	913802	127			

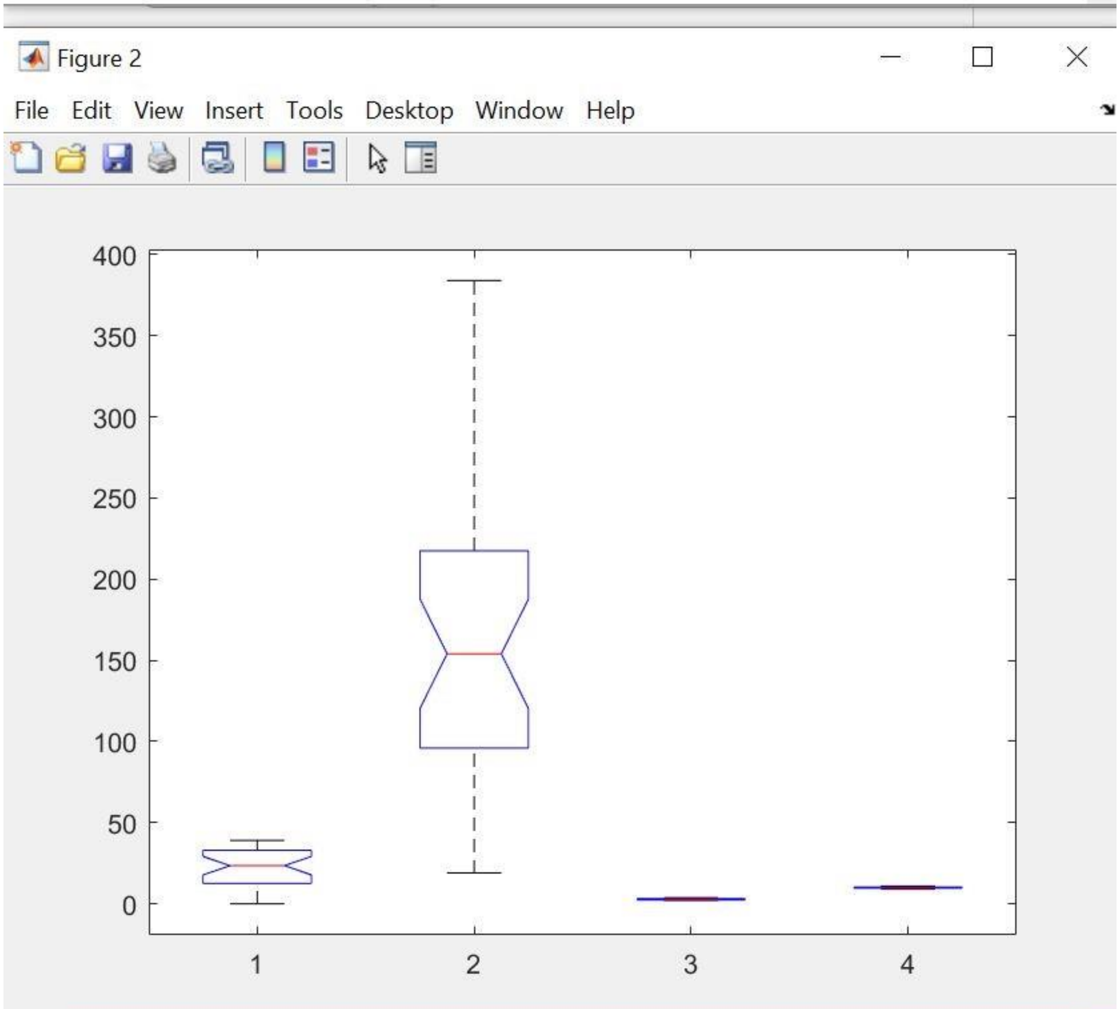


Figure G1: One-Way ANOVA Test

Figure G1 shows an ANOVA test run that was created. It displays the ANOVA table, as well as the plot. The variables are defined as follows:

SS: Sum of squares due to each source. ANOVA partitions the total sum of squares (SST) into sum of squares due to between-groups effect (SSR) and sum of squared errors (SSE). We obtained our SS with the equation below in MATLAB R2020b:

$$\underbrace{\sum_i \sum_j (y_{ij} - \bar{y}_{..})^2}_{SST} = \underbrace{\sum_j n_j (\bar{y}_{.j} - \bar{y}_{..})^2}_{SSR} + \underbrace{\sum_i \sum_j (y_{ij} - \bar{y}_{.j})^2}_{SSE},$$

df: Degrees of freedom associated with each source. Suppose N is the total number of observations and k is the number of groups. Degrees of freedom was calculated with the equation:

DF (Factor) = k– 1

MS: Mean squares for each source, which is the ratio:

SS/df.

F: F-statistic, which is the ratio of the mean squares.

Prob>F: p-value, which is the probability that the F-statistic can take a value larger than the computed test statistic.

ANOVA testing is relevant to our project because it allows us to know which independent variables are mostly related to the race time for each sprinter. The test will provide three essential values to determine the correlation of the line of attack, starter gun reaction time, stride length, and impulse from the race's starting block. We will run an ANOVA test on each measurement with respect to time for 32 trials, for best accuracy. If the p-value (Prob>F) is less than 0.05, the measurement's correlation to time has significance and should be taken into effect for the linear regression model to formulate the predictions with an output of time. Taking into consideration the Prob>F value being greater than 0.05 but has a very large F value, stating high relation to the time, the use of the Cohen's value, d, would aid in determining the individual measurements' overall effect to the output, sprinter speed/time.

Module Description

To successfully create our Launch Monitor Pro prototype, we utilized several different modules. The first module was the CAD software of Creo Parametric 6.0 to create parts and drawings for the base station. The next module was the hardware, which we used a Raspberry Pi 4B for our on-board processor. Finally, we used the ANOVA function in MATLAB R2020b to create our prediction model. These models will be further explained in the following subsections.

Base Station CAD Model

To create the prototype base station, Creo was used to model each side, top, and base with the proper dimensions and necessary holes. The sides were created individually to snap together like puzzle pieces once fabricated, so that a laser cutter could be utilized. Below is a fully assembled and labeled model of all Creo parts.

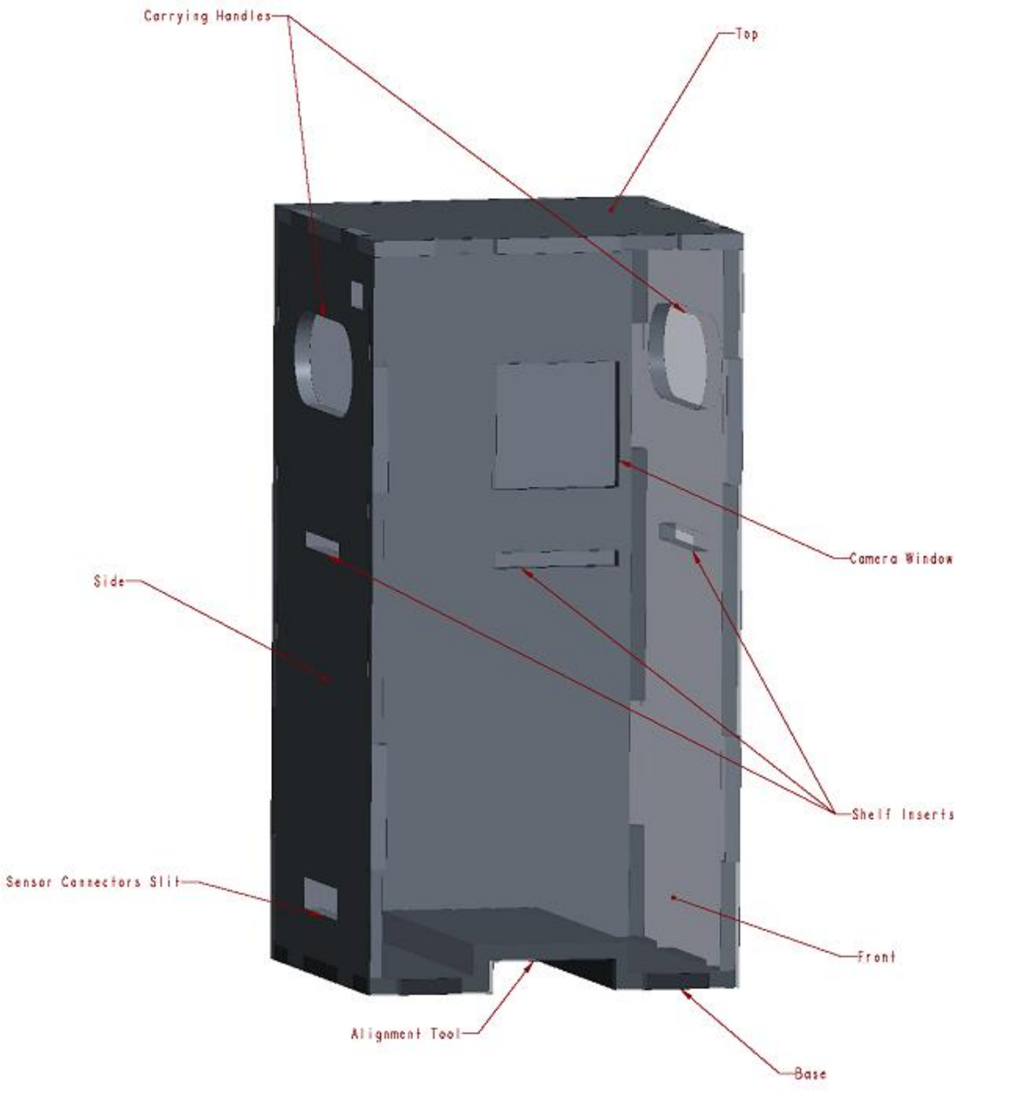


Figure G3: Labeled Base Station Assembly

In the Figure G3, above, the base station assembly can be analyzed with the labeled parts and holes. More detailed drawings for each individual part can be found in Appendix H.

Raspberry Pi 4B Implementation

Implementation of the sensors to the breadboard and Raspberry Pi 4b processor required an unacquainted skill that our team did not have. Integration of the sensors would be simpler, yet still somewhat strange for the team. The process requires a datasheet of the components being used and some soldering of the components and wires used. Difficulty was faced in creation of the pseudo-program using the Raspberry Pi processor, all that is required is to get the ports to output data to the serial screen, but this proved far more difficult than was originally anticipated. Upon connecting the sensors and resistors, if needed, Team 521 planned to calibrate the components, retrieve the measurement readings during testing, and analyze the general data through the ANOVA process.

ANOVA Software

Using MATLAB R2020b, one-way ANOVA tests were run for each measurement with respect to time. These tests were used to identify correlation between measurements and race times for each individual sprinter. These correlations would lead to a prediction model that the coaches and sprinters could analyze and utilize according to their desires.

Integration

After finalizing the CAD model of the base station, we were able to assemble the physical prototype. Using a resin base adhesive, we adhered and assembled the housing of the base station, which was composed of laser cut sections of acrylic and a 3D printed base. The shelf was placed on two adhered sets ~2-3mm in extruded distance from the adhered acrylic. After the housing of the base station was assembled, we were ready to assembly the rest of our parts.

Unfortunately, much of our parts have not been delivered yet, but when they do, they will be placed thoughtfully in the base station housing. A pane will be placed to protect the internal components from environmental interaction. After the pane is placed, the camera will be placed onto the shelf and adhered using Velcro or any reasonable adhesive. After the camera is fully adhered, the breadboard (40-60 terminals) will be placed into the housing to have the sensors connected to it. The power source will be placed in to provide a source connection through the power switch and breadboard. The switch/button will be adhered to the opening on the top area of the side of the base station housing. A series of wires from the external infrared sensors (with their respective resistors) will be inserted to the board and Raspberry Pi 4B processor. The same will be done to connect the impulse sensors and camera (have a good means of knowing which ports the sensors and camera are connected to, writing them down will suffice) – as the camera would mostly be connected to the processor and battery through two holes in the shelving it is placed on. This will be an opening formed by the shelving and the closing section of the acrylic housing. The audio sensor will be connected directly to the breadboard to be operated through wires connecting to the processor as well, similar to the infrared sensor connections. The male to female USB port will be connected from the Raspberry Pi 4B processor to an opening at another top side section of the base-station. Upon complete connection of all electrical components, the back of the base-station can be properly adhered.

The completed base station will be placed coincident to the starting line on the track after placing the infrared sensors across the track at ten-meter intervals, impulse sensors on the starting block, and setting the tape measure next to the sprinter. Using a USB 2.0 connection, the user will be able to directly collect data during operation of the device. Videos and starting sound will be provided by initiation of the independent measurements.

Operation

Upon opening the box to our Launch Monitor Pro, the user will find the base station with a charging cable and USB connector sticking out, two impulse sensors, and one-hundred meters of wire with infrared sensors at each ten-meter mark. Once at the track, the user will set the base station approximately two lanes from where they want the sprinter to run. Using the alignment tool at the bottom of the base station, they will position it in such a way that will guarantee the same reference angle in each trial. They will then roll out the cable with the IR sensors attached.

The final steps in the setup will be to have the runner place the dots on their body, and to place the impulse sensors on the starting blocks. Once this is complete, the base station is ready to be powered on. The user will press the power switch and then connect their laptop using the USB connecter. When the program is loaded on the laptop and the runner is ready, the user will click start on the laptop. This will send a signal to the Launch Monitor Pro to start the three-pitch starting sequence. At the third pitch, the runner will know to start the race. The high-speed camera will capture the line of attack, as well as the second step and associated stride length. The force sensor will measure the impulse of the runner's strongest foot, and the IR sensors will record the average velocity as the runner travels down the track. Upon completion of the race, the Launch Monitor Pro will calculate all of the measurements and display it on the user's laptop.

If the user simply wants the Launch Monitor Pro to retrieve the measurements of the sprinter for one race, then the training process is complete. Otherwise, if the user would like to use the prediction model of the device, then the process must be repeated 32 times to get an accurate ANOVA prediction. The ANOVA prediction will give the user the correlations between each measurement and time, letting them know which measurement is significant for each runner. The coach and sprinter can decide how to use this information from there, depending on their desires for the individual training session.

Troubleshooting

There were several issues encountered during this project. One of the biggest issues we faced was our lack of knowledge about raspberry pi's and the Python language. Another huge issue was the delay in our parts getting delivered. Since we had minimal knowledge about 3D printing and laser cutting, this created some difficulties as well. Our final issue was deciding which statistical analysis software to use, then how to implement it in our project specifically.

In regard to our lack of knowledge about raspberry pi's and the python language, it would have been very beneficial if we were able to meet with our advisor and other professors sooner for help. Thankfully, Dr. Hooker provided very much help with understanding which parts to order and how to implement them. But, unfortunately we reached out to him much later than we should have and had little help from previously involved professors/advisors. To avoid this issue in the future, it would be very beneficial to have a computer and/or electrical engineer on the team. If this is not possible, then at the very least, the team should allow for optimal time to learn the software and hardware to run the program and retrieve the measurements.

The issue with the delay in our parts being delivered created a lot of limitations for us. Since we did not have our raspberry pi and sensors, we could not start learning how to use the pi and implementing the sensors. Luckily, we found old raspberry pi's in the Senior Design Lab, but they were different versions and different compatibility. Since we did not have our camera and other base station parts, we had to hold off on the final design and measurements of our base station housing. Although we did not wait very long to order our parts, in the future it would be beneficial to know to order parts immediately after the purchasing module opens.

The Innovation Hub was a huge help in 3D printing and laser cutting our base station. Since we had little knowledge about this process, it took much longer than needed to finalize the measurements and cuts. We initially planned to 3D print the whole housing; but after speaking with the Innovation Hub and researching different options, it was decided that laser cutting acrylic would be the better option. We recommend to future teams to really utilize the help of the Innovation Hub in choosing the right material and method.

Finally, we wish we would have planned a simpler method of prediction model from the beginning. Throughout the whole project, we planned to use machine learning for our prediction model. When it came time for implementation, we decided that ANOVA would be the better and simpler method for us. For future teams, it would be beneficial to really plan what needs to come of the prediction model and research all valuable options before deciding. This delayed decision created a rush in our prediction model that could have been avoiding.

Conclusion

All in all, our project was a huge success given our limited time and expertise. We look forward to seeing what can come of future projects with all the knowledge we have learned and advice we have provided.

Appendix H: Engineering Drawings

Below are the CAD drawings for each of the parts in the base station. These final dimensions can be used to recreate/modify/print future prototypes.

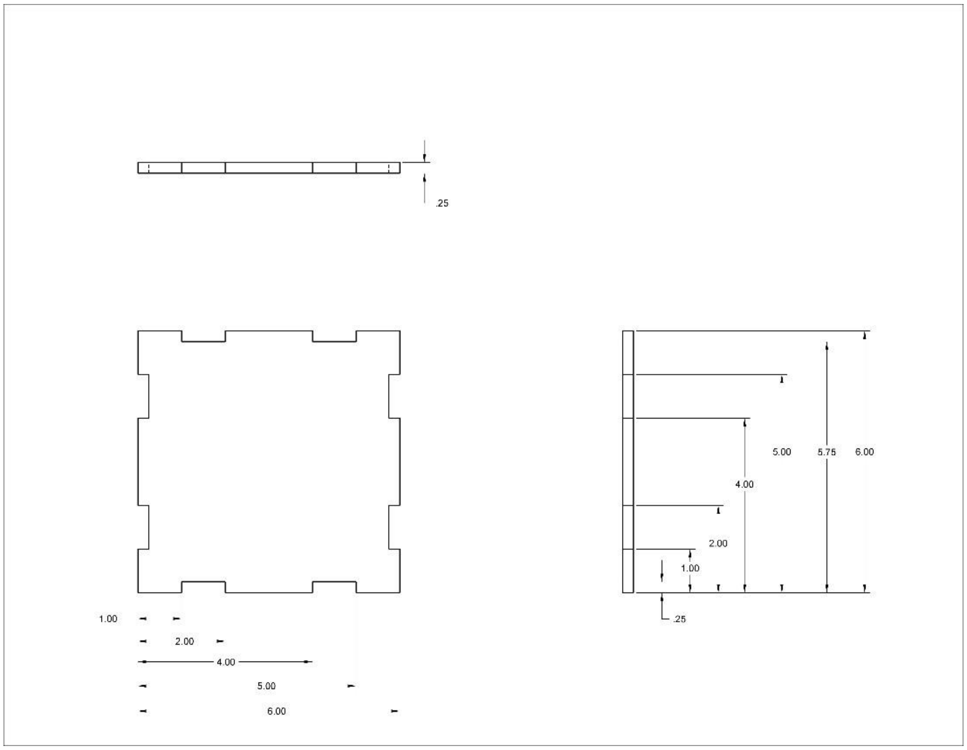


Figure H1: Top

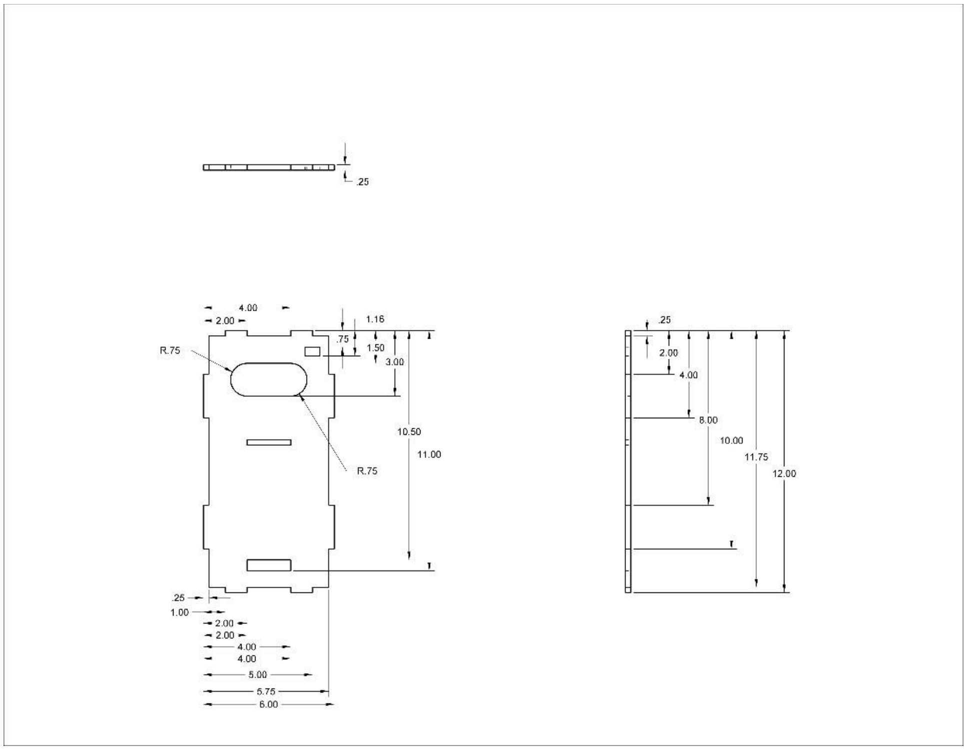


Figure H2: Side 1

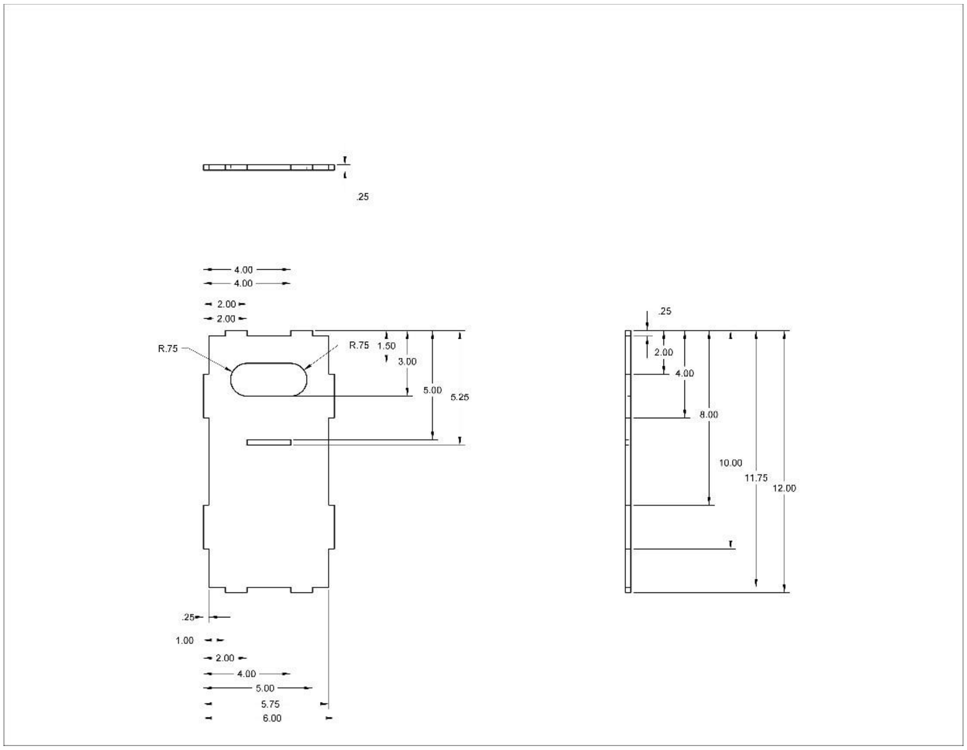


Figure H3: Side 2

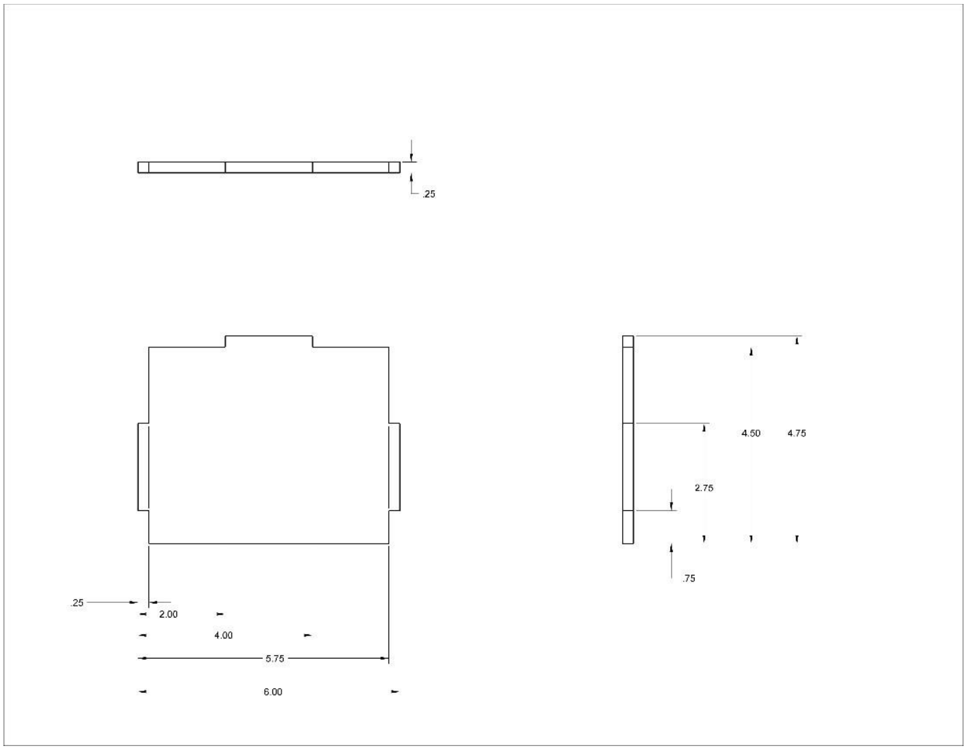


Figure H4: Shelf

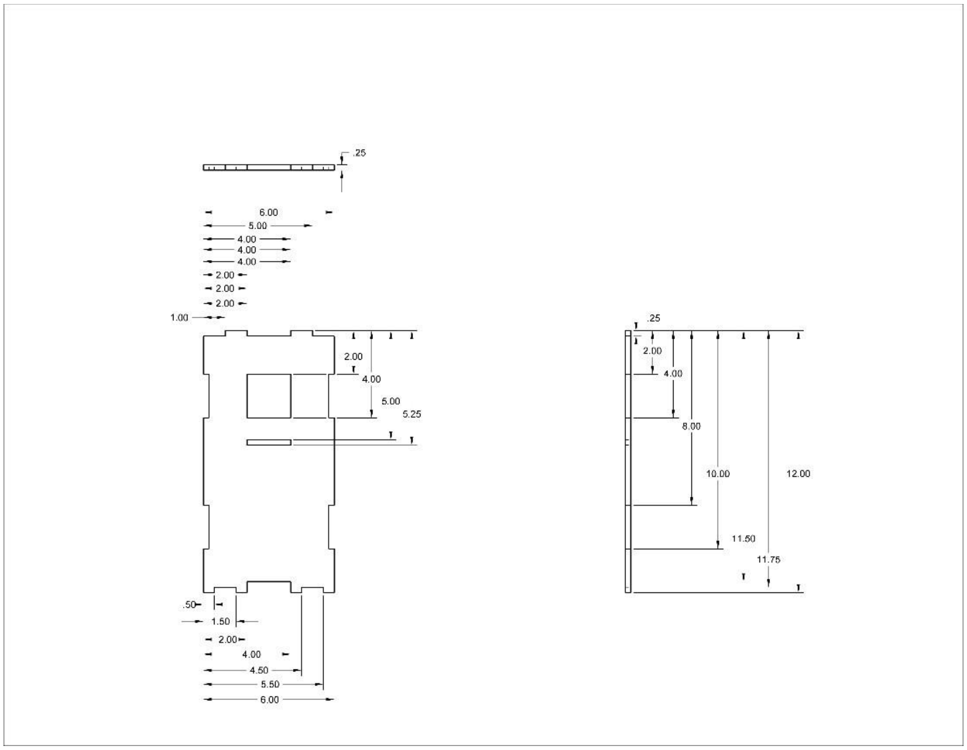


Figure H5: Front

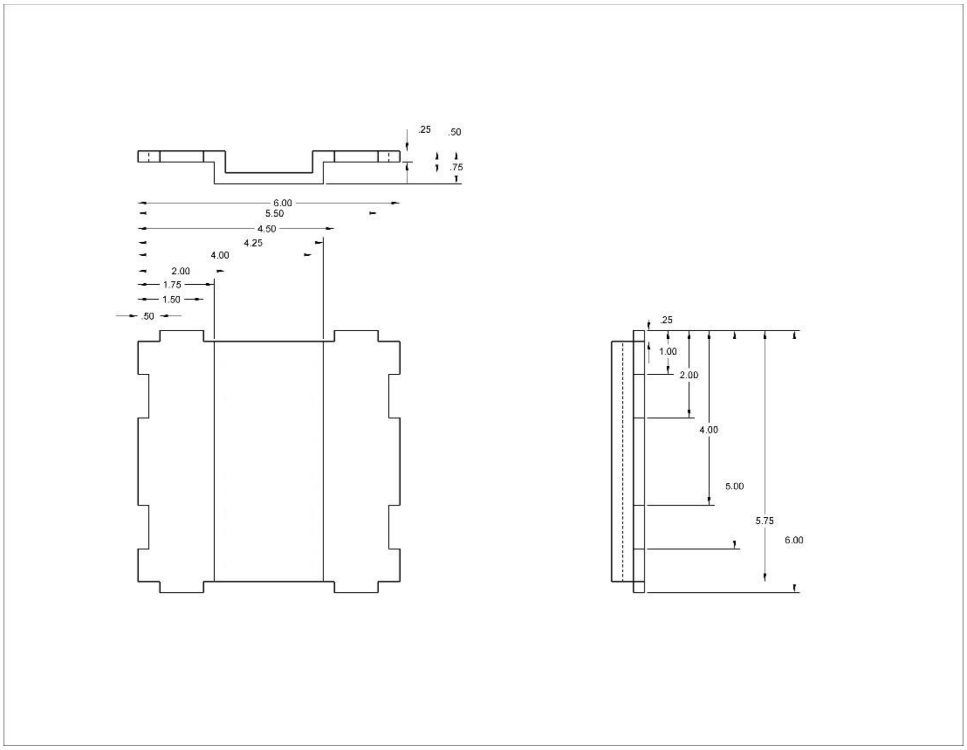


Figure H6: Bottom

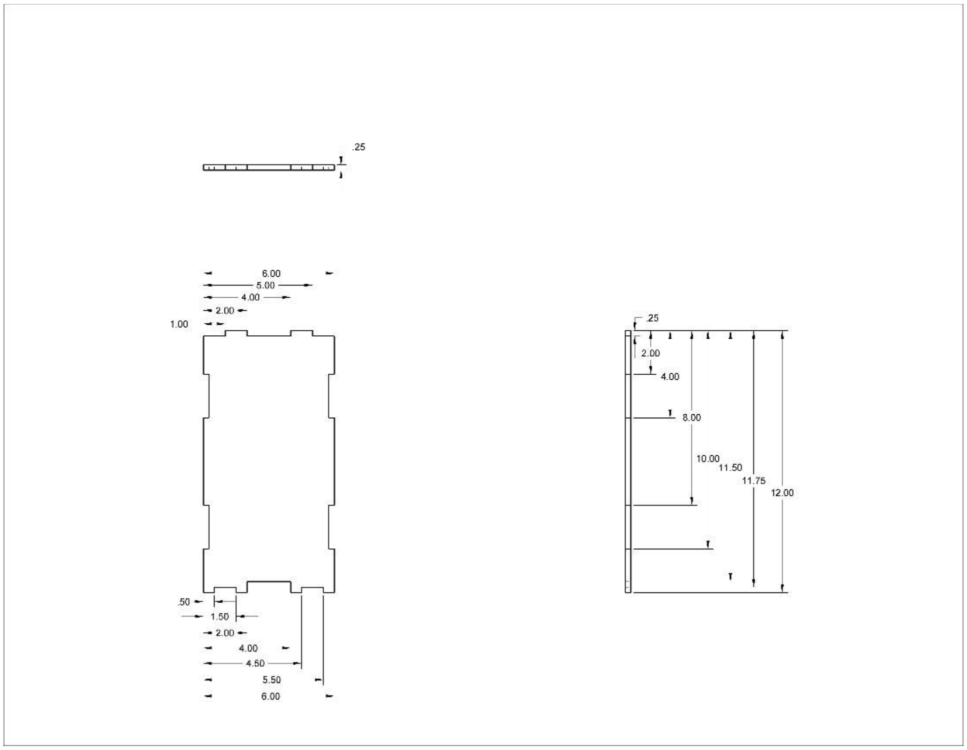


Figure H7: Back