The Passing Board

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The Passing Board Final Report

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Abstract

This senior design project works to address a lifelong issue that the author and many soccer players who have looked to train individually have experienced or been affected negatively by. As the individual behind this project, John Fitzgerald, is a lifelong soccer player, a member of the University of Akron’s Men’s Soccer Team, and a mechanical engineering major here at the University of Akron (UA), this design looks to combine his experiences at UA into a passion project that has been accumulating for years.

The issue being addressed is the lack of individual training equipment for soccer players. Players, when they are training on their own, do not have much or any selection of equipment to help them improve their passing accuracy and control of the ball. They are often forced to use a variety of random objects, such as trashcans and benches, to create a surface in which a ball can be passed onto and receive a pass back from. This is all to raise the level of one’s soccer ability by trying to recreate game-like scenarios so that a player is better suited or prepared when official games are played.

This project began with research into existing soccer training equipment to ensure that the need for a tool that can replicate real game passing scenarios while minimizing the need for a partner exists. This research and analysis revealed a handful of attempts at such a product; however, they eliminate themselves from most of the targeted audience by being made of a poor material, larger than needed, and not easily transported.

The design worked on throughout this project looks to address all these areas. An effort was made to have the design be lightweight, easy to transport, small in frame, inexpensive or more cost efficient, and connectable to allow for multiple uses and the ability to get creative with its applications to training sessions. These were the main considerations when starting the design.

The design process was completed by taking a long thought about idea and taking it through the four stages of design to ensure a complete and respected process was followed. The use of the computer software SolidWorks was implemented to start the three-dimensional design, address many of the subcomponents of the design, and determine the dimensions of each element of the board. The final design was curated over several months of concept generation, ideation, and eventual design decisions.

Research was done to determine the expected range of forces and ball velocities the design would be likely to experience. This research helped determine the appropriate weight and size of the design using the concepts of impulse and change in momentum.

A small prototype was created but a physical product was not able to be made or finished due to the time constraints experienced by the senior project author. A solid base was formed through research, design, and calculations for the author, or anyone else who desires to address the previously discussed initial problem, to continue work upon and/or create a Passing Board of their own.
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1. Introduction

To understand the importance, inspiration, and motivation behind this senior design project one must know a little bit about its author, myself John Fitzgerald. Along with being a fifth-year mechanical engineering major here at the University of Akron (UA), I have also been a member of the Men’s Soccer Team here at UA since I started in the Spring of 2019. With this very brief introduction, it isn’t hard to see that throughout my career here at the University of Akron my experience has been influenced and dependent on two main topics: soccer and engineering. Being a student-athlete has been my identity for the past five years and one that has challenged me tremendously along the way. However, the student/engineering side of my life has always been separated from my career in soccer here at Akron. With that said, as I got closer to my last year of school, the senior design project provided me with the perfect opportunity to blend the two passions behind my career at UA into one final project.

Being born and raised in the city of Tallahassee, located in the Panhandle of Florida (Northeastern part of the state), there was not much of a soccer presence anywhere nearby. I was constantly traveling to the South of Florida to get better competition and I ended up moving across the country to Arizona when I was fourteen to continue my soccer career, however, that is a completely different story. I bring this up to help give context to the issue my senior design project is addressing. I had to do a lot of individual training by myself growing up and even into my college career whenever I would come home to Florida. This can be a difficult thing to do as one training by themselves does not have anyone to pass to or receive the ball from. Growing up I went through a catalog of techniques to solve this problem, including passing off benches, trash cans, goal posts, other soccer balls, shoes, etc. This brief introduction gives my personal background behind the issue my senior design project is trying to solve and the one I have been struggling with since my childhood.

The larger issue at hand is that there is a complete lack of individual and team training equipment for soccer players and teams in general. The analysis of such products on the market will be further discussed and analyzed throughout this report.

To solve this lingering issue, I came up with the idea of the Passing Board. Throughout research and design, I was able to make the Passing Board a lightweight, easily transported, small in frame, and connectable for innovative uses. Using locking hinges, the board can fold out to form a large surface to which the ball is passed upon and then retract to make for easy transportation and storage. The board can be connected to other boards on each side to increase the surface area to aim a pass at. This design feature also allows for unique configurations of the multiple connected boards that individuals can get creative with to elevate or alter their training sessions.

The concepts of impulse and change in momentum were comprehended to ensure stability of the board through the collision with the soccer ball. Much research was done to identify the expected range of velocities and forces from an average pass in soccer. This helped in the material selection process to identify suitable materials for the design.

This report goes further into depth about the entire design and research processes. It discusses the results, what could have been improved, and where this idea can be taken in the future.
2. Outline of Subject Material

2.1 Introduction

This portion of the report begins to discuss and analyze the entire process and procedures for my senior design project. It breaks down the project into several chapters that work to address each step made throughout the journey of the Passing Board until its final design and the conceptualization of a prototype. These chapters include design procedures, design details, verifications, costs, and codes and standards.

The design procedures chapter introduces the phases of design that were followed throughout the design process. It addresses the initial problem statement and goes through the prior research done to gain knowledge and ensure such a design was in need. As this passion project has been in the back of my mind for several years, the concept generation and evaluation process were highly valued. With that said, the majority of this report focuses on strictly following the phases of design and creating a final design that solves this lifelong issue.

The final design is then dissected and analyzed throughout the design details chapter. This chapter provides a detailed explanation for each design decision. It gives an in-depth look at the final design, how it was achieved, and provides images for support. From the outside this product may just look like a simple board that can be used to kick a soccer ball against. However, it is much more complicated than that and this chapter works to gain appreciation for the final design and the thought processes that went into each component.

The verification chapter goes through the research done to identify a range of forces and ball velocities that the design would be expected to handle. It discusses the making of a prototype and analyzes any challenges experienced throughout the design process or up until this point.

The cost of the board was then analyzed in the next chapter. The design is rather simple, so it was estimated how much time and material was needed to create one product. A bill of materials is also provided and the potential for mass-production is discussed. Some issues experienced throughout the design process are discussed here.

Several codes and standards were addressed and followed throughout this entire process. This chapter discusses the importance of these standards and the work done to ensure the safety of the Passing Board’s design and manufacturing.

2.2 Design Procedure

Before any work was done with designing, research had to be done to ensure that a need for such a product was present. As a lifelong soccer player and one who has played at extremely high levels, I had my own experience and testimony for such a product and the lack of training equipment for soccer in general. However, an analysis of similar products was also conducted. Through brief research some similar products were found. Of these products some were too expensive, others too large and cumbersome, and some were not suited for the forces that would be expected when using the board at a high level as they were made with a poor material. With
this said, none of these prior designs fully captured what I wanted to accomplish with this project.

As this is a personal passion project for me and one that has been in the back of my head for several years now, I naturally had an excess of ideas for the overall design and any potential subfunctions. To help guide me through the design process and slowly narrow down all my ideas into one design I followed the four phases of design, which are product definition, conceptual design, embodiment design, and detail design. Starting with product definition, it was important to identify a need for such a product or design. This need is well described by the expanded design brief that follows below:

There is a need for an inexpensive, light weight, and small framed board that can be used to replicate in-game passing scenarios while eliminating the need for a partner. This board is meant for individual soccer trainings but can be implemented into any circumstances, whether that is group or team trainings as well. The board should be large enough to bounce a soccer ball off but with a small enough frame to be transported with ease. It is required that the board stay static or in the same place through contact with a pass. Preferably the board should be able to fit in the back of a car or trunk.

With the problem defined, I began working on the conceptual design phase. Before this process began, it was determined that a morphological chart would be used to guide me through my excess of ideas and concepts. This initially involved determining the main and sub-functions that were of the upmost importance to me, what I was wanting to accomplish with the Passing Board, and what the other similar products had not achieved with their designs. The main function of my design can be described as providing a surface that one could pass a soccer ball against and receive a bounce pass from while the surface stays static or unmoved through contact with the pass. This is the most significant design function as it directly solves the problem discussed in the design brief and is the base of which the rest of the design will focus upon.

This main design function has already been solved by a handful of other products, however, as mentioned they do not do so in a manner that is not ideal for the average soccer player. This is where I wanted to thrive with the Passing Board and make a product meant for soccer players. To achieve this, I prioritized the subfunctions of my design. These included the ability to be quickly moved or rotated on the field, stability through contact with the pass, ability to extend or alter the passing surface, and ability to be stored with ease or small areas.

Each subfunction had its own importance and reasoning behind it. Stability through contact with the pass relates back to the main function of the design and is essential for providing players with a consistent surface that can be relied upon. Ability to be quickly moved or rotated on the field is of importance as a training session the surface should be moved around or used in several different ways, and it should not be a hinderance to do so. Ability to extend or alter the passing surface is included because providing a way to alter the angle of return of the soccer ball or creating different shapes with multiple boards in use gives users the ability to become creative with and level up their training sessions. Ability to be stored with ease or in small areas was included because the majority of soccer players, myself included, usually are driven or must
drive to the soccer fields. With that said, the design should be considerate of such limitations due to transportation.

With the subfunctions defined, concept generation was done and many of the ideas I have had kept in the back of my head for several years had to be put down on paper for the first time. These ideas were drawn by hand and a morphological chart was made to help organize each concept into the subfunction it was performing. An image of the finalized morphological chart used during my conceptual design phase can be seen in Figure 1, all figures and tables can be found in Chapter 2.8.

Using Figure 1, three separate concepts for the design of the Passing Board were made. These concepts are marked on the chart by the different color zig-zag line combinations. Concept A is represented by the light blue colored line, concept B by the red colored line, and concept C by the yellow colored line. The initial handmade drawings of each concept can be seen in Figure 2.

To reduce the number of these potential designs into one, concept evaluation was performed. To ensure reliability and the best accuracy, a weighted decision matrix was used. Prior to completing the weighted decision matrix, the evaluation criteria had to be decided upon. This was accomplished by making an objective tree, which can be seen in Figure 3.

In Figure 3, each evaluation criteria can be seen connected to the Passing Board at the top of the objective tree. The red numbers within the circles at the bottom of the figure represent the weighting factors that will be used later in the weighted decision matrix. These numbers were found by multiplying up through the objective tree and they all add up to unity, or equal to one. The black numbers represent each individual weight for an evaluation criterion. These weights are all essentially the same as the weighting factors apart from that of the “accessibility” criteria as it has its own sub-criteria. In this case, the black weights under “ease of movement” and “ease of storage”, 0.75 and 0.25 respectively, add up to unity and represent the division of the “accessibility” criteria’s weight of 0.25. In other words, 75 percent of the “accessibility” criteria’s weight goes to “ease of movement” while the remaining 25 percent goes to “ease of storage”.

The evaluation criteria were derived from the desired subfunctions while also considering the entire design process. It is evident accessibility, low cost, and stability are considered some of the priorities and of higher significance. This is because they directly relate to and address the problem statement this design is trying to solve. On the other hand, criteria such as aesthetics, low number of parts, and simplicity have less value as they are do not directly relate to any of the desired subfunctions or address the problem statement. Simply put, they should be considered but are not the most critical measurements when comparing multiple designs.

With the evaluation criteria established, the weighted decision matrix could then be completed. This can be seen in Table 1. The scoring system (or rating) of one through five was used to determine how well each design satisfies the specified evaluation criteria. In this case, one is unsatisfactory, poor, or unusable. Three is adequate, usable, or satisfactory. While five is ideal or excellent.
In evaluating Table 1, it is evident that Concept B had the highest total weighted value, surpassing the values associated with the other two concepts. Consequently, I made the strategic decision to advance Concept B to the next phase of the design process. It should also be noted that this design not only did well in terms of overall weighted value, but also accomplished the main function and all subfunctions at a level I was satisfied with. This justified my decision to continue with this concept to the embodiment design phase and through the rest of my project.

To begin the embodiment design phase, the configuration design was considered first. This step was performed to determine the shape or type of each component and how/where they connect to each other. The major design decision made during this process involved how the board would perform its folding motion. The possibilities that were considered included a few different types of hinges and a rod with spring contraption. Other ideas addressed during the configuration design were much smaller design decisions. For example, the shape of the end of the sides of the board, shape of stakes and verticals holes and placement of handle. The ideation and thought process behind these decisions were made through hand drawings. A collection of a few of these drawings can be seen in Figure 4. The red outlined drawings indicate the components that were chosen.

The embodiment design phase includes a failure mode and effects analysis (FMEA). The design for Passing Board does not include many safety precautions, therefore, it was determined such an analysis was not suitable or required. As for the procedure for decision making on dimensions and shape of each piece, the calculations and research that guided these decisions can be found in Chapter 2.4.

### 2.3 Design Details

The fourth step and final phase of the design process was performed mainly through the computer program SOLIDWORKS. Using such a program I was able to take my design concept from paper and turn them into a three-dimensional model.

This chapter will look at the final design of the prototype for the Passing Board. Through images of the design each component will be analyzed, slight design changes will be discussed, and any difficulties experienced along the way will be mentioned.

The thought process and calculations for the material selection is discussed in Chapter 2.4. Based off that information, it was decided that a wooden prototype would be the best material for the initial design. Aluminum was considered to be the ideal material for the final product; however, this design is only addressing the prototype.

To begin, the isometric view of the final design of the Passing Board can be seen in Figure 5. In this figure the board is opened and in its working state. This is what the board would look like when being used on the field and receiving passes against it.

The final design has three main parts: the center piece and the left and right sides. Both side pieces are an inch thick and two feet long.
Figure 6 shows the isometric view of the final design of the Passing Board when it is closed. This is what the board would look like when not in use or being transported from place to place. One of the subfunctions of the design was to have the ability to store or transport the board with ease. It was essential that the design was able to fit into the trunk space of an average car. From [1], it is estimated that the average mid-sized sedan has a trunk (or cargo) space of 14–16-cubic feet. For the most subcompact car, the trunk space lowers to 10–12-cubic feet. Based on the dimensions of the closed shape of the board seen in Figure 6, our design only takes up around 2 cubic feet of space.

In Figures 5 and 6, the models of the final design have been colored to resemble the expected material of the prototype for each piece. It should be noted that one-inch-thick pieces of wood are used for both sides and the structure that creates the center piece. An additive manufactured piece is used to fill the area of the middle structure and provide a place to put the handle. This area, which can be seen in Figure 7, can also act as location to put loose items or even more weight if special uses of the board are needed.

Figure 7 shows the center piece of the board. It is a one-inch-thick wooden frame that is one foot tall and two feet long. It is cut diagonally which leaves a large open area in the middle of the frame. This open area is filled in with an additive manufactured piece that fits to the required dimensions. To accomplish one of the subfunctions of the Passing Board a handle was required to allow for the ability to quickly moved the board around the field with ease. As discussed in Chapter 2.2 and Figure 1, the placement of the handle was originally thought to be best on the top of the board. However, through designing the three-dimensional model and finding the center of mass it became evident that the handle placement needed to be moved.

2.4 Verification

Since only a prototype of the design was able to be made, most of the verification process for this design was done through calculations and the use of research on subjects like impulse forces, change in linear momentum, and statics.

For the calculations in this chapter, it should be noted that the act of kicking the soccer ball is not taken into consideration. Only the velocity and momentum of the soccer ball after the initial kick will be analyzed and examined. The collision between the ball and the board will also be considered elastic and the energy loss to heat, sound, and deformation will not be taken into consideration. It should also be noted that for many of the calculations the most extreme conditions i.e., ball pressure, ball diameter, coefficient of restitution, etc., will be used to ensure that the worst of circumstances are still within the capability of the design. Other factors such as air resistance and drag are assumed non-influential and will not be looked at when evaluation the soccer ball’s velocity before or after the collision.

The design for such a product as the Passing Board heavily involves the concepts of change in momentum and impulse. Linear momentum allows one to understand the relationship with motion and the interactions, or collisions, between objects. In the case of this report, it helps me calculate and estimate the kind of forces my design should be expecting to experience and
withstand. We know that momentum is defined as the product of an object’s mass and velocity [2]. This is demonstrated in Equation (2.1).

\[ p = m \times v \]  

(2.1)

where \( p \) is the momentum, \( m \) is the mass of the object, and \( v \) is the velocity at which the mass is traveling. Linear momentum is a vector quantity and has the same direction of the object’s velocity. From a basic understanding of my design, it is evident that the board and the soccer ball will come into a nearly elastic collision. It should be noted that the collision is assumed to be elastic and the loss of energy to sound and heat will not be addressed. The design needs to not only withstand the contact from the ball but also produce an equal and opposite reaction to propel the ball back in the direction it came from and back towards the user. This corresponds almost identically with Newton’s third law of motion, as one object exerts a force on a surface that surface will exert an equal but opposite force on the object [3]. It also implies a large change in momentum experienced by the ball and a subsequent large impulse force on the board from the collision. To take a closer look at the defining equations behind this concept of change in momentum Newton’s second law of motion needs to be defined:

\[ F = m \times a \]  

(2.2)

where \( F \) is force, \( m \) is the mass of the object, and \( a \) is the acceleration at which the mass is traveling. Newton’s second law of motion states that force is equal to an object’s mass multiplied by its acceleration. To help relate this back to momentum and impulse, compare Equations (2.1) and (2.2). Understanding that acceleration is simply change in velocity over change in time, shown in Equation (2.3), the relations below can be made.

\[ a = \frac{dv}{dt} \]  

(2.3)

\[ F = m \times \frac{dv}{dt} \]  

(2.4)

\[ F = \frac{dp}{dt} \]  

(2.5)

This sequence of equations shows how the relationship between force and momentum is made. It is worth mentioning that a constant mass is assumed throughout these equations and calculations. This is because in the application of my design a soccer ball’s mass remains constant and is not changing as it comes into contact with the board. From [4], we can see by substituting Equation (2.3) into (2.2), force can be defined as mass times the change in velocity over time, seen in Equation (2.4). As we have assumed a constant mass, we can then relate back to Equation (2.1) and define force as the change in momentum over time, or Equation (2.5). This equation is another version of Newton’s second law of motion. The only difference is that force is related to momentum not acceleration. According to [5], Equation (2.5) is the, “relationship Newton himself presented in his Principia Mathematica, although he called it “quantity of motion” rather than “momentum.”
With the connection between force and momentum made, the concept of impulse can now be discussed. By further manipulating Equation (2.5) and referencing [2], impulse can be defined as either a force applied over a period of time or the change in momentum of an object.

\[
\text{Impulse (} J \text{)} = F \Delta t = \Delta p
\]

(2.6)

where \( F \) represents a force, \( t \) represents time, and \( p \) momentum. Equation (2.6) demonstrates the impulse-momentum theorem. This theorem is of utmost importance when analyzing collisions and objects experiencing a change in momentum. According to [6], Equation (2.6) also proves the concept of the conservation of linear momentum if the mass stays constant and no external forces are put on the system. The impulse-momentum theorem is demonstrated in the experiment performed in [7].

When starting this project, I had assumed that testing would be needed to identify the range of forces that the design would be expected to experience from the pass of a soccer ball. However, finding that [7] and [8] performed experiments to find the peak impact force of a soccer ball eliminated the need of repeating a similar process. To accomplish this, the experiments in [7] and [8] used a sensor they called a wireless force platform (made by Pasco Scientific), attached it to a surface, and kicked soccer balls into the wireless force platform. This sensor measured the peak force experienced normal to its surface during the collision. The use of the Pasco Capstone video analysis program was also implemented. This program was able to measure the velocity of the ball before and after it contacted the wireless force platform. They then considered Equation (2.6) and calculated the impulse experienced by the board/platform.

This experiment performed in [7] and [8] is one that I had originally planned to do, however, their results provide enough information to rely on. From the video of the experiment in [7], it is the kicks they were testing were closer to shots rather than passes. Meaning they were kicked with much more force than I needed to account for. The tests from [7] had a range of results from 587 Newtons (N) to 789 N and the average measurement for the peak impact force experienced was approximately 667 N. This provides a decent baseline for the answer to how much force my design needs to be able to withstand. When analyzing the results from [8], the range of expected forces grew vastly larger as the range of peak impact forces for a size 5 soccer ball was measured to be 196-4667 N, with a duration of impact between 0.0055-0.017 s. These impact forces were measured from a soccer ball with an initial velocity between 15-30 m/s. The size 5 soccer ball is the most standard and the size used for all levels above youth leagues, so its results provide the most valuable information. In the experiment performed in [8], the number of tests and data points is increased dramatically compared to that of [7], 600 kicks to four kicks respectively. This is because in [8] they were testing the differences in ball size, ball pressure, and ball weight and how they affect peak impact force. Therefore, more tests were made. They also collected data for soccer balls that had been submerged in water to see the effects it had on the weight of the ball and the resulting peak impact force.

According to [9], the International Federation of Football Association (FIFA) and the International Football Association Board (IFAB) require a soccer ball have a mass of 410-450 grams (g) and a pressure of 0.6-1.1 atmospheres (atm). The testing done in [8] provides data
from soccer balls within and outside of these ranges. I believe this to be helpful as not all players will have the same ball and a range of different conditions must be considered. With that said, Table 2 displays Table 3 from [8] and provides the average peak force for each ball size at different pressures. Table 2 shows that at the maximum allowable pressure according to [9] and an initial ball velocity of 14-17 m/s, the mean peak impact forces of a size 5 ball was measured at 3606 ± 340 N. It is evident this result varies greatly from those measured in [7]. However, as the experiment in [8] collected more data and ran more trials its results must be relied upon and considered more accurate. During the experiment in [8] a dimensional analysis was conducted with “peak impact force as the output and the four most important inputs were assumed to be inflation pressure (p), mass (m), diameter (d), and incoming velocity (v) (of the soccer ball).” The conclusion from their results was that the velocity of the ball has the greatest effect on peak impact force with nearly three times greater effect on the force than the second highest factor, pressure. They also noted that the increase in mass from the balls with water absorption makes the mass have a larger effect on impact force than pressure.

Continuing with the information provided by [7], apart from their tests for peak impact force they also used the PASCO Capstone video analysis program to measure the velocity of the ball before and after the collision with the sensor. Figure 9 shows the position versus time graph used in the experiment from [7]. By then using the relation that velocity equals change in position over time, they measured an initial velocity of 15.7 m/s and a velocity of 9.38 m/s after the collision. The velocity measured after the collision is negative as the collision changed the balls direction and it returned in the direction it came from. We can use Equation (2.6) to calculate the impulse. They also measured the soccer ball to have a constant mass of 0.412 kg, so the calculations done from [7] can be seen below:

\[
\text{Impulse } (J) = \Delta p = m(\Delta v) = 0.412 \text{ kg} (-9.38 - 15.7) \text{ m/s} = -10.3 \text{ Ns}
\]

These calculations give valuable information concerning my design. The time of the collision can be estimated by trying to emulate Figure 1.4 in [10] with Figure 9 from this report. From Figure 9 we can approximate the amount of time the ball is colliding with the surface to be 0.015 s. This corresponds well with the duration of impact measured in [8], which measured a range of 0.0055-0.017 s. By rearranging Equation (2.6), into Equation (2.7), the average force the ball exerts on the surface can be calculated.

\[
\bar{F} = \frac{J}{\Delta t} = \frac{-10.3 \text{ Ns}}{0.015 \text{ s}} = -706.67 \text{ N}
\]

This average force represents the force experienced on the surface over the duration of impact. It is an important calculation that gives more a more accurate representation of what forces my design will experience.
To cross-check this information, it can be seen by the research done in the study “Analyzing pace-of-play in soccer using spatio-temporal event data” from [11] that the average speed of a soccer ball during an English Premier League game, the highest level of soccer in the United Kingdom and arguably the world, can be estimated to be around 6-18 m/s. With values higher than his range being closer to the speed of an average shot and not that of a pass. Comparing this data with that from [12], which conducted an experiment to analyze the difference between a kick with the instep, or upper middle part, of the foot and a kick with the inside of the foot, we can narrow down an expected velocity range that would resemble the most common speed of pass my design is expected to withstand. In [12] the maximum speed of the soccer player’s kick was tested for. The results found the averages for a kick with the instep and side of the foot for females was $22.50 \pm 1.0$ m/s and $21.5 \pm 1.0$ m/s, respectively. For men, the same types of kicks were measured at $27.9 \pm 1.3$ m/s and $26.9 \pm 1.3$ m/s, respectively. This data corresponds well when compared to the results from [13], which measure the speed of a full instep kick along with the speed of a “pass-kick”. This “pass-kick” was defined by its $67\%$ knee extension compared to the $86\%$ knee extension in the full instep kick. The results from [13] gave the velocity of the ball as $21.6$ m/s from the full instep kick and $18.3$ m/s speed for the slower “pass kick”.

This research gives an accurate representation of the speed of a typical pass in soccer. It is evident from [8], [12], and [13] that when kicking the ball as hard as possible, similar to a shot, the expected velocity of the ball after the kick would be anywhere from 20-30 m/s. By comparing those results with the information from [11], it is evident that the average speed of a pass in a soccer game is closer to 6-18 m/s.

With the expected range of velocities for the soccer ball prior to colliding with the board found, calculations can now be made to find the expected range of forces from such velocities. It was found in research that [10] reported, a soccer ball has a coefficient of restitution ($e$) of 0.8 when colliding with a hard surface and $0.6$ when bouncing or colliding with the ground/grass. From [14], we know the coefficient of restitution is defined as:

$$e = \frac{\text{speed of separation}}{\text{speed of approach}}$$

where speed of separation is the velocity of the ball after the collision and speed of approach is the velocity of the ball prior to the collision. If we use the velocities found in the experiment from [7] in Equation (2.8), a coefficient of restitution of 0.6 is found. This resembles a value closer to the collision with grass versus a hard surface. This decrease in the coefficient of restitution can be attributed to the surface of the wireless force platform, in which the ball was colliding, being not as hard as the surface tested in [10] and causing a greater decrease in velocity after the collision. With that said, the coefficient of restitution will still use a value of 0.8 in the following calculations as it is more accurate to my design and a good way to ensure more extreme conditions are accounted for.

The range of velocities my design will be experiencing the most is approximately 6-18 m/s and we know from [10] that a soccer ball experiences a twenty percent decrease in speed after a collision with a hard surface. Therefore, the expected range of forces can be estimated. If we
start with a velocity before the collision of 6 m/s, Equation (2.8) can be altered to find the speed after the contact, this is shown below.

\[ v_f = (e)(\text{speed of approach}) = (0.8)(6 \text{ m/s}) = 4.8 \text{ m/s} \]

The impulse can then be found by using the impulse-momentum theorem displayed in Equation (2.6). Considering [9] and the regulated range of mass of a soccer ball being 410-450 grams, a constant mass of 0.43 kg will be used in the calculations.

\[ \text{Impulse (J)} = m(\Delta v) = 0.43 kg(-4.8 - 6) \text{ m/s} = -4.6 \text{ Ns} \]

The smallest impact time, 0.0055 s, in the range found from [8], was assumed to account for the most extreme conditions and to ensure a greater level of safety for the design. The average force for a pass with the initial velocity of 6 m/s can then be estimated using Equation (2.7), shown below.

\[ \bar{F} = \frac{J}{\Delta t} = \frac{-4.6 \text{ Ns}}{0.0055 \text{ s}} = -836.36 \text{ N} \]

This same process can be followed for the range of velocities between six and 18 m/s. Table (3) shows the results from these calculations for the expected range of velocities.

From Table 3 we can get an understanding of what kind of forces my design is expecting for most of its work. The numbers from Table 3 are slightly extreme as we used a minimal time of contact, a constant mass and pressure, and we assumed the collision was elastic.

The range of expected forces along with the peak impact forces have now been researched and identified. This was a key step to help decide what material would be best suited for my design. The material selection process was done by calculating the stress the material will experience under the peak impact force and comparing that to the material’s yield strength to ensure no permanent deformation occurs. The formula for stress is known as force over area and is shown below.

\[ \sigma = \frac{F}{A} \quad (2.9) \]

where \( \sigma \) is stress, \( F \) is the applied force, and \( A \) is the area in which the force is concentrated. According to [9] a soccer ball is required to have a circumference of 27-28 inches. The required diameter can then be calculated by using the relation that diameter is equal to circumference divided by \( \pi \). These calculations give a required diameter of 8.6-8.9 inches. As we are solving for the maximum conditions a diameter of 8.9 inches, or 226 millimeters (mm), will be used throughout the calculations. The area of the cross-sectional area of a soccer ball is then found and the stress experienced under the peak impact force found in [8] can then be calculated using Equation (2.9).

\[ \sigma = \frac{F}{A} = \frac{4667 \text{ N}}{\pi(226)^2} = 0.1163 \text{ MPa or 116.3 KPa} \]

The stress from the peak impact force is found to be 116.3 KPa. The peak impact force used was recorded in the experiment from [8] and represented the top limit of the range of impact forces.
and ball velocities, estimated at 30 m/s, measured. To account for any passes that exceed this impact force the maximum stress expected from the collision is multiplied by a factor of 2. By doubling the stress this safely ensures that a material with the appropriate strength is chosen. After applying this safety factor, we end with a stress value equal to 0.2327 MPa. With this value found, we must choose a material that has a yield strength greater than the stress we have just calculated. Based on information of material’s properties found from [15], we can decide on an appropriate material.

It is believed that the best option for such a design is to make a prototype out of pine wood as, according to [15], it has a sufficient compressive and shear strength. This prototype would be nothing more than a test to get a feel for the manufacturing process and provide valuable information about manufacturing the design.

The ideal material for the design of the Passing Board would be aluminum. This is based on the information from [15], which states that aluminum has a yield strength of approximately 95 MPa. The cost and availability of aluminum also comes into play but will be discussed later in Chapter 2.6.

### 2.5 Codes and Standards

Throughout the entire design process and when analyzing the task of manufacturing the Passing Board, a handful of different codes and standards were considered and followed to ensure safety and a respectable process was being used.

After some research, it was discovered that not many standards or guidelines were provided by the governing figures of the sport of soccer for such a product. It should be noted that the FIFA Quality Programme exists but is more involved in the analysis and quality verification of soccer balls and the playing surfaces in games of soccer is played. Tests are outlined to ensure a standard is upheld for ball parameters such a pressure, shape, bounce, etc. There is also a consideration until these standards for future technologies related to the sport are assessed. This normal deals with advancements in technologies for the improvement of accuracy of the enforcement of the rules of the game. Such a standard or testing for training equipment does not seem to exist. With that said, I believe a FIFA quality mark from the FIFA Quality Programme should be a goal for the design of the Passing Board. Having such a mark signifies this design has been held up to a certain standard and is approved by the leading body in the world of soccer. According to [16], such quality marks are given out after testing is performed by independent testing institutes. These independent institutes look to verify the functionality of such products in the world of soccer and apply one of three quality marks. The one most suited for my design would be the FIFA Basic mark. This mark states, “The test requirements for this standard are designed to identify products that fulfil basic performance, accuracy, safety and durability criteria for football. The focus is on setting minimum standards while ensuring affordability for use at all levels of the game” [16]. The tests for my product may have to be created or designed as research does not show any precedent. However, with no history of a similar product getting a FIFA quality mark this could be what sets my design apart...
from similar products already on the market. If a testing process and verification can be
designed and performed than obtaining a quality mark should be a goal of my product.

Several other codes and standards were considered and followed throughout my design
process. These includes the American Society of Mechanical Engineers (ASME) Y14.5. 
Y14.5 deals with the dimensioning and tolerance of the design and each of its components
[17]. This is usually meant for drawings; however, I applied the standards to my three-
dimensional modeling, and this can be seen in Figures 8 and 9.

When considering the dimensions of each piece of the design and the product as a whole,
the regulated size of the soccer ball was the determining factor. As mentioned earlier,
FIFA and IFAB have standards for the size, weight, inflation pressure, and much more
for the parameters of a soccer ball [9]. These standards were the initial basis for deciding
how long and tall the rebounding surface should be designed. As mentioned before in
Chapter 2.4, the required diameter of ball is between 8.6-8.9 inches. With several design
criteria trying to limit the design to be as small and light weight as possible, these
standards for the required size of soccer ball gave a good minimum for the dimensions of
the design.

It was difficult to identify many standards or codes that directly applied to the application of my
design. With that said, a couple that loosely applied to such a product or situation is the
ASTM F2650-17e1, Standard Terminology Relating to Impact Testing of Sports Surfaces and
Equipment [18], and ASTM F355-16e1, Standard Test Method for Impact Attenuation of
Playing Surface Systems, Other Protective Sport Systems, and Materials Used for Athletics,
Recreation and Play [19]. Both refer to the terminology or testing of impacts for sports
equipment or facilities. It was important to uphold these standards so that this report and the
design in general is held to a respected process and a high level of quality. It also ensures that
this report falls into accordance with the standards held around the world. This allows such a
design and report to be accepted internationally if so desired.

2.6 Costs

The design discussed throughout this report is addressing the prototype of the Passing Board. It
is expected to be made from pine wood and not the desired aluminum of the final product. This
was done because of the availability and cost of materials, to make it more realistic for my senior
project. With that said, both material’s costs will be addressed in this chapter. The pine wood
prototype is what is being analyzed heavily though.

The final design of the Passing Board requires a few components that would be purchased and
not manufactured on site. To account for this a bill of materials has been made and can be found
in Table 4. As only an additive manufactured prototype was made, the bill of materials is
approximated with prices found online. Table 4 refers to the cost of materials for a singular
board.

It was assumed that the wood pieces along with the additive manufactured center piece were
produced on sight and therefore their costs were not included within the bill of materials. With
that said, a goal of this report is to provide the ability for anyone to discover it and have a base for this design to then replicate with their own materials. To help in that process, references [20] and [21] refer to the prices of the wood that could be used to complete the manufacturing for this prototype.

This product does have the potential for mass-production and a large commercial use if pursued further. Table 5 refers to the bill of materials if the required parts for the design were bought in bulk. It is estimated from the dimensions of the board and the materials bought that approximately 100 boards can be manufactured based off the bill of materials in Table 5.

It is a simply manufacturing process for the wooden prototype. If all the materials and equipment were present than only a few different actions would need to be completed. It would start with marking the dimensions and cutting of the wood pieces. This could be done using any type of method, whether it’s with a machine or by hand. After cutting, the pieces would need to be sanded down or smoothed to prepare them for connection. The wood pieces would then need to be screwed together to form the base structure for the center of the board. The hinges could then be screwed into place on each side. Last the center piece with the handle would need to be screwed in and secured.

The manufacturing time can be estimated to take around two to three hours. Based on this estimate and the labor cost formula, Equation (2.10), the cost of labor for the manufacturing of one board can be calculated.

\[
\text{Cost of Labor} = \text{ideal salary (hourly rate) x actual hours spent x 2.5} \tag{2.10}
\]

Using Equation (2.10) with an estimated hours spent of 3 and an ideal salary of 18 dollars per hour, this salary is based on information about manufacturing jobs from [22], the cost of labor can then be calculated. After calculations the cost of labor comes out as 135 dollars for the manufacturing of one Passing Board.

Based on the calculations done with Equation (2.10) and Table 4, the cost of the prototype for the Passing Board was much higher than I originally intended or set out for. It would come out to a total cost of $161.22. Most of this cost is going to the cost of labor as the bill of materials for one prototype, Table 4, is only $26.22. This price does exclude the cost of materials as it was assumed to be provided. It also does not take into consideration the cost of aluminum, which is the desired material for the final product. With that said, the price of my designed prototype did not quite accomplish my goal of being low cost.

If an attempt to go commercial with the design is made and mass-production is needed, a manufacturing process such as computer numerical control (CNC) or programable logic controller (PLC) would be the most efficient. Take CNC for example, assuming that such a manufacturing machine is already owned or in use, this type of manufacturing would help speed up the process greatly. The CNC machine could take the dimensions of each piece and work continuously to provide precise parts that could then be put together by hand or other machines. The final steps of manufacturing the product would most likely be best done by hand but would take a significantly less amount of time compared to the manufacturing process of one board.
mentioned earlier. The only steps that would need to be executed by hand would be drilling the pieces and components together, as all the pieces would be cut, drilled, and sanded by a machining process. This could lower the cost of labor significantly, however, if such CNC machines are not owned than that only pushes the break-even point further into the future.

To address the costs of the desired final product made of aluminum it must be stated first that the dimensions of the design would be altered to fit what is appropriate for such a material. With that said, the cost of a couple different aluminum alloys that have the required yield strengths can be found from [23]. This is added to help anyone pursue a similar design.

2.7 Conclusion

The senior design project has allowed me to pursue a problem I have been pondering for several years. It finally gave me the incentive to solve it while gaining the experience of taking an idea all the way through the design process. This is something I am truly grateful for and believe will benefit my future career in engineering massively.

The final design of the Passing Board accomplished several of the design goals I initially set for it. Through its size and ability to fold open the board can be easily transported to and from the soccer field. It can stay static and in place through contact with the pass as the stakes and central back support provide stability. The design can be moved or modified with relative ease due to the handle implemented and the range of motion of the sides. The surface can also be extended to create different shapes or surfaces with the addition of more boards.

With all of this said, I am left slightly unsatisfied with my final design. I accomplished a lot of my initial goals, however, there are still some areas I did not succeed in and would like to address. The cost is one of them. As discussed previously, having a low cost was one of my evaluation criteria and as I took this design further and further down the process, I realized this may not be the best design for cost efficiency. I am also left wanting more mobility or a quicker way to move the board around the pitch. As I went further into the design process, my priorities switched from making a light weight, easy to move board to making a quality product that is made from a strong, reliable material and does not shift during the collision with the pass. I do not regret this decision; I am just pointing out there is still more to accomplish with this idea.

I believe this is the most exciting part of my design; all the potential it still has left. This design has the potential to be mass produced or made by any individual that has the desire. It also still gives me inspiration for future developments. I have spent a significant amount of time on this base design, but I still wonder if lights/electronics could be added to the design and allow for the lights of multiple boards to be programmed together so that reaction and vision can be integrated into the training session. I still wonder if another design may accomplish all my subfunctions and evaluation criteria better. I still wonder if another design could be of low cost and made with a strong, reliable material. These are the issues I have left unsolved and plan on addressing in the future as I continue trying to solve my expanded design brief to the level that completely satisfies all the requirements I established for it.
As I look back on my senior project, that is what gives me the biggest sense of accomplishment. I may not have made the best design or achieved everything I initially wanted. However, I took an idea I have been sitting on since my childhood and put it through the design process. Through research and calculations, the basis for myself or anyone else to come and try to solve my original problem statement is there. That is what engineering is. Failure is expected and going to happen, but a lot can be learned throughout the process of failing. Failure should not be looked at as a negative either. It only means one is another step closer to achieving their goal. That is the mindset an engineer must have in situations like this. As I think to myself this design may have turned out not as successfully as what I wanted, however, now I know the process and have established a great base of information to potentially make another effort. What is great about this senior project is that now all my work can be found and used by anyone to potentially make their own design.

My design or initial problem statement may not have a huge impact on the global or economic scale. However, this is what I believe is so special about engineering. I have identified a problem and made an initial effort to solve it. This first effort may not be the ideal solution, but the information and idea are out in society now. The world of engineering is a constant plug and chug system; if one idea does not work, move onto the next. It is only a matter of time before this design is addressed again, by myself or someone else, and then again, until the full problem statement is accomplished. This would provide soccer players around the world with access to a product that would lower the price of the individual training equipment and give them the ability to train at a high-level individually. This senior project may not have been able to achieve those effects on society or the global soccer economy itself, but it made the first strides towards accomplishing that. Through my future developments and efforts with this design or problem I hope to establish an environment friendly and cost-effective product that is inexpensive and accessible to all soccer players around the world. Achieving this with the design of the Passing Board will lower the cost gap that currently exists for players looking to improve their abilities in soccer. As soccer is becoming a more money driven sport, products that are low cost are essential for keeping the sport in the hands of its players. This gives equal opportunity for soccer players everywhere to get a piece of training equipment that can be used to better their game and raise their level. As I continue to develop this design and product, this is an essential goal of making the global soccer community aware of the discrepancy between the cost of the sport around the world and how it prevents some players from ever achieving their true potential.

2.8 Figures and Tables

This section provides all the figures and tables mentioned throughout the report. There is a section for figures, Chapter 2.8.1, and a section for tables, Chapter 2.8.2. They are placed in the order they were mentioned in the text. A title is included for each figure and table for a brief description. A more in-depth look of each can be found in their respective chapters in which they are mentioned and discussed. Zooming in on the figures may be necessary to see the smaller details.
2.8.1 Figures

Figure 1: Morphological Chart used for subfunction designs for the Passing Board

Concept A: [Description of Concept A]

Concept B: [Description of Concept B]

Concept C: [Description of Concept C]

Figure 3: Objective Tree used for conceptual design of the Passing Board
Figure 4: Drawings for the configuration design process

Figure 5: Isometric view of the final design when it is fully opened
Figure 6: Isometric view of the final design when it is closed

Figure 7: Isometric view of center piece of the board with dimensions
Figure 8: Location of hinges with respect to the center piece

Figure 9: Position versus time chart used in the experiment from [7]

\[ v_i = 15.7 \frac{m}{s} \]

\[ v_f = -9.38 \frac{m}{s} \]
2.8.2 Tables

Table 1: Weighted Decision Matrix used in the conceptual design of the Passing Board

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Weighting Factor (W)</th>
<th>Concept A</th>
<th>Concept B</th>
<th>Concept C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility (Ease of motion &amp; Ease of storage)</td>
<td>0.1875</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.0625</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Low cost</td>
<td>0.13</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Simplicity</td>
<td>0.07</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Stability</td>
<td>0.13</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Light weight</td>
<td>0.10</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0.03</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Small frame</td>
<td>0.10</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Flexibility of use</td>
<td>0.10</td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Low noise</td>
<td>0.02</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Low number of parts</td>
<td>0.05</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Potential for future development</td>
<td>0.02</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

ΣWᵢ = 1.0  ΣVᵢWᵢ = 3.305  ΣVᵢWᵢ = 3.9675  ΣVᵢWᵢ = 3.3025

Table 2: Data from Table 3 of [8] giving the mean peak impact force of all experimental trials within a 14-17 m/s velocity range

<table>
<thead>
<tr>
<th>Pressure, in bar (psi):</th>
<th>Mean Impact Force (in N) (+/- Standard Deviation) for Size 4:</th>
<th>Mean Impact Force (in N) (+/- Standard Deviation) for Size 4.5:</th>
<th>Mean Impact Force (in N) (+/- Standard Deviation) for Size 5:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.28 (4)</td>
<td>2508 (± 368)</td>
<td>2440 (± 340)</td>
<td>2669 (± 136)</td>
</tr>
<tr>
<td>0.55 (8)</td>
<td>2858 (± 455)</td>
<td>2688 (± 380)</td>
<td>2895 (± 817)</td>
</tr>
<tr>
<td>0.83 (12)</td>
<td>3167 (± 444)</td>
<td>2961 (± 346)</td>
<td>3284 (± 60)</td>
</tr>
<tr>
<td>1.10 (16)</td>
<td>3644 (± 334)</td>
<td>3093 (±326)</td>
<td>3606 (± 340)</td>
</tr>
</tbody>
</table>
Table 3: Measurements of the average force during the impact with a solid surface from a soccer ball at different velocities

<table>
<thead>
<tr>
<th>Initial velocity (m/s):</th>
<th>Velocity after Collision (m/s):</th>
<th>Impulse (N/s):</th>
<th>Average force (N):</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>-4.8</td>
<td>-4.6</td>
<td>-836.36</td>
</tr>
<tr>
<td>8</td>
<td>-6.4</td>
<td>-6.19</td>
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<td>10</td>
<td>-8</td>
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<td>16</td>
<td>-12.8</td>
<td>-12.38</td>
<td>-2250.91</td>
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<tr>
<td>18</td>
<td>-14.4</td>
<td>-13.93</td>
<td>-2533.09</td>
</tr>
</tbody>
</table>

Table 4: Bill of Materials for manufacturing of one prototype of the Passing Board

<table>
<thead>
<tr>
<th>Part:</th>
<th>Manufacturer:</th>
<th>Quantity:</th>
<th>Unit Price:</th>
<th>Total Cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stakes</td>
<td>Growneer</td>
<td>4</td>
<td>$1.58</td>
<td>$6.32</td>
</tr>
<tr>
<td>Locking Hinges</td>
<td>TopDirect</td>
<td>4</td>
<td>$3.60</td>
<td>$14.40</td>
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<tr>
<td>Screws</td>
<td>Uxcell</td>
<td>40</td>
<td>$0.0625</td>
<td>$2.5</td>
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<tr>
<td>Rubber Mallet</td>
<td>Pittsburgh</td>
<td>1</td>
<td>$3.00</td>
<td>$3.00</td>
</tr>
</tbody>
</table>

Table 5: Bill of materials for mass-production of prototypes for Passing Board (approx. 100)

<table>
<thead>
<tr>
<th>Part:</th>
<th>Manufacturer:</th>
<th>Quantity:</th>
<th>Unit Price:</th>
<th>Total Cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stakes</td>
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<td>400</td>
<td>$1.58</td>
<td>$632</td>
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<tr>
<td>Locking Hinges</td>
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<td>$3.60</td>
<td>$1440</td>
</tr>
<tr>
<td>Screws</td>
<td>Uxcell</td>
<td>4000</td>
<td>$0.0625</td>
<td>$24.98</td>
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<tr>
<td>Rubber Mallet</td>
<td>Pittsburgh</td>
<td>100</td>
<td>$300</td>
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</table>

2.9 References


