

DESIGN OF AN ANTERIOR CRUCIATE LIGAMENT INJURY REPRESSION SYSTEM

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CONTEXT

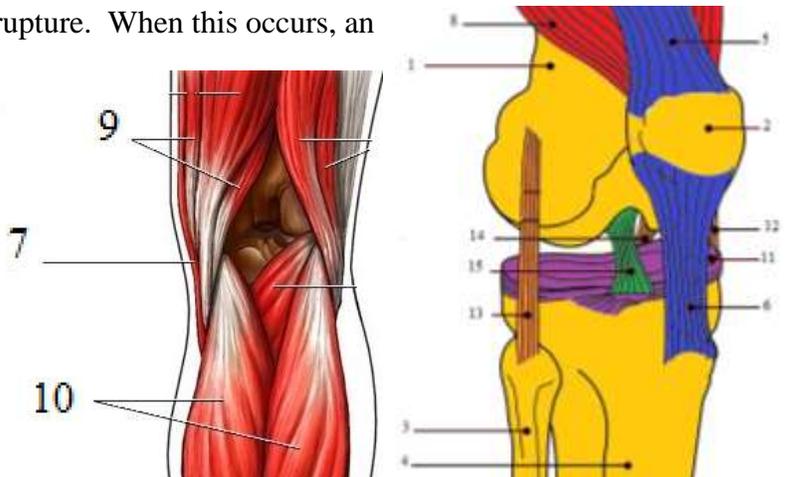
In 1972 the Higher Education Act of 1965 was amended and Title IX was born. This amendment provided equal opportunity for female athletes, allowing them to participate in college level sports. Since then, there has been an over 600% [16] increase in female participation in college sports. With that increased participation there had also been an increase in female dominant injuries, specifically anterior cruciate ligament injuries (ACLI).

ACLI generally occur when an athlete is participating in a sport. What happens is the athlete will be performing a specific move that changes direction in some manner and something will go awry.

$$B \text{ Visual}_t + B \text{ Understanding}_t + B \text{ Planning}_t + B \text{ Action}_t = A \text{ Action}_t$$

In the competitive ideology of sports, Athlete B is motivated to equate the above equation.

An athlete will perform a move in a dangerous way or their muscles will not be able to facilitate proper form. This causes a disproportionate amount of stress on the ACL that leads to its rupture. When this occurs, an athlete must have reconstructive surgery performed on them using a graft usually from another location in their body. This process take anywhere from 6 months to 9 months to recover from. After surgery the athlete will go through rehabilitation to get their body back until playing level. Even after all of that, only 44% [19] of college athletes return to sports.

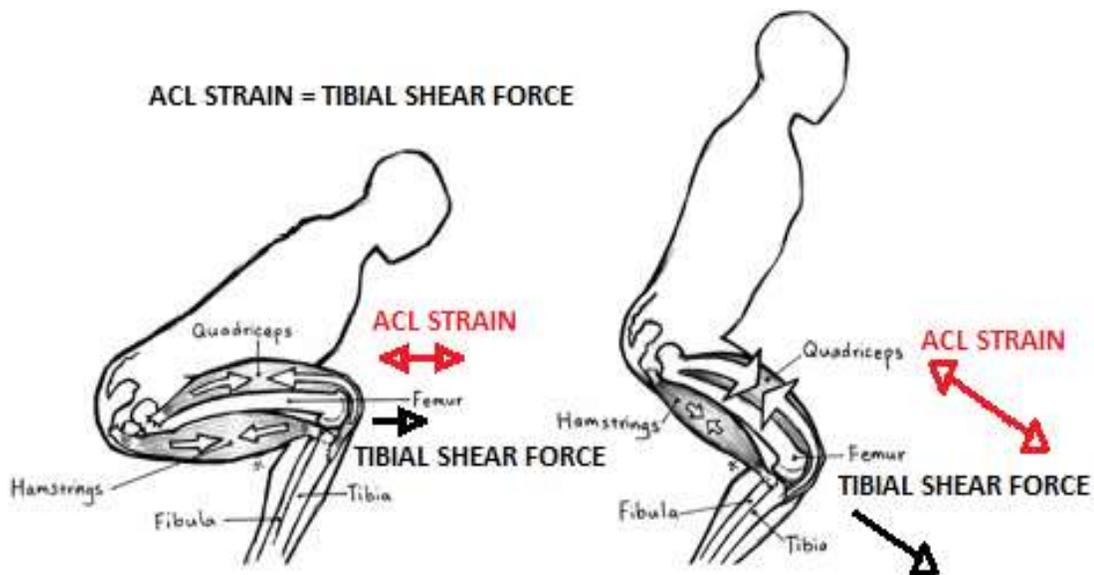


Female athletes have been shown to have roughly three times more ACL injuries than male counterparts [24]. Females on average have a larger Q-Angle than males, 16 degrees and 12 degrees respectively [31]. A recent study also showed that women tend to be more quadriceps dominant than men [14]. Therefore the contributing factor to the difference between ACL injuries between female athletes and male athletes are Q-angle and Quad-dominance. Deriving these two factors extrapolated the gender influence from the gender disparity problem. These factors are able to be focused on an individual basis because women and men both have q-angles and levels of quad-dominance.

THE KNEE SYSTEM

Before going on, it is important to know the knee system. The knee is made up of many sections. These can be broken down into five main sections; bones, muscles, tendons, meniscus, and ligaments. The first section (image 1) depicted in yellow (numbered 1 - 4) are the bones, the femur, patella, fibula, and tibia. These provide the structure to the leg and help it hold its form. The second section depicted in blue (numbered 5 - 7) is the tendons that are used for the graft, quadriceps tendon, patellar tendon, and hamstring tendon. Third, are the muscles shown in red, quadriceps, hamstring, and calf, (numbered 8 - 10) used to allow movement in the knee. Next, is the meniscus shown in purple (numbered 11). This, along with the synovial fluid (not depicted) located between the femur and the tibia provide cushion, shock absorption, as well as prevent the bones from rubbing together causing arthritis.[8] Last are the ligaments (numbered 12 - 15) depicted in orange and green. The orange ligaments are the medial collateral ligament, lateral collateral ligament, and posterior cruciate ligament (numbered 12 - 14) these help with stability. The anterior cruciate ligament (ACL) colored green (numbered 15) is what the paper is on. This little ligament, the size of a quarter plays a major role in knee stability. Without it, the femur tends to slip forwards causing excruciating pain.

Quad dominance is the tendency to stop a jumping motion between zero to 60 degrees. [19] The associated angles the human skeleton has to be in to keep from falling over in a quad dominant position causes the knee system to create large Tibia Shear Force.



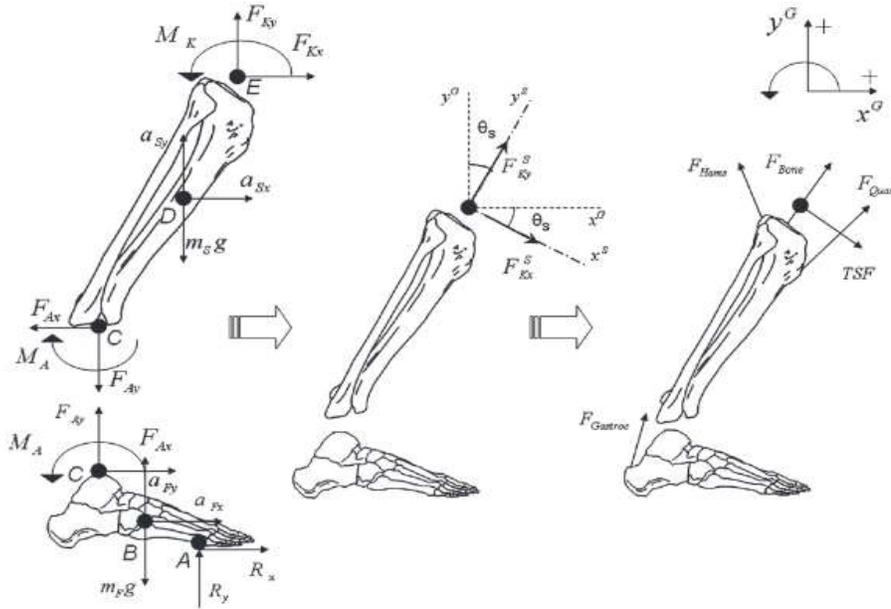
[Figure 3] The figure on the left is landing with good form while the figure on the right is landing with Quadriceps dominant form. [30]

Tibia Shear Force (TSF) is integral to understanding the mechanism of injury. It is derived from a physical model that relates muscle forces, bone angles, and bone weight.

$$TSF = Tibial Shear Force \approx ACL Strain$$

$$T S F = m_s [a_{s x} \cos \theta_s - (a_{s y} + g) \sin \theta_s] + m_f [a_{f \cos \theta_s} \cos \theta_s - (a_{f y} + g) \sin \theta_s] - R_x \cos \theta_s + R_y \sin \theta_s - \sum F_{C a l f}^S - \sum F_{Q u a d}^S - \sum F_{H a m}^S$$

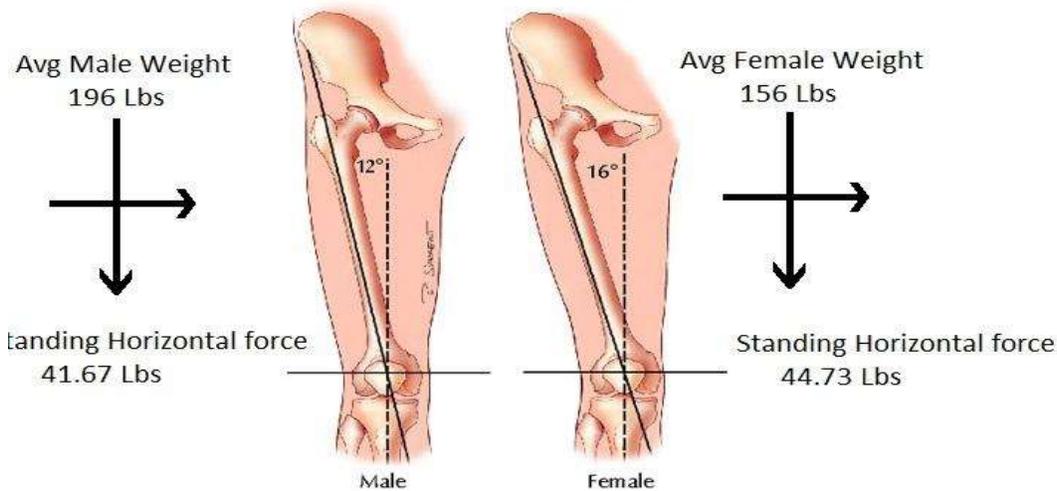
$$T S F = f(\text{Neuromuscular Form, Skeleton Mass, Muscle Strength})$$



[Fig. 4][18]

Q-angle is the angle of the femur takes to the tibia. Women have been shown to have larger q-angles but this input has been extrapolated for use of our model.

Comparison of male and female Q angles



$$\text{Horizontal Force} = \text{Weight} * \tan(\text{Q-Angle})$$

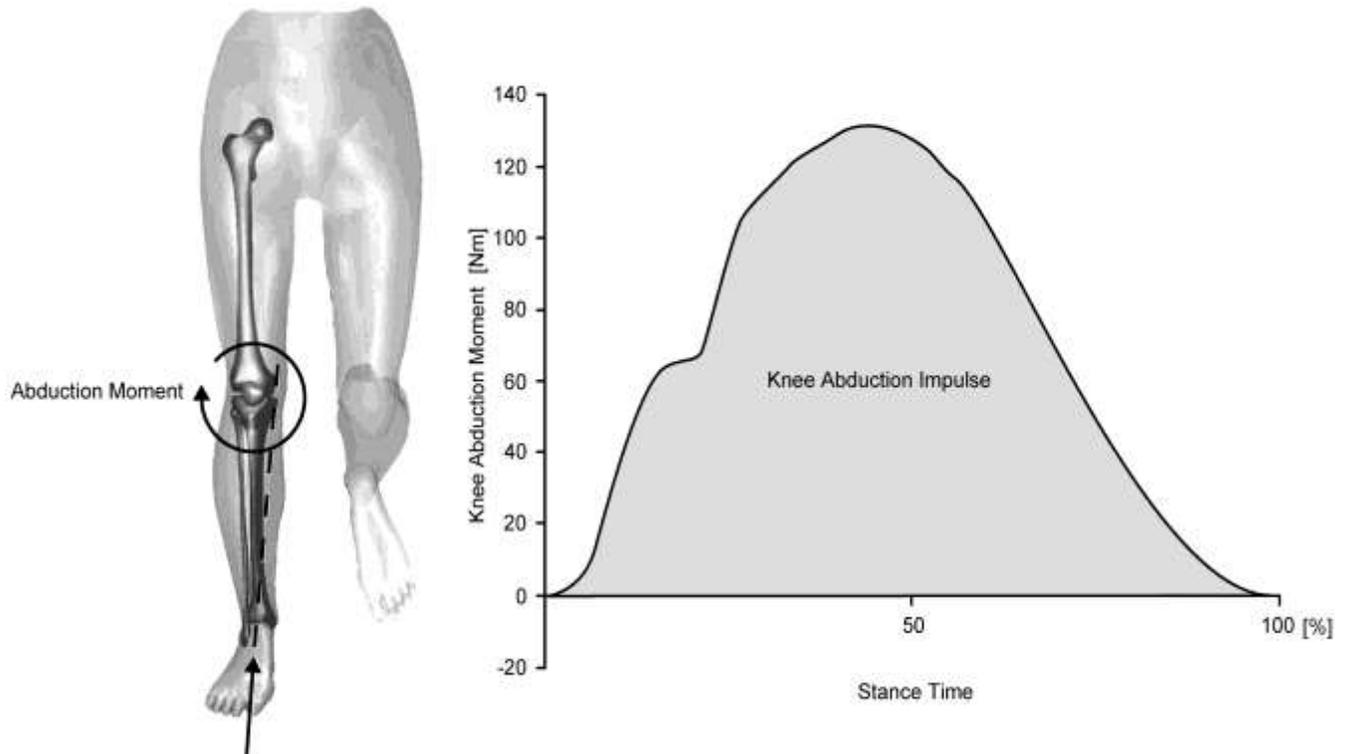
On Average a woman experiences 7 percent more horizontal force on the knee system

[Fig. 5]

The higher the q-angle, the higher the horizontal force to the knee system is [Fig. 5]. This along with the tibia length gives a value for knee abduction moment. Knee Abduction moment is the value given to the rotational force caused on the knee system by the femur and tibia [Fig. 7].



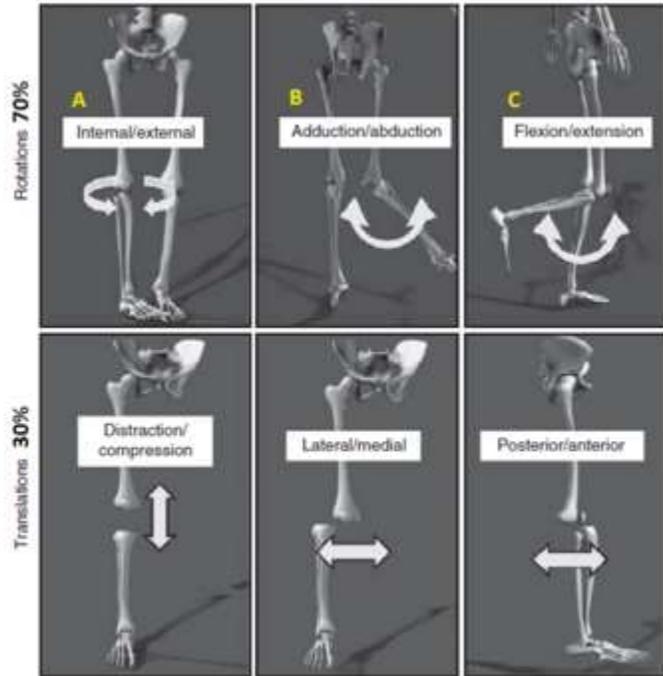
[Fig. 6]



[Fig. 7]

ANTERIOR CRUCIATE LIGAMENT INJURY

The anterior cruciate ligament (ACL) allows the knee to move in a hinge like manner. ACLI occur when the upper part of the leg (femur) continues in one direction and the lower part (tibia/fibula) continues in another. ACLI can be broken up into two categories, rotations (non-contact) which make up 70% [20] of ACLI and translations (contact) which make up 30%. [20] The



non-contact injuries can be broken down even further into five categories, internal/external (A 16%), adduction/abduction with rotation (A&B 37%), flexion/extension with rotation (A&C 1%), adduction/abduction alone (B 9%), and flexion/extension alone (C 37%).[25]

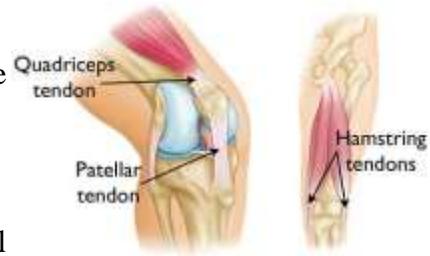
These rotational ACLI are a result from cutting, jumping, or pivoting incorrectly during a sport whereas, the translation injuries tend to result from being hit or tackled by great forces during a small window of time. Both of these types of ACLI place an excess strain on the anterior cruciate ligament (ACL). The natural human ACL can support $2150 \pm 157N$, [10] however, when the forces exceed that, the ACL Tears. Due to the fluid in the knee, known as synovial fluid, which has the main purpose of absorbing shock and allowing for easy movement, the ACL cannot mend itself. The fluid prevents the two ends from meeting and forming a platelet bridge to help the healing process. This inability to heal itself causes the knee to require a graft in order to regain its entire mobility and function.

SUB SYSTEMS

The overarching system has three subsystems. The subsystems are repression, reconstruction, and rehabilitation. Currently there are some uses in effect today but like all systems they are all faulty. The repression subsystem that is in effect today is not widely practiced or advertised. Only about 33% [22] of coaches require their athletes to perform ACLI repression training, even though it can reduce ACLI by up to 62% [2]. The coaches tend to be of the opinion that the repression programs detract from their practice time even though there is evidence proving that it helps an athlete perform better in a given sport. The repression programs focus on having a person do some athletic movements and a training coach watch for errors or defects in the action. After observation the person may be given an exercise to perform to strengthen an area. [3]

For reconstruction, grafts are typically taken from one of three areas. The patellar tendon, quadriceps tendon, or hamstring tendons. These can be broken down into two types of grafts, bone tendon bone (BTB) or bone tendon ligament (BTL).[11] Patellar and quadriceps are BTB and hamstrings are BTL. Each of these types of grafts has a risk associated with them. BTB grafts take 8[9] weeks to heal and have a 1.3% [1] chance of fracturing the patella. BTL have a 7% [1] chance of the graft being placed in the wrong spot and take 12 [9] weeks to heal. Currently, both grafts are done arthroscopically, through the surgeon making small incisions into the knee and using an arthroscope (camera on a stick) to perform a minimally invasive surgery.

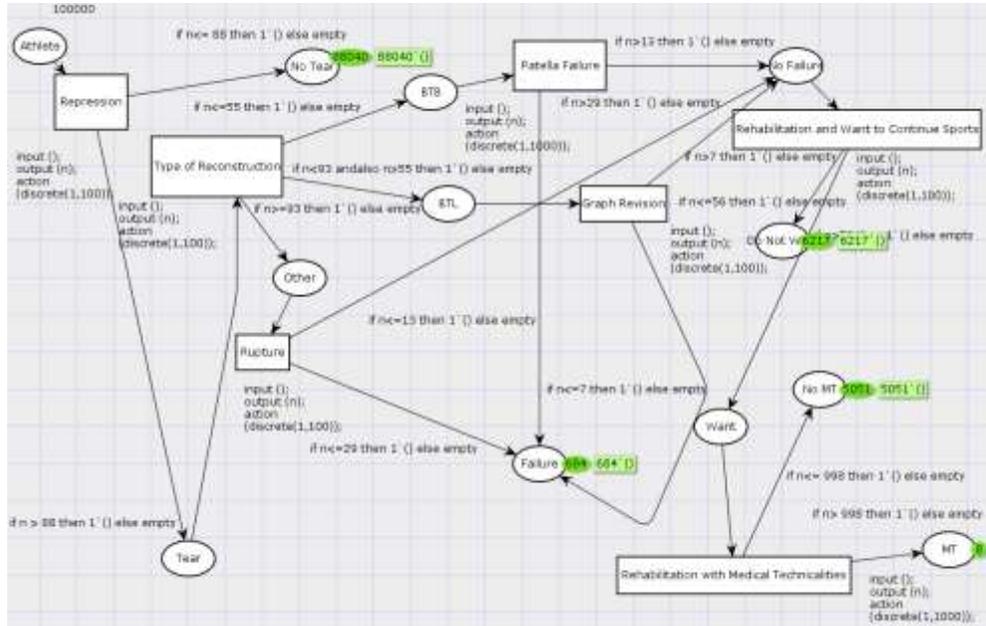
Rehabilitation usually consists of a series of movements that are performed to increase flexion, balance, and strength after the surgery. After surgery, only about 44% of athletes will return to their previous level of sports.



PROJECT SCOPE

Finding common factors and stakeholders that flowed through all the subsystems was difficult. Therefore it was decided that it would be best to model the failure rate of each system. The model was made using CPN tools. It had athletes for inputs and failures for outputs. Some of the outputs are athletes that do not tear their ACL, athletes that do tear their ACL and then have a failure during surgery, athletes that tear their ACL, go through surgery, and then do not want to return to sports, and athletes that tear their ACL, go through surgery, want to

return to sports, but cannot do to medical technicalities such as infection. A sample run through the system looks like the depicted model below.



The failure rate was calculated using the below equations and then normalized. These equations show that repression has the largest weight. Therefore we will be focusing on trying to minimize error there. As a side note, this model is fairly linear. Therefore if we are able to change something in the beginning, it should affect the process later on too. Also, most repression concepts can also be used for rehabilitation.

$$\text{Repression Failure Rate} = \frac{\text{Failure During Repression}}{\text{Athletes in the System}} = 63.38\%$$

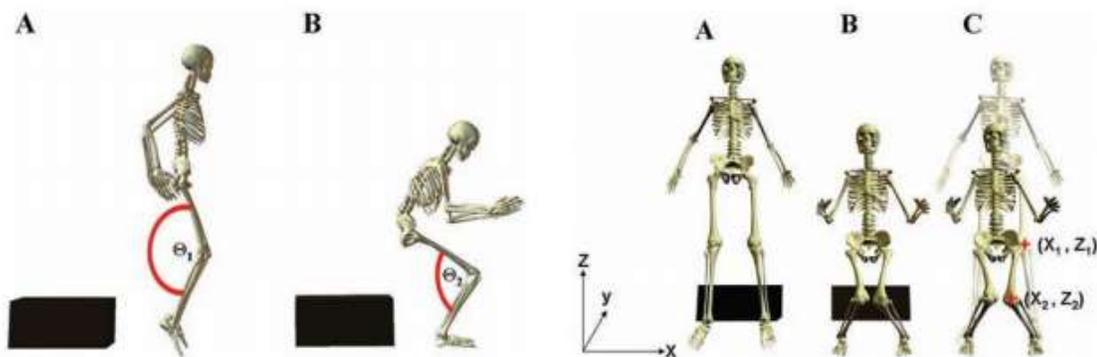
$$\text{Reconstruction Failure Rate} = \frac{\text{Failure During Reconstruction}}{\text{Athletes With a Tear}} = 3.63\%$$

$$\text{Rehabilitation Failure Rate} = \frac{\text{Failure During Rehabilitation}}{\text{Athletes With Successful Reconstruction}} = 32.99\%$$

RISK FACTORS

There are some factors that play a role in ACLI; the main ones are body mass, tibia length, knee valgus motion, knee flexion range, and quadriceps hamstring ratio. Body mass is the weight of the individual in kg. The higher the mass the higher the force the body has to absorb. Tibial length is the length of the shins. This relates to torque, the longer the tibia, the more force applied. The equation is Knee Abduction Moment = Body Mass * Gravity * $\tan(Q)$ * Tibia Length. [14] Neuromuscular factors relate to Knee valgus distance and Knee flexion range of motion.

Knee valgus motion is the change in distance the knee moves in the Sagittal plane during a drop jump movement. This applies more horizontal force to the ACL. Knee flexion range of motion is the difference in flexion angle at the beginning of an athletic movement and the end. The equation is Knee Flexion Range of Motion = $(1 - 2)$ [14]



Quadriceps Hamstring Ratio is the muscular forces acting on the knee and ACL. Contraction of the quadriceps tends to pull the tibia forward while contraction of the hamstrings tends to pull the tibia backwards. Hamstring activation tends to help stabilize the knee and support the ACL during landing and cutting movements. Quadriceps Hamstring Ratio

can be written as Quadriceps Hamstring Ratio = Quadriceps Strength Hamstring Strength [5]. The whole equation is listed below (derived from Myer et. al. study). There are three other main factors that play a role in ACLI but we have yet to determine the exact correlation. Those are fatigue level, shoe-surface interface (coefficient of friction), and hormones.

$$x = -0.285714 \text{ flexion} + 0.390625 \text{ mass} + 6.66667 \text{ ratio} + 4.16667 \text{ tibia} + 4.61467 \text{ valgus} - 94.4315$$

<i>if x</i>	{	> 56	$< .1$
		$56 - 72$	$\frac{x - 56}{106.67} + .1$
		$> 72 - 100$	$\frac{x - 72}{56} + .25$
		$> 100 - 114$	$\frac{x - 100}{93.33} + .75$
		$> 114 - 130$	$\frac{x - 114}{228.57} + .9$
		$> 130 - 144$	$\frac{x - 130}{700} + .97$
		$> 144 - 172$	$\frac{x - 144}{3111.11} + .99$
		> 172	$> .999$

STAKEHOLDER ANALYSIS

Below are the determined stakeholders that will be affected by our system.

PRIMARY STAKEHOLDERS

The primary stakeholders are the people who the system impacts directly.

1 Collegiate Athletes (CA)

Their main objectives are to increase average playing time and increase media exposure. An ACL tear may end the college scholarship for CAs. It may reduce their opportunity in going to the professional level. It may develop a fear from the sport. It may develop depression and

anxiety that affect that may affect their educational performance. CA would benefit from the ACL Repression Program because it would reduce the probability of an ACL tear.

2 Head Coaching Staff

They coach's main objective is to increase winning percentages. In order to achieve that, the coach needs to have the whole team available, ready, and their fitness level are up to the desired level. If a valuable athlete is injured, they may need to change the lineups and the way the whole team plays. The Repression program aims to increase winning percentages, which correlates with the goals of the coaching staff.

3 Athletic Trainers

The trainers are professional who are assigned to develop sport medical programs that aims to maintain or improve the athlete's' fitness level. The Repression program will not have any effect on the trainers because they will be needed to develop neuromuscular, strengthening, and conditioning training programs to reduce the probability of the ACL tear. [28]

4 Insurances

These Insurances will pay for the ACL reconstruction surgery. Their main objective is to make profit. The Repression Program will be beneficial to them if it cut on the number of ACL injuries per year because it will reduces their average spending on ACL surgeries.

5 National Collegiate Athletic Association (NCAA)

The NCAA regulates the rules of collegiate sports. They determine participants' eligibility of colleges and student athletes, and which division they will compete in. The NCAA

are considered as a non-profit organization, in which the money flow coming in from media rights are used to benefit only NCAA participants.

6 Team Physician

Team Physicians have the power to determine athletic exposure eligibility for student athletes. If the student athlete was injured or at high risk levels of injury, the head coach cannot make the student athlete play, and athletic trainers are instructed by the team physician to develop a sport medical program that meets the need of the student athlete.

SECONDARY STAKEHOLDERS

Secondary stakeholders are people who are impacted indirectly by the system.

1 Family of FSCA

They include the parents and the siblings of the injured athletes. The family generally cares about the well-being of the injured athlete. An ACL tear may take time, money and effort from the family to support the athlete during recovery period. Since the Repression program aims to reduce the probability of a tear, it correlates with the goals of the family.

2 Teammates

The teammate's main objectives are the wellbeing of their fellow student athlete who is at high risk of injury, as well as to increase average playing time and increase media exposure. The Repression Program will also benefit them because it would reduce their probability of an ACL tear.

3 Orthopedic Surgeons

An ACL reconstruction surgery is one of the most common procedures done by orthopedic surgeons. The Repression program would reduce the amount of ACL reconstruction surgeries needed, which may decrease the demand for orthopedic surgeons. However, the impact may not be as big because the ACL reconstruction surgery is just one out of many surgeries performed by orthopedic surgeons.

4 Physical Therapists

Physical therapists are experts who have the knowledge to restore the pre-injury fitness level of the injured athlete. Although the Repression program would decrease the amount of patients who will go through rehabilitation, physical therapists are still needed to develop injury prevention programs.

5 College Institutions

Although there is a huge debate in the value of college sports since its expenses are generally higher than its revenues, one of the primary goals of college institutions is to increase media exposures to attract more students to apply. An increase of winning percentages leads to more media exposures. Although the current system uses heart rate monitors, it does not used in the context of ACL prevention, meaning a coach will not pull the student athlete from the field if the risk levels of an ACL tear increased. The Repression will make change the use of such products; but it may not influence the demand for them since they are already widely used.

STAKEHOLDER TENSIONS

The NCAA regulates the athletic competition for the competing athletic departments from each college. To be able to pay for athletic expenses such as athletic staff salaries, athletic

equipment (support gear, monitoring gear, and motion analysis tools), athletic clothing, transportation for away games, and other expenses, colleges need to fund the athletic department. Additional to these cost, the NCAA require that the athletic department also pays for insurances that covers up to \$90,000 athletically related injuries paid to orthopedic surgeons and physical therapists for ACLI patients. The higher ACL injury rates, the higher the demand for them. Team physician have the authority over the head coaches and athletic trainers to determine the eligibility for athletic exposures, this relates with the goals of the college institutions.

1 Athletic Clothing Brands

They are companies that have financial motives to gain out of the athletic competition regulated by the NCAA; they will gain by selling their athletic clothing to the athletic departments. The Repression program does not influence them.

2 Tool Manufactures

Tool manufacturers create equipment for different types of training.

2.1 Motion Analysis Manufactures

They develop products that aim to collect and analyze data about the moving subject, such as gait analysis. Because the current system uses visual analysis to determine the risk factors for ACL, they are not needed as much. The Repression will be beneficial for motion analysis manufacturers because it will make use of such products; thus increasing the demand for their products.

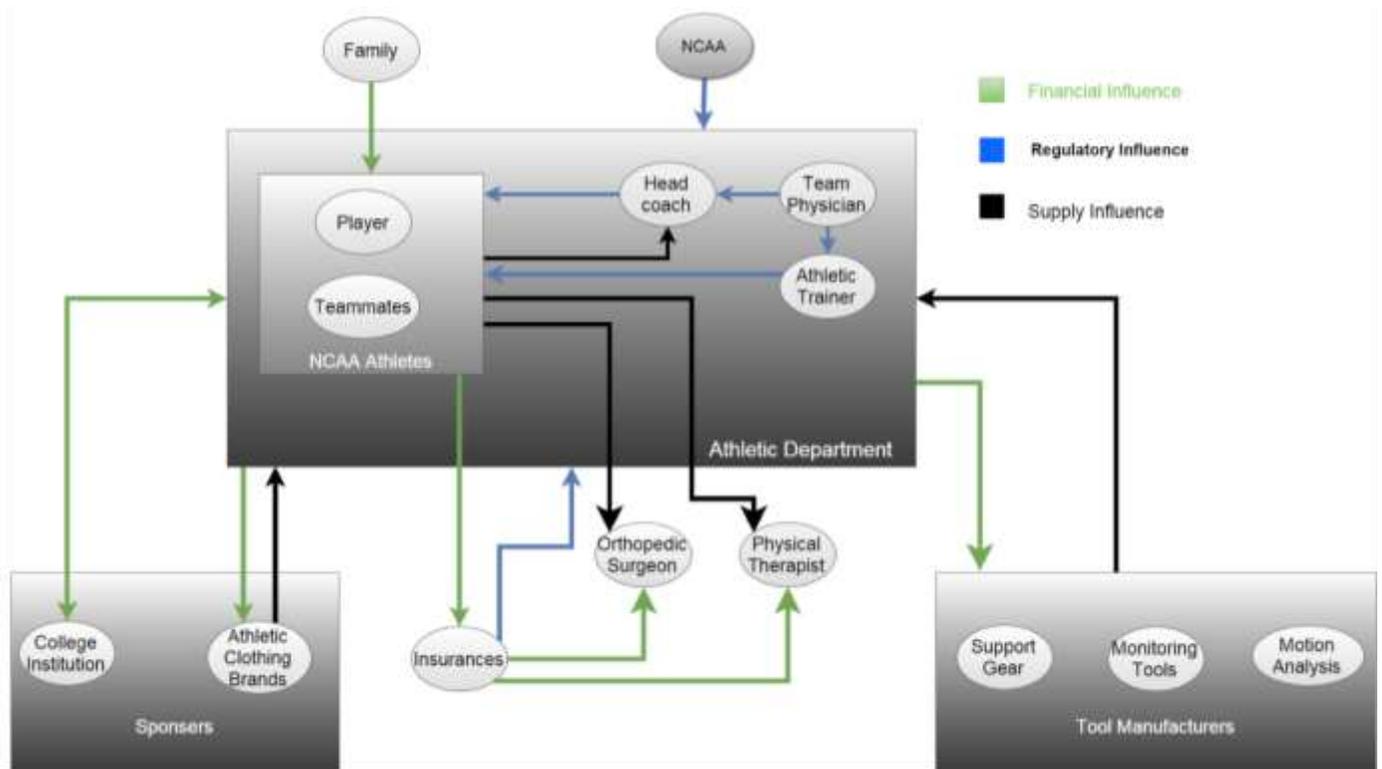
2.2 Support Gear Manufacturers

They develop products that aim to support the knee joints, and reducing the likelihood of an ACL tear. Usually, only athletes with previous injury records would use support gear.

However, the Repression program will make use of such products because it will make athletes with high risk of ACL as users of their products; thus increasing the demand for their products.

2.3 Monitoring Gear Manufacturers

They develop products that aim to monitor the risk levels of moving subject during a game, such to alert the presents of fatigue.



PROBLEM AND NEED

There are a couple gaps in the existing system. One, only 33% of colleges implement injury prevention programs even though they have been shown to reduce the likelihood of an ACLI. And two, current visual analysis done by the colleges that actually implement prevention programs do not quantify ACL load, and cannot determine the internal structure during load bearing activities.

PROBLEM STATEMENT

This brings us to our problem statement, from our research we have determined 13% of NCAA athletes participating in dynamic sports tear their ACL in non - contact injuries each year, only 33% of coaches implement a repression training, and nobody is accountable for preventing an ACLI.

NEED STATEMENT

The need statement that will create a win - win scenario is there needs to be a precise system that quantifies the risk of an ACL tear, lowers the probability of an ACL tear resulting from non - contact athletic moves by XX%, and a way to implement and enforce the system to all athletes throughout their college career.

CONCEPT OF OPERATIONS

Below is the user-oriented design that describes the characteristics for the proposed system from the viewpoint of our stakeholders.

STAKEHOLDER UNIFIED ACTION PLAN

In our need statement, we isolated the necessity for a method to enforce an ACLI repression system. We conducted stakeholder analysis with the George Mason University soccer team to find out if there is an enforcement system already in place. After interviewing John C. Delgado, the assistant strength and conditioning coach who runs the current repression for the female teams, we found out that there is no mandated repression program in place by the NCAA. This information combined with information from a study that states that only 33% of high

school coaches implement a form of repression [17], we isolated the need for a method to enforce ACLI repression programs for college athletes.

The reason we chose to focus on college athletes is because from our further research into authority of the NCAA, we found a few NCAA regulations that we could leverage to enforce a repression program.

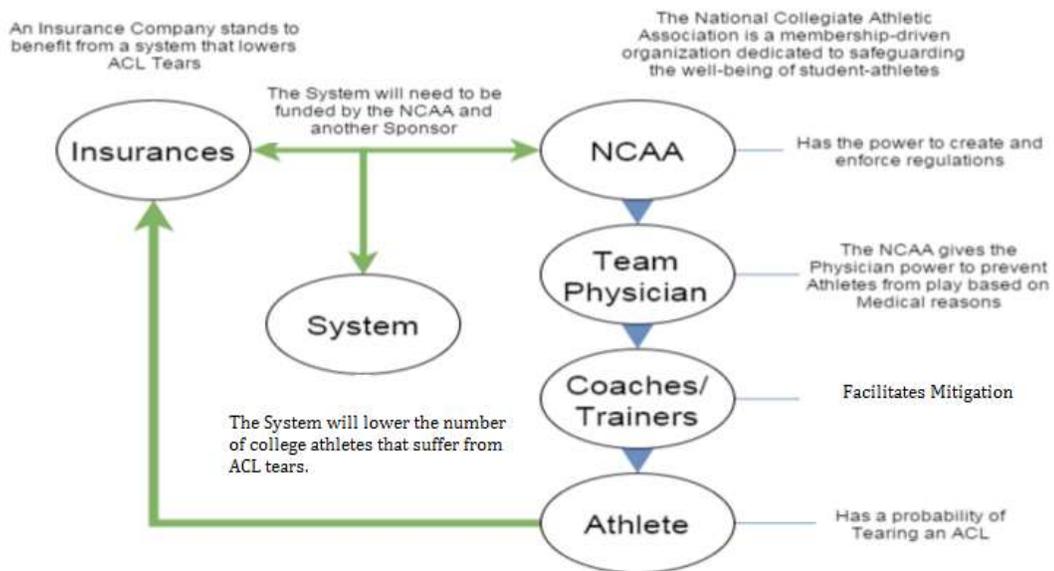
“A member of the institution’s sports medicine staff should be empowered to have the unchallengeable authority to cancel or modify a workout for health and safety reasons, as he or she deems appropriate. A member of the institution’s sports medicine staff should be empowered and protected when reporting events thought to endanger a student athlete or conflict with the institution’s medical care and safe environments policies.”[19]

A team physician has the authority to remove a player from a workout or competition for health and safety reasons. This shows us that there is an enforcement method that we could leverage if we could show that there are different probabilities of ACL tear based on individual metrics. Also if we could define a certain level of probability of ACL tear, say 30% based on our simulation model, we plan on defining a medical syndrome following this logic. If a player is found to be above our defined probability of tear then they would have that medical syndrome, high tear syndrome. With this defined syndrome, the NCAA could make a regulation that would enforce the team physicians to look for high tear syndrome and then remove those athletes from play or workout.

To define a medical syndrome based on probability of tear, we will need a study showing that there is a proven increased risk for some athletes to tear their ACL’s. This study is being laid out by this senior design project. Since our project is showing the capability of a repression

system, the further undertaking to adapt the system will be enacted by a larger study with a good amount of funding.

This larger study will use our logic and method of analysis on a larger scale to develop the necessary identifying mechanism of ACL injuries. Also this study will fund the implementation of our system. Our system will cost \$XX and therefore will need contributions from a large economical stakeholder.



From further stakeholder analysis we found that Insurance Companies are the ones that have the most economical impact on ACL injuries. They also stand to benefit by the decrease of the number of ACL injuries.

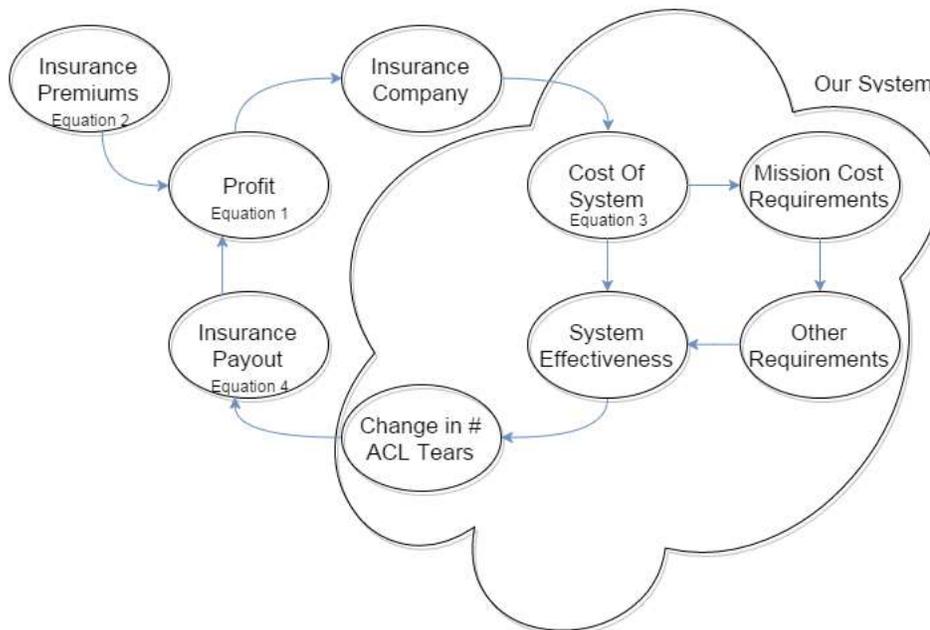
- 1) *Insurance Profit = (Total Premium Intake) –
(Total Cost of Implementing System) –
(New Payout Cost after Implementing System)*

- 2) *Total Premium Intake = (# of insured athletes)*
(Premium rate of athletes)*

- 3) *Total Cost of Implementing System = (Identify Costs) +
(Mitigation Costs) +
(Warn Costs)*

- 4) *New Payout Cost after Implementing System = (Current # of ACLI's) *
(1 – Δ%System Reduction Requirement)*

These equations show that the insurance companies stand to profit by the effectiveness of our system. Leveraging the Insurance companies is key to the implementation of our system and the overall lessening of ACLI occurrences.

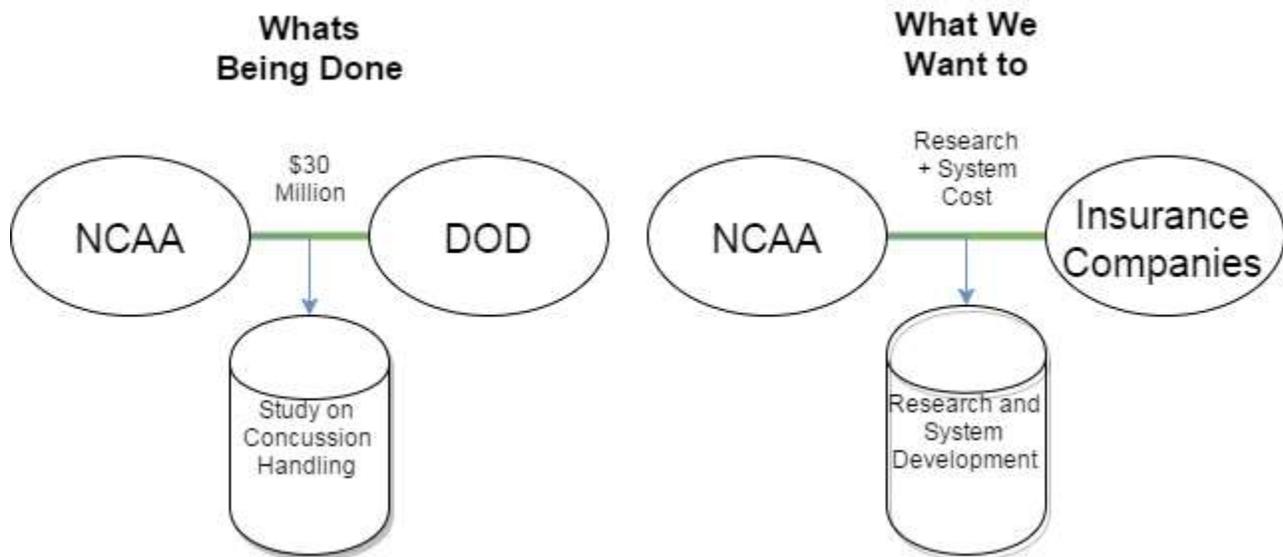


This above flow chart shows the relationship between an insurance company's profit and the effectiveness of our system.

PREVIOUS ATTEMPTS

We base our stakeholder leverage strategy on a recent study on concussion handling by the NCAA and the DOD. In 2015, the NCAA teamed up with the DOD to fund a \$30 million dollar project into investigating the causes of concussion and researching mitigation and handling strategies pertaining.[21]

We plan on using the same strategy but with a different economic stakeholder. Since we have observed that the insurance companies stand to profit by the implementation of our system, we plan on having them team up with the NCAA to facilitate our project.



REQUIREMENTS

Below are the requirements for our simulation. These are specific to our system with its three sub-systems, identification, mitigation, and warn.

MISSION

The mission requirements were derived from our stakeholders. The first requirement is the main need for our system. The second one shows that it will be customizable. Three through six discuss the lifecycle of the system through an athlete's college career.

Number	Requirement
MR.1	The system shall reduce the probability of ACLI in collegiate athletes by XX%.
MR.2	The system shall work with individual athlete's ranges of motion specific to the sport.
MR.3	The system shall cost no more than 80% the profit of the insurance company.
MR.4	The system shall cover an athlete through their entire NCAA career.
MR.5	The system shall not detract from a coach's coaching time.
MR.6	The system shall be maintained throughout an athlete's NCAA career.

FUNCTIONAL

The first four functional requirements display how the strain in the ACL shall be reduced and by how much. The next three discuss how identify and mitigate probability of tear, as well as, warn about fatigue. Functional requirement 4.1, 4.2, and 4.3 show the start and stop of the system in regards to an athlete. Functional requirement 6.1 shows how the system will react to new scientific studies.

Number	Requirement
FR.1.1	The system shall decrease ACL strain caused by knee valgus angle by XX%
FR.1.2	The system shall decrease strain caused by mass by XX%
FR.1.3	The system shall decrease strain caused by quadriceps/hamstring ratio by XX%.
FR.1.4	The system shall decrease strain caused by knee flexion angle by XX%.
FR.2.1	The system shall identify an athlete's probability of tear with XX% confidence.
FR.2.2	The system shall use team training, private training, and/or supports to mitigate an athlete's probability of tear by XX%.
FR.2.3	The system shall use warning tools monitor athlete's fatigue level with XX% confidence.
FR.4.1	The system shall start when an athlete starts a college sport.
FR.4.2	The system shall end when the athlete chooses to leave the sport.
FR.4.3	The system shall end when the athlete becomes ineligible to compete in the sport.
FR.6.1	The system shall receive updates within 30 days of a new and confirmed scientific study suggesting change.

DESIGN

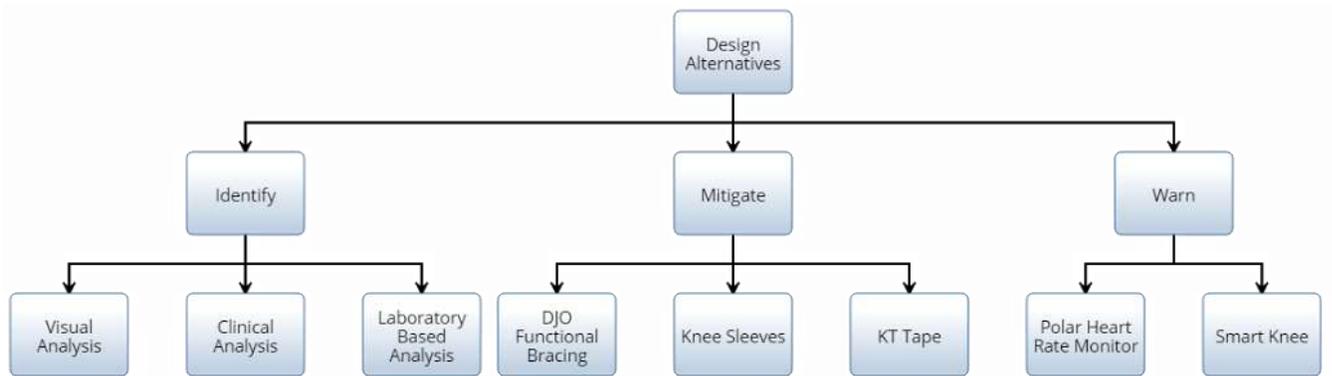
Design requirement one discusses the material the physical aspects of the system shall be made out of. Requirement 2 - 4 show how long each sub-system should take to use. Requirements 5 - 7 show how often each sub - system should be done and what will determine it. Design requirement 8 makes sure that the athlete is still able to play their sport. Design requirement 9 shows the need for all the subsystems.

Number	Requirement
DR.1	The system shall have non - dangerous, NCAA approved materials for equipment.
DR.2	The system shall take no longer than XX minutes to identify the probability of ACL tears through each iteration.
DR.3	The system shall take no longer than XX minutes per week to mitigate.
DR.4	The system shall be able to monitor for a minimum of XX minutes per day.
DR.5	The system shall identify high risk athletes every 8 weeks.
DR.6	The system shall suggest a way to mitigate p(tear) based on how it was identified.
DR.7	The system shall suggest a way to warn the coach of fatigue based on heart rate.
DR.8	The system shall not decrease an athlete's athletic ability.
DR.9	The system shall decrease an athlete's p(tear) by identifying, mitigating, and warning

of fatigue.

DESIGN ALTERNATIVES

We have up with three sets of design alternatives, identify mitigate, and warn. Identify and mitigate have three options and warn has two.



IDENTIFY SYSTEM ALTERNATIVES

The design alternatives for identify include visual, clinical, and laboratory based analysis. These are three different ways to determine athletes at a high risk of an ACL tear.

VISUAL ANALYSIS

Visual analysis is the current as-is system for teams that do prevention programs, a physical trainer will monitor a team of athletes performing various dynamic movements, and assess the athlete's probability of tear visually. A few advantages of this design alternative are that it provides direct observation or description of injury mechanism, has no side effects, and is comprised of primary or secondary information. This design alternative also has limitations, it cannot determine internal structure stresses/strains, the physical trainer has to focus on one

athlete at a time, and it is error prone. The additional cost of visual analysis would consist of the number of extra hours a physical trainer would need to perform the analysis on a full athletic team.



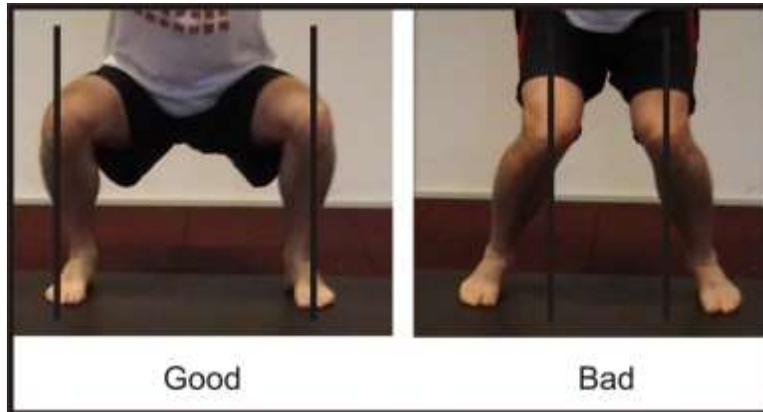
Free Image Bank <2015>

CLINICAL ANALYSIS

The clinical analysis alternative would be similar to an athlete's' yearly physical exam with the addition of performing a drop-jump test to view neuromuscular deficiencies.

Advantages of this alternative are it evaluates the athlete's probability of tear during times of high knee load, has an adequate specificity of 60-72%, [15] and can be performed during the athletes' yearly physical. Limitations of clinical analysis are, the lack of data on internal stresses/strains, the need for trained team physicians, risk of injury during the drop-jump test, and it has a low sensitivity ranging from 67-87%. [15] The additional cost of clinical analysis

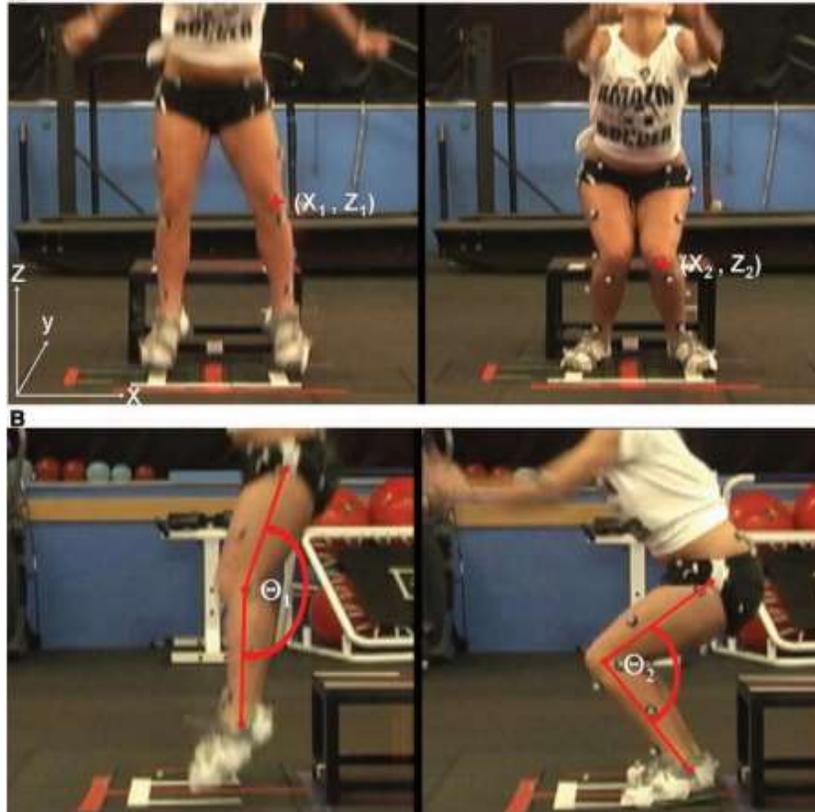
would comprise of the number of extra hours needed multiplied by the team physicians hourly rate.



Precision Nutrition <2015>

LABORATORY BASED ANALYSIS

During a laboratory based analysis an athlete performs dynamic movements while wearing node clusters and being recorded by multiple cameras. The resulting recordings are then used to recreate the movements in a computer software, and are then analyzed. Advantages of this alternative are that it returns metrics to the athlete; it uses highly sensitive cameras during the analysis, provides the athlete with a 3D model of their body, and is able to take into account knee abduction angle and knee abduction moment. [29] Limitations of this alternative are that it requires supervision, takes an hour to calibrate, and the total system costs 9600 dollars plus. [12]



Myer et. al. <2010>

MITIGATION SYSTEM ALTERNATIVES

The mitigation design alternatives provide ways an athlete may reduce the chance of tearing their ACL.

DJO FUNCTIONAL BRACING

DJO functional bracing provides knee support to counteract excess horizontal force on the knee. This alternative reduces an athlete's' ACL strain by 50%. The advantages of the DJO functional bracing are it can control rotation instability, reduces tibial shear force applied on the tibia by the quadriceps, and increased knee flexion angle by seven degrees. Limitations of this alternative are that it is most effective in rehabilitation, some braces contain metal or hard plastic

which can be dangerous, is expensive, and may have a negative effect on performance. The additional cost of this alternative is 899.99 dollars per person.



DJO Global <2015>

KNEE SLEEVES

Knee sleeves are another alternative for the mitigation system. They are similar to the DJO functional bracing in terms of providing the knee system support during times of heavy load. Some advantages are they relieve pressure on the knee, improve coordination, and are significantly less costly than the DJO functional bracing. A main limitation of knee sleeves is the lack of data on ACL strain reduction. The cost of knee sleeves is 39.85 dollars per athlete.



Rogue Fitness <2015>

KT TAPE

KT tape also provides the knee system with support during dynamic movements to reduce the likelihood of suffering an ACL tear. Advantages of this alternative are that it supplies support to the joint by restricting movement and is the cheapest alternative for the mitigation system. The main limitation of this alternative is there is uncertainty on the short term and long term side effects. The side effects could consist of decreased performance due to lack of mobility and the potential of weakening the knee system. The cost would be 12.99 per person.



KT TAPE <2015>

WARN SYSTEM ALTERNATIVES

The warn design alternatives provide the coaches and athletes a way to monitor the fatigue level of an athlete.

POLAR HEART RATE MONITOR

The Polar heart rate monitor tracks the athlete's' level of fatigue through heart rate readings. Athletes' could wear this alternative during games underneath their jersey, and the heart rate of the athletes' could be tracked by the coach through the accompanying software. Increased fatigue level in athletes' can lead to poor neuromuscular form during dynamic

movements, which can make athletes have a higher probability of incurring an ACLI.

Advantages of this alternative are that it can be used by coaches during practice as well as official games, it does not have any side effects, and has a battery life that can be used for twenty-four hours a day for two weeks. A large limitation of this alternative is that it does not measure any metrics related to the knee system, and solely measures the athlete's fatigue level. The additional cost for a twenty five man team would be 15660 dollars.



Polar <2015>

SMART KNEE

Smart knee by Bendlabs is a knee brace with sensors that is able to track complex knee motion. This alternative uses silicon sensors to measure knee system angles, estimated amount of knee load, and an estimated q-angle during dynamic movements. The data gathered by the sensors are sent via Bluetooth to a device with the accompanying software to be analyzed and displayed as quantitative metrics. Advantages of the Smart Knee are that it provides metrics in real time, it is simple to use and read data from, and it is safe to use with no side effects. The limitations of this alternative are that it is more effective during the rehabilitation of the ACL and it is currently in the beta development phase.



Bendlabs <2015>

METHOD OF ANALYSIS

The objective of our simulation is to simulate our system concept using inputs from a kinematic model and different values for our design alternatives. Since our systems function is to lower the overall probability of tear for a population, the outputs will be probabilities of tear with a confidence interval specific to each design alternative.

SIMULATION REQUIREMENTS

The model that we will be developing over the winter break has a specific set of requirements. Requirement one and its sub-requirements deal with the different types of inputs used to calculate out the probability of tear. They are all body metrics and error rates associated with each type of identify, mitigate, and warn option. Requirement two describes the output. It is a probability of tear with a specific confidence interval. Requirement three and four state that there will be personas and the probabilities will be sourced. The personas will have values for

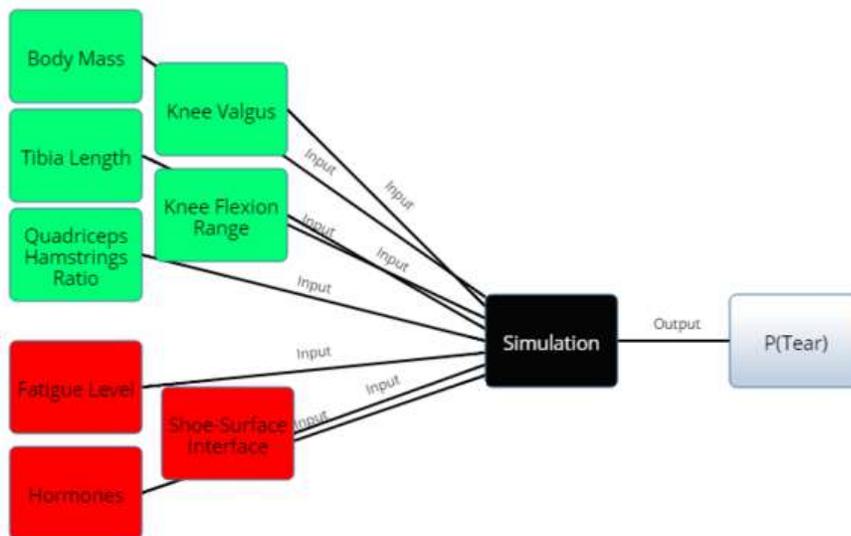
tibia length, mass, quadriceps hamstring ratio, knee flexion angle, knee valgus motion, identification error rate, mitigation error rate, and warn error rate. Each persona will have an associated probability of tear. Requirements five and six describe how the simulation will run using a Monte Carlo simulation.

Number	Requirement
SR.1	The simulation shall have human metrics for inputs.
SR.1.1	The simulation shall have mass for an input.
SR.1.2	The simulation shall have quadriceps/hamstring ratio for an input.
SR.1.3	The simulation shall have knee flexion angle for an input.
SR.1.4	The simulation shall have tibial length for an input.
SR.1.5	The simulation shall have knee valgus motion for an input.
SR.1.6	The simulation shall have an identify method error rate for an input.
SR.1.7	The simulation shall have a mitigation option error rate for an input.
SR.1.8	The simulation shall have a warning tool error rate for an input.
SR.2	The simulation shall have probability of tear for an output with a specific confidence interval.
SR.3	The simulation shall model an individual persona.

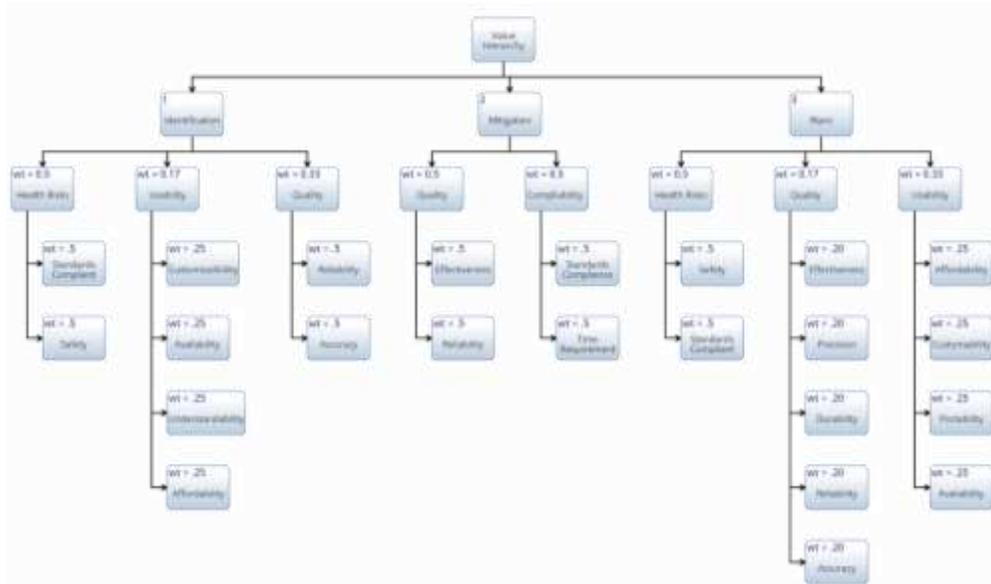
SR.4	The simulation probabilities shall be sourced.
SR.5	The simulation shall simulation 100 different athlete combination.
SR.6	The simulation shall run each athletic persona 100 times to model a monte carlo simulation.

SIMULATION

The simulation will involve the previously listed inputs and compute the aforementioned output. As mentioned before, we do not have a working model yet. We will be developing our simulation over winter break. The picture below is a visual representation of what our simulation will look like. The green boxes are the inputs that we know how they relate to ACL tears. The red boxes are inputs that we know exist but are not sure how they relate to ACL tears yet. The black box represents the model. This will be the error percentages associated with each sub system. The output in blue is the probability of tear with the associated confidence interval.

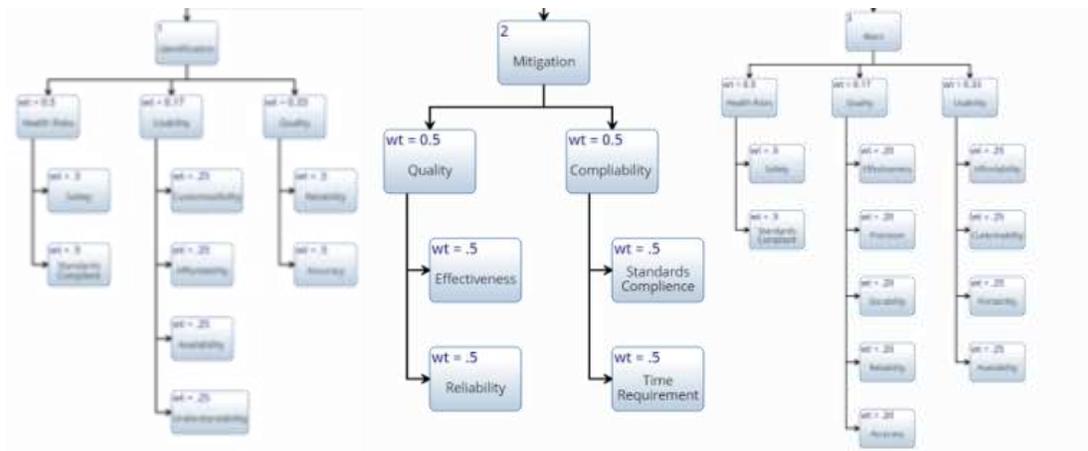


VALUE HIERARCHY



Our value hierarchy was broken into three sections identification, mitigation, and warning. For identification there are three categories, health risks, usability, and quality. Mitigation has two categories, quality and compliance. And warn has three categories, health risks, quality and usability.

After talking with the stakeholders we determined these weights. The main stakeholder we talked with was the GMU athletic trainer. The weights are in the upper left corner.



DESIGN OF EXPERIMENTS

The design of experiment will consist of a table of personas being tested for their probability of tear. From there the persona will be given a mitigation option and a warn option each with a likelihood of working. The persona table will look like the below table.

Input			Simulation					Effectiveness	
Persona	Tibia Length (cm)	Mass (kgs)	Quad Ham Ratio (%)	Knee Flexion Angle (deg)	Knee Valgus Motion (cm)	Identify Error Rate (%)	Mitigation Error Rate (%)	Warn Error Rate (%)	P(Tear)
1	26	70	59	4	12	20	10	2	0.76
2	50	55	75	22	7	25	13	5	0.45
3	48	60	55	45	11	5	12	3	0.66
4	35	100	60	80	5	10	9	7	0.88
...
100	41	40	66	97	3	15	7	4	0.48

RESULTS

The results for our simulation will show the identification rate, mitigation rate, and successful warn rate for each combination of the design alternatives.

UTILITY VS. COST ANALYSIS

After we determine our results, we will create a utility versus cost analysis. This will show us the combination of design alternatives that give us the most for the specific cost we are willing to settle for. The graph will show the best combinations of design alternatives multiplied the weights in our value hierarchy against the total cost of those combinations of design alternatives. This will also show which alternatives meet the requirements and which should not even be considered. A Utility vs Cost analysis is integral to leveraging the Insurance companies and therefore the implementation of our system. A key factor will be how the insurances profit will result from the effectiveness of our system.

SENSITIVITY ANALYSIS

After we analysis our results from our simulation, we will run a sensitivity analysis. From here we may change the weights of the -ilities. This may open up some other options that may have been just short of the cut off.

CONCLUSION AND RECOMMENDATION

Once finished with the simulation results, utility versus cost analysis, and sensitivity analysis we will be able to give recommendations and come to conclusions about our model.

PROJECT MANAGEMENT

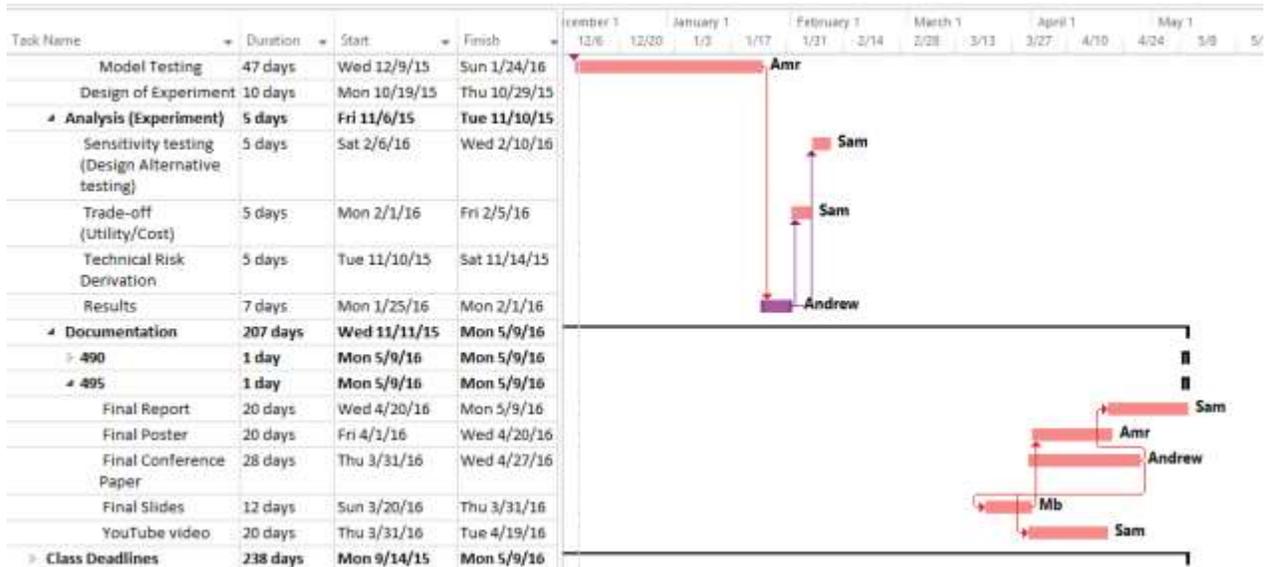
The project management section will depict our budget (and how we calculated it), responsibilities, risks, how close we are to the target goal and plans for next semester.

NEXT STEPS

Before the project is completed we have six more main tasks that must be achieved. One, we need to work with the kinematic model from the Meyer et. al. study to optimize our simulation and make it more accurate. Two, we need to create a more detailed project plan for next semester, filling in the steps in between the main milestones already in place. Three, we need to contact major insurance companies and the NCAA to bet the business plan underway and fully understand all the components necessary for this process. Four, using our utility versus cost analysis, we must define the most cost effective system that we can offer to our facilitating stakeholders and perform a sensitivity analysis for them. Five, we must research the need and develop requirements for the specific analysis options. And six, we must develop the relationship between brain and neuromuscular inputs to optimize our system.

GANTT

Below is an image of our gantt chart for the winter break and next semester. There is a gap between the sensitivity analysis and the start of our final report. This space is for mock presentations, competitions, and other deadlines that will be announced next semester.



RACI

We broke up our responsibilities in our WBS into seven categories, analysis, CONOPS, modeling, project management, requirements, research, and documentation. The letters used in the RACI matrix each stand for a type of duty. R stands for responsible, A stands for accountable, C stands for consulted, and I stands for informed.

	Amr	Andrew	Maribeth	Sam
Analysis	A	R	R	R
CONOPS	R	A	R	R
Modeling	C	C	A	C
Project Management	I	A	R	I

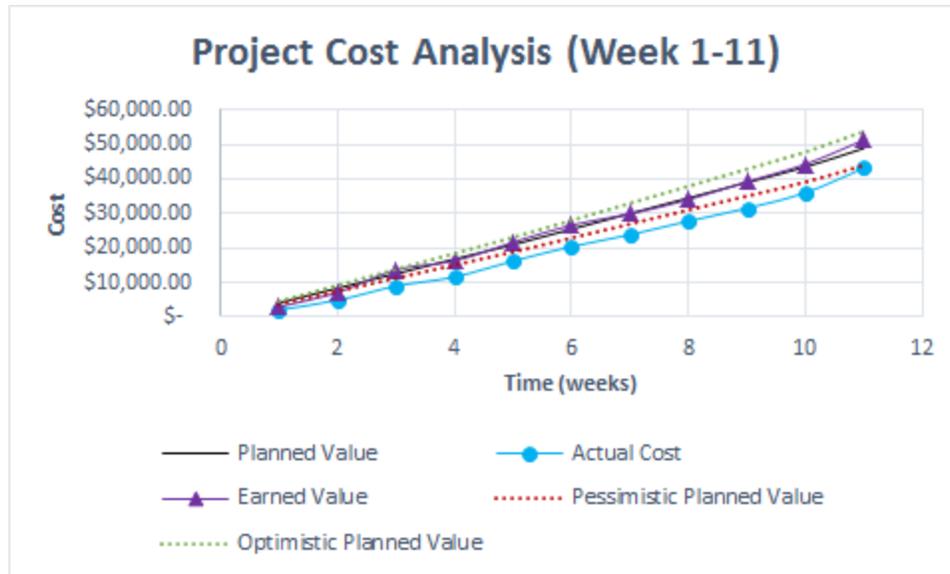
Requirements	A	C	R	C
Research	R	A	R	R
Documentation	R	R	A	R

BUDGET

We developed our budget using Microsoft project and excel. First we listed the tasks in project using our best judgement to estimate the duration and order of the tasks. We then assumed the four of us would be doing 20 hour work weeks each week. This put us at 2,560 hours. We then gave ourselves a 3% acceptable variance should we go over in hours. This put us at 2,649 total hours. From there we broke down the allotted hours to the different categories derived from our WBS, management, research, CONOPS, requirements, analysis, modeling, and documentation. Therefore our project budget for our project is \$174,834.

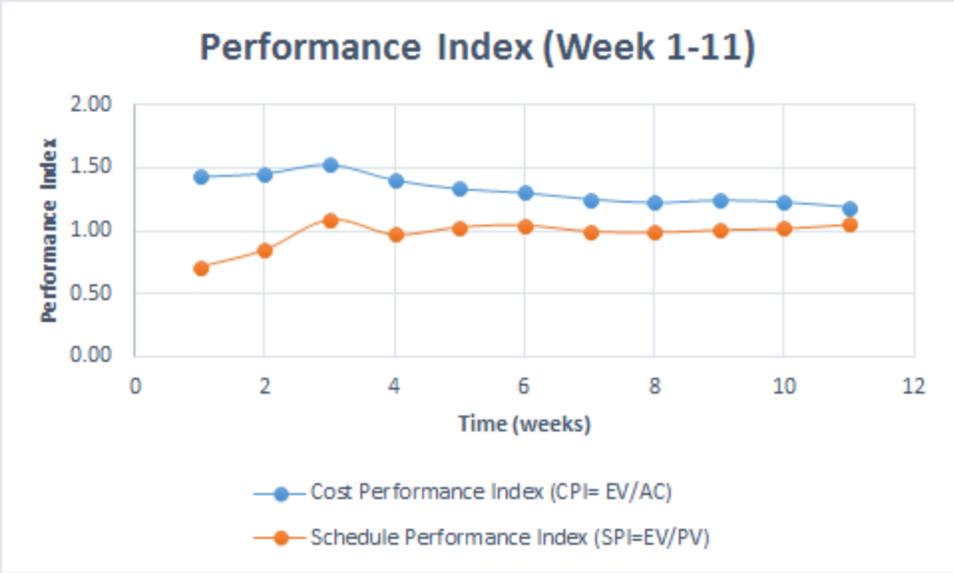
EARNED VALUE

So far, we are on currently on target with earned value analysis (purple triangle). We are within our range of acceptable costs (optimistic and pessimistic values). The difference between earned value and planned value is miniscule, earned value being slightly above the planned value. The difference between actual cost and planned value is minute, actual cost is only slightly lower than planned cost. All of this means that we are safely within our project budget and production limitations.



CPI AND SPI

Our cost performance index has been from 1 to 1.5 and our scheduled performance index has been from .7 to 1.15. Since both CPI and SPI are close to 1 currently, this means that we are not wasting money or time. Changes in our initial project idea caused an early disparity in production. Modeling this better in our schedule could have increased our SPI score and give a better approximation earlier on. From all this we learned that you should never underestimate research time needed and to model research as ongoing in original project plan.



RISKS

As of now, there are currently four major risks. One, insurance companies do not like the idea that we are proposing; if this problem arises we will have to find another financially strong stakeholder to facilitate the study with the NCAA. Two, our simulation and model does not solve the problem, this can be mitigated by performing periodic verification testing. Three, our model and simulation is inaccurate; this can be solved by periodic validation testing. And four, the simulation and model are not developed on time; this can be mitigated by creating milestones for the code and meeting them. Below is the risk matrix showing the consequence (x axis) and probability (y axis) of each major project risks.

	Negligible	Minor	Moderate	Serious	Critical
High					
Medium High		Model late	Code inaccurate		
Medium				Insurance Don't	
Medium Low					Model not solve
Low					

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