SPORTS ANALYTICS

DESIGNING A DECISION-SUPPORT TOOL FOR
GAME ANALYSIS USING BIG DATA

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1.0 CONTEXT

1.1 INTRODUCTION TO VOLLEYBALL

Indoor Volleyball is a competitive team sport played by men and women in United States and across the world. The objective of the game is to score the most points by grounding the ball in the opponent’s side of the court.

To understand the benefits of the decision-support tool being designed as part of this senior-design project, it is important to have a general understanding of the game of Volleyball. The game of volleyball has six categories:

i. Serve is an initial hit of the ball which travels over the net to the other side of the court to begin a rally. A serve can have three outcomes: a serve ace, a service error, or zero serve. A service ace is counted when the ball either hits the court on the opponent's side untouched or a contact is made but the ball is not kept in play. A service error results when the ball goes out of bounds or is trapped by the net. A zero serve means the ball is kept in play.

ii. Passing is an initial contact after serve. For every serve, there is a reception attempt. Each pass can result in two outcomes: a reception attempt and a reception error. A reception attempt is made by a player receiving the ball after the serve to keep the ball in play. If the player is unable to keep the ball in play, a reception error is recorded. For receptions events that follow after an attempted attack, a successful reception attempt is considered a dig.

iii. Set is considered an overhead pass near the net leading to an attack. Usually the second ball contact after a serve, it can result in three different outcomes: an assist, an assist error, or zero assist. Whenever an overhead pass (set) leads to a successful attack and a point, it is considered an assist. If an error is made in this transition from a set to an attack, an assist error is recorded. If the set leading to an attack does not result in a point but the ball is kept in play by the other team, then it is considered a zero assist.

iv. Attack is a strategic hit by a player with the intent of scoring a point. An attempted attack can have three different outcomes: a kill, an attack error, or a zero attack. A kill means an attack lead directly to a point. An error is recorded if the ball goes out of bounds, hits the net, is blocked by the opposing team players, or an illegal contact is made. An attack error means a point for the other team. Zero attack translates into an attempted attack that was successfully defended and the ball was kept in play by the opposing team.

v. Block is an act of preventing the ball from coming to your team’s side of the court. Depending on the number of players who jump near the net to block the ball, it can be either counted as a block solo if one person successfully blocks the ball or block assists if two or more players successfully
blocks the ball. Blocks by definition can only lead to a point. Hence, if a player touches the ball but it is kept in play, it is not considered a block.

vi. Points are the process by which teams keep the score and define their win or loss.

1.2 MARKOV CHAIN GAME MODEL

To define all the transitions that can occur in a volleyball game, we are using a Markov Chain game model. A serve can have four different outcomes. If a serve is successfully received as a pass, it can then enter into eight different states of a volleyball game, out of which a set has the highest probability. A set can then lead to three different outcomes with a high probability of an attack. An attack can be followed by a possibility of five different combinations. If a block is intercepted following an attack, it can then lead to two different transitions. These transitions continue until one a point is scored by one of the teams.

![Figure 1: Example Transitions for a Markov Chain Game.](image-url)
1.3 VOLLEYBALL LEVELS AND PROCESSES

In any sport there are beginner and advanced levels ranging from age to skill level. Volleyball for both men and women has the same progression from a novice to professional level.

![Diagram showing volleyball levels]

Figure 2: Focus of case study is at the collegiate level.

Figure 2 depicts this progression from an elementary school, or beginner level, to a National or Olympic level. In this diagram the collegiate level is bolded because volleyball at the collegiate level will be the main scope for the system. All college and university athletics are encompassed at the collegiate level. Collegiate volleyball, as well as many of the other universities sports programs, competes at the collegiate level in the National Collegiate Athletics Association (NCAA).

The National Collegiate Athletic Association, more commonly known as NCAA was founded approximately one hundred years ago. It was originally named Intercollegiate Athletic Association of the United States. (IAAUS) and then it turned into NCAA in 1910. The NCAA was implemented to encourage the practice of academics and sport for student-athletes. There are three specified divisions attributed to the Nation Collegiate Athletics Association. Members of the NCAA are affiliated and classified into one of the three divisions, Division I, Division II, or Division III. NCAA holds approximately 72 sports with over 400,000 student-athletes. NCAA organizations expands to over 1,000 colleges, oversees 89 championships within 23 sports. Division I contains 346 institutions. Division I (D-I) is the highest level of intercollegiate athletics sanctioned by the National Collegiate Athletics Association (NCAA) United States.

The mission of the National Collegiate Athletics Association is to uphold integration, fairness, and equitable competition. The NCAA foundation was based on student pursuing higher education through athletics. The goal of this association was to give the youth a chance to participate and excel in academics and sports. It was also essential for this association to enforce equal opportunity giving fairness to all athletes regardless of gender. Each division sets its own educational requirements that are bounded and upheld by the NCAA. Regardless of differences in requirements set forth by each division, academics are paramount to NCAA. The division I association to NCAA implements their academic policies by requiring all institutions to document academic progress rate, federal graduation rate, graduation success rate and grade point averages.
Being the highest level of intercollegiate athletics in the NCAA, Division I is known as the “major power house” and is comprised of the most competitive teams in the NCAA. Historical trends of Division I teams show correlations between competitive success and large fiscal budgets, high expectations, high coaches’ salaries and the quantity of scholarships given to these teams.

Given the amounts of budgets spent in sports, it is fair to say that the business side of sports is rapidly growing as well as the marketing side. In an article from the NCAA database, Herbert said “Commercialization is evidenced when large college sport programs derive 60-80% of their revenues from commercial sources…. evidenced as millions of dollars are spent on the renovation and building of new sport facilities…. ”.[8]

This is reflected in the budget spending of schools in their sports programs; where there are schools that spend millions of dollars to promote their sports teams. Fig. depicts the average budgets for the top ten spenders on athletics in the NCAA. As one can see, these budgets in millions of dollars are projected to grow exponentially throughout the years 2015 and 2020 where they are expected to reach as much as $254 Million.

![Top athletics budgets exceed $250 million in 2020](image)
Such large amounts of budget are the main reason behind the emphasis on competitive success. Coaches undergo a lot of pressure to ensure their teams meet the expectations and if they fail to do so, they are simply replaced by better coaches who in turn receive more salaries to meet their school’s expectations. In an article found in the NCAA database, Wolverton says: “An additional indicator that participation in athletics can become tainted with emphasis on winning and commercialization is the high rate of turnover and escalated increases of salaries in coaching positions.”

![Figure 4: Pre-Season, Season, and Post Season Process.](image)

Volleyball played at a collegiate level has three procedures the programs must complete before being crowned champion. These three procedures begin with pre-season games, then proceeding to the regular season games, and then lastly, if the program qualifies ends with the post season games.

In the post season the volleyball program competes in scrimmages and prepares for the regular season. During the regular season is when the program competes against its opponents in conference and non-conference games. All of the games played during the regular season determine the programs overall record, as well as, their eligibility to proceed to the post season. The post season is broken down further into two processes the conference championship, process level one, and the NCAA championship, process level two. In order for a team to proceed from the regular season to the conference championship in, or process level one of the post-season, the program must achieve competitive success. The regular season games are essential and on the critical path for the program to proceed to the post season. The qualification to process level one is the same for men’s and women’s division one volleyball programs. Process level two is very different for men’s and women’s NCAA division one volleyball.

There are three general regions for men's volleyball: "West", "Mid-West", and "East". The three major conferences that currently represent these regions are the Mountain Pacific Sports Federation (MPSF),
Midwestern Intercollegiate Volleyball Association (MIVA), and Eastern Intercollegiate Volleyball Association (EIVA). The EIVA is where George Mason’s Men’s Division I volleyball program resides. [1]

The conference championships are comprised of the top four seeded teams the conference competing in a single elimination tournament where in the first round the fourth seeded team plays the first seeded team and the second seed plays the third seed. The winners then play each other for the conference championship. Once a conference champion is crowned they receive an automatic bid to NCAA championship, or process level 2. The NCAA championship for Women’s Division I volleyball consists of 4 total teams. Once the conference champions are determined, these teams provide 3 of the 4 total teams. The other team is determined and picked by the American Volleyball Coaches Association based on criteria to receive an at-large bid to the NCAA tournament. The criteria programs are judged on are their head-to-head competition, their rating performance index, and their win-loss significance. The tournament is very simple since it only consists of 4 teams its format is the same as the conference championship.

![Figure 5: Men’s volleyball’s conference bracketing and Seeding Process.](image)

Process level 2 for NCAA women’s division I volleyball championship begins with the conference championships. These conferences include the following: America East, Atlantic Coast, Atlantic 10, Big East, Big Sky, Big South, Big Ten, Big 12, Big West, Colonial Athletic Association, Conference USA, Horizon League, Ivy league, Metro Atlantic (MAAC), Mid-American, Mid-Continent, Mid-Eastern, Midwestern Collegiate, Missouri Valley, Northeast, Ohio Valley, Pacific-10, Patriot, Southeastern, Southern, Southland, Southwestern Athletic, Sun Belt, West Coast, and Western Athletic. The conferences are then divided into Districts, which is in relation to regions. There are a total 8 districts. District 1 holds 47 schools, district 2 holds 39 schools, district 3 holds 33 schools, district 4 holds 41 schools, district 5 holds 31 schools, district 6 holds 39 schools, district 7 holds 38 schools and district 8 holds 26 schools. [1]
George Mason’s Women’s volleyball program competes in the Colonial Athletic Association (CAA). The conference championships are comprised of the top four seeded teams the conference competing in a single elimination tournament where in the first round the fourth seeded team plays the first seeded team and the second seed plays the third seed. The winners then play each other for the conference championship. Once a conference champion is crowned they receive an automatic bid to NCAA championship, or process level 2. The NCAA championship for Women’s Division I volleyball consists of 64 total teams. Once the conference champions are determined, these teams provide 30 of the 64 total teams. The other 34 total teams are determined and picked by the American Volleyball Coaches Association based on criteria to receive an at-large bid to the NCAA tournament. The criteria the programs are judged on are their head-to-head competition, their rating performance index, and their win-loss significance. The tournament is very rigorous and volleyball programs must win 6 straight games before they can be crowned champion.

Figure 6: Women’s volleyball’s conference bracketing and Seeding Process.
Figure 7: Inputs, outputs and feedback loops.

The processes of a Volleyball Program are depicted in the diagram figure 7. The main focus of a volleyball program is to perform in the games and evaluate/analyze each game during the post-game analysis. The steps would essentially go as follows:

1. Starting with match-box, the team plays a match where data is collected.
2. Post-game analysis on the data.
3. The analysis helps plan the training development where coaches evaluate and formulate plans and objectives for the team and its players or recruits.
4. Coaches may also choose to undergo a recruiting process to fulfill the needs based on the post-game analysis.
5. Both the training development and recruiting then feedback into the actual training and physical practices/out of practice drills.

The primary focus would be on what the coaches can control:

1. Recruiting–new players and replacing old positions.
2. Training – physical and skills training.
3. Game Decisions – what players are on the court and tactics.

**1.4 COACHES’ EVALUATION**

Now that we understand what processes occur in volleyball and what aspects of volleyball coaches are able to control, we can take a look at how coaches are evaluated by the athletics department.
The athletics department, being the head of sports programs, evaluates coaches on a yearly basis by developing a committee to assess the coaches’ performance. The evaluations are essentially a reflection of the team and coach’s performance. The following hierarchy shows a breakdown of the evaluation criteria.\[1\]

![Coach Evaluation Hierarchy](image)

**Figure 8: Coach Evaluation hierarchy.**

Leadership comprises 75% of the evaluation and is based on the following criteria:

- **Academic Success (30%)**: Measures the team’s academic performance in terms of GPA, Graduation Success Rates and Academic Progress Rates.
- **Competitive Success (30%)**: Measures the team’s competitive performance in terms of Win/Loss Record, Conference performance, NCAA performance, Post and Pre-Season Performance.
- **Team Cohesion (30%)**: Measures the team’s ability to maintain professionalism in playing volleyball in addition to obeying rules and regulations.
- **Program Development (10%)**: Measures the team’s development in terms of visibility, teams’ ability to project a positive image within the college/ institution, athletic growth, and school involvement.

Management comprises 25% of the evaluation and is based on the following criteria:

- **Fiscal Responsibility (50%)**: Measures the coach’s ability to make appropriate decisions and use of discretion. It also measures their ability to manage budget and operate within the allocated funds in addition to adhering to traveling, recruiting and reconciliation policies.
- **Scheduling Philosophy (20%)**: Measures the coach’s professional work habits such as submitting assignments on time, completing appropriate paperwork, adhering to policies for home and away games, and program attendance.
- Sport Specific Development (15%):
- Planning (15%): Measures the coach’s ability to achieve strategic plans in recruiting, daily agenda, and developing Players.

The focus of this project is geared towards the heavier weight of the hierarchy, which is leadership. More specifically the focus is on competitive success because it is one of the few things in the hierarchy that the coaches are able to control. As mentioned previously, intercollegiate volleyball undergoes two main processes of championships. The first level is the conference level within which teams within a conference compete to obtain the conference championship. In order to understand how well George Mason’s volleyball teams are doing, an analysis of where the team stands within their conference was done in terms of winning percentage record (W-L record).

As noted previously, the women’s volleyball team plays in the Colonial Athletic Association (CAA) and currently competes against eight teams listed as follows:
- Northeastern
- Delaware
- Towson
- Georgia State
- Hofstra
- James Madison
- UNC Wilmington
- William & Mary

The following bar graph shows all the schools that compete in CAA and their overall winning percentages throughout the years 2000-2012.\textsuperscript{2,3}

\begin{itemize}
  \item \textsuperscript{1} \url{www.caasports.com}; Colonial Athletics Association Website.
  \item \textsuperscript{2} \url{www.gomason.com}; Mason’s Athletics Website.
  \item \textsuperscript{3} \url{www.ncaa.com}; NCAA Career Records.
\end{itemize}
The black line on the graph illustrates the average of the conference, which is at 52.1% and the red line shows the average of George Mason’s winning percentage which is at 47.8%.

With the assumption that being able to defeat the top competitor in the conference will allow George Mason’s team to defeat all other teams in their conference, an analysis of George Mason’s team’s winning percentage compared to Northeastern’s winning percentage was performed. The following bar graph illustrates the winning percentages of Northeastern (The top competitor in the CAA) compared to George Mason.

Figure 9: Women's Overall Win %.

Figure 10: GMU VS. NE in CAA conference.
The black line across the graph reflects Northeastern’s average winning percentage (61.4%) while the red line reflects George Mason’s winning percentage (47.8%). It is evident that George Mason’s winning percentage average is significantly below that highest average.

In addition to the average winning percentages, it was also essential to develop a trend analysis for George Mason’s performance over the years to evaluate their fluctuations and variability. The following graph is a plot of George Mason’s winning percentage over the years 2000-2012 against Northeastern’s winning percentage over the same years.

![GMU VS. Northeastern Overall Win %](image)

**Figure 11: GMU VS. Northeastern Trends Analysis.**

The blue line, equation and variance belong to George Mason while the red line, equation and variance belong to Northeastern.

There are two main things that can be pointed out from this plot:

1. George Mason’s team has been fluctuating at a decreasing trend while Northeastern’s team has been fluctuating at an increasing trend.

2. George Mason’s winning percentages have a higher variance than Northeastern’s winning percentages which reflects inconsistency in George Mason’s competitive performance.

To sum up, it is evident that George Mason's performance over the past 12 years has been significantly below the top opponents’ performance. Moreover, George Mason has been less consistent and has been experiencing fluctuations in their winning percentage at a decreasing trend.
The same analysis can be conducted for the men’s team to understand where they stand in their conference. The men’s team competes in the Eastern Intercollegiate Volleyball Association (EIVA) against seven teams listed as follows:

1. NJIT
2. Harvard
3. Sacred Heart
4. Penn State
5. St. Francis
6. Rutgers-Newark
7. Princeton

The following bar graph shows all the schools that compete in EIVA and their overall winning percentages throughout the years 2006-2012.\(^6\)

\[ \text{Men's Overall Win %} \]

[Graph showing Men's Overall Win % with bars for each school and lines for average and GMU average]

Figure 12: Men's Overall Win %.

The black line on the graph illustrates the average of the conference, which is at 49.2% and the red line shows the average of George Mason’s winning percentage, which is at 55%.

To better understand where George Mason’s team stands, it’s not sufficient to look at the average of the conference, especially since they are competing well in their conference. It is important to look at the average of the top competitor in the conference to truly understand where George Mason’s performance stands. The

\(^6\) [www.eiva.com; Eastern Intercollegiate Volleyball Association Website.]
\(^7\) [www.gomason.com; Mason’s Athletics Website.]
\(^8\) [www.ncaa.com; NCAA Career Records.]
The following bar graph illustrates the winning percentages of Penn State who has been in the lead for years now, plotted along with George Mason to visualize the performance gap for George Mason.

Figure 13: GMU VS. Top Opponent in EIVA.

The black line across the graph is the highest average of the conference, which belongs to Penn State at 79.8%. It is evident that George Mason’s winning percentage average is significantly below that highest average.

Just as we previously looked at the consistency of the women’s team, we can develop a similar trend analysis for George Mason’s performance over the years to evaluate their fluctuations and variability. The following graph is a plot of George Mason’s winning percentage over the years 2000-2012 against Penn State’s winning percentage over the same years.

Figure 14: GMU VS. Penn State’s Trends Analysis.
The blue line, equation and variance belong to George Mason while the red line, equation and variance belong to Northeastern.

There are two main things that can be pointed out from this plot:

1. George Mason’s team has been fluctuating at a decreasing trend while Penn State’s team has been fluctuating at an increasing trend.
2. George Mason’s winning percentages have a higher variance than Penn State’s winning percentages which reflects inconsistency in George Mason’s competitive performance.

To sum up, it is evident that George Mason’s performance over the past 12 years has been significantly below the top opponents’ performance. Moreover, George Mason has been less consistent and has been experiencing fluctuations in their winning percentage at a decreasing trend.

### 2.0 STAKEHOLDERS ANALYSIS

#### 2.1 STAKEHOLDERS HIERARCHY

![Stakeholder Hierarchy Tree]

Figure 15: Stakeholder hierarchy tree.

This stakeholder hierarchy provides a view of the level of communication between the stakeholders. The NCAA being a governing body over George Mason’s athletic department. The athletic department then governs over the volleyball programs. The volleyball programs then consist of the coaches and the players who are under the direction of the coaches. The administration of the athletic department tries to ensure the volleyball programs success by allocating them the required resources they demand.
2.2 Stakeholders Objectives

The stakeholders displayed in figure 1.6 can be broken down further and their primary objectives are:

1. NCAA – to give student-athletes the opportunity to participate in sports programs within set regulations.

2. Athletic Finance Department – To provide and allocate funds for sports programs.

3. Athletics Administration – To ensure that the mission of the athletics department is met.

4. Volleyball Programs – To meet the standards of ICA & NCAA.

5. Head Coaches – To ensure that the athletes meet ICA & NCAA standards.

6. New & Existing players – Achieve academic and competitive success.

7. Trainers – To ensure players’ growth development and safety

8. Opponents – To compete to win against George Mason’s program

9. Officials – To ensure the safety and fairness of the game

The primary focus with the stakeholders will be the interactions between the stakeholders that are directly affected by our system, these stakeholders being the NCAA, the volleyball programs, the coaches, and the players.

2.3 Stakeholders Interactions and Tensions

In figure 16, each stakeholder is displayed and grouped respectively. After completing a stakeholder analysis the interactions and tensions between the stakeholders could be determined. The NCAA, consisting of the sports committee, the finance committee, academic affairs, the officials, and George Mason’s opponents, main interaction is with the ICA in reimbursing them for how their teams have competed and how successful their sports programs have become. The ICA consists of: the athletic director, the finance operations, and the academic coordinator. The ICA’s interaction with the NCAA is mainly to establish their affiliation by paying dues and representing its college or university in one of the NCAA’s divisions. ICA’s main interaction is with the volleyball program by investing and providing budget, as well as, allocating resources to the volleyball programs.

The volleyball programs each consist of: the head coach, the assistant coaches, the trainers, and the players. The volleyball program interacts with both the NCAA and the ICA. Their primary interaction is to meet the standards set by the NCAA and ICA, as well as, players to remain eligible with the ICA in order to
compete. The main tensions the volleyball programs must handle are remaining competitive through process one and two when competing against opponents and the coaches’ evaluation demand with the ICA, which 30% of the management 75% is competitive success.

The coaches must remain competitive in the NCAA, as well as, to demonstrate to the ICA their coaching is successful under the criteria assessed in the evaluation. One of the main tensions with the volleyball programs is through the NCAA in assessing the programs and evaluating them on the governing regulations and principles set by the NCAA. The NCAA must assess teams to assure they are eligible to compete in their respective division level.

![Diagram depicting stakeholder interactions and tensions](image)

Figure 16: Diagram depicting the stakeholder interactions and tensions
3.0 PROBLEM & NEED

3.1 WOMEN'S PROBLEM AND NEED STATEMENTS

Looking at the competitive game performance, we define the problem for Women’s Volleyball Team at Mason to have an average win percentage lower than their top competitors in the CAA conference, such as Northeastern University for the years 2000 to 2012. In addition, the Women’s Volleyball Team has a higher variance in their win percentage over these years as compared to Northeastern. A higher variance signifies greater fluctuations in the levels of performance on the court by women volleyball players. In addition, George Mason won 3 out of 13 matches played against Northeastern between the years 2006-2012. This sets GMU’s winning percentage against NE at 23.07%.

Over next 6 years, GMU’s women’s team needs to increase their overall conference winning percentage by more than 27.15% to compete, as a top contender, for the lead in their conference. Moreover, there is a need to reverse the decreasing trend and maintain consistency by reducing the variance of their winning percentages by about 77.5%. In order to satisfy this need, GMU’s women’s volleyball team needs to win at least 50% or more of their matches, each season, against their top competitor. In order to compete at the top competitor’s level, there is a need for a decision-support tool that can identify and quantify required transitional events that can yield at least a 50% winning percentage against the top competitor.

3.3 MEN'S PROBLEM AND NEED STATEMENTS

Looking at the competitive game performance, we define the problem for Men’s Volleyball Team at Mason to have a lower overall win percentage as compare to Penn State, the strongest competitor in the EIVA conference. In addition, Men’s Volleyball Team also has a higher variance compared to Penn State signifying greater fluctuations in the level of performance by players on the court. Moreover, George Mason won 2 out of 26 matches played against Penn State between the years 2006-2012, which sets GMU’s winning percentage to 7.7% against Penn State’s men’s volleyball team.

Overtime, the men’s volleyball team needs to increase their average overall winning percentage by more than 43.7% in order to take the lead in their conference. They also need to reverse the decreasing trend and maintain consistency by reducing the variance of their winning percentage by about 72.25%. In order to satisfy this need, GMU’s men’s volleyball needs to win at least 50% or more of their matches, each season, against their top competitor. In order to compete at the top competitor’s level, there is a need for a decision-support tool that can identify and quantify required transitional events that can yield at least a 50% winning percentage against the top competitor.
4.0 DESIGN ALTERNATIVES

4.1 INTRODUCTION TO DESIGN ALTERNATIVES

As mentioned in previous sections, there are hundreds and thousands of transitions that can occur in a volleyball match. Sport specific research has indicated that volleyball is centered on 5 essential skills, which are serving, passing/receiving, setting, attacking and blocking. Studies have shown that the difference in performance with respect to each skill determines the success of a team.

The focus for this study was transitions that directly lead to points. Scoring skills such as serves, attacks and block are essential in volleyball because they are offensive tactics and skills need to score points to win a match. It has to be noted that most points are procured by way of offensive skills and tactics but it is not the only way to have win or have a success team. Errors made by a team are points that contribute to the opposing team’s score. Therefore, minimizing the amount of error made by a team can make the difference in terms of which team wins and losses.

Therefore, GMU’s men’s and women’s volleyball team’s design alternatives are the following:

i.) Alt. 1: Increasing Serves to Points (Aces)
A service ace occurs when a team serves the ball and that ball transitions directly to a point for that team without undergoing any other transitions.

ii.) Alt. 2: Increasing Blocks to Points (Blocks)
Blocks are used to strategically land the ball in the opposing team’s side of the court by way of deflecting the ball being spiked by the opposing team, resulting in a point.

iii.) Alt. 3: Increasing Attacks to Points (Kills)
A kill is a particular type of an attack that results in a direct point by grounding the ball in the opposing team’s side of the court.

iv.) Alt. 4: Decreasing events that increase opposing teams points (Errors)
Errors include multiple transitions because an error can occur between multiple actions. Includes service errors; ball-handling errors, from passes and sets; blocking errors; receptions errors; and attacking errors.

There were not any analyses of combinations of alternatives conducted in this study. Each design alternative was analyzed independently and tested independently, all other transitions that were not related to the design alternative remained at their original probabilities.
4.2 DESIGN ALTERNATIVES TREND ANALYSIS

Official NCAA box scores were used to validate the baseline distribution for these design alternatives. After assessing over 640 data points, which includes service aces, service errors, reception errors, hitting errors, hitting attempts, kills, set assists, blocks, and ball handling errors (from NCAA official box scores) the following information was assessed for 3 non-winning and 3 winning seasons for both GMU women’s and men’s volleyball teams against their associate top opponent:

<table>
<thead>
<tr>
<th>Team</th>
<th>Service Aces and Points</th>
<th>Blocks and Points</th>
<th>Points Contributed from Opposing Team’s Errors</th>
<th>Attacks and Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMU</td>
<td>4.71%</td>
<td>12.30%</td>
<td>31.23%</td>
<td>51.76%</td>
</tr>
<tr>
<td>Penn State</td>
<td>6.55%</td>
<td>10.26%</td>
<td>26.68%</td>
<td>56.51%</td>
</tr>
</tbody>
</table>

Figure 17: Men’s volleyball Point-Scoring Percentage Breakdown.

<table>
<thead>
<tr>
<th>Team</th>
<th>Service Aces and Points</th>
<th>Blocks and Points</th>
<th>Points Contributed from Opposing Team’s Errors</th>
<th>Attacks and Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMU</td>
<td>6.2%</td>
<td>9.2%</td>
<td>28.9%</td>
<td>55.6%</td>
</tr>
<tr>
<td>NE</td>
<td>6.16%</td>
<td>7.7%</td>
<td>29.78%</td>
<td>56.36%</td>
</tr>
</tbody>
</table>

Figure 18: Women’s volleyball Point-Scoring Percentage Breakdown.

For the men’s volleyball team, on average, has a lower percentage of 51.76% for scoring points through attacks as compared to Penn State with a 56.51% attack percentage. GMU men’s volleyball team earns 31.23% of its points in a game due to errors made by the opposing team. However, the errors that contribute to the opponent’s points by way of GMU’s women’s volleyball make up 26.68% of their point scored. Thus, approximately 68.77% of the points scored for GMU are by GMU’s men’s volleyball team’s offensive skills including service aces, kills and blocks. Where as, 73.32% of the points scored for PSU are by PSU’s men’s volleyball team’s offensive skills including service aces, kills and blocks.

For the women’s volleyball team, on average only 71.0% of the points scored for GMU-WVBP are from GMU’s women’s volleyball team’s ball contact actions that led to a point for their team, whereas 28.9% of GMU’s women’s volleyball team’s points are by way of their opponents errors. For Northeastern’s University’s women’s volleyball team, 29.78% of their points are due to errors made by GMU’s women’s volleyball team and 70.22% of ball contact actions made by NE’s team led to point for their team.
4.3 Design Alternatives Statistical Analysis

In order to understand how GMU’s volleyball team is currently performing with respect to the design alternatives, a statistical analysis was conducted, using historical data of matches. The statistical analysis was used to determine how the occurrence of one event correlates with a particular outcome, in comparison to the opposing team. Each design alternatives (transitions that directly lead to points) number of occurrences for both GMU’s men’s and women’s volleyball teams and their respected top opponent was accounted for and evaluated.

Men’s Volleyball Design Alternatives Hypothesis Testing

<table>
<thead>
<tr>
<th>Number of Occurrences of Kills</th>
<th>Number of Occurrences of Aces</th>
<th>Number of Occurrences of Blocks</th>
<th>Number of Occurrences of Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMU</td>
<td>PSU</td>
<td>GMU</td>
<td>PSU</td>
</tr>
<tr>
<td>1</td>
<td>44</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>4</td>
<td>1</td>
</tr>
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<td>21</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>(\bar{x})</td>
<td>28.677</td>
<td>3.000</td>
<td>11.500</td>
</tr>
<tr>
<td>(s)</td>
<td>10.900</td>
<td>1.414</td>
<td>5.863</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>37.417</td>
<td>4.000</td>
<td>10.667</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>46.167</td>
<td>5.000</td>
<td>20.400</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>5.000</td>
<td>2.908</td>
<td>9.833</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>10.667</td>
<td>2.714</td>
<td>35.000</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>32.833</td>
<td>5.854</td>
<td>30.667</td>
</tr>
</tbody>
</table>

Figure 19: From 2007-2012, GMU vs. PSU’s men’s volleyball team hypothesis testing.

Women’s Volleyball Design Alternatives Hypothesis Testing

<table>
<thead>
<tr>
<th>Number of Occurrences of Kills</th>
<th>Number of Occurrences of Aces</th>
<th>Number of Occurrences of Blocks</th>
<th>Number of Occurrences of Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMU</td>
<td>NE</td>
<td>GMU</td>
<td>NE</td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>3</td>
<td>3</td>
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<td>4</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>(\bar{x})</td>
<td>15.500</td>
<td>1.600</td>
<td>5.400</td>
</tr>
<tr>
<td>(s)</td>
<td>3.912</td>
<td>1.517</td>
<td>1.517</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>18.000</td>
<td>1.500</td>
<td>3.800</td>
</tr>
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<td>20.400</td>
<td>2.200</td>
<td>2.200</td>
</tr>
<tr>
<td>(\bar{x}_{\text{ave}})</td>
<td>44.400</td>
<td>44.400</td>
<td>44.400</td>
</tr>
</tbody>
</table>

Figure 20: From 2008-2012, GMU vs. NE’s women’s volleyball team hypothesis testing.

A T-test was performed to assess the differences in the mean number of occurrences for all design alternatives between each team. This study was conducted at a 95% confidence interval where, null hypothesis (H₀) states that \(X_1 = X_2\) (there is no difference in the mean number of occurrences) and the
alternative hypothesis \( (H_a) \) states that \( X_1 \neq X_2 \) (there is a difference in the mean number of occurrences) and \( \alpha = 0.05 \) (p-value of significance is < 0.05).

Note that the standard rejection criterion for a T-test is the following: Reject Ho (null hypothesis) with probability of false rejection \( \alpha \) under the following conditions, \( t_{n-1} \) is the value of the t distribution with \( n-1 \) degrees of freedom. For a two tailed test, reject Ho (null hypothesis) if the p-value is less than \( \alpha \) or, equivalently, if, \( T > t_{\alpha, n-1} \) or \( T < -t_{\alpha, n-1} \).

There were 6 matches accounted for between GMU’s men’s volleyball team and Penn State’s men’s volleyball team in years 2007-2012. There were about 5 matches accounted for between GMU’s women’s volleyball team and Northeastern’s women’s volleyball team in years 2008-2012. The hypothesis test conducted in this study used the data from these specific seasonal matches as a sample size.

**MEN’S RESULTS OF (TWO-TAILED) T-TEST**

<table>
<thead>
<tr>
<th>Number of Occurrences</th>
<th>Number of Occurrences</th>
<th>Number of Occurrences</th>
<th>Number of Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kills</td>
<td>Aces</td>
<td>Blocks</td>
<td>Errors</td>
</tr>
<tr>
<td>GMU Limits</td>
<td>GMU Limits</td>
<td>GMU Limits</td>
<td>GMU Limits</td>
</tr>
<tr>
<td>PSU Limits</td>
<td>PSU Limits</td>
<td>PSU Limits</td>
<td>PSU Limits</td>
</tr>
<tr>
<td>( T = 3.24 )</td>
<td>( T = 3.65 )</td>
<td>( T = 0.65 )</td>
<td>( T = 1.08 )</td>
</tr>
<tr>
<td>( PS = 0.0089 )</td>
<td>( PS = 0.13 )</td>
<td>( PS = 0.53 )</td>
<td>( PS = 0.305 )</td>
</tr>
<tr>
<td>STDEV = 9.36 ( DF = 10 )</td>
<td>STDEV = 2.10 ( DF = 10 )</td>
<td>STDEV = 1.45 ( DF = 10 )</td>
<td>STDEV = 6.89 ( DF = 10 )</td>
</tr>
<tr>
<td>( t = 2.228 ) ( \alpha = 0.05 )</td>
<td>( t = 2.228 ) ( \alpha = 0.05 )</td>
<td>( t = 2.228 ) ( \alpha = 0.05 )</td>
<td>( t = 2.228 ) ( \alpha = 0.05 )</td>
</tr>
</tbody>
</table>

Figure 21: Results of T-test for Men’s Volleyball team.

**WOMEN’S RESULTS OF (TWO-TAILED) T-TEST**
Figure 22: Results of T-test for Women’s Volleyball team.

The graphs above, for both the men’s and women’s volleyball teams, represent the distributions for each design alternative in comparison to their top competitor. Also listed above the graphs are the associated information listed in the table above. On the left hand-side of each graph represents GMU’s distribution and of the Right represents top opponent’s distribution. The line below represents the lower limit and the top line represents the upper limit. The line in the middle represents the mean with respect to the distribution. The values, to the left of each graph, represent the number of transitional occurrences to the specific design alternative. For the men’s volleyball, the critical t-value for each test is 2.228 given that the degree of freedom (DF) is 10, the alpha ($\alpha$) is 0.05 and the sample size is 6. For the women’s volleyball, the critical t-value for each test is 2.306 given that the degree of freedom (DF) is 8, the alpha ($\alpha$) is 0.05 and the sample size is 5.

The graphical comparison showed the distributions of the two groups. If the p-value is low, chances are there will be little overlap between the two distributions. If the p-value is not low, there will be a fair amount of overlap between the two groups.

According the rejection criteria, it was concluded that one rejects the null hypothesis for kills; the mean number of occurrences are statistically significantly different at the significance level. Fail to reject the null hypothesis for aces, blocks and errors; there is no statistically significant difference in their mean number of occurrences.
In the analysis of the men’s volleyball team, PSU’s mean number of occurrences is slightly greater in aces and slightly lower in errors, whereas, GMU’s team is slightly higher in blocks. PSU’s men’s volleyball team exceeds in their number of occurrences for kills in comparison to GMU’s men’s volleyball team. Thus, when bringing GMU to the level of not having a statistically significant difference in mean number of occurrences in comparison to the other team, then GMU is as competitive and playing at a fairly similar or equal level. At this point there is evidence that suggest that GMU’s men’s volleyball team has had a great chance of loss due to the imbalance performance level of kills.

According the rejection criteria, it was concluded that one rejects the null hypothesis for blocks because the mean number of occurrences are statistically significantly different at the significance level for women’s volleyball team. Fail to reject the null hypothesis for aces, kills and errors; there is no statistically significant difference in their mean number of occurrences. GMU’s women’s volleyball team exceeds in their number of occurrences for blocks in comparison to NE’s women’s volleyball team.

In the analysis of the women’s volleyball team, NE’s mean number of occurrences is slightly greater in kills. Whereas, GMU’s women’s volleyball team exceeds in their number of occurrences for blocks in comparison to NE’s women’s volleyball team. Studies have shown that kills and errors occur more frequently and blocks and aces occur less frequently between the design alternatives. In conclusion it appears that even though GMU’s women’s exceeds in blocks, on average there are not enough blocks obtained to impact GMU’s women’s volleyball’s win/loss percentage against NE.

These statistical analyses for both the men’s and women’s volleyball team was helpful in drawing our focus on an area that needs improvement; however, all factors are still accounted for and are not deemed negligible in this study. When interpreting the complexity of the game the smallest change or difference can determine whether one to wins over the other team and it also can have an impact significant impact on the overall winning percentage.

These statistical analyses also put into perspective the types of simulation scenarios that are needed to address the problem and need statement with respect to the design alternatives. There are two types of simulation runs that are performed in this study, the first simulation run will always yield a 50% chance of winning, where there is not statistical significant differences in mean of occurrences, when treating each alternative separately. This means GMU and their top competitor has an equal chance of winning a match. The second simulation run will always yield a 90% chance of winning, where there is a statistical significant difference in mean of occurrences, when treating each alternative separately. This means the competitor only
has a 10% chance of winning against GMU. In these simulation runs, GMU exceeds in the mean number of occurrences in either aces, blocks, kills and is significantly lower in mean number of occurrences for errors.

5.0 SIMULATION DESIGN

5.1 MARKOV CHAIN GAME MODEL

The objective of this project is to create a computer-aided analysis tool (CAAT) that will carry out tasks that will solve the current and future problems of the volleyball programs. The CAAT is a robust volleyball decision making tool that analyzes volleyball data in new and futuristic ways. It is built and reformed through the knowledge and expertise of the volleyball coaches and the design team. It is a knowledge and mathematical-based system, meaning that it compiled of combinations of historical data, statistics and data from match videos. It is a computer-based system comprised of two parts; one that is written in java to simulate volleyball matches and one written as a python script that can parse collected data to calculate probabilities of transitional events in matches.

The purpose of the tool is to simulate, analyze and evaluate volleyball matches. It runs a Monte Carlo simulation of a volleyball match based on Markov Chains concepts of transitional probabilities between events that occur in volleyball. It analyzes the cause and effect relationship between transitional probabilities and the outcome of the match. This helps identify target transitional probabilities that optimize winning percentage. The CAAT is a post-game analysis tool that can guide the coaches’ decision-making when it comes to training development and recruiting.

As mentioned previously, the CAAT employs a Markov Chain Model because it is a mathematical system that undergoes transitions from one state to another. Markov chain can statistically model real-world processes, like volleyball game. In order to study and simulate volleyball games, we have developed a Markov Chain Model that evaluates the probabilities of all the various states and combinations for any given volleyball game. There are twelve states for any volleyball game and they are as follows:

1. Serve (Team A)  
2. Pass / Receive (Team A)  
3. Set (Team A)  
4. Attack (Team A)  
5. Block (Team A)  
6. Serve (Team B)  
7. Pass/Receive (Team B)  
8. Set (Team B)  
9. Attack (Team B)  
10. Block (Team B)
11. Point (Team A) 12. Point (Team B)

Figure 23: Absorbing Markov Chain Volleyball Model.

Figure 23 represents the ‘Absorbing Markov Chain Game Model’ used throughout this study, which distinguishes transient states, absorbing states and transition probabilities. It displays the standard volleyball actions and processes of an actual volleyball game.

The first ten states listed above are transient state(s), which are the standard volleyball actions played in the game of volleyball. These are functions in our simulation. The first and sixth states, Serve (Team A) and Serve (Team B) listed above, are called transient ephemeral states because they must and can only start from those states. Also, once you start from this state you can only leave from this state and cannot return until you land in an absorbing state. When starting from those two states the transition probabilities allow them to move to the other states based on the probability that the action will occur. Mentioned above was a term called ‘absorbing state.’ In our model there are two absorbing states and they represents a state where they can only ever enter, state of winning points. Volleyball is a game where two teams must compete against one another until one team wins a point, the set and or match. In the Markov model you win a rally by landing in the absorbing states Point (Team A) or Point Team (B).
All in all, there are also 70 combinations within all twelve states represent the actions that a player can take when playing on the court. The combinations are dependent upon the parameters, NCAA rules and regulations of the game. Each of transitions (combinations) has a specified probability associated to and from another state. These were determined, examined, and calculated by our team, using previously recorded games. This information is stored in an excel file and then transferred over to the ‘Results of a Markov Chain Transition Matrix Table.’

After the simulation has run its course, the program can count the number of times the each team went in an absorbing state. This is divided by the total number of times both teams went into an absorbing, thereby quantifying the percentage of winning and losing against an opponent. In a game of volleyball, in order to win a set a team must obtain 25 points and be more than 2 points ahead of the opposing team. The team that has won at least 3 sets has won the match. This is a technical requirement that this system must perform in order to emulate a volleyball game accurately. The results of the simulation, design alternatives, and sensitivity analysis tie back to the need of winning points and matches contribute to higher winning percentage.

### 5.2 MARKOV CHAIN MATRIX AND CALCULATIONS

In order to perform Markov chain matrix calculations, the probabilities of transitions are put into a matrix of the following form, where the sampled data in the figure comes from watching volleyball matches against top opponents and calculating the probabilities of all transitions that occur in the match.

![Markov Chain Matrix](image)

Figure 24: Markov Chain Matrix.
The left column blocks are the initial states known as \([i]\), and the top row blocks are the final states known as \([j]\). Every entry reflects the probability of transitioning from a state \(i\) to a state \(j\). The ‘0’ entries are transitions that did not occur or cannot occur due to the nature of the game. For instance, a serve in team A, cannot go to a serve in team A or team B. Hence, it was given a probability value of ‘0’.

The values in this matrix represent the input of our simulation in our sensitivity analysis; this matrix is where we are going to make changes to certain probabilities within certain limitations to see how they change the outcome at the end.

The boxes highlighted in red, are just an example of one of the several transitions that can be tracked in this matrix. For instance, if we are interested in knowing the probability of our attacks leading to points for our team, we would look at the transition that starts in an \(Atk\ A\) and ends in a \(Pnt\ A\).

As previously mentioned, we are modeling an absorbing Markov chain and the two elements of our matrix are the transient states and the absorbing states. The transient states are located to the left and above the blue lines, while the absorbing states are located to the right and below the blue lines. The absorbing states are referred to as \(Pnt\ A\) and \(Pnt\ B\). Once a transient state goes into an absorbing state, it cannot leave that state and in our volleyball model, it means a new rally is started with a serve for team that scored the point.

There are three main calculations that are essential in obtaining useful results from our absorbing Markov chain, but before we can go into further details, we have to identify sub-matrices within our Markov chain matrix.

The matrix \(Q\) is a 10 x 10 matrix of the transient states combinations as shown in the below diagram:

![Figure 25: 'Q' Transient Matrix.](image)

The matrix \(R\), is the right most 10 x 2 matrix of our absorbing states as illustrated in the following diagram:
There is one more essential matrix in our calculations, and that is the identity matrix (I) which is a 10 x 10 identity matrix with ones on the main diagonal and zeros elsewhere that is created to perform the necessary calculations.

Now that we know what matrices are used for the calculations, we can proceed to introduce the calculations:

1. \((I-Q)\): This first calculation subtracts the transient matrix \(Q\) from the 10 x 10 Identity matrix \(I\), it is only a preliminary calculation to lead up to the following two calculations.

2. \((I-Q)^{-1}\): Taking the inverse of the first calculation results in what is known as Markov’s fundamental matrix. This matrix shows the expected number of times a transient state \(i\) goes to a transient state \(j\) before being absorbed.

3. \((I-Q)^{-1}R\): This final calculation which multiplies our fundamental matrix by our absorbing matrix yields the final 10 x 2 matrix which illustrates the probability of each transient state moving to an absorbing state.

The following diagram is an illustration of this final calculation and what can be depicted from it:
As previously mentioned, we were tracking the probability of an attack leading to a point for our team, and this final matrix shows the probability of that event occurring throughout the entire game and after the several transitions that occur within the game.\(^7\)

### 5.3 Verification and Validation

In order to calculate an overall measure of performance from the resulting 10 x 2 matrix shown above, the following equation was derived to calculate the point scoring probability for each team.

\[
P_{ps} = \frac{\Sigma [(I-Q)^{-1}R]_{ij}}{s}
\]

Figure 28: Equation for the probability of scoring points.

Where the point scoring probability for the team is the sum of all probabilities of transient states going to absorbing states for the team, divided by the total number of transient states. The result of the equation was used to verify collected data by calculating the point scoring probabilities for the teams based on the official box score of the match, where the point scoring probability of team A is the total points scored by team A divided by the total number of points scored in the whole match. Moreover, the simulation outputs point scoring probabilities for every run of simulated matches and the output of the simulation was compared to hand-calculations of the point scoring probability to verify and validate the simulation’s accuracy. The percent

error of the simulation relative to the data was at 2.11% for the men’s volleyball team and at 2.56% for the women’s volleyball team.

\[
P_{j} = \sum (I-Q)^{i}R_{j}
\]

Figure 29: Average of \((I-Q)^{i}R\) Matrix.

### 6.0 Method of Analysis

#### 6.1 Computer Aided Analysis

As previously mentioned, the CAAT is a post-game analysis decision-support tool to be used after matches are over and data is collected for the played matches. Recalling the volleyball input-output process figure introduced in section 1, we can fit the CAAT tool in the “post-game” block to reflect how the process would change and how post-game analysis would now rely on statistical data rather than coaches’ hunches.

Figure 30: Volleyball analysis process.
The CAAT v 1.0 was developed using the IDE (Integrated development Environment) eclipse. It was programmed in Java and also has an additional Python script for parsing. The simulation works in two phases, the parsing phase and the simulation phase. The parsing phase uses the python script to parse the raw data and then again after a simulation has been run parse the output data. The simulation works by receiving the outputted text file generated from the python script and then runs through the specified number of matches specified by the user in the interface.

![Simulation Phases Diagram](image)

Figure 31: Simulation Phases.

To go in more detail of the simulation phases, first the python script is run through the raw data file(s) and generates the text files for import into the simulation. This script goes through the raw data file while noting each transition that occurred throughout the game. Upon completion of the parsing of the raw data it is outputted into a text file with each team's probability within a transition matrix shown previously. Once this text file is generated we can then import it into the simulation using the import menu item on the simulation interface. (See figure below)
The structure of the simulation is as follows; it operates using 5 classes, Team class, a match class, a game class, a driver class, and the interface class. The team class deals with importing the text file and setting probability values for each team. It uses a java scanner to read through the text file and gather the team probabilities. Once the transitional probabilities are established the driver class imports the probabilities and runs the amount of matches specified in the interface using the match class. The match class keeps track of games within a match. The game class runs an entire game until the one team reaches 25 points and wins by two. The match class runs a best of 5 series of games and keeps track of the scoring efficiency for each team, as well as, it returns the winner of the match for calculating the winning efficiency. Within the game class all of the transitions are recorded and each game is outputted into a text file exactly like the raw data was recorded. The output of the simulation is the score efficiencies and wins percentages for each team throughout the matches simulated, which is outputted into the labeled text fields in the middle of the interface.

The interface itself is comprised of a few features, there are two menu items, outputs printed out in the middle of the interface with the initial values, two functionalities by using the simulate button and the change probabilities dropdown menu. Once the interface has been initiated the first screen is blank and the tool tips give descriptions on what must be done and the functionalities of the features. First a user must select a team, or file output from the python script. Once a team file has been selected the simulate button becomes active.
and the user can run a specified number of matches by inputting a positive integer into the ")# of matches" text field. When the user clicks the simulate button the driver is run for the number of matches specified by the user, after the run is complete the score efficiency and win percentage for the number of matches is outputted onto the labeled text fields on the screen and the raw data from the simulation is outputted into a folder to be further processed.

Figure 33: Simulation Interface.

7.0 SENSITIVITY ANALYSIS

7.1 SENSITIVITY ANALYSIS RESULTS

A sensitivity analysis of the simulation results was conducted to understand the cause and effect relationship between transitional probabilities and the outcome of the match. For every design alternative for both teams, the transition indicated by the alternative was gradually incremented and for each increment, the simulation was run to calculate the point scoring probability outcome of the match.
The figure shows a sample of the sensitivity analysis that was conducted in Excel. The table above the graph shows the design alternative to increase serve aces for team A (GMU). A serve may transition to one of the three following states:

1. Point for A
2. Pass by B
3. Point for B

The red box in the top left highlights the column of the original probabilities of these three transitions based on the collected data from match videos. Every column following that column reflects the experimental probabilities of these transitions. The row highlighted in yellow reflects the design alternative that is experimented; in this case it is the transition of a Serve A to Point A. The row highlighted in pink reflects the amount of increase made to the transitional probability of the design alternative. The last row in the table shows the average point scoring probability for every column of transitional probabilities above it. One can see that as the transitional probability of Serve A to Point A increases, the point scoring probability also increases. The plot under the table is a depiction of that cause and effect relationship.

Since increasing Serve A to Point A was the focus of the simulation, the remaining two transitions had to be normalized every time an increase was made to ‘Serve A – Point A’. In order to calculate and update the probabilities for ‘Serve A – Pass B’ and ‘Serve A – Point B’, we used Saaty’s equation that comes from his book “Analytical Hierarchy Process” in his section about performing a sensitivity analysis of this form. The
equation used is also implemented in the simulation to automatically update probabilities when changes are made.

For every design alternative, the key information that was taken from the sensitivity analysis is the exact probability value that is required to reach the breaking-even point. That represented a 50% winning percentage which meant that both teams were competing at the same level. From the graphs and the simulation results, the probability that resulted in approximate a 0.5 point scoring probability was recorded and used for developing the design of experiment as it will be shown in the next section.

In order to look at and compare the design alternatives based on the sensitivity analysis, three of the design alternatives were combined in one plot: Increasing Serve Aces, Increasing Kills and Increasing Blocks while Decreasing Errors was plotted in a separate graph.

![Serves, Blocks and Attacks Transitional Probability VS Point Scoring Probability](image)

Figure 35: Results of Sensitivity Analysis for aces, kills, and blocks.

![Errors Transitional Probability VS Point Scoring Probability](image)

Figure 36: Results of Sensitivity Analysis for each error.
One can see how increasing serve aces, increasing kills and increasing blocks results in an increase in the point scoring probability and what is more interesting is the fact that increasing serves is the most sensitive to change out of these three alternatives. When this was discussed with the men’s coach, he agreed that serving aces is a high-reward even that is also associated with high-risk. He also said that serves have a heavy weight in determining the outcome of the match.

Similarly, the Decreasing Errors plot reflects how a decrease in errors increases the point scoring probability. It is worth mentioning here that increasing one error at a time does not do much for the point scoring probability. Therefore, when implementing the design of experiment, all errors were decreased simultaneously.

8.0 DESIGN OF EXPERIMENT

8.1 SIMULATED SCENARIOS

In order to provide the coaches with a range of least optimal outcome and most optimal outcome, two scenarios were simulated for all the design alternatives for both teams.

1. **Scenario 1:** George Mason’s team is competing at the level of its top opponent and winning at least half of the matches played against the top opponent, which means that George Mason’s team has a winning percentage of at least 50% against its top opponent.

2. **Scenario 2:** George Mason’s team is competing at a higher level compared to its top opponent and winning most of the matches played against the top opponent, which means that George Mason’s team has a winning percentage of at least 90% against its top opponent.

Both scenarios were then compared to the baseline (current scenario) which reflects the current status of the team. The comparison was done with regard to the probability values that yield the corresponding winning percentage of each scenario.
8.2 DESIGN OF EXPERIMENT

The design of experiment for the men’s and women’s teams is shown in the tables below. As previously mentioned, the values came from the sensitivity analysis that helped identify the probabilities that yield a 50% winning percentage and those that yield a 90% winning percentage.

**MEN’S VOLLEYBALL TEAM**

![Figure 37: GMU Men’s volleyball’s design of experiment.](image)

<table>
<thead>
<tr>
<th>Design Alternatives</th>
<th>Transitional Probabilities</th>
<th>Number of Occurrences</th>
<th>Experimental Probabilities</th>
<th>Number of Occurrences</th>
<th>Transitional Probabilities</th>
<th>Number of Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aces</td>
<td>0.0359</td>
<td>3</td>
<td>0.22</td>
<td>29</td>
<td>0.525</td>
<td>33</td>
</tr>
<tr>
<td>Blocks</td>
<td>0.406</td>
<td>12</td>
<td>0.906</td>
<td>24</td>
<td>0.996</td>
<td>(N/A)</td>
</tr>
<tr>
<td>Decrease Errors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serves</td>
<td>0.1052</td>
<td>9</td>
<td>0.0652</td>
<td>7</td>
<td>0.0152</td>
<td>2</td>
</tr>
<tr>
<td>Passes</td>
<td>0.0102</td>
<td>2</td>
<td>0.0062</td>
<td>0</td>
<td>0.0022</td>
<td>0</td>
</tr>
<tr>
<td>Attacks</td>
<td>0.1408</td>
<td>14</td>
<td>0.0608</td>
<td>5</td>
<td>0.0208</td>
<td>4</td>
</tr>
<tr>
<td>Blocks</td>
<td>0.3775</td>
<td>10</td>
<td>0.1775</td>
<td>5</td>
<td>0.0275</td>
<td>1</td>
</tr>
<tr>
<td>Kills</td>
<td>0.2675</td>
<td>30</td>
<td>0.4675</td>
<td>39</td>
<td>0.5675</td>
<td>47</td>
</tr>
</tbody>
</table>

**WOMEN’S VOLLEYBALL TEAM**

![Figure 38: GMU Women’s volleyball’s design of experiment.](image)

<table>
<thead>
<tr>
<th>Design Alternatives</th>
<th>Transitional Probabilities</th>
<th>Number of Occurrences</th>
<th>Experimental Probabilities</th>
<th>Number of Occurrences</th>
<th>Transitional Probabilities</th>
<th>Number of Occurrences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aces</td>
<td>0.0223</td>
<td>6</td>
<td>0.1223</td>
<td>15</td>
<td>0.3223</td>
<td>24</td>
</tr>
<tr>
<td>Blocks</td>
<td>0.1623</td>
<td>15</td>
<td>0.3624</td>
<td>17</td>
<td>0.6623</td>
<td>30</td>
</tr>
<tr>
<td>Decrease Errors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serves</td>
<td>0.0864</td>
<td>11</td>
<td>0.076</td>
<td>4</td>
<td>0.0614</td>
<td>2</td>
</tr>
<tr>
<td>Passes</td>
<td>0.1023</td>
<td>15</td>
<td>0.0623</td>
<td>13</td>
<td>0.0223</td>
<td>13</td>
</tr>
<tr>
<td>Set</td>
<td>0.0229</td>
<td>9</td>
<td>0.0088</td>
<td>4</td>
<td>0.0048</td>
<td>2</td>
</tr>
<tr>
<td>Attacks</td>
<td>0.104</td>
<td>14</td>
<td>0.0941</td>
<td>8</td>
<td>0.0641</td>
<td>3</td>
</tr>
<tr>
<td>Blocks</td>
<td>0.313</td>
<td>16</td>
<td>0.2887</td>
<td>14</td>
<td>0.2137</td>
<td>13</td>
</tr>
<tr>
<td>Kills</td>
<td>0.1575</td>
<td>18</td>
<td>0.2575</td>
<td>30</td>
<td>0.4075</td>
<td>35</td>
</tr>
</tbody>
</table>

The first column lists the design alternatives that were implemented or in other words the transitions that were experimented in the simulation. The second column shows the baseline (current scenario) against which the two simulated scenarios were compared. The third column shows scenario 1 (50% winning percentage) and the fourth column shows scenario 2 (90% winning percentage). In the table, each scenario has two columns; one for the probability value of the design alternative and one for the number of occurrences of the
design alternative per match. This helped identify target transitional probabilities that can yield at least a 50% winning percentage to fulfill the need for the teams to compete at their top competitors levels.

Key points to mention with regard to the design of experiment:

- The men’s team did not have any ‘Set’ errors, which means that all their sets transitioned to any state but a Point for the opposing team.

- When the men’s block – point transition was increased to 1. Meaning that all their blocks lead to points, their winning percentage only reached a 60% and therefore was not applicable for the 90% scenario in the design of experiment.

- All errors were decreased simultaneously because decreasing errors individually does not increase the winning percentage or point scoring probability significantly. It does not even reach a breaking-even point.

- Each alternative was tested independently; there were no combinations of design alternatives tested in this project.

9.0 RESULTS & RECOMMENDATIONS

9.1 COMPARATIVE ANALYSIS OF SIMULATION RESULTS

In this study, the robust model was used to tests all design alternatives under conditional scenarios with extreme variations in input assumptions, where the opposing teams performance remains consistent in transitional distributions and performance variations. The results will give foresight into scenarios such as a significantly optimal outcome at 90% winning percentage, and a target winning percentage of 50% and the most probable at current status winning percentage for both George Mason University’s men’s and women’s volleyball teams against their top competitor. The simulator parsing processor function quantifies the experimental probabilities into actual values of occurrences.

A comparative analysis was performed to find differences and similarities between the results of two different simulation runs (scenarios). These two simulation runs were then compared to the average transitional probabilities that yield the current average winning percentage of GMU’s volleyball teams against their associated top competitor. There were not any comparative-analyses of combinations of alternatives conducted in this study. Each design alternative was analyzed independently and tested independently, all
other transitions that were not related to the design alternative remained at their original probabilities. The bar chart is a graphical representation that shows the amount of occurrences needed for each design alternative to obtain the associated winning percentage, given that all other transitions remain at the current winning percentage’s transitional probabilities. This was an assumption made prior to testing each simulation scenario.

As of the design alternative errors, the experimental studies conducted throughout this study have shown that reducing one of any type of errors produced by George Mason University’s volleyball team to a minimum of 0 probability will not have any significant affects or yield any major improvements toward the overall point scoring outcome; thereby, obtaining a low winning percentage close to that of the current winning percentage. However, decreasing several if not all errors simultaneously does have an impact of the point scoring and winning percentage. In this study, all errors are taken into account for the purpose of being consistent and unbiased.

![Bar chart showing design alternative probabilities](image)

**Figure 39:** GMU men’s and women’s simulated run based on conditional scenarios.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Design Alternative</th>
<th>Amount of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Increasing Kills</td>
<td>+9</td>
</tr>
<tr>
<td>2</td>
<td>Increasing Blocks</td>
<td>+12</td>
</tr>
<tr>
<td>3</td>
<td>Decreasing Errors</td>
<td>-18</td>
</tr>
<tr>
<td>4</td>
<td>Increasing Aces</td>
<td>+26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rank</th>
<th>Design Alternative</th>
<th>Amount of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Increasing Blocks</td>
<td>+2</td>
</tr>
<tr>
<td>2</td>
<td>Increasing Aces</td>
<td>+9</td>
</tr>
<tr>
<td>3</td>
<td>Increasing Kills</td>
<td>+12</td>
</tr>
<tr>
<td>4</td>
<td>Decreasing Errors</td>
<td>-22</td>
</tr>
</tbody>
</table>

The blue bar represents the current average number of occurrences given both the GMU’s men’s and women’s volleyball average winning percentage from year 2006-2012 against that associated top competitor. The red and green bars represent the number of occurrences that always yield a 50% and 90% chance of winning, respectively. The comparative analysis indicates that each type of alternative will need a significant amount of improvement in order to obtain achieve a winning efficiency of 50% and 90% from the current winning efficiency.
Note that as a design alternative for the men’s volleyball team, blocks do not reach a winning percentage of 90% considering that all of other transitions in all other states remain at their current status. When GMU men’s volleyball team’s blocks to points transitional probability was increase to a probability of 1 for their team, the maximum winning percentage considering all other factors remain at their current status was 63.17%. Thus, blocks, as a design alternative was consider not applicable because it could not reach a 90% winning percentage at its maximum transitional probability. Hence, the zero (0) represents that increasing blocks was negligible for the 90% chance of winning percentage case scenario for the purposes of this study.

The tables below represent the results of the simulation for the 50% chance of winning because 50% winning percentage is the lowest winning percentage that addresses the need and problem. The values in the table are the absolute value of the amount change needed to obtain a 50% chance of winning. Each design alternative was ranked in a descending order, where the least amount of modifiability needed to obtain a target winning percentage is ranked the highest. According the 50% chance of winning simulation results, increasing kills would require on average the least amount of change for the men’s volleyball team and for the women’s volleyball team, blocks ranked highest.

### 9.2 Utility Results

A utility function was developed to weigh the importance of two main aspects in decision-making done by the coaches. The two main utility attributes are trainability (\(TR\)) and modifiability (\(MO\)). Modifiability is the amount of changes needed, from current winning percentage to yield the target winning percentage. Modifiability was determined based on the simulation results of always achieving a 50% chance of winning. Trainability, of existing players, is sub-divided into efficiency (\(EFFY\)) and effectiveness (\(EFFT\)). Efficiency is defined as the time, effort, and resources needed for the intended task to achieve new standards. Effectiveness is defined as the capability of the team producing the desired results. The utility is denoted as \(U(x)\), which equates to the following

\[
U(x) = (0.5)TR + (0.5)MO
\]

\[
TR(x) = (0.5)EFFY + (0.5)EFFT
\]

The utility values are based on always achieving a 50% chance of winning because this is the minimum target outcome that will address the problem and satisfy the need of both GMU’s men’s and women’s volleyball teams. The weights for the utility were determined by way of a discussion with the GMU head coaches. Since these stakeholders are the primary decision-makers in sport-specific development it was only suitable to obtain their experiences and input into the decision-making process. Using a 0-3 scale, where
zero (0) is the worst and three (3) is the best, each design alternative was surveyed by both the women’s and men’s volleyball coach.

The figure shown below depicts how each design alternative was scored based on the weighted attributions. In conclusion, the highest value that a design alternative can be ranked is 3. Therefore, the highest utility that a design alternative can be scored is a 3. Because coaches have reasonable preferences of alternatives in various circumstances, the utility function values are able to describe these preferences based on the criteria of the listed decision-making attributes.

**Utility Score**

<table>
<thead>
<tr>
<th>GMU Women's VB</th>
<th>(0.5) Trainability</th>
<th>(0.5) Modifiability</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Alternatives</td>
<td>(0.5) Efficiency</td>
<td>(0.5) Effectiveness</td>
<td></td>
</tr>
<tr>
<td>Increasing Aces</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Increasing Blocks</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Decreasing Errors</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Increasing Kills</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GMU Men's VB</th>
<th>(0.5) Trainability</th>
<th>(0.5) Modifiability</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Alternatives</td>
<td>(0.5) Efficiency</td>
<td>(0.5) Effectiveness</td>
<td></td>
</tr>
<tr>
<td>Increasing Aces</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Increasing Blocks</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Decreasing Errors</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Increasing Kills</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 40: Rates of each design alternative.

In conclusion the utility yielded the following results for the GMU women’s volleyball team; increasing blocks has the highest score, making it the best alternative in terms of utility. Decreasing errors came in second. Increasing aces came in third. Increasing kills was the lowest scoring design alternative. According to the utility values for GMU men’s volleyball team, decreasing errors has the highest score and is better alternative with respect to the utility. Increasing kills came in second. Increasing blocks came in third. Increasing aces was the lowest scoring design alternative with respect to the utility.

9.3 Utility vs Risk Analysis

Utility functions can also be related to risk measures. In this study, each design alternative was also rated based on a risk assessment, measuring the magnitude of failure. There are risks involved with each design alternatives, in terms of attempting to execute either alternative. This was determined based on the
coach’s experience. Therefore, the design alternative with the highest utility and lowest risk is an idle preference for the coach. This analysis was conducted to make the coach’s risk informed decision-makers.

Although increasing aces was an alternative that showed the most reward as far as point scored as well as the most change need to improve from current winning percentage, it is the only alternative that does not involve rally-scoring. It is also an alternative that if properly executed by the team then the team gets a chance to start the next serve, which gives them another chance making an ace. If this process is repeated there is high reward to this particular design alternative. However as noted in the utility score, training to serve aces and execute service aces in a match is hard, rare and sometime unpredictable. In attempting to serve an ace, it is more likely that a service error will occur. This is an observation often noted by the volleyball coaches. Many coach’s prefer a serve-rally, which is an transition between their serve and a reception by the other team, that will allow the coach and team to implement tactics or provide opportunities where their team can play the ball with more control.

Blocking is an event where the ball undergoes a rally; however, a block does not start the rally. A block has an advantage for the defensive team that by placing the ball immediately back to the opponent’s court it forces them to put up another attack. However, this tactic does not have much gain other than the fact that it gives more opportunities to rally. A block does not count as a team contact or a pass; therefore, if your team attempts a block but the ball makes it over the net, your team still has three contacts available in the rally. Thus, there is very low risk in executing a block.

The ideal sequence of transitions is a pass, set and hit combination. This sequence is primarily used to exhaust all three contacts, in the hopes of setting up a good tactical play, where a team will try to set up an attack for a kill. The point of the third contact is to hit the ball into the opposing team’s side of the court, where it is difficult or impossible for the opposing team to return or recover the ball to put the ball back in play for another rally. Similarly to a service aces, attempting to kill the ball has some chance of obtaining a hitting error, therefore creating a risk. An attack occurs more often than any other type of point-scoring transitions, due to rally scoring. Since an attack is typically the third and final contact before the ball goes into the opposing team’s side of the court, it shows some risk in that it may not be properly executes due to the transitions that preceded the attack.

Minimizing errors does not obtain points for a team, however, it in essences mitigates the number of points the opposing team obtains by way of an illegal volleyball event or an action that lead the ball to go out-of-bounds for that team. In terms of volleyball, in order to decrease errors, the team and coach would have to decide to play the game safe. This means take fewer chances in executing transitions such as aces, blocks and
kills. This will lend them to have more chances in rallying the ball, however, it will also giving the opposing team easier ball to have control over. So, George Mason University men’s and women’s volleyball teams will take a defensive stances most of the time when lowering the amount of errors that contribute to their competitor’s score. Often times a team will win on an offensive stance, unless the opposing team makes more errors that out weigh their offensive points-scored. This is why decreasing is a medium to high risk.

![Men's Utility vs Risk](image1)

**Men's Utility vs Risk**

- High
- Medium
- Low

- Increasing Aces
- Increasing Blocks
- Decreasing Errors
- Increasing Kills

![Women's Utility vs Risk](image2)

**Women's Utility vs Risk**

- High
- Medium
- Low

- Increasing Aces
- Increasing Blocks
- Decreasing Errors
- Increasing Kills

Figure 41: Men’s vs Utility Risk Analysis

Figure 42: Women’s Utility vs. Risk Analysis
Again, the design alternative with the highest utility and lowest risk is an idle preference for the coach. In terms of the GMU men’s team’s utility vs. risk analysis, increasing aces has the lowest utility and highest risk amongst all other design alternatives. Increasing blocks has the second lowest utility and lowest risk out of all the other alternatives. Decreasing errors has a medium to high risk and the highest utility value. Lastly, increasing kills has a low to medium risk and the second highest utility value amongst all other design alternatives.

According to the Utility vs. Risk Analysis for the GMU women’s volleyball team, increasing aces has the second lowest utility and highest risk amongst all other design alternatives. Increasing blocks has the highest utility and lowest risk out of all the other alternatives. Decreasing errors has a medium to high risk and the second highest utility value. Lastly, increasing kills has a low to medium risk and the lowest utility value amongst all other design alternatives.

9.4 RECOMMENDATIONS

The following recommendations are based on yielding a 50% chance of winning percentage from the Utility vs. Risk Analysis, mentioned in the previous section:

<table>
<thead>
<tr>
<th>Team</th>
<th>Rank</th>
<th>Simulation Results</th>
<th>Change Required</th>
<th>Utility Results</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Men</td>
<td>1</td>
<td>Increasing Kills</td>
<td>+9</td>
<td>Decreasing Errors</td>
<td>Medium - High</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Increasing Blocks</td>
<td>+12</td>
<td>Increasing Kills</td>
<td>Medium - Low</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Decreasing Errors</td>
<td>-18</td>
<td>Increasing Blocks</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Increasing Aces</td>
<td>+26</td>
<td>Increasing Aces</td>
<td>High</td>
</tr>
<tr>
<td>Women</td>
<td>1</td>
<td>Increasing Blocks</td>
<td>+2</td>
<td>Increasing Blocks</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Increasing Aces</td>
<td>+9</td>
<td>Decreasing Errors</td>
<td>Medium - High</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Increasing Kills</td>
<td>+12</td>
<td>Increasing Aces</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Decreasing Errors</td>
<td>-22</td>
<td>Increasing Kills</td>
<td>Medium - Low</td>
</tr>
</tbody>
</table>

Figure 43: Ranking Design alternatives based on simulation and utility results.

For the GMU men’s team, although decreasing errors has the highest utility, it’s also associated with high risk. Therefore, increasing kills would be the best alternative to improve the men’s team’s performance and compete at Penn State’s level. According to the statistical T-test analysis, GMU men’s volleyball is more then often losing due to PSU men’s volleyball having stronger hitters and killing the ball significantly more. In order to always yield a 50% chance of winning, where there is no statistically significant differences in means of occurrence given that kills is the best design alternative; it was determined that the men’s coach should focus of training on increasing kills on average by 30%, where approximately every 4 out of 10 attacks or
more are kills when competing against PSU. A recommendation as far as recruiting would be to focus on attaining strong servers.

Since increasing blocks has the highest utility and lowest risk, for the GMU women’s volleyball team, the recommendation would be to focus training on blocks in order to improve the team’s performance and compete at Northeastern’s level. Currently, GMU women’s volleyball team has slightly better blockers compared Northeastern, which was depicted in the T-test. The recommendation is to exceed in blocking where there is no overlap in mean distribution. In order to achieve, this goal GMU women’s volleyball needs to on average increase their block by 30% where about 3 out of 10 blocks or more lead directly to a point for GMU women’s volleyball team. A recommendation as far as recruiting would be to focus on attaining strong hitters and strong servers.

10.0 PROJECT MANAGEMENT

10.1 WORK BREAKDOWN STRUCTURE (WBS)

The Work Breakdown Structure is categorized into 5 major components: Management, Research & Analysis, Development, Deployment, and Results.

1) Management: Tasks related to preparing for presentations and reports were assigned under the category of Management. It also included tasks such as defining the project schedule, evaluating the earned value throughout both the semesters, tracking the Cost and Schedule Performance through CPI and SPI Indexes, as well as calculating the project budget.

2) Research and Analysis: Tasks in this subcategory included identifying and meeting with important stakeholders, understanding the context of the problem, collecting initial raw data through box scores, evaluating videos of volleyball games played by men’s and women’s volleyball teams.

3) Development: Tasks in this subcategory involved working in the design of the project, identifying the problem and the mathematical model which can be used as a part of the solution. It also involved identifying the design alternatives.

4) Deployment: Tasks in this subcategory were responsible for building the simulation, working with the defined mathematical model to calculate game-state probabilities, and verifying as well as validating the simulation.

5) Results: Tasks in this subcategory included discovering the results based on the simulation and design alternatives; it also included tasks related to sensitivity analysis.
10.2 PROJECT SCHEDULE

The pert chart highlights the critical path in red beginning from the video analysis and data collections, which needed to be accomplished before running the simulation of game model followed by results.

PERT CHART

Figure 3: Pert Chart Highlighting the Critical Path in red.
10.3 PROJECT BUDGET

For the project, the total budget is estimated to be at $127,604.05. It includes the labor cost of $59,992.50 derived from the five categories in the work breakdown structure and the overhead charge for the research done at mason.

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Est. Resource Work Hours</th>
<th>Normal Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANAGEMENT</td>
<td>264</td>
<td>$11,880.00</td>
</tr>
<tr>
<td>RESEARCH &amp; ANALYSIS</td>
<td>680</td>
<td>$28,050.00</td>
</tr>
<tr>
<td>DEVELOPMENT</td>
<td>315</td>
<td>$11,812.50</td>
</tr>
<tr>
<td>SIMULATION &amp; TESTING</td>
<td>120</td>
<td>$4,950.00</td>
</tr>
<tr>
<td>RESULTS &amp; RECOMMENDATIONS</td>
<td>80</td>
<td>$3,300.00</td>
</tr>
<tr>
<td>Labor Cost Total</td>
<td>1459</td>
<td>$59,992.50</td>
</tr>
<tr>
<td>Total Budget Cost</td>
<td></td>
<td>$127,604.05</td>
</tr>
</tbody>
</table>

10.4 EARNED VALUE MANAGEMENT

For the second semester, our earned value (EV) was less compared to the planned value (PV). Our actual cost was also less compared to the planned value. This indicates that we had probably overestimated the amount of time that would be required to complete our project in time. There were also some changes made in the scope of the project during the second semester. Hence, the higher planned value compared to the low actual cost also indicates this changes since less time was now needed to complete the project when compared to the original status present in the beginning of the semester.
For the second semester, the Cost Performance Index (CPI) had spiked for the month of December. This was due to the fact that video analysis of the volleyball games was still pending at the end of the first semester. Since the collection of raw data from the videos was required to complete any statistical calculations and discover distributions, many additional hours were spent collecting such data in December. The overall CPI of the project was on average above 1, which indicates that we had spent more time completing the tasks in comparison to our original estimates. The Schedule Performance Index (SPI) was on average around 1, which indicates that for the second semester the project stayed on schedule as originally planned.
10.6 RISK MITIGATION

For our project, we identified a few risks that can have a negative impact on the project. To mitigate these risks, different strategies were implemented. One of the biggest risks to the project was incompletion of video analysis. To mitigate, the collection of video analysis was divided among group members equally in order to expedite the process. Another high risk to the project was the errors in the simulation. To mitigate, the simulation was constantly tested after few incremental changes to help in discovery of errors. Finally, errors in sensitivity analysis posed threat towards the completion of the project. To mitigate, simulation was run multiple times in order to validate the results.

<table>
<thead>
<tr>
<th>Risk #</th>
<th>Risk</th>
<th>Timeframe Start</th>
<th>Timeframe End</th>
<th>Risk Level</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Incompletion of video analysis</td>
<td>12/10/2012</td>
<td>03/1/2013</td>
<td>High</td>
<td>• Implementation of a python parser to accelerate process</td>
</tr>
<tr>
<td>2</td>
<td>Simulation errors</td>
<td>12/27/2012</td>
<td>02/15/2013</td>
<td>High</td>
<td>• Testing and validation of results using markov chain hand calculations and official box scores to measure adequate percent error</td>
</tr>
<tr>
<td>3</td>
<td>Sensitivity analysis errors</td>
<td>02/20/2013</td>
<td>03/20/2013</td>
<td>High</td>
<td>• Research proper formula to adjust changes in probabilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Ran 10 simulations (5000 runs each) to validate results</td>
</tr>
</tbody>
</table>

Figure 48: Risk and Mitigation Matrix.
10.7 LESSONS LEARNED

• Identify bottlenecks early in the project plan.
• Develop back-up plans to ensure smooth processing of bottlenecks.
• Conflicts may arise within the group as well as between stakeholders, it is important to always find a way to move forward.
• Identify limits of project given the timeframe.
• How to communicate ideas to different audiences.

11.0 REFERENCES

4. www.caasports.com; Colonial Athletics Association Website.
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