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Utilizing Analytics in American Football to Improve Decision Making on Fourth Down

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Utilizing Analytics in American Football to Improve Decision Making on Fourth Down

An Integrated Project

Submitted to the Faculty

Of

Department of Engineering Management

By

Daniel David Reid Ferguson

In Partial Fulfillment of the Requirements for the Degree

Of

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Abstract

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Utilizing Analytics to Improve Decision Making on Fourth-down
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The purpose of this paper was to investigate what advantages, if any, an analytical approach using historical data could have in guiding critical game decisions in order to maximize a team’s chances of winning. The analytical approach described in this paper involves using expected point values that correspond to an offensive team’s location on the field and historical first down conversion rates. From this information a decision is made that chooses the fourth-down option that yields the highest amount of expected points. Using historical, data a fourth-down Strategy Sheet was developed based upon expected point values. The Strategy Sheet was used in a simulation and comparison studies, which compared actual values to expected values. Both studies showed with statistical significance the developed analytical approach outperformed traditional football strategy. After determining the validity of the analytical approach, the next step was to determine how often coaches abide by the analytical approach. The results from a survey given to 104 coaches found that a majority, 61.5%, make decisions that disagreed with the analytical approach. The author argues the reason that coaches underutilized analytics was due to multiple biases and the Ellsberg paradox. Overall, this study of fourth-down decision making has concluded that analytics are beneficial in guiding decision making, and current coaches underutilize them.

Key Words {Engineering Management, Analytics, Football, Expected value}
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Definitions and Abbreviations

Figure D1 shows the playing field for football games. Included in the figure are the dimensions involved with the playing field, along with the labels for important parts of the field.

Figure D1: Schematic of a typical American football field [1]

The following terms and abbreviations are important in the investigation of fourth-down strategies in the game of football.

**DEF**

DEF is the abbreviation for defense, which is the group of players on one team that is trying to prevent the opposing team from scoring.

**OFF**

OFF is the abbreviation for offense, which is the group of players on one team that is trying to score against the opposing team’s players.
**Line of Scrimmage**

The line of scrimmage is where the offense begins their play. The yard line in which the offense ends its next play is where the new line of scrimmage is located.

**First down Line**

The first down line represents the distance that a team must reach with the ball in order to gain a first down. Teams have four plays to gain ten yards in order to get a first down. If a team fails to get to the first down line in four plays, the opposing team gains possession of the ball.

**Convert**

Convert is a term used in football when a team successfully moves the ball across the first down line.

**Goal Post**

A goal post is located at both ends of a football field. The goal post has a cross bar that is 10 feet above the ground, 18.5 feet wide, and post that go up 20 feet from the crossbar. In order to get a better physical representation of a goal post, refer to Figure D1.

**Field Goal**

Field goals occur when the offensive team kicks the ball in between the goal post. If the team successfully makes the field goal, then they receive three points. However, if the team misses the field goal, the opposing team gains possession of the football from the spot on the field that the field goal was kicked.

**Touchdown**

A touchdown occurs when an offensive player gets the ball over their team’s goal line. The goal line is labeled in Figure D1 for reference. The team can either run across the goal line with the
ball or catch a pass in the end zone to score a touchdown. A team receives six points for every touchdown they score.

**Extra Point**

An extra point is a field goal that occurs after a team scores a touchdown. The ball is spotted at the two-yard line for an extra point attempt. If the team makes the extra point, they receive 1 point.

**Punt**

A punt is a play that occurs when the offensive team decides to kick the ball down the field to the opposing team in order to gain a field position advantage. Punts typically occur on fourth-down.

**2-Point Conversion**

After a team scores a touchdown, it has the choice to forgo the extra point kick and instead try for a 2-point conversion in one play. When a team elects to try for a 2-point conversion, it is given possession of the football on its own two-yard line and must either run or pass the ball into the end zone.

**Drive Summary Statistics**

Football statisticians collect statistics for every possession a team has had, including where the possession began, length of the possession, how many plays were run in the possession, and the end result of the possession.

**Read Option**

Read option is a play type in the game of football in which the quarterback has the option of giving the ball to the running back or keeping it to run himself. The decision is made by the quarterback after he determines what he thinks the defense will do.
Introduction

American football is a popular sport that has millions of viewers each weekend during the season [2]. The game consists of two teams attempting to gain control of a ball and move it across a 100-yard playing field in order to have the opportunity to score points. Figure D1 in the Definitions and Abbreviation section shows the layout of a typical football field. There are three main ways of scoring: touchdowns, which occur when the offensive team crosses the opponent’s goal line with the ball, field goals, which occur when kicking the ball through a goal post; and extra points, which are field goals that are attempted after touchdowns from the two-yard line. Touchdowns are worth 6 points, field goals are worth 3, and extra points are worth 1 point.

One critical aspect of the game is getting a first down, which allows the offensive team to continue to have possession of the ball. When a team gets the football, they have four plays to move the ball 10 yards to obtain what is called a first down. If they haven’t obtained a first down in the first three plays, then they have to choose between three options on their next play: punting the football, which entails kicking the ball to the opponent, attempting a field goal, or trying to obtain a first down. Failing to obtain a first down or missing a field goal gives possession of the ball to the opponent at the spot where the failed fourth-down attempt occurred. Punting is a common choice made by coaches on fourth-downs when their team has the ball on their side of midfield. Punting gives possession of the ball to the opponent, but typically at a further distance from their goal line. The game at the professional and collegiate levels is sixty minutes long and broken into four quarters of play. The team with the most points at the end of the fourth quarter is the winner. In the event that both teams have the same score after four quarters, the game goes into overtime. However, since overtime rules vary for different leagues and levels, it will not be discussed in this paper.
The purpose of this investigation is to use a team’s punt, field goal, and first down data to help guide its fourth-down decisions. Using Historical data, expected point totals can be calculated for each fourth-down decision. The analytical approach will choose the option that will maximize the amount of expected points. The analytical approach relies on using recent historical data to make decisions based on the best long-run outcomes. Analytics are commonly used across different industries to generate forecasts for markets, but are underutilized in football. While teams have statisticians that might track fourth-down data for making suggestions, there is no indication from watching the games that coaches are actually utilizing the analytical tools given to them. Other factors such as time left in the game, current score, injuries, and weather conditions potentially play a larger role in a coach’s decision to attempt a first down.

Historical data for this study was taken from the last two seasons of Rose-Hulman Institute of Technology’s Fighting Engineers football seasons. The Fighting Engineers are a collegiate Division III football team in Terre Haute, Indiana. This project is being done for a single Division III team because the concept of analytical thinking is not widely applied to the game of football. The investigation must start with lower division teams and build significant evidence of effectiveness in order for the concept to be utilized in higher division teams. Football as a whole is a proof of concept industry. In order for something to change, it must be successfully applied at the lower levels before it is attempted at higher levels [3]. One great example of this is the “read option” used by athletic quarterbacks. Twenty years ago, the average National Football League quarterback would rarely run what is called the read option; but today a majority of teams have it in their playbooks due to the success of the concept at the lower collegiate and high school levels[4]. The sport is a proof of concept industry because as
the level of competition increases the amount of money at stake also increases. Just like a good company tests effectiveness of a product in a market before they begin mass producing it, football teams want to see how effective a new concept or strategy is before implementing it into their own game plan.

The core concept discussed in this paper is that analytics and historical data can be used to guide critical game decisions made by coaches in order to improve their chances of winning. This approach removes biases in a coach’s play calls and looks at decisions from a simple cost to benefit analysis. A team can then use quantitative evidence to select the option that will allow it to maximize its chances to win more games on average.

Another important aspect of this study is to explore why the majority of coaches do not use an analytical approach to aid them in their fourth-down decision-making process. The author proposes that some coaches have limited knowledge of statistics and quantitative decision making, so they often dismiss analytical approaches for being too aggressive in their fourth-down decision-making. Using long-run expected values to make decisions goes against how they have been taught by their own coaches and mentors. Football is a game that has unwritten rules for making decisions that have just recently begun to be questioned [5]. Coaches who dare to go against these passed down rules are seen as football outsiders with a high probability of losing their jobs. This entails the final major factor that prevents analytics from being widely used in football. Job security is necessary for making a living and providing for a family; it is hard for individuals with little knowledge of statistical and mathematical concepts to put faith in an analytical approach when their careers are at stake. The reason for lack of job security in coaching football is due to the importance of winning. Winning is a difficult task to accomplish and can’t be guaranteed [5]. Lacking a guarantee is why it is difficult for teams to
make decisions that go against traditional methods. Innovators are often put under more scrutiny than others who follow traditional strategies. Losing while using a radical approach will more than likely cause a coach to be out of a job.

Football is not an unbiased game of chance with a predictable long-run outcome of winning. This is why generating an analytical approach is very difficult. The unpredictable nature of the game is something that is hard to measure, and as more games are played, the strategy must evolve to include this additional data that may change decisions made on a week-to-week basis.

Many games of chance are unbiased. This means that the odds of an event occurring do not change regardless of other events around it. Unbiased games of chance are very common in casinos, and Blackjack is one of the most played casino games in the world [6]. Assuming that a Blackjack player is not counting cards and following a basic strategy, and there are six decks being played, the player’s odds of winning a hand is 43.36% [6]. This means that no matter where they play, the long-run odds of them winning is always 43.36%. The unbiased nature of Blackjack is what allows for a simple Strategy Sheet for winning to be followed. The sheet contains the best analytical move for a player based upon the given cards in play. Deviation from basic strategy will often result in lower win percentages, and experienced Blackjack players know this. Developing an analytical strategy for football is not as simple as creating a strategy for Blackjack because the strategy is based on an individual team’s performance in the past. However, when the necessary data is collected and analyzed, a strategy can be developed that will work just like the basic strategy in Blackjack and maximize a team’s chances of winning.
In the game of football, the skill of the opposing team changes week to week; therefore, it does not make sense to approach decisions the same way that other teams do. Teams that are not as good as their opponents put themselves at a major disadvantage when they play the game with the same mindset as their opponents. Teams that are less skilled must take a different approach to the game in order to maximize their probability of winning.
Current Fourth-down Decision Making

Understanding how fourth-down decisions are made currently is an important first step in determining what coaches consider when making a fourth-down decision. Coaches often make their decisions in real time based upon their team’s current performance, momentum, weather conditions, and intuition. Often making strategical decisions in the moment is very stressful and can lead coaches to make poor or improper decisions. Multiple psychological studies have shown that even mild amounts of stress have a significant impact on an individual’s ability to make correct decisions [7]. This is what makes an analytical strategy so practical; it allows for emotions to be eliminated and reduces stress associated with fourth-down decision making. Since coaches know what their decisions are ahead of time, then they can focus more of their attention on other aspects of the game.
How Analytics Can Guide Decision Making

The analytical approach to the game of football proposed by the author revolves around the core concept of expected value. The expected value approach uses conditional probabilities to determine an expected result for a set number of trials. The expected value is determined by multiplying the probability of an event occurring by the number of trials or samples recorded. For example, suppose that an individual rolls a fair six-sided die. Each of the six possible outcomes has a probability of $\frac{1}{6}$. If the person rolls the die 60 times, the expected value of obtaining a “2” is $\frac{1}{6} \times (60) = 10$. As another example, the expected value of obtaining an odd-numbered roll is $\frac{1}{2} \times (60) = 30$.

Decision trees, used by organizations to make decisions through quantitative reasoning, revolve around expected values. Decision trees use conditional probabilities of different events to determine which decision will bring the greatest benefit to the organization. Often this benefit is a measure of financial success for the organization. The decision with the maximum expected value is the option the organization should take from an analytical point of view. Figure 1 shows an example of a decision tree.
Figure 1: Example diagram of a decision tree used to decide between three business options. The potential revenues for each project are located to the left of all the blue triangles.

From the business decision tree shown in Figure 1 there are three options, invest in project A (cost $500), invest in project B (costs $320), and finally, do nothing (costs 0). The expected value of each decision is found by multiplying the potential revenue values (how well the project does) by their corresponding probabilities of occurrence. The revenue values are dependent on the success of the product. Then the resulting products are summed together to get the expected revenue. After the finding the expected revenue, the next step is to subtract the cost of the project, and the resulting value is the expected profit. Since the “do nothing” option has no revenue or cost it results in zero profit. Therefore it is clear from performing expected value calculations that project A is the option that the company should choose.

The use of a decision tree can aid a decision on fourth-down by showing a team the choices it has and the possible outcomes from these choices. Instead of showing financial benefit to a company, this decision tree will show expected value of points scored. Figure 2 is a decision tree for a fourth-down play call in a game.
Figure 2: Decision tree that shows the three choices a team has when facing a fourth-down.

The decision tree shown in Figure 2 depicts the same decision-making process that was used to determine which project a company should choose in Figure 1. This decision tree also provides three options, attempting a first down, attempting a field goal, or punting the ball.

There are three main factors that determine which decision a team should make on fourth-down. The first factor is which team gains possession of the ball at the end of the play. Outcomes that allow the offensive team to retain possession of the ball are positive points, and outcomes that result in the opponent gaining possession are negative points. The second factor is the distance the offensive team needs to move the ball to reach a first down. Historical third and fourth-down rates can be used to determine the probability a team gets the necessary yardage to gain a first down. The final factor is the distance that the team is from its end zone. Using drive data from previous seasons, an expected point value can be assigned to each yard line on the field.
Attempting a First Down

The two outcomes that are possible from attempting the first down are successfully getting the first down or forfeiting the ball over to the opposing team. The expected values from these outcomes can be determined by multiplying the probability of a first down conversion by the points scored for the two outcomes. One important assumption being made is that the expected number of points from a given yard line $X_1$ is approximately the same for each team. $X_2$ represents the location on the field that the offensive team must get to in order to gain a first down. $P_c$ is the probability of getting a first down conversion, given the ball is at yard line $X_1$ and the offense needs to get to yard line $X_2$ for a first down.

\[
P_c(X_2|X_1) = \text{Probability of Conversion} \\
EP(X_1|X_2) = \text{Expected Points}
\]

Utilizing the conversion probability, an expected point value can be determined for the decision to attempt to gain a first down. The two outcomes from this decision are failing to convert a first down ($EP_F$) and converting a first down ($EP_C$). These two expected point values are based upon getting a first down at yard line $X_2$ starting from the $X_1$ yard line. Adding these two resulting expected point values together gives an expected point value for the overall decision ($EP_T$).

\[
\]

\[
EP_F = (1 - P_c(X_2|X_1)) \cdot EP(X_1|X_2) \\
EP_C = P_c(X_2|X_1) \cdot EP(X_1|X_2)
\]

The two outcomes from kicking a field goal can be determined in a similar manner to the method for determining the expected points scored from attempting to gain a first down. Failed field goals result in the defense gaining possession of the ball at the location of the missed fourth-down. The expected points scored from that location is multiplied by the probability that the field goal is missed. Expected points from made field goals are calculated...
by multiplying the probability of making the field goal ($P_m(X_1)$) by 3, which is the number of points scored on a successful field goal, given the ball is at yard line $X_1$. The following equations represent the two outcomes from kicking a field goal:

$$EP_{FG} = P_m(X_1) \cdot 3$$
$$EP_{FG'} = (1 - P_m(X_1)) \cdot EP(X_1 | X_2)$$

Punting is common at all levels of football. In fact, during the 2017 season, Rose-Hulman ended an offensive drive 55 times with a punt. This means that the team ended approximately 33% of its offensive possessions by punting during the course of the 2017 season [8]. The decision to punt is comparable to the decision to do nothing in the business world. However, the major advantage to not punting is that the cost of each decision is the same. This is not to say that the result of all three choices is zero, but picking any of the three choices does not cost a team any points to make. Therefore punting is an unappealing option because it will always have a negative expected point value. Punting should only occur when it results in the lowest amount of points lost from each of the three choices. The equation for determining the expected points from the outcome of punting is:

$$EP_p = - EP(X_3),$$

where $X_3$ is equal to the location of the football after the punt

This equation says that the location of the ball after punting is equal to the position of the football after the offensive team punts the ball. The expected amount of points given up is found by using the resulting expected value of points scored from the ending location of the ball after the kick.
Explanation of Spreadsheet

The entire analytical approach to fourth-down decision making is rooted in the expected value of points scored from any given yard line. Using a team’s drive summary statistics, a plot of the drive summary data can be generated in order to depict the starting point of the drive on the x-axis and the number of points scored on the respective drive on the y-axis. After the data is plotted, a linear trend line can be used to generate a formula to determine the expected point values from each yard line on the football field. The data used in this investigation of fourth-down decision making came from drive summary data from the 2016 and 2017 seasons of Rose-Hulman Football seasons [9,10]. The data used for this investigation is from games in which the team faced teams of similar talent (similar records) and ended with close scores (winning or losing by 10 or less points). In selecting these games, data from games that were not competitive was avoided. Using data from non-competitive games would have increased the likelihood for the team to attempt first down conversions more often. Since the goal of this study was to gain a competitive advantage over an opponent, including data from games with non-competitive opponents did not make sense. The drive summary data from the Rose-Hulman 2016 and 2017 seasons was collected and an average point value for each ten yards on the field was determined. The averages of these values is in Table A.
Table A: Drive summary data from the 2016 and 2017 Rose-Hulman Institute of Technology football seasons (395 data points in total)

<table>
<thead>
<tr>
<th>Average Points Scored</th>
<th>Location of Football from the End Zone (yards)</th>
<th>Average Distance (yards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.000</td>
<td>0-10</td>
<td>5</td>
</tr>
<tr>
<td>4.769</td>
<td>10-20</td>
<td>15</td>
</tr>
<tr>
<td>4.611</td>
<td>20-30</td>
<td>25</td>
</tr>
<tr>
<td>3.773</td>
<td>30-40</td>
<td>35</td>
</tr>
<tr>
<td>3.741</td>
<td>40-50</td>
<td>45</td>
</tr>
<tr>
<td>2.607</td>
<td>50-60</td>
<td>55</td>
</tr>
<tr>
<td>2.318</td>
<td>60-70</td>
<td>65</td>
</tr>
<tr>
<td>1.807</td>
<td>70-80</td>
<td>75</td>
</tr>
<tr>
<td>1.054</td>
<td>80-90</td>
<td>85</td>
</tr>
<tr>
<td>0.923</td>
<td>90-100</td>
<td>95</td>
</tr>
</tbody>
</table>

The data from Table A was used to create a linear regression model for points scored versus the distance a ball was from its end zone and is represented in Figure 3.

![Expected Points Scored Based upon Historical Data from the 2016 and 2017 Rose-Hulman Football seasons.](image)

Figure 3: Graph showing the expected point values assigned to individual yard lines on the field for the Rose-Hulman football team. These values were based upon the results of 395 possessions.

The resulting linear trend line for the data plotted in Figure 3 was

\[ y = -0.0553x + 5.9245, \]
where $x$ is the yards from the end zone and $y$ is the expected points scored. In order to determine if a linear model is appropriate to use, the residuals, which are the actual minus the predicted values, were analyzed. The residuals were checked for normality and whether they were independent and identically distributed. The analysis of the residuals was done in Minitab, and the results found that the residuals appeared to follow a normal distribution (P-value=0.549), which can be seen in Plot A of Figure 4. Plot B showed how there is independence over observation order. Plot C showed how there is constant variance with a mean of zero. The residuals were also independent and identically distributed, which can be seen by the randomness in Plot D. Since all four residual assumptions are met, it is appropriate to use a linear model.

Figure 4: Four-in-one plot developed in Minitab to determine if the residuals of the linear regression followed normality and were independent and identically distributed.
The coefficient of determination, $R^2$ for the linear regression was 0.9789. The $R^2$ for the linear fit was found by using the regression model tool in Minitab. $R^2$ values are calculated by comparing how much variation there is between the mean and the actual value and the mean and predicted value. This means 97.89% of the variation in points scored can be explained by field position. The equation generated from the linear regression can be utilized to determine an approximant expected point value for each yard line on the playing field.

Understanding that there is a linear correlation between field position and points scored is valuable, though not surprising. The reason this concept is valuable is because it allows for decision making based upon the ball’s position on the field $X_i$ and who has the possession of it at the end of a play. Determining all of the possible outcomes based on a single decision and comparing them allows a coach to make the most optimal decision for their team.

Using a team’s historical data, a spreadsheet was developed in Excel that generates a fourth-down Strategy Sheet based on data entered by coaches. Figure 5 displays the data entry section of the spreadsheet.
The data entry section in Figure 5 requires historical team conversion rates at given distances, field goal percentages that correspond to various distances, and the average net punt. Once all of the required data is entered into the cells from Figure 5, then all of the yellow cells will turn green. Once all of the cells are green, the user can refer to the Strategy Sheet to gain insight into all fourth-down situations. Figure 6 shows what a sample Strategy Sheet looks like. Development of the Strategy Sheet will be explained later in the paper.
The Strategy Sheet was designed to be convenient. When using this sheet, the user simply locates the distance from the end zone on the vertical axis, then goes across the row until they reach the distance they are away from a first down conversion. Once the proper cell is found, a recommendation can be found inside the cell, along with a color that indicates what the team should do. The black cells indicate events that cannot occur. For example, it is impossible for a team to gain 10 yards if the ball is on their own 1-yard line.

The Strategy Sheet works by utilizing the equations described in the “Attempting a First Down” section to determine which decision will maximize expected points. Figure A1 in the appendix shows the expected point totals from fourth-down and one yard at any position on the field. The same process was followed for all fourth-down situations up to 20 yards. The expected points scored by attempting to convert a first down is shown in the column labeled “Try for First,” the expected points from punting is located in the column labeled “Punt,” and the expected points from attempting a field goal is located in the column labeled “Field Goal.”

Figure 6: Sample Strategy Sheet for fourth-down decision making
Net EP.” The last column labeled “Decision” uses a maximum function, which determines the largest of the three possible expected point values. Along with the maximum function in Excel, an “If” statement is used to produce a resulting phrase for the proper analytical decision to make. Simply stated, the decision column cells are designed to determine which column produces the optimal result. The optimal result is the decision that yields the largest expected point value.
Development of Strategy Sheet

The development of the Strategy Sheet required that data be easy to enter in order to generate an accurate analytical fourth-down strategy. It was important to create a system that was simple to use and could easily communicate results. Along with ease of use, the system had to be capable of producing results for any possible situation that a team could face in a game situation. Before developing a user interface, it was critical to understand how coaches would want an analytical strategy sheet to work. After hours of consulting with 12 different coaches about what strategy tools that they currently use during a game, the investigation showed that an overwhelming majority refer to a 2-point conversion chart. This chart tells a coach, based upon the score of a game, whether or not his team should attempt a 2-point conversion. The chart is clear and easy to use; coaches simply find the row and column that match their situation and then the result is clearly displayed to them. Figure 7 shows an example 2-point chart used by Butch Jones, the current head coach of the Tennessee Volunteers. After analyzing the chart in Figure 7, the decision was made to model the analytical fourth-down Strategy Sheet after the design shown in the 2-point chart. After much deliberation, it was determined that the sheet would utilize rows and columns. Instead of an interface that would require a user to input data on a given fourth-down scenario. The rows would indicate the position of the ball on the field $X_f$ and the columns would indicate the distance to convert a first down, $X_d-X_f$. After going to the appropriate row and column for a given situation, a clearly colored and labeled cell will indicate the proper analytical decision. However, the main difference between the 2-point conversion chart and the analytical fourth-down Strategy Sheet is the need for historical team data. The fourth-down Strategy Sheet requires kicking data and historical conversion percentages for each team. While the 2-point
conversion charts for most teams are similar, the fourth-down Strategy Sheets can vary greatly due to the quality of the kicking game from team to team, as well as a team’s ability historically to convert first downs at various distances.

Figure 7: Tennessee Football 2-point conversion chart [11]
Proof of Concept

Simulation Study

In order to see the impact of utilizing analytics, studies were performed to show how the analytical approach matched up against traditional football philosophy. The first study utilized a popular football simulation based game, Madden 18. This game was created to provide a realistic approach to the game of professional football. The game assigns specific skill ratings to players based upon their physical and mental abilities. In this study, The Cleveland Browns were chosen because they were one of the worst teams in the game, which is evident by their winless 2017-2018 season. It was decided to simulate the Browns 2017-2018 season five times to determine the average number of wins for the season and the average margin of victory. The average margin of victory is the average number of points a team wins or loses by each game for a season.

\[
\text{Average Margin of Victory} = \frac{\text{Total Points Scored} - \text{Total Points Scored Against}}{16 \text{ games}}
\]

Two settings were altered to ensure that minimal variance would occur from season to season. The first adjustment was to turn injuries off. This was done so that no players would be injured in one season and not in the others. The second modification was to eliminate trades in order to prevent changes in the roster that would affect the team’s ability to win. During this five-season simulation, the computer made fourth-down decision calls based upon the last decade of historical fourth-down calls in the NFL. At the conclusion of each season, the team’s game scores were recorded, along with their overall win and loss record. The data from the five single year simulations were recorded and displayed in Table B.
Table B: Summary of Cleveland Brown’s 2017-2018 season simulated five times using conventional fourth-down decision making.

<table>
<thead>
<tr>
<th>Season</th>
<th>Wins</th>
<th>Loss</th>
<th>OFF Points Per Game</th>
<th>DEF Points Per Game</th>
<th>Average Margin of Victory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>12</td>
<td>22.1</td>
<td>33.9</td>
<td>-11.8</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>14</td>
<td>18.3</td>
<td>33.3</td>
<td>-15.0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>13</td>
<td>19.5</td>
<td>34.4</td>
<td>-14.9</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>14</td>
<td>17.3</td>
<td>33.2</td>
<td>-15.9</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>8</td>
<td>24.1</td>
<td>29.1</td>
<td>-5.0</td>
</tr>
<tr>
<td>Average</td>
<td>3.8</td>
<td>12.2</td>
<td>20.26</td>
<td>32.8</td>
<td>-12.5</td>
</tr>
</tbody>
</table>

The data from this chart was then used to determine the average margin of victory over the five seasons, which was -12.5 points. This means, on average, that the Browns lost each game by 12.5 points over the course of the five season simulation. The Browns also only averaged 3.8 wins per season over the five-season study.

The first part of the study served as a baseline to be able to compare the results of traditional fourth-down strategy and the analytical strategy developed and explained previously. In order to create a fourth-down analytical Strategy Sheet for the Browns, kicking data was used from the five seasons that were simulated with traditional football strategy. Table C shows net punt averages and field goal accuracy over the five seasons. The field goal percentages are broken up into four categories based upon field goal distance, “less than 30 yards,” “31 to 40 yards,” “41 to 50 yards,” and “greater than 50 yards.” Once the average kicking data was gathered, it was entered into the fourth-down strategy data entry page to generate an analytical fourth-down Strategy Sheet for the Browns. One important assumption about the generated sheet is that the expected points for each yard line is the same as the values calculated for the 2017 Rose-Hulman football team. Figure 8 shows the analytical Strategy Sheet for the Browns.
Table C: Kicking data over the course of the five season simulation of the Cleveland Browns 2017-2018 season

<table>
<thead>
<tr>
<th>Season</th>
<th>Net Punt</th>
<th>FG&lt;30</th>
<th>FG 31-40</th>
<th>FG 41-50</th>
<th>FG&gt;50</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45.2</td>
<td>100%</td>
<td>90%</td>
<td>100%</td>
<td>20%</td>
</tr>
<tr>
<td>2</td>
<td>45.2</td>
<td>80%</td>
<td>100%</td>
<td>90%</td>
<td>40%</td>
</tr>
<tr>
<td>3</td>
<td>45.5</td>
<td>100%</td>
<td>90%</td>
<td>80%</td>
<td>80%</td>
</tr>
<tr>
<td>4</td>
<td>45.9</td>
<td>90%</td>
<td>87%</td>
<td>100%</td>
<td>50%</td>
</tr>
<tr>
<td>5</td>
<td>46</td>
<td>100%</td>
<td>100%</td>
<td>90%</td>
<td>50%</td>
</tr>
<tr>
<td>Average</td>
<td>45.56</td>
<td>94%</td>
<td>93%</td>
<td>92%</td>
<td>48%</td>
</tr>
</tbody>
</table>

Figure 8: Strategy Sheet for fourth-downs that was utilized to make fourth-down decisions for the Cleveland Browns 2017-2018 season

After generating the fourth-down Strategy Sheet, the original study was repeated. The Browns 2017-2018 season was simulated five times, except in this simulation, the Browns made all of their fourth-down decisions based on the fourth-down Strategy Sheet. The results from using an analytical approach proved to be quite significant. The resulting margin of victory and win totals is shown in Table D.
Table D: Breakdown of the five season experiment using the fourth-down Strategy Sheet

<table>
<thead>
<tr>
<th>Season</th>
<th>Wins</th>
<th>Losses</th>
<th>OFF Points Per Game</th>
<th>DEF Points Per Game</th>
<th>Average Margin of Victory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>10</td>
<td>25.06</td>
<td>27.56</td>
<td>-2.5</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>9</td>
<td>23.13</td>
<td>26.06</td>
<td>-2.9</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>7</td>
<td>24.19</td>
<td>24.69</td>
<td>-0.5</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>9</td>
<td>23.81</td>
<td>24.44</td>
<td>-0.63</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>8</td>
<td>24.00</td>
<td>25.13</td>
<td>-1.13</td>
</tr>
<tr>
<td>Average</td>
<td>7.4</td>
<td>8.6</td>
<td>24.04</td>
<td>25.58</td>
<td>-1.54</td>
</tr>
</tbody>
</table>

The average margin of victory over the course of the five simulated seasons in which the fourth-down Strategy Sheet was used was -1.54 points and the average number of wins per season was 7.4 wins. The data from the second part of the study was entered into Minitab, and 1-sample $t$-tests were performed with both the average margin of victory data and total win data.

The hypothesized mean for the average margin of victory was -12.5; this value is equal to the average margin of victory from the first study in which the computer made decisions based upon historical trends. The hypothesized number of wins was 3.8, which was the average number of wins over the first part of the study. In both cases, the $t$-tests were performed to determine if the actual mean was greater than the hypothesized mean. The corresponding $p$-values for the $t$-tests were 0.001 for the average margin of victory and 0.032 for the number of wins. These $p$-values were small enough to reject both hypothesizes at level of significance $\alpha=0.05$. Statistically speaking, this means that the analytical approach is the superior approach. The standard deviation from both tests along with the means were used to generate distributions. The distributions were generated under the assumption that both sets of data followed a normal distribution. Both strategies were plotted on the same plot for each test and can be seen in Figures 9 and 10.
Looking at the comparisons, it’s clear that there is minimal overlap between the traditional strategy and the optimal strategy. This lack of overlap shows why the $p$-values for both the average margin of victory $t$-test and average number of wins $t$-test was sufficiently low enough to strongly suggest that the use of the fourth-down Strategy Sheet had a strong correlation with the improving number of wins and the average margin of victory for the Cleveland Browns.

![Distribution Plot of Average Margin of Victory](image)

**Figure 9:** Comparison of distributions of average margin of victory for each strategy

![Distribution Plot of Number of Wins](image)

**Figure 10:** Comparison of distributions of number of wins for each strategy
Expected Values Versus Actual Values Study

Another approach to validating the analytical approach was to compare the expected values obtained by analytical decision making and the actual values resulting from decisions made that go against the suggested analytical strategy. The study was performed by analyzing drives from Rose-Hulman’s 2017 football season in which the coaches made decisions on fourth-down that were not in line with the analytical fourth-down Strategy Sheet that was generated for this team [10]. When analyzing the data, the drives that occurred in non-competitive games or at the end of the half were ignored in order to provide a more accurate comparison of the two methods. Overall, there were 22 drives from their 2017 season that disagreed with the Strategy Sheet. Table E shows the data corresponding to the 22 drives in the study.
Table E: Data points of the actual results versus expected results study. The table includes the information necessary to preform the study.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Opponent</th>
<th>Distance to Convert</th>
<th>Distance From End Zone</th>
<th>Actual Decision</th>
<th>Actual Result</th>
<th>Strategy Decision</th>
<th>Expected Points Difference</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Illinois College</td>
<td>6</td>
<td>69</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-1.68</td>
<td>-1.68</td>
</tr>
<tr>
<td>2</td>
<td>Illinois College</td>
<td>1</td>
<td>12</td>
<td>Field Goal</td>
<td>3</td>
<td>Go For First</td>
<td>3.37</td>
<td>0.37</td>
</tr>
<tr>
<td>3</td>
<td>Illinois College</td>
<td>6</td>
<td>56</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-0.96</td>
<td>-0.96</td>
</tr>
<tr>
<td>4</td>
<td>Illinois College</td>
<td>6</td>
<td>58</td>
<td>Punt</td>
<td>-3</td>
<td>Go For First</td>
<td>-1.07</td>
<td>1.93</td>
</tr>
<tr>
<td>5</td>
<td>Illinois College</td>
<td>2</td>
<td>78</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-0.92</td>
<td>-0.92</td>
</tr>
<tr>
<td>6</td>
<td>Illinois College</td>
<td>1</td>
<td>71</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>7</td>
<td>Millikin University</td>
<td>6</td>
<td>36</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>8</td>
<td>Millikin University</td>
<td>5</td>
<td>45</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-0.09</td>
<td>-0.09</td>
</tr>
<tr>
<td>9</td>
<td>Millikin University</td>
<td>2</td>
<td>47</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>10</td>
<td>Hanover College</td>
<td>6</td>
<td>31</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>11</td>
<td>Hanover College</td>
<td>5</td>
<td>79</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-1.92</td>
<td>-1.92</td>
</tr>
<tr>
<td>12</td>
<td>Hanover College</td>
<td>4</td>
<td>51</td>
<td>Punt</td>
<td>-3</td>
<td>Go For First</td>
<td>-0.06</td>
<td>2.94</td>
</tr>
<tr>
<td>13</td>
<td>Hanover College</td>
<td>4</td>
<td>47</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>14</td>
<td>Hanover College</td>
<td>2</td>
<td>46</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>15</td>
<td>Franklin College</td>
<td>3</td>
<td>59</td>
<td>Punt</td>
<td>-7</td>
<td>Go For First</td>
<td>-0.18</td>
<td>6.82</td>
</tr>
<tr>
<td>16</td>
<td>Franklin College</td>
<td>3</td>
<td>70</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-0.79</td>
<td>-0.79</td>
</tr>
<tr>
<td>17</td>
<td>Bluffton University</td>
<td>5</td>
<td>60</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>-0.87</td>
<td>-0.87</td>
</tr>
<tr>
<td>18</td>
<td>Bluffton University</td>
<td>12</td>
<td>25</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>19</td>
<td>Anderson University</td>
<td>4</td>
<td>47</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>20</td>
<td>Mount Saint Joseph's</td>
<td>6</td>
<td>43</td>
<td>Punt</td>
<td>-3</td>
<td>Go For First</td>
<td>-0.24</td>
<td>2.76</td>
</tr>
<tr>
<td>21</td>
<td>Mount Saint Joseph's</td>
<td>2</td>
<td>32</td>
<td>Punt</td>
<td>0</td>
<td>Go For First</td>
<td>1.63</td>
<td>1.63</td>
</tr>
<tr>
<td>22</td>
<td>Mount Saint Joseph's</td>
<td>6</td>
<td>71</td>
<td>Punt</td>
<td>-7</td>
<td>Go For First</td>
<td>-1.79</td>
<td>5.21</td>
</tr>
</tbody>
</table>
The resulting point values from each decision made was recorded and put in the actual result column. The actual result values were determined by recording the points that the team scored or gave up as a result of the decision. For example, in Sample 1 in Table E, Rose-Hulman punted the ball against Illinois College at a distance of 69 yards from the end zone. Then on the opposing team’s possession after the punt, Illinois College scored zero points. Therefore, the actual points given up by the decision made in the game was equal to zero points. In order to calculate the expected points from the analytical Strategy Sheet, the expected points scored formula was used. The conversion distance and the distance from the end zone from was entered into the EP formula (Page 16) for each sample. This resulted in a corresponding expected points scored value for each sample.

The difference between the strategy’s expected points and actual points indicated whether the analytical decision from the fourth-down Strategy Sheet was garnered more points than the actual decision made by the coaches. In order to see if the differences in the two values were significant, a 1 sample \( t \)-test was performed utilizing all 22 of the difference values. The initial hypothesis was that the difference between the expected points scored and the actual points scored was less than or equal to zero, the alternate hypothesis suggested the difference was greater than zero. However, before a \( t \)-test could be conducted the data had to be checked for normality. The Ryan-Joiner normality test was performed on the data in Minitab, and the results are shown in figure 11. The results from the normality test suggest that the data is not from a normal distribution. Therefore, the data was bootstrapped in order to determine whether the fourth-down Strategy Sheet statistically outperformed the decisions made by the coaching staff. The important assumption made when using the bootstrapping method is that the data being used is an accurate representation of the entire sample and is independent and identically distributed.
From the wide range of games the data was collected over and the plot of the residuals in Figure 12 it is appropriate to assume both assumptions are met.

Figure 11: Normality test for the difference between actual points scored and expected points scored

Figure 12: Plot generated in Minitab to examine if residuals are independent and identically distributed
Five thousand bootstrap sample means were produced and graphed using the online statistical package StatKey. Figure 13 shows the one tail 95% confidence interval generated from five thousand bootstrap sample means from the difference data in Table E.

![Confidence interval graph](image)

Figure 13: Confidence interval for the difference between expected and actual points scored [12]

From Figure 13 it is clear that the 95% confidence interval does not contain zero; therefore, evidence supports rejecting the initial hypothesis that the difference between expected points scored and actual points scored is less than or equal to zero. This means that the mean differences between the expected and actual points scored are statistically significant. The data suggest that the analytical approach is more effective than the strategy employed by the Rose-Hulman coaching staff during the 2017-2018 season.
Survey

A survey was utilized in this study of fourth-down decision making to show that coaches do not attempt first down conversions as much as analytics suggests. The survey was given to high school and college football coaches. Responses were collected from head coaches, offensive and defensive coordinators, and offensive and defensive assistants. The survey consisted of ten questions that dealt with making a decision on whether to punt or attempt a first down. The list of the survey questions is in the Appendix. The survey was conducted via Survey Monkey using a link that was sent out to multiple coaching staffs across the United States. Overall, there were 104 responses, and a breakdown of the responses by coaching position is shown in Figure 14.

![Breakdown of Survey Responses by Coaching Position](image)

Figure 14: Bar chart showing the number of responses from each different coaching position.

Question 10 in the survey, which asked “What decision would you make if your team faced a fourth-down and 3 at your own 40 yard line and trailing by 6 points with 6 minutes left in
the fourth quarter?” had 78% of the respondents vote that they would attempt to gain a first down. This was by far the highest percentage of all the proposed scenarios in each of the questions (nearly double the percentage of the next highest). Majority of the questions in the survey dealt with fourth-down decision making in different scenarios. Table F shows the given scenarios presented to the coaches and the percentage of respondents that voted for each option.

Table F: Data breakdown of responses to the scenario questions in the survey.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Quarter</th>
<th>Time (mins)</th>
<th>Point Margin</th>
<th>Punt</th>
<th>Go for First</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th and 3</td>
<td>1st</td>
<td>6</td>
<td>6</td>
<td>69%</td>
<td>31%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>1st</td>
<td>6</td>
<td>-6</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>2nd</td>
<td>6</td>
<td>6</td>
<td>58%</td>
<td>42%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>2nd</td>
<td>6</td>
<td>-6</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>3rd</td>
<td>6</td>
<td>6</td>
<td>66%</td>
<td>34%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>3rd</td>
<td>6</td>
<td>-6</td>
<td>57%</td>
<td>43%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>4th</td>
<td>6</td>
<td>6</td>
<td>73%</td>
<td>27%</td>
</tr>
<tr>
<td>4th and 3</td>
<td>4th</td>
<td>6</td>
<td>-6</td>
<td>22%</td>
<td>78%</td>
</tr>
</tbody>
</table>

The responses to question 10 show that coaches typically only attempt to gain a first down when they feel that it's the only option. The reason for this is that the time remaining in the game is short. The data from this study were analyzed based on two factors (1) coaching experience, and (2) offensive coaches versus defensive coaches. The experience factor was analyzed by comparing the responses of the fifty-two least experienced coaches to the responses of the fifty-two most experienced coaches in order to see what effect, if any, coaching experience had on the responses to the survey. For the second factor, a comparison of offensive and
defensive coaches’ responses was studied to show what dependency, if any, existed when looking at a coach’s side of the ball.

While analyzing the amount of coaching experience of the respondents, the average coaching experience of a respondent was determined to be 11.6 years with a median age of 8 years. That is why the break off point for the comparison of data was 8 years. Doing this allowed for a 50/50 comparison of the respondents based on age. The reason for the investigation based on age is to see whether or not fourth-down decision making is dependent on age. This is important to see whether less experienced coaches are more, less, or equally open to the idea of attempting to gain a first down on fourth-down. Figure 15 shows a visual representation of how the responses differed between the two groups of coaches (experienced and less experienced).

![Figure 15: Comparison of the responses by experienced and less experienced coaches on whether they would punt or attempt a first down conversion on fourth-down.](image-url)
The results from the two groups were statistically compared to determine if coaching experience affects a coaches fourth-down decision making. Chi-Square analysis was used to determine the statistical significance of all of the groups of data being compared from the survey. The equation for the Chi-Square analysis:

\[ \chi^2 = \frac{(O-E)^2}{E} \]

where variables \( O \) and \( E \) represent observed and expected values respectively.

After performing Chi-Square analysis on the resulting data from the survey, coaching experience was determined to have no significant effect on willingness to attempt a first down conversion. While the less experienced coaches in the study would attempt a first down conversion at a rate that was 12-percentage higher, Table G shows that the results are not statistically significant.

Table G: Data from coaching survey with coaches grouped into two categories, less experienced and experienced.

<table>
<thead>
<tr>
<th></th>
<th>Punt</th>
<th>Attempt First Down</th>
<th>Marginal Row Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experienced Coaches</td>
<td>14</td>
<td>38</td>
<td>52</td>
</tr>
<tr>
<td>Less Experienced Coaches</td>
<td>8</td>
<td>44</td>
<td>52</td>
</tr>
<tr>
<td>Marginal Columns Total</td>
<td>22</td>
<td>82</td>
<td>104</td>
</tr>
</tbody>
</table>

Calculation of expected value for chi-square analysis:

\[ E = \frac{F_c \cdot F_r}{n} \]

Where \( E \) is the expected outcome of a certain cell, \( F_c \) is the frequency of the column the cell is in, \( F_r \) is the frequency of the row the cell is in, and \( n \) is the total number of samples.

Once \( E \) is calculated, the chi-square formula can be used to determine the chi-square values

\[ \chi^2 = \sum \frac{(O-E)^2}{E} = \frac{(14-11)^2}{11} + \frac{(8-11)^2}{11} + \frac{(38-41)^2}{41} + \frac{(44-41)^2}{41} = 2.075 \]
The chi-square analysis tool was used in order to calculate chi-square values and their corresponding \( p \)-values. The \( p \)-value for this study was 0.150, which means that the data fails to find a strong correlation between coaching experience and fourth-down decision making at the \( \alpha=0.05 \) level.

While coaching experience was shown not to have a significant effect on fourth-down decision making, another comparison that was essential for the study was to determine the effect of being an offensive or defensive coach. This investigation was performed in order to see if the side (offense/defense) a football coach worked on affected their decision on whether or not to attempt to gain a first down. Figure 17 shows a visual representation of the responses from the two groups of coaches.

![Figure 16: Comparison of the responses by offensive and defensive coaches on whether they would punt or attempt a first down conversion on fourth-down.](image-url)
Table H: Data from coaching survey with coaches grouped into two categories, offensive vs defensive coaches

<table>
<thead>
<tr>
<th></th>
<th>Punt</th>
<th>Go For First</th>
<th>Marginal Row Totals</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Defensive Coaches</td>
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<td>27</td>
<td>44</td>
</tr>
<tr>
<td>Marginal Columns Total</td>
<td>19</td>
<td>68</td>
<td>87</td>
</tr>
</tbody>
</table>

Calculation of chi-square statistic from the data in table xx

\[ E = \frac{F_c \cdot F_r}{n} \]

Where \( E \) is the expected outcome of a certain cell, \( F_c \) is the frequency of the column the cell is in, \( F_r \) is the frequency of the row the cell is in, and \( n \) is the total number of samples.

Once \( E \) is calculated, the chi-square formula can be used to determine the chi-square values

\[ \chi^2 = \sum \frac{(O-E)^2}{E} = \frac{(2-9.39)^2}{9.39} + \frac{(17-9.61)^2}{9.61} + \frac{(41-33.61)^2}{33.61} + \frac{(27-34.39)^2}{34.39} = 14.715 \]

The resulting chi-square value from the data comparison of the two groups is 14.715.

From chi-square analysis performed in Minitab, the \( p \)-value for the data was found to be 0.0002. This means there is a strong correlation between coach type and fourth-down decision making at the \( \alpha=0.05 \) level.

While the comparison of the two groups shows that coaches have a conditional bias, this is not the most valuable result of the study. The most valuable result of this study is that it confirms that the majority of coaches are not attempting first down conversions at a similar rate to analytics. The distance to convert in all of the scenarios depicted in the survey was three yards. Analytically the situation is very optimal because, for most teams, a conversion of three yards is quite manageable. However, coaches as shown by the survey results, prefer not to attempt a first down conversion, unless it is later in the game. There are even cases of coaches
who still will not attempt a first down because they believe they still have enough time for another possession. This survey confirms that coaches overvalue late-game possessions because they are more willing to punt early in the game than later, given the same fourth-down scenario. This is a critical error that costs teams opportunities to win more games. This can be avoided by understanding that each possession is worth as much as the previous ones. When coaches wait for a better opportunity, they are hoping that they will not have to attempt to gain a first down later. However, this is a reality in many close games and hoping that the next possession is better is not a sufficient plan. Waiting for better options is like a CEO telling its shareholders at a quarterly meeting that “the company has struggled this quarter, but we are not going to make changes or take any chances because next quarter might be better.” This would not please any shareholder, because at the core of business people understand that you can only wait so long on better opportunities [13]. The concept of waiting for better opportunities holds true in the game of football, sacrificing a current possession (opportunity) in hopes for a better possession (opportunity) later on is not a solid strategy. This is why coaches must understand that when given an advantageous opportunity to score that they must take that opportunity, even if the end result is worse than if they had chosen to punt. Overall, this study of over 100 football coaches shows two major things. First, many coaches are overly optimistic about future possessions, and, secondly, a decent sized minority of coaches would rather lose due to no remaining opportunities, than failing to convert on opportunities earlier in the game.
Reasons for Lack of Implementation

While the analytical approach to fourth-down offers numerous advantages over conventional strategies, it is still not used to assist the majority of coaches. This calls into question why the analytical approach, which has been proven to be statistically more effective, is not more widely adopted across different levels of the sport. The are many factors that make adopting an analytical approach to fourth-down decision making difficult for coaches. These reasons are mostly due to different biases and stigmas that are associated with analytical thinking in the football community [14].

There have been multiple studies done on the topic of fourth-down decision making, but none more renowned than David Romer’s paper, “Do Firms Maximize? Evidence from Professional Football.” Romer is a well-known economics professor at Berkeley University. Romer concluded from his paper that NFL coaches made decisions based upon the result that gave the least amount of variance, instead of which choice increased their chance of winning the most. Romer concludes that the cause for this phenomenon is due to a coach’s reliance on “experience and intuition.” Romer believes that traditional football philosophy is controlled by the Ellsberg paradox [14]. The Ellsberg paradox shows how people, when given a choice between two options, tend to choose the one that has the clearest and defined expected outcome. Daniel Ellsberg designed a study that proposed a scenario were 90 marbles were placed into a container. 30 of the marbles were yellow, and the rest where black and red, but the quantities of both were unknown. Ellsberg asked participants questions that dealt with making wagers on what color a marble would be if it was randomly selected. Overwhelmingly, respondents tended to pick wagers that dealt with selecting or not selecting a yellow marble. This study showed how people favor making decisions based upon known expected outcomes versus outcomes that
have no known expected result. Another way of explaining these results is that in general, individuals are more comfortable with the evil they do know versus the evil they do not know [16].

The basic principles of the Ellsberg paradox explain why coaches typically choose to punt when they should actually be attempting a first down conversion in order to increase their chances of winning. The reason coaches choose to punt is due to its predictable result, whereas attempting a first down conversion leads to a more unforeseen result. This is the explanation and reasoning Romer gives for why coaches make strategic decisions that do not maximize their ability to win games.

The Ellsberg effect has created a bias in coaches, and it is important for coaches to recognize and acknowledge this bias. Implementing debasing practices will prevent coaches from making a decision that lessen their team’s chances of winning. Understanding that intuitive and instinctive decisions can lead to poor results, coaches that choose to adopt an analytical approach to fourth-down decisions will reduce the effects that biases play into their decision-making process. Early adopters of the analytical approach will see the most benefit. The reason for early adopters getting the most benefit is due to their opponent choosing to play with a traditional strategy that lowers their chances of winning. One quote from Billy Beane (General Manager for the Oakland Athletics) that does a great job of explaining the effect of early adoption “When your enemy's making mistakes, don't interrupt him.” When coaches fail to use the analytical approach, they are making decisions that benefit their opponent and hurt their overall chances of winning.
Conclusions

The goal of this paper was to investigate the effectiveness of utilizing analytics to make fourth-down decisions in the game of football. Over the course of multiple studies, the analytical approach has proven to be statistically more effective than traditional methods. Along with showing the effectiveness of analytics in fourth-down decision making, this study also has shown that coaches underutilize analytics when making fourth-down decisions. The survey, which was given to 104 coaches, showed that even in optimal situations, a majority of coaches would punt over attempting a first down conversion. Change is a difficult process for football coaches due to the numerous number of biases affecting their decision making, and the real chance of losing their position with a bad decision. However, teams that adopt the analytical approach to fourth-down decision making will gain an advantage over their opponents. If this approach is more widely adopted, it will change the game of football as we know it today.
Risk Management

One of the major terms used when discussing analytics in football is risk. Many say that analytical decisions are too risky. However, the word “risk” is not being used properly. Risk can be defined as a potential situation that results in danger or harm to an individual or group. While not getting a first down hurts a team’s chance to win a game, it doesn’t create a situation in which someone is in serious harm or danger. Therefore, the proper term would be that a coach is too aggressive. Risk should only be referenced when a coach makes a decision that could cause harm to one or more of his players. One proper example of a risky football decision would be putting a player with a known head injury into the game. This player could potentially have a concussion, which could worsen if the player has more collisions to his head.

While analytics suggests that teams should attempt to gain more first downs, other factors must be considered in the decision-making process. That is why it is essential that risk analysis is performed on the effect of attempting more first down conversions. Adopting an analytical approach to fourth-downs means that offenses may generally run more plays. The key assumption in this analysis is that on any given offensive play, a player has the same chance of getting injured. This leads to the overall conclusion that as the number of plays increases, the risk of injury to an offensive player increases. However, the opposite effect holds true for defensive players. The more a team’s offense is on the field, the less its defense is. This means as the number of offensive plays increases, the number of defensive plays decreases, and then the risks associated with defensive players getting injured decrease when adopting the analytical approach to fourth-down decision making.
While the risks on plays from the line of scrimmage does not change much for players when using the fourth-down analytical strategy, it majorly benefits special teams players. Special teams players play on all plays that involve a change of possession. In the case of the analytical approach, teams will generally punt fewer times. This helps decrease the risk of special teams players suffering an injury. In fact, the chances of a player getting hurt on a special teams play is significantly higher than a player’s chances of getting hurt on a play from the line of scrimmage. According to the Associated Press, 2010-2016 special teams plays in the Ivy League football conference resulted in 23.4% of recorded concussion injuries, even though they only made up 5.8% of the total plays in the game. After seeing this data Athletic Directors from the conference concluded that major rule changes must be made in order to prevent high injury rates on special teams plays [17].

The Ivy League is not the only organization that sees the dangers with special teams. The NFL has considered making dramatic changes in special teams plays in order to reduce the amount of full speed collisions that occur. Some football experts are even advocating for the elimination of some special team plays entirely [18].

Overall, the analytical approach to fourth-down decreases the risk of injury to special teams players because teams that adopt the analytical approach will generally have fewer punts per game compared to their opponents. Since special teams plays have a much higher rate of injury, this means adopting the analytical approach to fourth-down is not only beneficial for helping teams improve their odds of winning, but also reduce the risk of injuries to their defensive and special team players. The only negative aspect of this strategy is that it will increase the risk of injuries to offensive players due to the reality that teams that adopt the analytical approach will typically run more offensive plays per game than teams who do not.
One solution to this issue could be to play more players on offense in order to give the main players on the offense a break in order to reduce their risk of becoming injured due to fatigue. Overall, football is a very dangerous game, and it is nearly impossible with the way the game is currently set up to eliminate risk. It is important to recognize how a change in strategy affects the risks to different players in order to develop a plan that protects players who are exposed to more risk.

**Discount Factor**

Discount factors are often used when making financial decisions that push into the future. Companies use discount factors in order to forecast the present value of future money. The reason that companies do this is because a dollar today is worth less tomorrow. This is because there is an opportunity cost associated with time. Getting a dollar today gives an individual the ability to invest and start making money now. The discount factor is the multiplier at which companies determine the present value of their cash flows based on the money they expect to earn in the future. The discount factor is determined by two factors; discount rate and time. The discount rate is the rate at which an organization discounts their money. Time is the amount of time it takes to generate the future income. Most companies use a discount rate that is close to the annual growth rate of the S&P 500, which is usually around 10%. However, some companies modify their discount rates based upon the risk of an investment. Projects with higher risks will be assigned higher discount rates and projects deemed less risky will have lower discount rates [19]. The effect of the discount rate is shown in Figure 19.
Figure 17: Example of how discount rates affect the present value of money earned in the future

Discounting money is a beneficial accounting practice that guides organizations to decide where they should invest their money. The discounting process allows organizations to consider the time value of their money in order to make decisions that will bring the greatest amount of value to the organization. The concept of discount factors could be used in the game of football to assign the proper value to each possession. During the course of a game, the value of points should be discounted to show how points scored now are worth more than points scored later in the game. This is because scoring points early provides teams with more opportunities than waiting to score later. This is why scoring a touchdown in the first quarter is more valuable than scoring a touchdown in the fourth quarter. Discounting the value of points based upon the time remaining in a game would properly value possession at the beginning of the game. These possessions have been traditionally undervalued compared to possessions at the end of the game. The perspective held by many coaches of overvaluing late-game possessions is logically flawed. The logical issue is that coaches act as if possessions are infinite at the beginning of the game, when in fact there is only a set number of possessions due to time.
restrictions in a game. Therefore, each possession should be seen as equal because in any given position, the most points a team can score is 8 points (touchdown with a successful two-point conversion). Discounting possessions shows that once a possession is completed, the amount of opportunities for a team is decreasing and their ability to score becomes less likely.

Undervaluing early possessions is why coaches often choose to punt; in business, this is comparable to the “Do Nothing Option.” The “Do Nothing Option” means passing on current options in hopes for better options later. This strategy is not a great plan for the future of an organization. This concept holds true with football teams as well. Eventually, coaches give up the opportunity to choose when they attempt to gain a first down. In the beginning of the game, coaches can choose to attempt first down conversions at short opportunistic distances. However, as time in the game dwindles, coaches will eventually be forced to attempt a first-down conversion on fourth-down due to lack of remaining opportunities.
Appendix

Survey Questions

1. What is your current coaching position?

2. How many years have you worked coaching football?

3. For the following questions, you will be asked to make a 4th down decision based on the given information. Consider the following assumptions when making your decisions.
   - Your opponent is of similar skill level to your team
   - The game is being played at a neutral site with optimal weather conditions
   - The outcome of the game is important to both teams
   - No key players have been injured before or in this game
   - Momentum is neutral
   - The drive isn't your team's first possession of the game or half
   - You have already converted one first down on the drive
   - No previous record with opponent
   - The game is occurring in the middle of the season

The first situation is 4th down and 3 yards to go for the 1st down conversion at your own 40 in the first quarter of a game that you are currently winning by 6 points.

4. 4th and 3 at your own 40 in the first quarter of a game that you are currently losing by 6 points.

5. 4th and 3 at your own 40 in the second quarter of a game that you are currently winning by 6 points.

6. 4th and 3 at your own 40 in the second quarter of a game that you are currently losing by 6 points.

7. 4th and 3 at your own 40 in the third quarter of a game that you are currently winning by 6 points.

8. 4th and 3 at your own 40 in the third quarter of a game that you are currently losing by 6 points.

9. 4th and 3 at your own 40 in the fourth quarter of a game that you are currently winning by 6 points.

10. 4th and 3 at your own 40 in the fourth quarter of a game that you are currently losing by 6 points.
Figure A1: Breakdown of the data being used to generate a decision based on fourth-down and one at various distances from the goal line.

<table>
<thead>
<tr>
<th>yards from end zone</th>
<th>4th down distance</th>
<th>Conversion</th>
<th>Successful Conversion</th>
<th>Field Goal Attempt Distance</th>
<th>Field Goal</th>
<th>Field Goal Miss</th>
<th>Field Goal</th>
<th>Punt</th>
<th>Failed Conversion</th>
<th>Try for first</th>
<th>Decision</th>
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<td>18</td>
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<td>0.45</td>
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<td>3.44</td>
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<td>0.62</td>
<td>2.33</td>
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<td>-2.30</td>
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<td>0.82</td>
<td>1.78</td>
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<td>57</td>
<td>0.00</td>
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<td>-2.61</td>
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