

A Decision Support System for the Professional Soccer Referee in Time-Sensitive Operations

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Abstract— The growing popularity of soccer in terms of TV revenue and betting, as well as ubiquitous use of instant replay, has placed increased pressure on referee’s to make accurate decisions. Although the speed and agility of the game and scrutiny of referee decisions (e.g. slow motion replay from multiple camera angles) has increased over time, the human decision-making ability of the referee has remained constant. For example, in the 2010 World Cup, 8% of the decision events were inaccurate. To maintain the integrity of the game, the accuracy must be improved significantly.

Interviews conducted with Subject Matter Experts and an analysis of 17 English Premier League (EPL) games identified on average 627 decision events per game. Analysis of inaccurate calls identified excessive distance from the referee to the event, and referee blindspot as the two phenomena that resulted in inaccurate referee decisions. Three design alternatives were developed to address the distance and blindspot issues faced by the referee: vehicle propelled transportation (e.g. Segway), 2 official referees, and an overhead camera.

Analysis of the performance of these design alternatives in 100 games, simulating ball movement and referee position, showed that the overhead camera relaying information to the official referee improves the referees decision accuracy of missed calls due to blind-spots by 20.26% and 11.31% over Segway and the two refereeing system, respectively.

I. INTRODUCTION

A. Context

SOCCER is one of the most recognizable sport in the world and is gaining popularity rapidly in the United States. The outcome of the game hinges on the accuracy of the official referee, where decisions in game changing events can determine the outcome of the game. Figure 1 shows a previous study representing assistant referee accuracy of 82.5% of offside situations where 17.5% decisions were incorrect.

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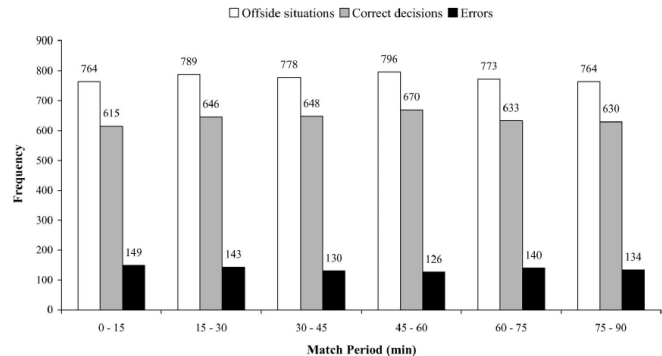


Figure 1: Only 82.5% of AR decisions were correct. source: Offside decision making of assistant referees in the English Premier League: Impact of physical and perceptual-cognitive factors on match performance

Popularity of the sport, game complexity/speed, and amount of money involved are all increasing while human decision-making ability of the referee has remained constant.

The Margin of victory has decreased over time to an average of 1.35 goals per game. For example, 17 out of 64 matches in World Cup 2010, games were decided by a 1 goal margin of victory [3]. The importance of who scores the first goal is important as 46 matches showed that whomever scored first goal also went on to win the match. Only 4 out of the 64 matches did the team make a comeback to win after not scoring the first goal. Figure 2 shows the winning margin for top three leagues and World Cup’s in the past 10 years.

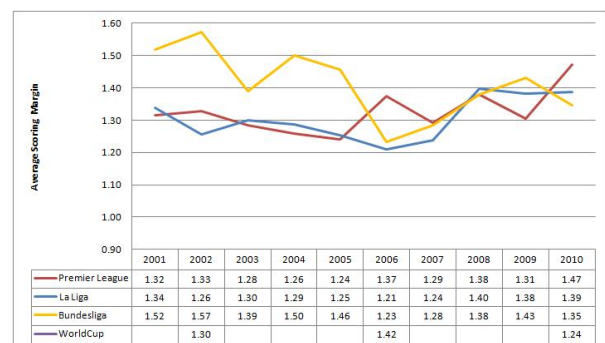


Figure 2. Average scoring margin of matches in the top 3 Leagues for the past decade [4].

The probability of a team winning after trailing by 1 goal in the 30th minute is 11% and decreases to 2% in the 70th minute, emphasizing the importance of a single goal. Figure 3 displays the win probability for a team trailing by 1,2,3 or 4 goals in a 90 minute match.

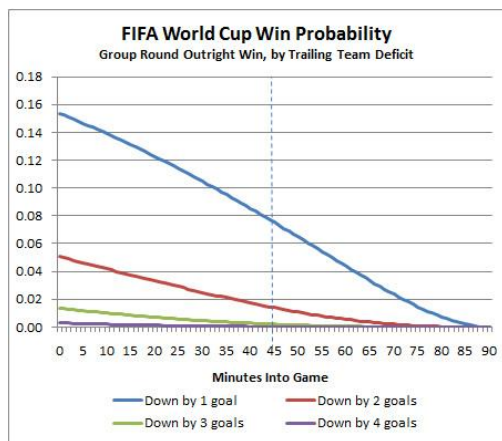


Figure 3. Win Probability of a trailing team down by 1,2,3 or 4 goals in a 90 minute match [7].

These factors impact the referee's overall performance in which decisions have profound consequences. Most importantly, the referee's decisions are highlighted more than ever before through instant replay where inaccuracies can be justified but are just used as a post-game assessment. Instant replay creates *multiple* lines of sight which creates multiple viewing angles of the field for decision analysis. Referees are limited to their *single* line of sight where constraints to the human vision allow only one event to be viewed at one time and not multiple events at the same time.

Teams are playing more strategically and faster which makes the ability to score more complicated. Soccer players are now running faster; top speeds recorded at 18.4 mph for 2010 World Cup, and covering 15 km per game which requires referees to cope with the high demand of increasing game dynamics while maintaining high degree of fitness [5]. Figure 4 reveals a referees degree of fitness of high intensity workload where the mean maximum heart rate (HR_{max}) amongst FIFA referees are 180 beats per minute.

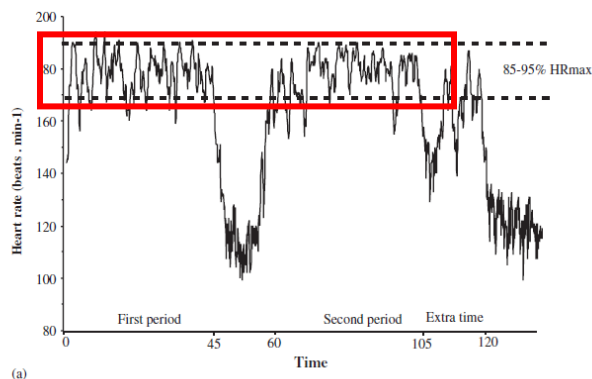


Figure 4. Heart Rate recordings over time for the Official Referee [8].

Referees exhibit high workload that creates fatigue that has been shown to affect decision-making and reveals that performing at the highest international standard, work rate profiles are higher than, those of players [8].

These complexities are exposed through TV/Media coverage as well as the referee's inaccuracies. Social

behaviors are also reflected on decisions made by the referee. Winning and losing teams need to be justified through accurate officiating leaving the teams knowing the win or loss was NOT due to a missed or inaccurate call, but was indeed a fair game.

B. STAKEHOLDER ANALYSIS

The primary stakeholders are those whose financial or personal situation is correlated directly with the performance of the system.

The International Football Association Board (IFAB) and Fédération Internationale de Football Association (FIFA), governing bodies of soccer, are responsible for the election of referees to officiate national matches and worldwide tournaments. The stakeholders are driven by two categories: Politics and Revenue. IFAB is the holder of the Laws of the Game where any changes to the rules must be approved by an Executive Board. The IFAB, driven by politics, favors improving the game of soccer but feel reluctant to use technology as a remedy as the flow of the game may be disturbed. The Referees Association, who is the entity in need, is also driven by politics but is restricted from technological support from IFAB. FIFA, Technology Development Companies, Soccer Leagues, Soccer Clubs, Betting houses and TV/Media are all driven by money. A win-win situation occurs when the governing bodies of soccer, Referees Association and money driven stakeholders accept a decision support system where technological advancements can be made to project revenue while simultaneously increasing referee decision accuracy in adjudication of a fair game.

II. NEEDS STATEMENT

There is a need to increase the percent accuracy of the Referee to 99.9% in game adjudication of a fair game

III. DESIGN ALTERNATIVES

Analysis of 17 EPL games identified that on average there are 627 decisions a referee made by a referee in a 90 minute match. An analysis of 143 rules of the game was categorized by importance to the outcome of the game and frequency. Forty-two rules exhibited. The Expected Value, or importance value, ranks the game situation of highest importance. This is given by the equation:

Where $E.V.$ is the Expected Value of a game situation;
 f is the Frequency of the Game Situation multiplied by the Effect on outcome of the game. Table 1 shows the Referee Call Table of Events where the top 8 most problematic game situations are listed.

The top forty-two events identified the importance of two factors that affected the accuracy of the call: *Distance-to-the-Event* and *Blindspot*.

Referee Call table of Events	Effect	Freq	Importance
kicks or attempts to kick an opponent - in opponent's penalty area	Very High	10	10000
• trips or attempts to trip an opponent - in opponent's penalty area	Very High	10	10000
• jumps at an opponent - in opponent's penalty area	Very High	10	10000
• charges an opponent-in opponent's penalty area	Very High	10	10000
• pushes an opponent-in opponent's penalty area	Very High	10	10000
• tackles an opponent- in opponent's penalty area	Very High	10	10000
holds an opponent- in opponent's penalty area	Very High	10	10000
• handles the ball deliberately (except for the goalkeeper within his own penalty area)- in opponent's penalty area	Very High	10	10000

Table 1 Referee Call Table of Events filtered to show game situations with Very High Effect on outcome

To minimize distance-to-the-event and blindspot, three alternatives were proposed:

1. *Camera system (SkyCam)* hovering around the field capturing video of fouls, offside, goals, and other infringements for 4th Official analysis to support Official referee decision.
2. *Two Official Referees* on the field following the traditional Diagonal System of Control to decrease workload.
3. *Vehicle propelled transportation (Segway)* enabling a single referee to increase his speed to each event.

It is interesting to note that this analysis did not find sensors or ball positioning devices as useful in increasing accuracy.

A. Model Purpose

The alternatives are inputted into the simulation model to evaluate *Referee Performance*. The final accuracy rating for each decision support system will come from the average of all the probabilities of accuracy from the events generated by the simulation. Our sensitivity analysis will be based on utility weights measured against overall cost to determine the most effective decision support system.

IV. SIMULATION

A. Model Design

The aim of the model is to simulate and compare the performance of the alternative decision support systems. The model simulates events that occur during a 90 minute soccer match and calculates Correct, Incorrect and Missed calls due to Distance and Blindspot.

Results are based upon actual ball movement data collected from the 17 EPL games. The data collected was compiled into a Ball Movement Probability Table from which the model uses to simulate ball movement. Figure 5 depicts the simulation model.

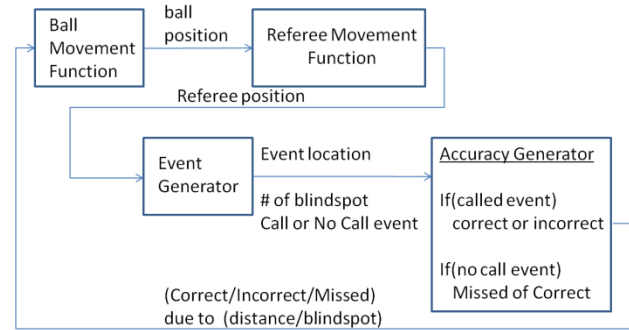


Figure 5 Simulation of referee performance

The model then takes the ball movement and computes how each alternative system would react accordingly. The equation of ball movement moving from *region i* to *region k* is shown by equation:

$$\frac{\sum(x_i, y_i \rightarrow x_k, y_k)}{\sum \text{All passes from } x_i, y_i} = P(x_i, y_i \rightarrow x_k, y_k)$$

Each system is designed slightly differently to model alternative methods of officiating.

B. FIGURES OF MERIT

When simulating how accurately a Referee System judges an event, the model considers how much distance is between the system and the event and also how many blind spots the event has. There is a certain distance threshold in which a referee can confidently make a call where referee's confidence in decision making decreases until a point where he is simply guessing. A Subject Matter Expert determined the distance thresholds to be 10m and 50m, shown in Figure 6. Using this information our model assumes the human referee is 95% accurate up to 10m and 50% accurate when further than 50m. Accuracy between 10m and 50m is represented by a linear function, shown in Equation 1.

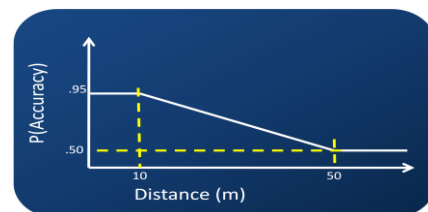


Figure 6 Probability of an accurate call summarized in Figure of Merit

$if(distance < 10)$
 $P(Accuracy) = .95$
 $if(10 < distance < 50)$
 $P(Accuracy) = slope * (distance - 10) + .95$
 $if(distance > 50)$
 $P(Accuracy) = .50$

Equation 1: Equation of the probability of accuracy

The numbers of blindspots are also factored into the accuracy of the Referee System, shown in Figure 7. Each event is randomly assigned between 1 and 5 blindspots using a uniform distribution. Depending on the number of blindspots, there is a probability of a Missed Call.

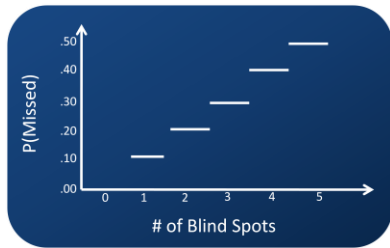


Figure 7 Probability of a missed call due to Blindspot Figure of Merit

C. EVENTS

Events are generated using a uniform random distribution based on actual event statistics from the 17 EPL games. Each event generated has a number of blindspots. When events occur during the simulation, the model computes whether or not each alternative accurately judged the event. Accuracy is dependent upon the distance from the system to the event and the number of blind spots generated by the event.

There are two types of events being simulated in the model: *Called Events*, events that require a stoppage of play and explicit decision from the referee, and *No Call Events*, events that do not require a stoppage of play or a explicit decision from the referee. An example of a No Call Event is when a referee sees a player slide tackled legally and requires no call. It is still considered in our model because this event still requires a decision from the referee which was *play on*.

The result of a Called Event is a decision by the referee systems. The model takes the two parameters of the event, Number of Blind Spots and Distance(s) from the Referee System, and simulates a decision by each referee system alternative where the decision is correct or incorrect.

The result of a No Call Event is different than Called Events, where the model again takes the two parameters of the event and simulates whether the event is seen or not seen. If the event is not seen, we count this occurrence as a *Missed Call*. Due to referees not calling certain infractions for the purpose of game flow, we assume that if the event is seen then it is judged accurately by the referee system

D. MODELING DESIGN ALTERNATIVES

All alternatives have a computed optimal location where the system attempts to position itself in. Movement equations of alternatives are shown by:

$$\begin{aligned}
 \text{Optimal Position} &= \text{Movement (Ball Position)} \\
 \text{Limited Movement} &= \text{System Speed} \\
 \text{Actual Position} &= \text{Current Position} \pm \text{Limited Movement}
 \end{aligned}$$

However, each system is limited by their constraints (fatigue, speed, etc) so they may or may not be in optimal position at all times. The first system modeled was the single referee Left Wing Diagonal System of Control, Figure 8. This is the baseline FIFA officiating method. Referees follow a path on the field designed to keep the play to one side of the official referee so that the assistant referee has the view of the play from the sideline. The model simulates this current system with a slow speed simulated at 13 km/hr, the speed of an average man; medium speed (baseline) simulated at 16 km/hr, the speed of an average soccer official; fastest speed at 21 km/hr, the speed of a champion long distance runner. This system also incorporates the variable of fatigue, shown by:

$$\begin{aligned}
 \text{Speed} &= \text{Speed} * e^{\left(-\frac{t}{24200.1}\right)} \\
 *t \text{ in seconds. } t &= 0 \text{ at start of match.}
 \end{aligned}$$

assuming the referee is 80% fatigued at the end of the match. Position of the diagonal is shown by:

$$\begin{aligned}
 \text{Optimal Position}_x &= \text{Ball Position}_x \\
 \text{Optimal Position}_y &= \text{LeftWingDiagonal (Ball Position}_x)
 \end{aligned}$$

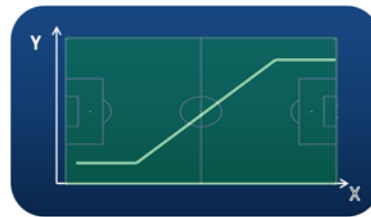


Figure 8 Left Wing Diagonal System of Control

The second system modeled was the referee on a Segway. This system uses the same Left Wing Diagonal; however, one major difference is running speed and fatigue of the official is no longer a factor. The speed of the system is simulated at 21 km/hr.

The third system modeled, Figure 9, was a Two Referee System. This system modifies the Left Wing Diagonal path to accommodate two referees. This system attempts to keep an official on either side of the play at all times. The design is to add one additional line of sight to the system to reduce blind spot errors. The system is modeled with two medium speed referees at 16 km/hr.



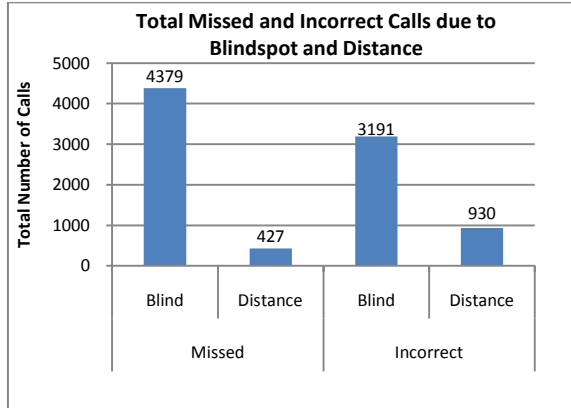
Figure 9 Two referee officiating system using Left Wing Diagonal System of Control

The fourth system is the SkyCam camera system. This system supplements the current officiating system by supplying a camera above the field to eliminate blind spots

completely. The system is modeled by using a medium speed referee (16 km/hr) running the Left Wing diagonal and a simulated camera with a speed of 57.6 km/hr.

V. RESULTS

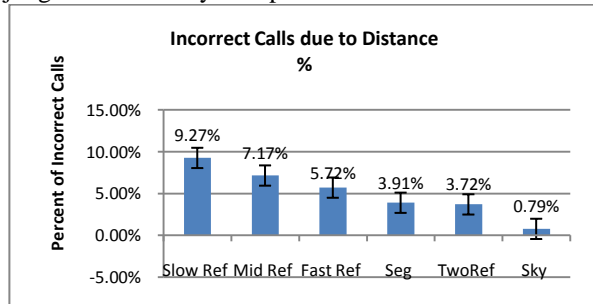
100 soccer matches were simulated where on average, 627.28 events per match were generated, and on average 30.41 of those events required an explicit call. Figure 10 shows 91.1% of missed calls and 74.4% of incorrect calls are due to blindspot events.



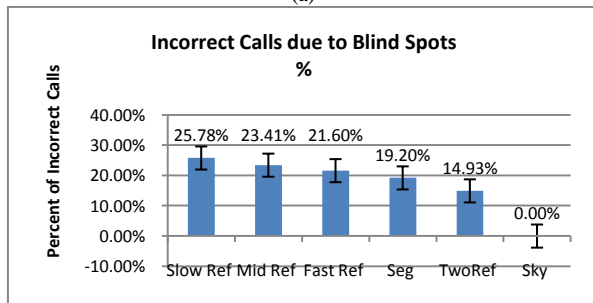
Total Missed		Total Incorrect	
Blind	Distance	Blind	Distance
4379	427	3191	930

Figure 10 Total number of missed and incorrect calls due to blindspot and distance

Of the 30.41 called events per game, the current officiating system judged 2.18 (7.17%) events incorrectly per game due to distance and 7.12 (23.41%) events incorrectly due to blind spots. These were used as a baseline to judge alternative system performance.



(a)

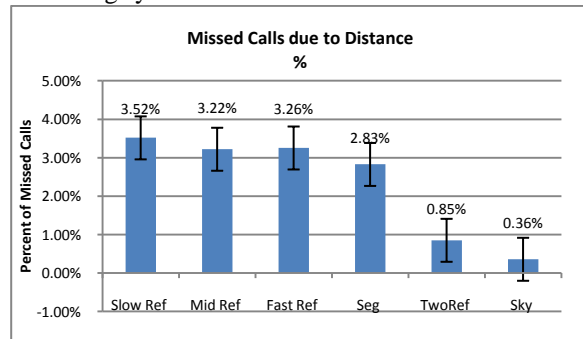


(b)

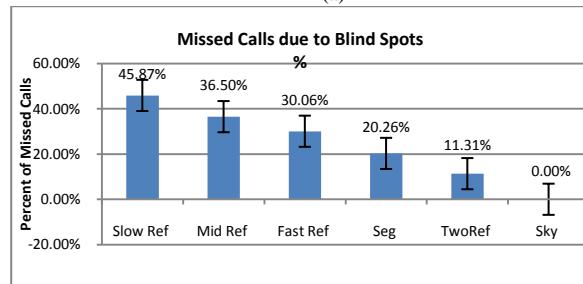
Figure 11 Incorrect calls due to (a) Distance and (b) Bindspot

There was noticeable improvement among the alternatives when considering calls missed due to distance. Alternatives with faster speed reliably improved the accuracy of the system. The Two Referee System, while more reliable than the baseline, was only 0.19% more reliable than the Single Referee on a Segway when faced with distance problems, shown in Figure 11a. However, the added line of sight, provided by the Two Referee System improved Incorrect Calls by 4.27%, Figure 11b, and Missed Calls by 8.95%, Figure 12b, when faced with blind spot issues compared to the referee on the Segway. The Sky Cam System was the best performer when dealing with Called Events.

Of the remaining No Call Events, 0.98 (3.22%) events were missed per game due to distance and 11.1(36.5%) events were missed due to blind spots by the current officiating system.



(a)



(b)

Figure 12 Percent of missed calls due to (a) Distance and (b) Blindspot

Accuracy by the Two Ref System improved 9% over the Segway system due to the one additional line of sight. The SkyCam again was the best performer when concerned with No Call Events. The Sky Cam system was the best performing system with 99% accuracy in both distance and blind spot problems.

VI. COST ANALYSIS

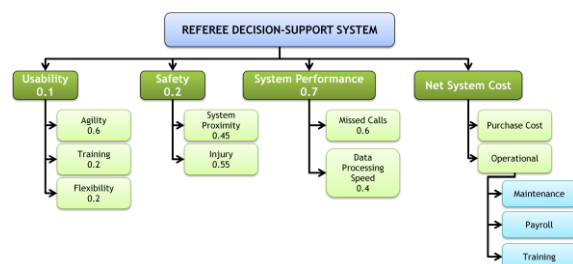


Figure 13 Value Hierarchy for Referee Decision Support System. Weights

verified by Subject Matter Experts.

The Value Hierarchy is broken down into three top level objectives, *Usability*: The ability for a single referee to operate the system in efforts to position themselves on the field; measured in meters/second, *Safety*: The ability of the system to prevent injuries due to collision on the pitch, and *System Performance*: The ability of the system to minimize missed calls due to distance & blindspot while maximizing speed of which data is transferred. The utility is evaluated against the cost for a cost benefit analysis. Table 2 shows the total cost for each alternative.

System Performance is the most desired top-level objective where the alternatives aim to aid the efforts of increasing decision accuracy. Figure 14 shows the Cost vs. Utility graph.

Alternative	Operation Cost	Implementation Cost	Total Cost (\$USD)
2 Referees	\$100,200	\$0	\$100,200
SkyCam	\$70,735	\$1,571,035	\$1,641,770
Segway	\$41,800	\$1,000	\$42,800

Table 2 Total Cost of alternatives for one season

Ranking for Utility vs Cost Goal

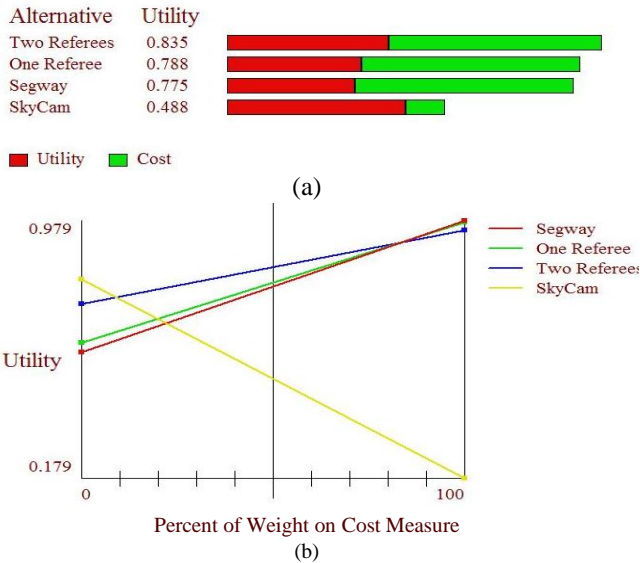


Figure 14. Rank of the alternatives based on Cost vs. Utility

Though the SkyCam system has the highest ranking alternative for system performance, the overall value of using a camera system is consistently lower than the values of the other two alternatives due to its relatively high implementation and operation cost.

Changing the weights of cost vs. utility shows that utility needs to be considered 10 times more important than cost for the camera system to rank first. This is saying if cost is not an issue, the camera system is the best alternative.

VII. CONCLUSION

Based on the simulation model results, though the

SkyCam system will cost the governing bodies of soccer \$1.5M for a season, the performance it contributes to the overall accuracy is considerably effective over the two refereeing system and Segway alternatives. "Missed calls due to blind spot" has SkyCam performing 20.26% and 11.31% better than Segway and the two refereeing system respectively. The two refereeing system needs to perform 27.4% more efficient to equal the performance of the camera system. To maintain integrity of the game, the team recommends a camera system such as SkyCam to improve referee accuracy, where it performs with 99% efficiency compared to the current officiating system of FIFA.

VIII. ACKNOWLEDGMENTS

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Andrew Chapin: Major League Soccer Professional Referee

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