A statistical insight to penalty shoot-outs in the FIFA World Cup tournaments

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Abstract

Penalty shoot-outs are used to decide the outcome of some very important football matches in the past and present. Throughout the paper, statistics will be analysed from previous World Cup penalty shoot-outs and it will be determined if penalties are taken at random, or if a strategy can be implemented to statistically increase a team's chance of winning a penalty shoot-out. This paper will investigate and attempt to justify implementing a definitive strategy.

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1. Introduction

1.1. FIFA World Cup

The FIFA World Cup is an international men's football competition which is played every four years since 1930, with the exception of 1942 and 1946 due to the Second World War [1]. The number of teams that have participated in each tournament varies. The first tournament, hosted by Uruguay, only had 13 participating national sides. This was because it was difficult and expensive to travel across the globe at the time. Very few teams could afford to travel to foreign continents, so decided not to participate. [2]

1.2. Competition structure

FIFA's current format for the World Cup, since 1998, consists of 32 national teams, competing over the course of a month, with a group stage followed by the knockout stage.

The group stage features eight groups, each made up of four teams, whom compete in a round robin style tournament (all play each other once). These matches can end either in one team winning, and the other team losing, or a draw. Each team receives 3 points for a win, 0 for a loss and 1 for a draw. The two teams with the most points in each group progress to the next stage of the tournament. If two teams have the same number of points, their goal difference is used to determine their final position. Table 1.1 below shows group A from the FIFA World Cup 2018.

Table 1.1

GROUP A	PLAYED (P)	WON (W)	LOSS (L)	DRAW (D)	GOAL DIFFERENCE (GD)	POINTS (Pts)
URUGUAY	3	3	0	0	5	9
RUSSIA	3	2	1	0	4	6
SAUDI ARABIA	3	1	2	0	-5	3
EGYPT	3	0	3	0	-4	0

[3]

From Table 1.1, it can be seen that Uruguay won the group with 9 points, and Russia finished runner up with 6 points. Both Uruguay and Russia, advanced to the next stage of the tournament. Meanwhile, Saudi Arabia and Egypt were eliminated.

The second stage of the tournament is a straight knockout. The winner of each group plays the runner-up from another group in the round of 16. The winners of these matches progress to the quarter-finals, then the semi-final and lastly the final. If any of these matches end in a draw, another 30 minutes are played as extra time. If a winner is not decided at the end of extra time; a penalty shoot-out will take place to decide the winner of the tie. This paper will be analysing the penalty shoot-outs during the knockout stages.

1.3. Golden goal rule

It is important to know that the golden goal rule was implemented for the 1998 World Cup. The rule would mean that, if a team was to score in extra time, the match would end with the winning team being the team that scored. The golden goal rule would only be used once more in the World Cup in 2002. By 2006 it was abolished due to its negative impact. [5]

1.4. Format of a penalty shoot-out

In a penalty shoot-out, the team to kick first is decided by a coin toss. Each team then takes it in turns to take a shot on goal from the penalty spot, which is located 12 yards from goal. The only opposing player allowed to defend the penalty is the goalkeeper, who must stay on the goal line when the kick is taken. The shoot-out consists of each team having a total of five shots (if required), which are to be taken by five different players. The winner of the shoot-out, is the team with the most successfully converted penalties. An example of this can be seen below in Table 1.2. Here, Team A has successfully converted all five penalties, but Team B has only converted four, and missed one. Therefore, Team A is the winning team.

Table 1.2

	1	2	3	4	5	Total
Team A	✔	✔	✔	✔	✔	5
Team B	✔	✔	✔	✔	✖	4

The shoot-out can finish early if a team has a lead that cannot be matched. For example, Table 1.3 shows that if Team A scores their first 3 penalties and Team B misses their first 3 penalties, the shoot-out concludes. Team A would be declared the winner in this example. This is due to the fact that Team B cannot possibly match Team A's score, from the remaining two penalties.

Table 1.3

	1	2	3	4	5	Total
Team A	✔	✔	✔	-	-	3
Team B	✖	✖	✖	-	-	0

If both teams are still tied after 5 penalties each, then the shoot-out continues in a sudden death format. The winner of the shoot-out is the team to score one more penalty than the other team with the same number of penalties taken each. Below, Table 1.4 shows that after five penalties, both Team A and Team B have scored four. Both teams then score and then both miss, so the shoot-out continues. On the 8th penalty, Team A scores and Team B misses, meaning Team A is the winner.

Table 1.4

	1	2	3	4	5	6	7	8	Total
Team A	✔	✔	✔	✖	✔	✔	✖	✔	6
Team B	✔	✔	✔	✔	✖	✔	✖	✖	5

1.5. When do penalty shoot-outs take place

Penalty shoot-outs only take place in the knockout stages of the FIFA World Cup. If a winner is not decided in full time then an additional 30 minutes is played, (extra time). If extra time ends in a draw, a penalty shoot-out will take place to determine the winner.

This paper only collects and analyses data from penalty shoot-outs during the knockout stages. Penalties taken in the regular 90 minutes and extra time are not processed.

2. Methodology

2.1. Data collection methods

Data for this paper has been collected from the last 11 World Cup tournaments from 1978 to 2018. In these tournaments, the same format was used, (a group stage followed by a knockout stage). However, it is important to note that the data does include a period where the golden goal rule was applied. The golden goal rule will not affect the data from penalty shoot-outs, but will affect how many matches in extra time went to a penalty shoot-out.

Every team that has participated in a penalty shoot-out has been recorded, along with their success rate. The data includes each individual penalty taken, with its direction horizontally and vertically, along with the direction of the goalkeeper's dive.

With the distance of a penalty taken from 12 yards, it is commonly believed that goalkeepers guess which direction to dive in. This is because they do not have enough time to react and then dive in the correct direction to save the penalty. Therefore, this paper will determine if there is a position where players should aim for to increase their chances of scoring. Or if the goalkeeper should dive in a specific direction, to increase his chance of saving the penalty.

2.2. Hypothesis

The data collected on penalties taken will be used to test the following hypothesis:

Null Hypothesis H_0: The direction a player chooses in a penalty shoot-out in the World Cup is random.

Alternative Hypothesis H_1: The direction a player chooses in a penalty shoot-out in the World Cup is not random.

This paper serves as an insight to whether penalties are taken randomly or if a general analysis can be performed to increase a player's chance of scoring a penalty or a goalkeeper's chance

of saving a penalty. The height and direction of the penalties will be analysed to determine if penalties are truly taken at random.

2.3. Mathematical method and other factors

The hypothesis that penalties are taken at random during a shoot-out can be assessed with a chi-squared test. A chi-squared test is a test of independence. It is a procedure for testing two categorical variables and a test for goodness-of-fit. The calculated value can be compared to a 95% significance level which evaluates the hypotheses.

If the goal is divided evenly with a 3x3 grid, then it is expected that around 1/9 of all penalties analysed will be taken in the direction of each grid. If this is not the case, it suggests that the direction a penalty is taken is not random and that specific areas of the goal are targeted over other areas.

It is important to know that around 80% of all professional football players are right footed [8]. This may be a factor which affects the results. However, the paper does not consider this variable in the analysis.

3. Results

3.1. Tournament statistics for penalty shoot-outs

Table 3.1 below shows how many teams participated in the World Cup, between 1978 and 2018, and how many knockout rounds were played in each tournament. It also shows how many knockout games went to extra time, and how many went to a penalty shoot-out.

Table 3.1

Year	Host nation	No. participating teams	No. knockout rounds played	No. matches that went to extra time	No. matches that went to a penalty shoot-out
1978	Argentina	16	1	1	0
1982	Spain	24	3	1	1
1986	Mexico	24	15	4	3
1990	Italy	24	15	8	4
1994	United States	24	15	4	3
1998	France	32	15	4	3
2002	Korea/Japan	32	15	5	2
2006	Germany	32	15	6	4
2010	South Africa	32	15	4	2
2014	Brazil	32	15	8	4
2018	Russia	32	15	5	4
Total	-	304	139	50	30

[1]

What is noticeable is 50/139, (35.97%), knockout matches, went to extra time. Additionally, of those 50 games, 60% went to a shoot-out. This means that when a World Cup knockout game ends in a draw after 90 minutes, it is more likely that a game will go to a penalty shoot-

out, than end after extra time. A total of 21.58% of knockout matches went to a shoot-out, so just over 1 in 5 matches required a shoot-out to decide the victor.

In today's format, a team must win 4 knockout matches if they are to win the tournament. The probability of any knockout match going to a penalty shoot-out is 0.2158, as given by Table 3.1. Therefore, the probability of the tournament winners having to participate in at least one penalty shoot-out, is given by:

$$P(pens)\ occurring = 1 - (1 - p(pens))^4$$

Equation 3.1

$$P(pens)\ occurring = 1 - (1 - 0.2158)^4 = 0.62181234187827$$

Equation 3.1

Equation 3.1 shows if a team is to win the World Cup, there is a 62.18% (rounded to 2 d.p) chance that they will have to participate and win in at least one penalty shoot-out, in the current World Cup tournament structure. Teams should be as prepared as possible to take part in penalty shoot-outs.

3.2. Chi-Squared test

Using the data from Table 3.2, a chi-squared test is performed to test the null and alternative hypothesis, H_0 and H_1. Table 3.2 below shows the data required for the Chi-Squared test. This data was recorded by splitting the goal in to nine equal sections, with respect to the kick taker. This evenly split the goal, as shown in Figure 3.1.

Figure 3.1

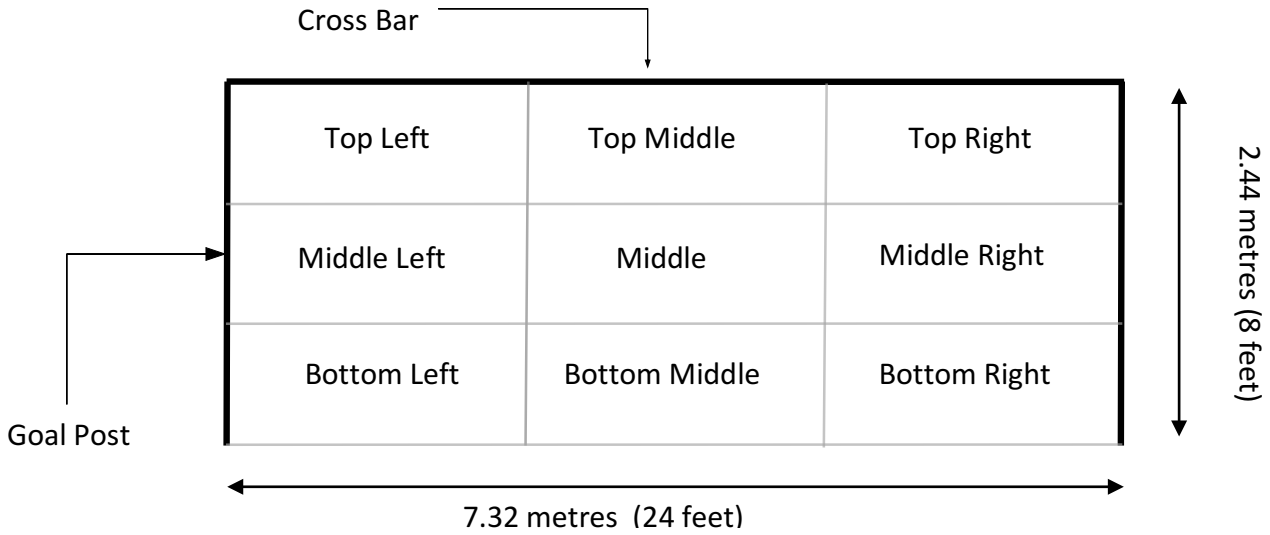

Table 3.2

Area of goal shot at w/ respect to shooter	Expected Frequency	Observed Frequency	(Obs-Exp)^2/Exp
Bottom Left	31	77	68.26
Bottom Middle	31	11	12.90
Bottom Right	31	44	5.45
Middle Left	31	32	0.03
centre	31	11	12.90
Middle Right	31	32	0.03
Top Left	31	28	0.29
Top Middle	31	20	3.90
Top Right	31	24	1.58
Total	279	279	105.35

From all World Cup penalty shoot-outs, a total of 279 penalties have been taken. With the goal split in to nine equal sections, (as shown in Figure 3.1), the expected frequency of each section of the goal is $\frac{279}{9} = 31$. To calculate Chi-Squared (χ^2), the following formula is used:

Equation 3.2

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

Equation 3.4

$$\chi^2 = 105.35\ (2\ d.p.)$$

Where o is the observed value and e is the expected value. Now calculating the degrees of freedom ($d.f$):

Equation 3.3

$$d.f = n - 1$$

Equation 3.4

$$d.f = 9 - 1$$

Equation 3.5

$$d.f = 8$$

The critical value for a Chi-squared distribution at 0.05 confidence interval with $d.f = 8$ is 15.51. [7]

Now comparing the Chi-squared value given from Equation 3. of 105.35, to the critical value 15.51, the Chi-squared value is significantly larger. This means the Null hypothesis is rejected and the alternative hypothesis, 'The direction a player chooses in a penalty shoot-out in the World Cup is not random', is accepted. This suggests that specific areas of the goal

are favored over others. The following part of the paper will look at where players score, miss or have their penalty saved.

3.3. Individual penalty kicks and saves statistics

Table 3.3-Table 3.7 show where each penalty, with respect to the kick taker, was taken, scored, missed, saved and where the goalkeeper dived. This data was collected from videos of shoot-outs and the data being recorded in an excel spreadsheet.

Table 3.3

Shot	Kick Takers Left	Middle	Kick Takers Right	**Total**	**Shot**	Kick Takers Left	Middle	Kick Takers Right	**Total**
Top	28	20	24	72	Top	10.04%	7.17%	8.60%	25.81%
Middle	32	11	32	75	Middle	11.47%	3.94%	11.47%	26.88%
Bottom	77	11	44	132	Bottom	27.60%	3.94%	15.77%	47.31%
Total	137	42	100	279	**Total**	49.10%	15.05%	35.84%	100%

Table 3.3 shows almost 50% of all the penalties taken, were directed to the left-hand side of the goal. The middle and right-hand side of the goal combined, made up the other 50% of the shots. If players were to randomly shoot to different sections of the goal, the expected results would show a 33% distribution across the right, middle and left of the goal (the null hypothesis). This means players clearly favour shooting to the left side of the goal, to the right side. This could be due to the fact that most players (80%) are right footed [8] and prefer to hit the ball across their body, towards the left-hand side of the goal. However, no conclusion can be drawn because this paper does not consider which foot the penalty is taken with.

Around 50% of the shots were shot low, with the other 50% of the shots being evenly distributed amongst the middle and top of the goal. A large number of shots were directed towards the shooters bottom left of the goal, with 27.6%. This is around 12% more than the next most popular section of the goal, the shooters bottom right, with 15.77%.

Table 3.4

Scored	Kick Takers Left	Middle	Kick Takers Right	**Total**	**Scored**	Kick Takers Left	Middle	Kick Takers Right	**Total**
Top	24	14	20	58	Top	12.24%	7.14%	10.20%	29.59%
Middle	20	9	19	48	Middle	10.20%	4.59%	9.69%	24.49%
Bottom	50	8	32	90	Bottom	25.51%	4.08%	16.33%	45.92%
Total	94	31	71	196	**Total**	47.96%	15.82%	36.22%	100%

Table 3.4 shows that, 196/279 (70.25%) penalties have been scored. Table 3.4 also suggests that around half of the penalties scored are low shots, with 90/196 goals scored being along the bottom. Again, the most goals scored is towards the bottom left with the bottom right the next highest proportional area of scoring.

Table 3.5

Saved	Kick Takers Left	Middle	Kick Takers Right	Total	Saved	Kick Takers Left	Middle	Kick Takers Right	Total
Top	0	0	0	0	Top	0.00%	0.00%	0.00%	0.00%
Middle	10	2	11	23	Middle	16.95%	3.39%	18.64%	38.98%
Bottom	22	3	11	36	Bottom	37.29%	5.08%	18.64%	61.02%
Total	32	5	22	59	**Total**	54.24%	8.47%	37.29%	100%

From Table 3.5, it is interesting to see that no saves are made at all in the top sections of the goal. This may be because it is much harder for goalkeepers to reach the top right and top left of the goal.

Table 3.6

Missed	Kick Takers Left	Middle	Kick Takers Right	Total	Missed	Kick Takers Left	Middle	Kick Takers Right	Total
Top	4	6	4	14	Top	16.67%	25.00%	16.67%	58.33%
Middle	2	0	2	4	Middle	8.33%	0.00%	8.33%	16.67%
Bottom	5	0	1	6	Bottom	20.83%	0.00%	4.17%	25.00%
Total	11	6	7	24	**Total**	45.83%	25.00%	29.17%	100%

It is not surprising that 75% of shots were aimed towards the middle (height) or bottom of the goal, as these shots carry a smaller risk of missing the target. As seen from Table 3.6, 14 of the 24 penalties that missed the goal altogether, were aimed towards the top of the goal. This suggests that aiming high has the highest risk of missing the target.

Table 3.7

Dived	Kick Takers Left	Middle	Kick Takers Right	Total	Dived	Kick Takers Left	Middle	Kick Takers Right	Total
Total	142	10	127	279	**Total**	50.90%	3.58%	45.52%	100%

Table 3.7 shows that goalkeepers dive almost evenly left and right. A very small percentage do not dive and stay down the middle. Goalkeepers have decided to dive left or right 96.42% of the time, meaning only 3.58% of the time do they decide to stay in the middle. If a goalkeeper is to randomly guess which way to dive/ stay central, the results would show a 33% split, across the three sections. It is clear that goalkeepers are more likely to dive than stay central.

From Table 3.3, it can be seen that one out of four penalties will go to the bottom left of the goal. In addition to this, 39.07% will go to the bottom left, or middle left. Now, if a team has to take five penalties in a shoot-out, if he keeper dived to the bottom left or middle left of the goal every time, with respect to the shooter, they would guarantee guessing correctly at least 2/5 times.

Every shot that was aimed to the top third of the goal and hit the target (did not miss the goal), was not saved by a goalkeeper. In other words, a goalkeeper never made a save in the top third of the goal area. Already discussed, this shot carries the highest risk in terms of

missing the target. However, if a player can make sure he hits the target in the top third of the goal, it has the highest chance of going in.

72 penalties taken were directed in the top-left, top-right or top-middle. 58/72 (80.56%) of these penalties were scored, 14 (19.44%) missed and 0 saved. Therefore, around 80.56% of penalties aimed towards the top were converted. This is just over 10% more than the average (70.25%).

75 penalties were aimed towards the middle (height). 48/75 (64%) were scored, 23/75 (30.67%) were saved and 4/75 (5.33%) were missed. This area is the lowest number missed. This means that the conversion rate of aiming towards the middle, (height), is around 64%.

132 penalties were aimed along the bottom of the goal. 90/132 (68.12%) were scored, 36/132 (27.27%) were saved and 6/132 (4.55%) were missed.

4. Conclusion

As this paper has shown, the Chi-Squared test has proven the alternative hypothesis true; players do not pick a random part of the goal to shoot at. The most popular section of the goal being targeted is the bottom left of the goal, with respect to the kick taker. A goalkeeper can decide before a shoot-out starts, that if he dives this way every time, he will guess correctly about 40% of the time. From 5 penalties, the goalkeeper will give himself a very good chance of saving 2 penalties, by diving to the kick takers left every time.

In terms of taking a penalty, players should try and aim for the top corners. These penalties may carry a higher risk of missing the target, compared to that of the bottom corners. However, if the intended target can be hit, the chance that the goalkeeper will make a save is low. Therefore, it is very likely the penalty is scored. Some players will not feel comfortable taking such a high risk penalty under pressure, so there is a 2nd choice penalty they could use. Due to the goalkeepers diving a significant amount of the time (96.42%), another safe penalty is straight through the centre of the goal. This penalty carries the lowest risk of missing the target. It will guarantee a penalty on target and is then down to the goalkeeper to save it. Players should aim to the top corners or straight through the middle of the goal, to have the highest chance of scoring.

Goalkeepers should try to consistently dive to the bottom left of the goal, with respect to the kick taker, to give them the optimal probability of making a save. This method should give one team's goalkeeper a very good chance to save around two penalties. In addition, the same team should have a very high chance of scoring each of their penalties taken. This will give a team a significant chance of winning the shoot-out, and the match, on their way to winning the World Cup.

Although, 14/24 penalties that were aimed at the top missed, out of all shots aimed at the top, 80.56% of them were scored and none were saved. Therefore, the conversion rate of aiming at the top stands at 80.56%. Comparing this to middle (height) with 64% conversion rate, bottom with 68.12% conversion rate and the average conversion rate of 70.25%, the

data suggests that the best chance of scoring a penalty is by aiming anywhere at the top. The analysis suggests that it is worth aiming for the top, (either top-left, top-middle or top-right), during a penalty shoot-out because the goalkeeper is likely to dive toward those directions the least. As mentioned before, these areas carry the highest risk of missing the target. However, according to the data, they also carry the highest percentage of scoring. Aiming towards the middle (height) and bottom may be technically easier for the shooter - the same can be said for the goalkeeper. The research suggests that although it is easier to keep a low/mid height shot on target, it is out-weighed by the easier save the keeper needs to produce to save the shot. In fact, it is statistically better to aim at the top-left, top-right or even top-middle and risk missing the target all together than aiming along the middle or bottom of the goal vertically.

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