A statistical model of Boy Scout disc golf skills

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Abstract: In an attempt to produce the best designs for the courses I am designing for Boy Scout Camps, I collected data on how far and how accurately Boy Scouts throw a disc. From this data, a model was developed for simulating large numbers of throws. From these simulations, questions about the appropriate length and shape of a fairway, and the impact of hazards, can be answered.

Methodology: Boy Scouts were asked to play a 200 foot long disc golf hole on flat level grass on days with little wind. Natural competition among peers assured that best attempts were made.

Numbered flags (corresponding to the number of the throw) were stuck in the ground where the discs landed. Scouts then measured and recorded the data.

Throws were measured for two parameters: distance from the previous lie, and remaining distance to the target. The amount by which the angle of the throw deviated from a line directly to the target was computed from this data. A total of 92 throws were recorded.

<u>Simplifying Assumptions:</u> No record of whether the throw went left or right of the direct line to the target was kept. Early attempts were made to collect L/R data. However, the extra complication of collecting this piece of data, as well as difficulty with the concept of "L/R of the intended line of throw" (as opposed to "on the L/R side of the fairway") turned out to be beyond the capacities of the scouts.

Therefore, it was assumed that *half of the throws go left* of the intended line of throw. (Or, it could be said that the model is trying to be totally fair to both lefties and righties.) The model could easily accommodate another parameter: "percent of throws that go farther left than intended".

Also, although records were kept by individual, no patterns could be discerned which would indicate that sub-groups of scouts should be treated separately. For example, 11 year-olds threw as far as the 17 year-olds, and the throws from wheelchairs were within the distribution of throws from foot.

Therefore, it was assumed that *all scouts belong to the same skill level.* (In term of tee colors, the skill level could be described as Deep Purple.)

The model assumes that *accuracy and Length of Throw are independent*. It is possible that players who can throw farther are more skilled overall, and therefore throw more accurately. (Alternatively, every once in a while, a throw turns out just right and goes far and accurately.) It is also possible that a player must sacrifice accuracy for length. Either way, if there is a relationship between the length and accuracy of a throw, it is not evident from the data.

In any event, the longest throws are over-represented in the data, so the accuracy is most appropriate for longer throws. Accuracy of short throws does not matter as much, because the disc doesn't go very far, no matter what the angle.

The Model: The model consists of probability distributions for two parameters: Length of Throw, and Angle of Error (a measure of accuracy).

With these two parameters, the location of the disc can be calculated. Think of the polar coordinate system, or map-and-compass orienteering.

Actually, this data generates two possible locations for a throw to land (right or left of the line toward the target). Both of these locations are the same distance from the target, and so are essentially equivalent mathematically. When running simulations, the computer randomly selects on or the other with equal probability.

<u>Length of Throw</u> is just what you'd expect, the straight-line distance from where the throw was made to where the disc stopped moving. Length of Throw was assumed to be dependant on both the maximum possible throw, and the remaining distance to the target. The maximum throw was set to 200 feet[1].

For tee shots, where the distance to the target was 200 feet, the average throw was 90 feet, with a standard deviation of 32.5 feet. A normal distribution fit well enough. This is expressed as 45% of the distance to the target, with a standard deviation of 16.25%.

To take into account the (usually) shorter distances to the target on second and third throws, the model expresses the length of the throw as a percentage of an artificial "distance". The artificial distance is a weighting of the distance to the target (DTT) and 200 feet.

The formula, in feet, is $(0.45 \pm 0.1625)*(200*DTT)/ ((.28*200) + (.72*DTT))$

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[1] The model is not sensitive to the particular value chosen for maximum throw. Any reasonably large figure would reproduce the correct distribution of lengths of throw, because the model was calibrated to match the data after the arbitrary maximum throw was chosen.

Where (0.45±0.1625) is a normal distribution with a mean of 0.45 and a standard deviation of 0.1625, and DTT is distance to the target.

A nice feature of this formula is that the Length of Throw approaches zero as the distance to the target gets shorter. Yet, the range of possible percentages of the distance to the target increases to beyond 100%. Also, the average throw length only slowly rises as the distance from the target gets farther. For example, if the target were 400 feet away, the average throw length would go up to only 105 feet, which seems reasonable. Players will throw extra hard when the target is farther, but they won't get more skilled.

Angle of Error is the amount (in radians) by which the throw ended up left or right of the line directly to the target. Angle of Error can never be less than zero (i.e. a throw can never be better than perfectly aimed.) An Angle of Error of zero would mean a throw that went directly toward the target. An Angle of Error of Pi/4 would indicate a fairly wild throw (shooting off at 45 degrees). An Angle of Error of Pi would indicate a throw that went backward.

A Gamma distribution with alpha = .575096 and beta = .53581 fit the data nicely.

This distribution implies that about two-thirds of the throws will be within 18 degrees (Pi/10 radians) right or left of where they are aimed, and about 1-in-50 will go completely sideways.

Simulations of 1,000 Scouts

Scores: The model is not designed to produce precise scoring averages. It is believed to accurately simulate the first few throws, until the disc gets within a few feet of the target. However, the probability of making putts at this skill level is not known. The probability is believed to be low enough to cause significant variations in scores.

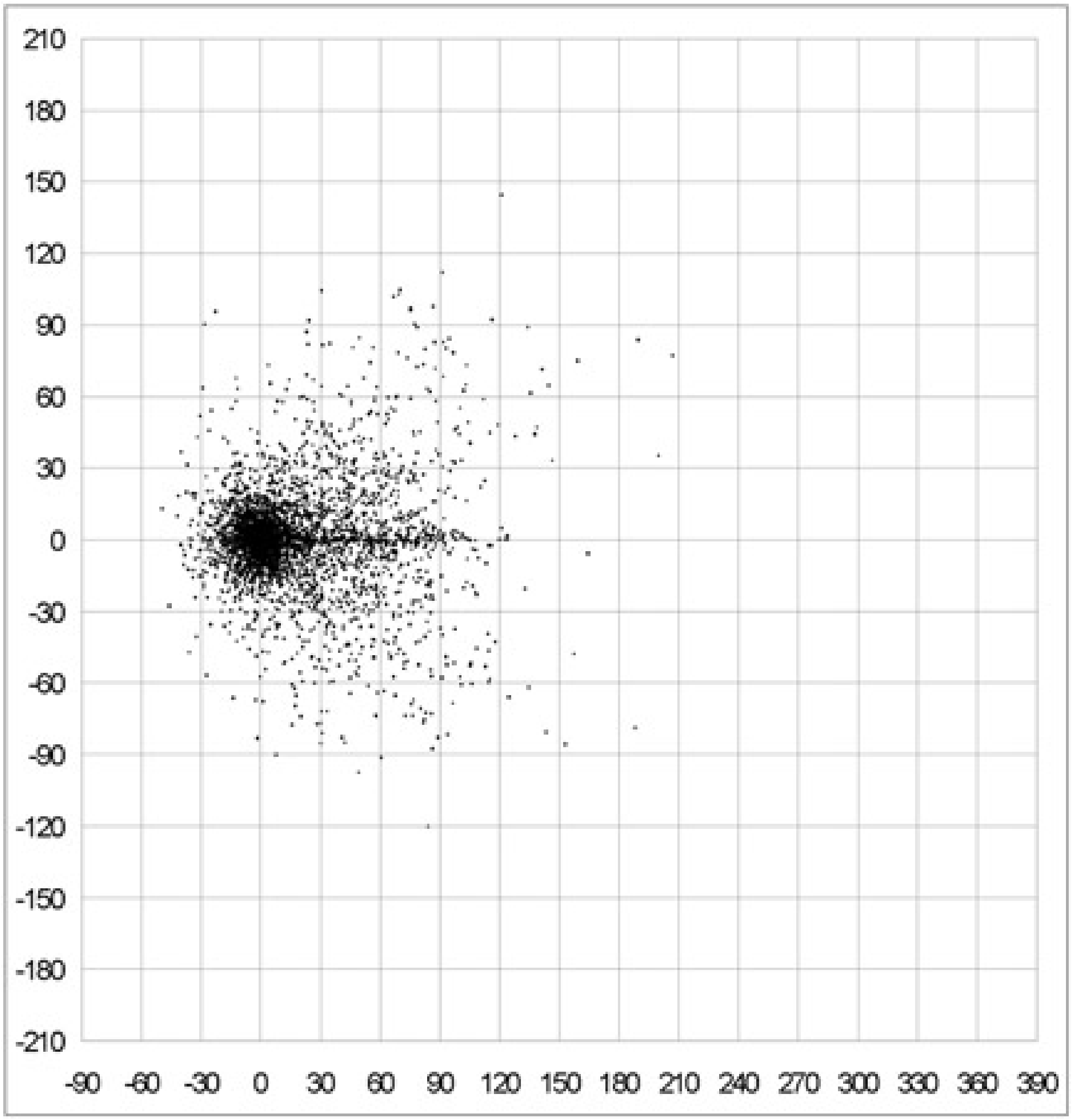
In any case, the model was built to design better fairways and trouble zones. For recreational play, it was not felt that scoring distributions are as important as they would be for tournaments.

That being said, most players get very near the target in four to five throws on a 200 foot hole.

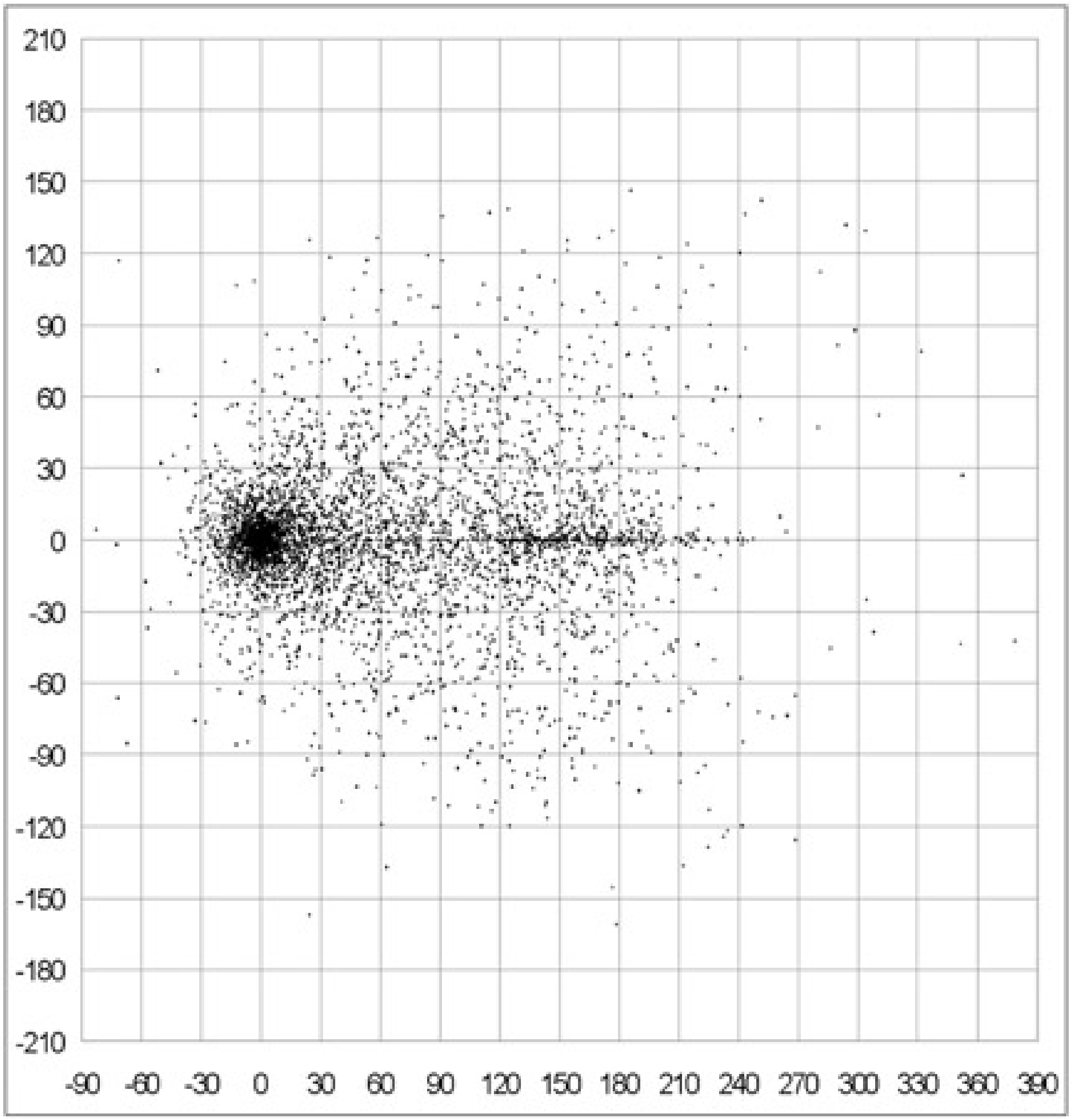
Pattern of Throws: The following three graphs show where the discs would land. The target is at (0,0) and the tee is at (120,0), (240,0) or (360,0).

You can picture this as a bird's eye view, if everyone left their marker discs behind for every throw.

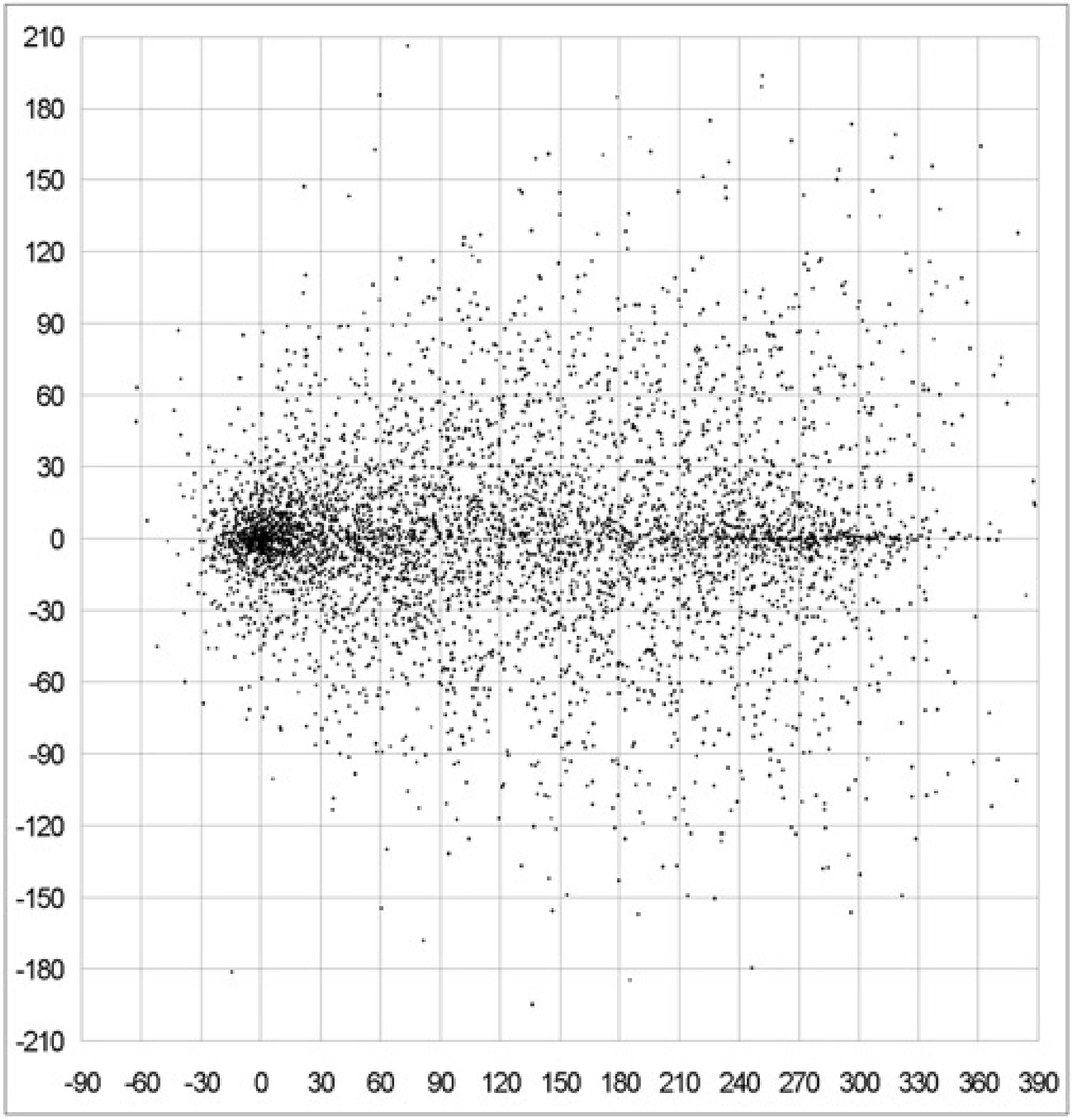
Pattern of throws, 120 foot hole.



Pattern of throws, 240 foot hole.



Pattern of throws, 360 foot hole.

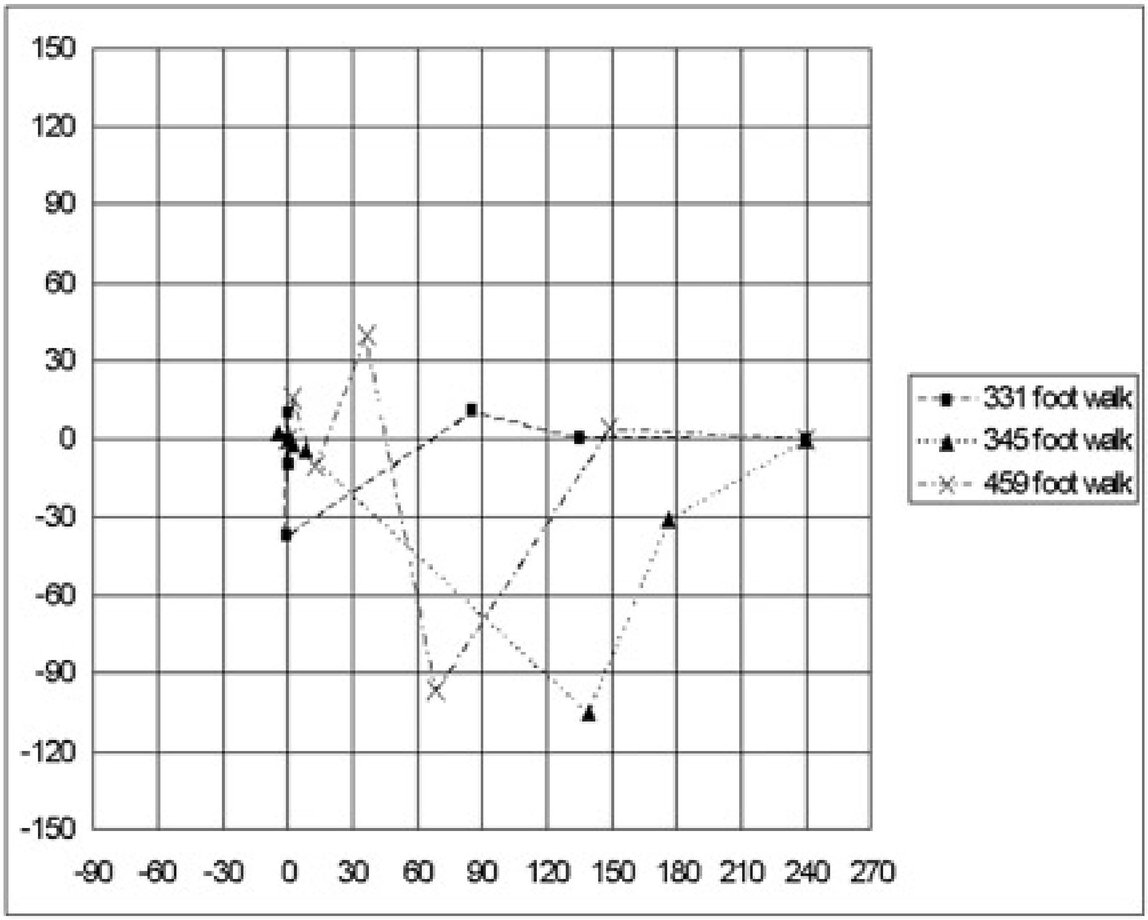


Player tracks

The above graphs show where the discs landed. To see where the players go, just connect the dots.

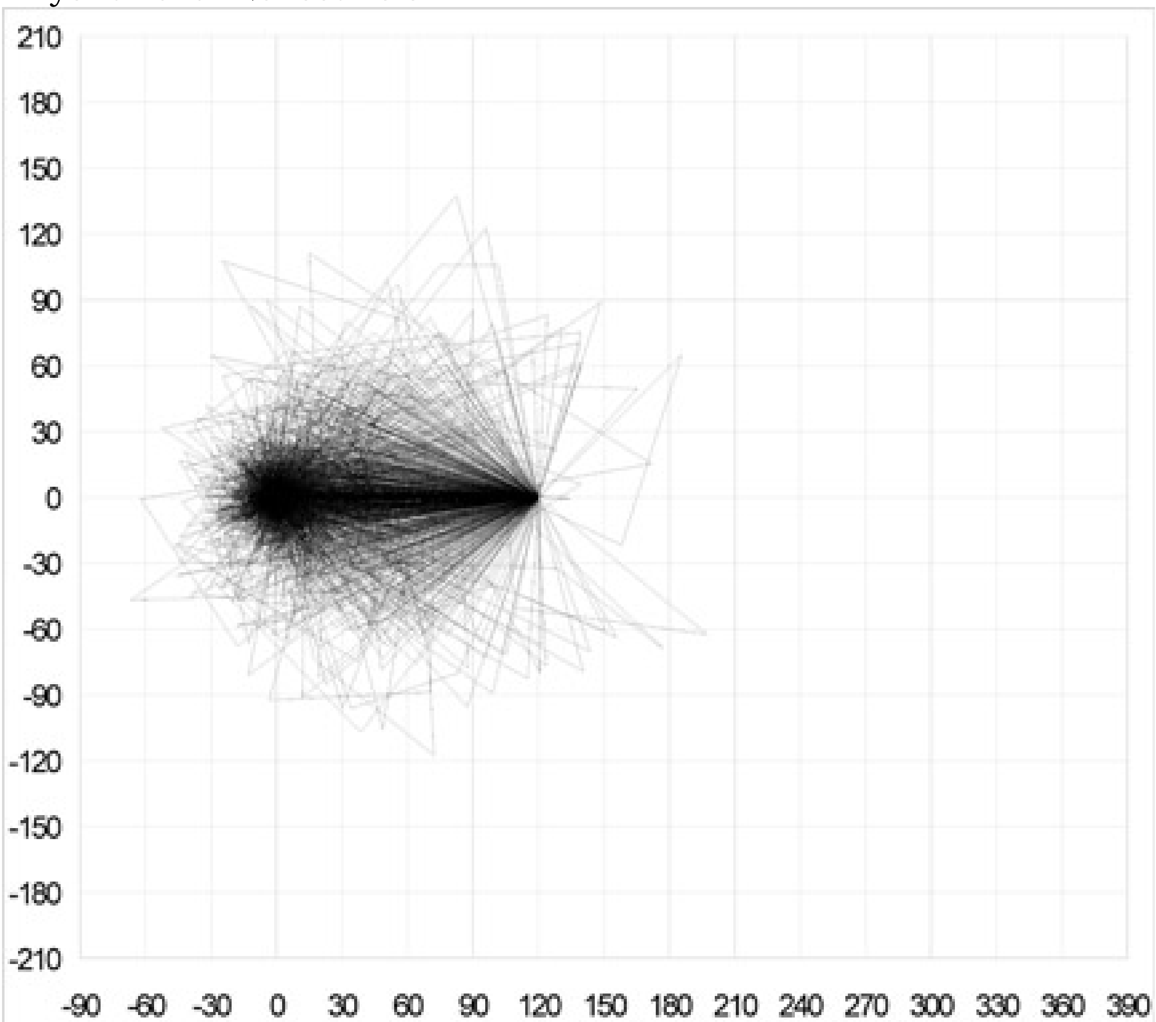
A by-product of the simulation is the ability to calculate how far each player walks, from the tee to disc (to the disc…) to the target. The wilder the throws, the farther the player must walk. The average walk was 331 feet, 2/3 of players walked 345 feet or less, and 5% walked farther than 459 feet.

Selected player tracks.

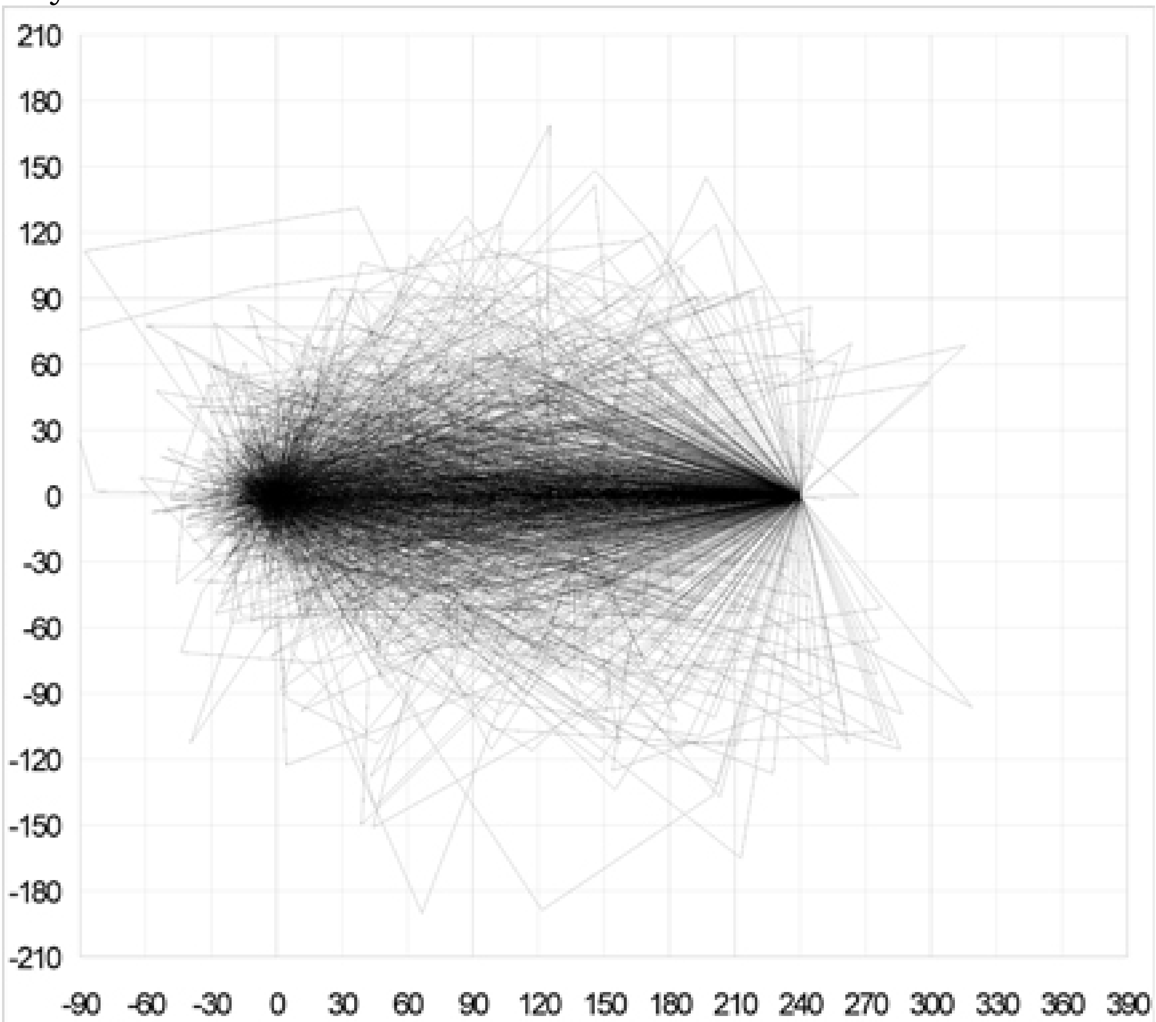


When all 1,000 paths are shown, it gives an idea of the places players will go.

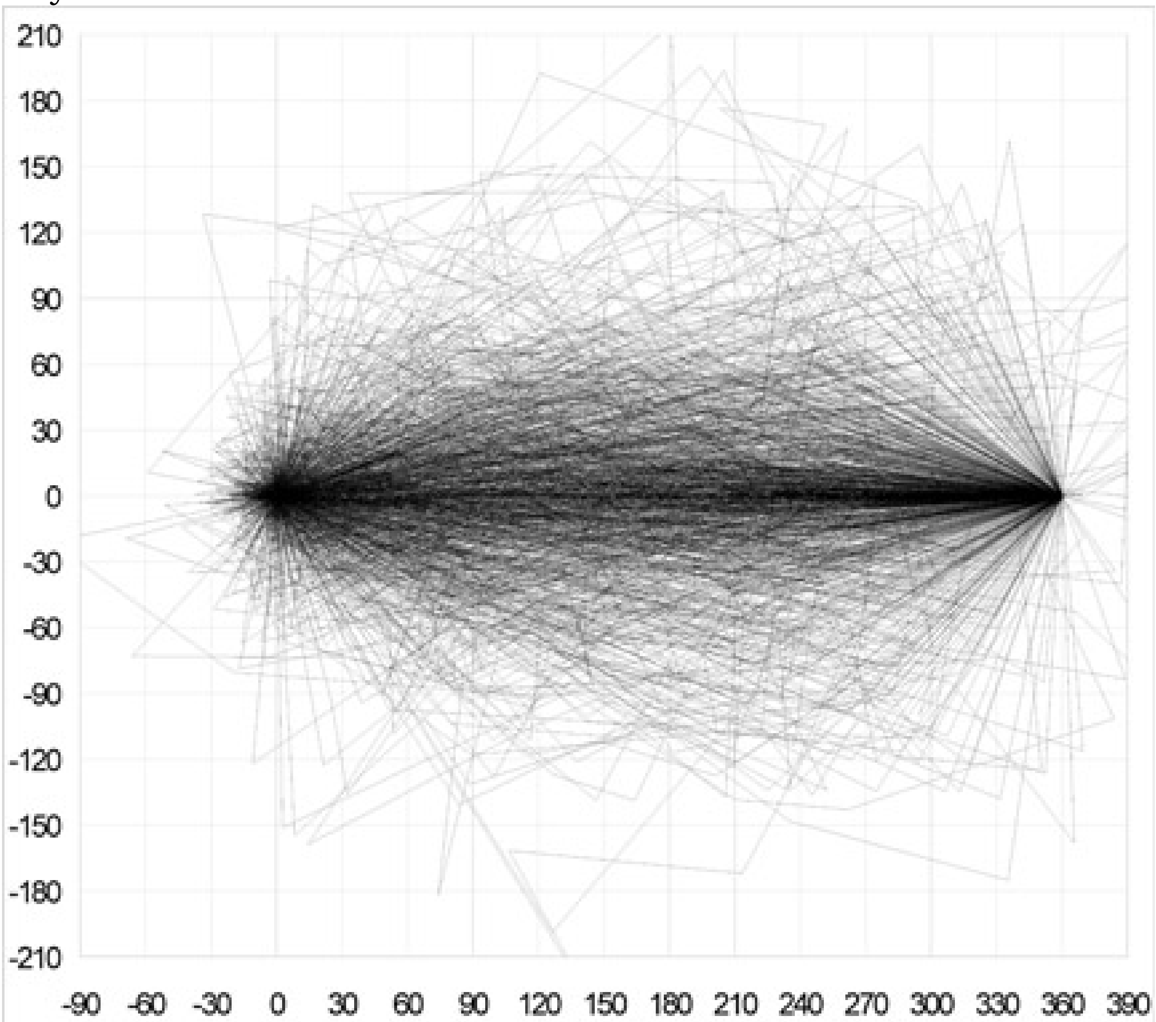
Player tracks 120 foot hole.



Player tracks 240 foot hole.



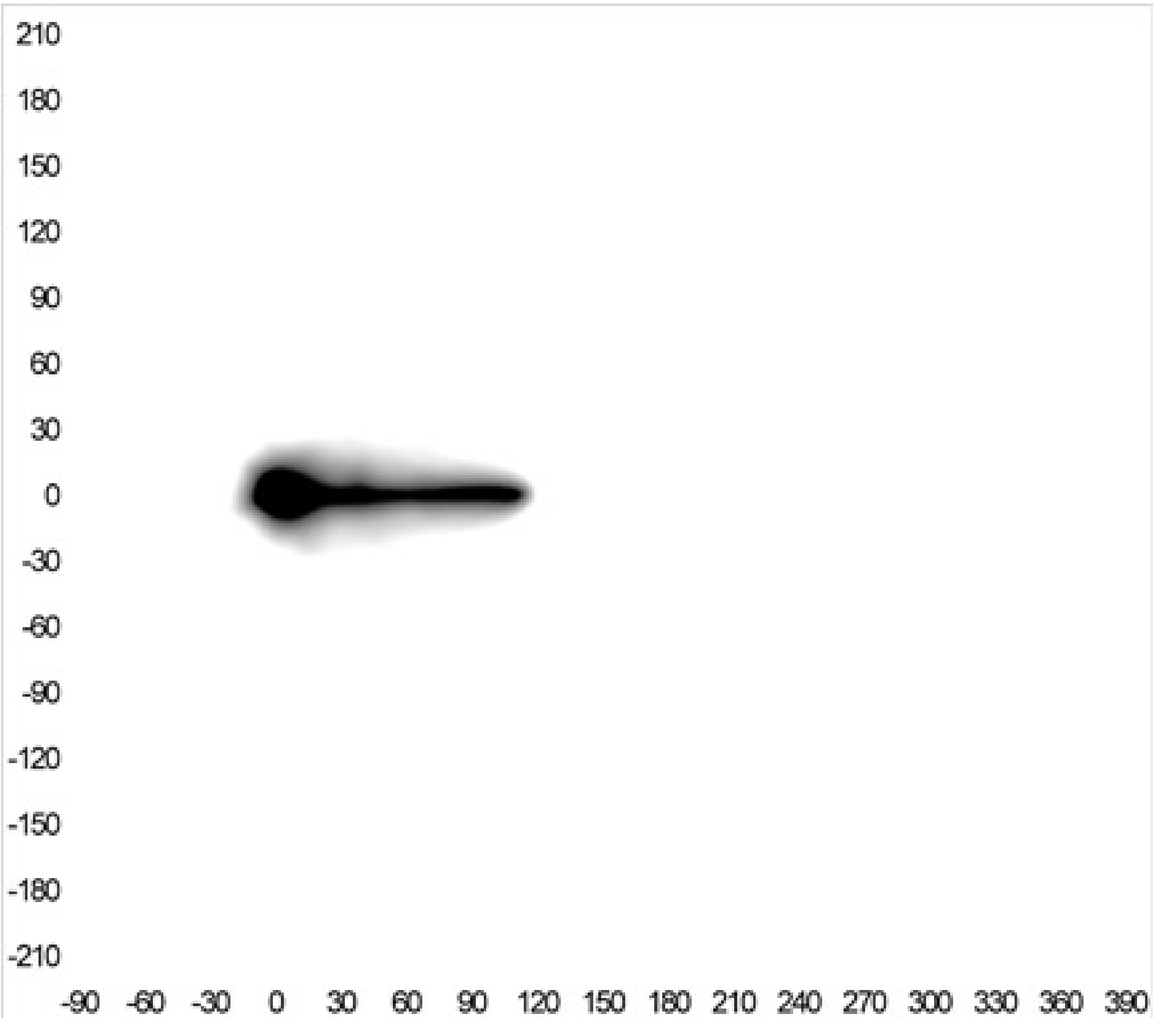
Player tracks 360 foot hole.



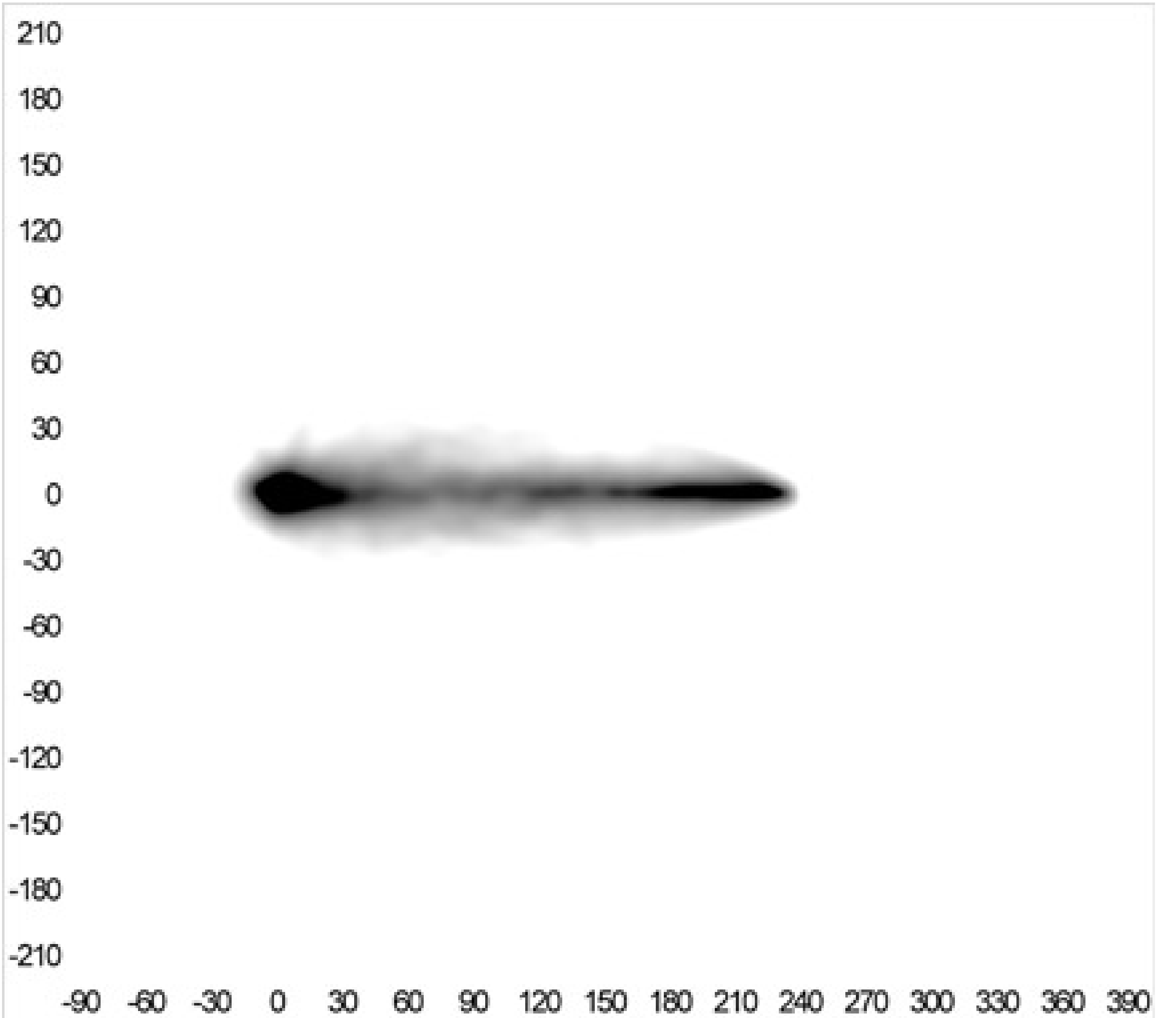
Heaviest Foot Traffic

By squinting at the player tracks graphs, you can see where erosion will happen first.

Heaviest Foot Traffic 120 foot hole.

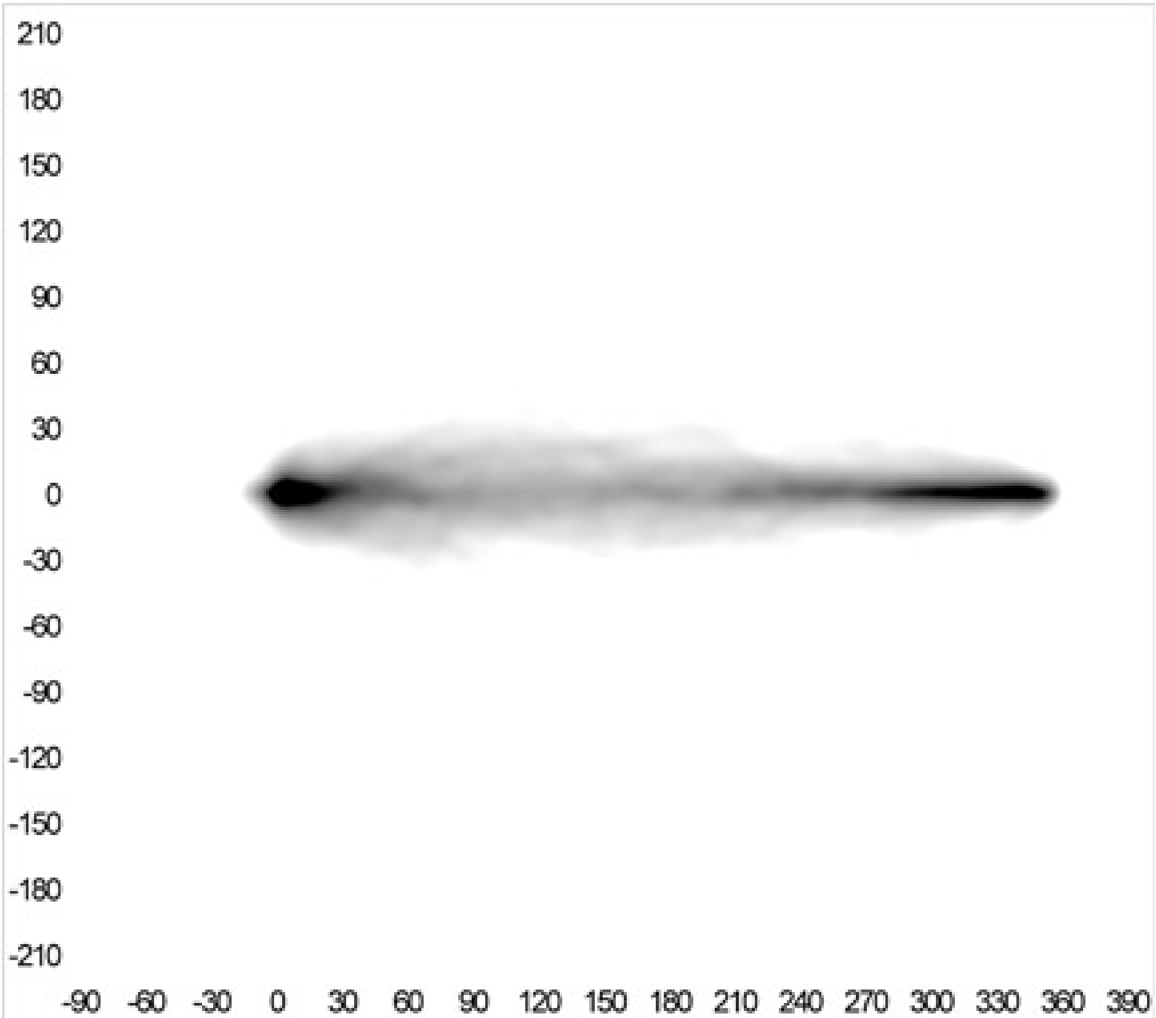


Heaviest Foot Traffic 240 foot hole.



Heaviest Foot Traffic 360 foot hole.

Compare this to the 120 foot hole. Note that the severity, and even perhaps the total amount of area affected by intense foot traffic, is less for a longer hole than a shorter hole.

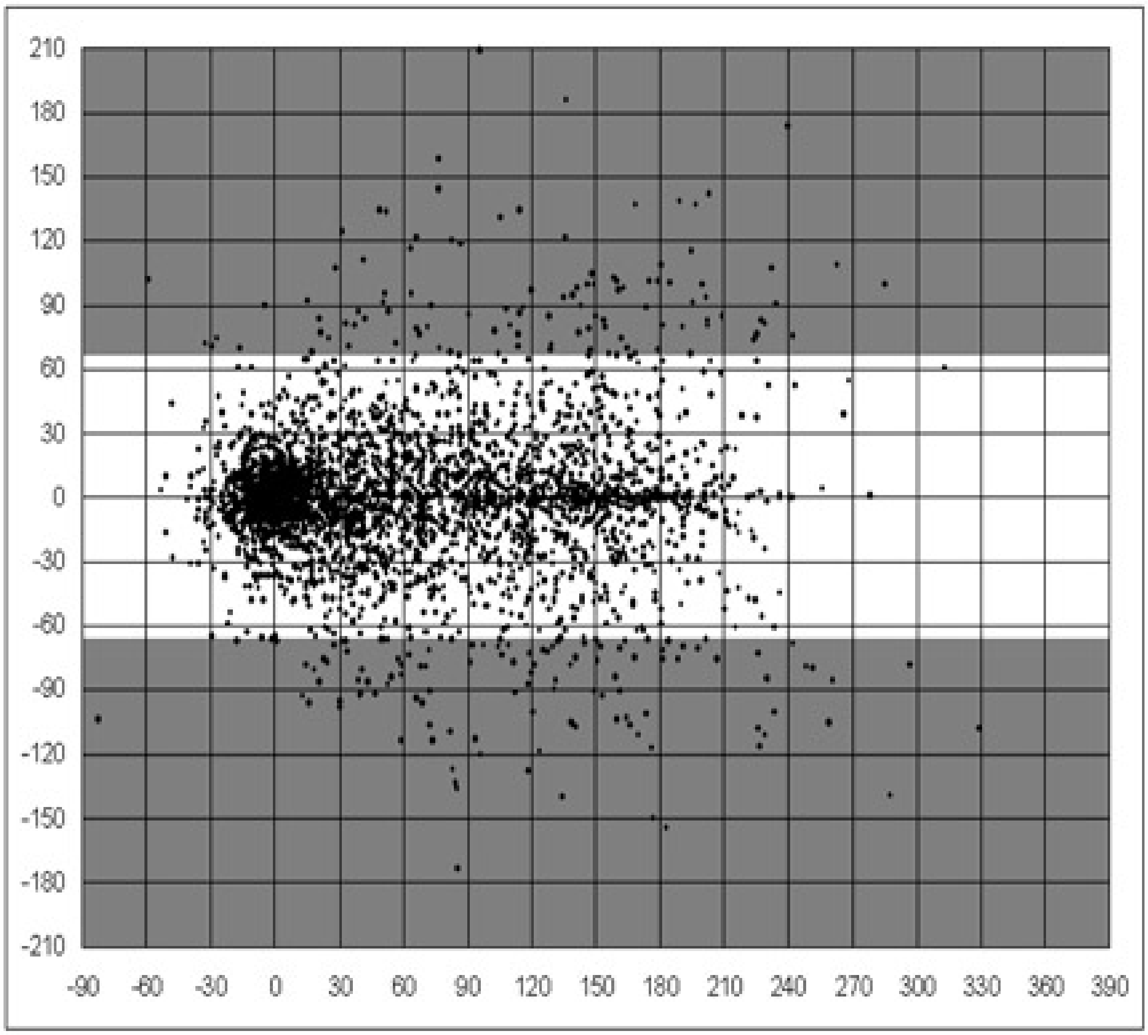


Trouble Zones

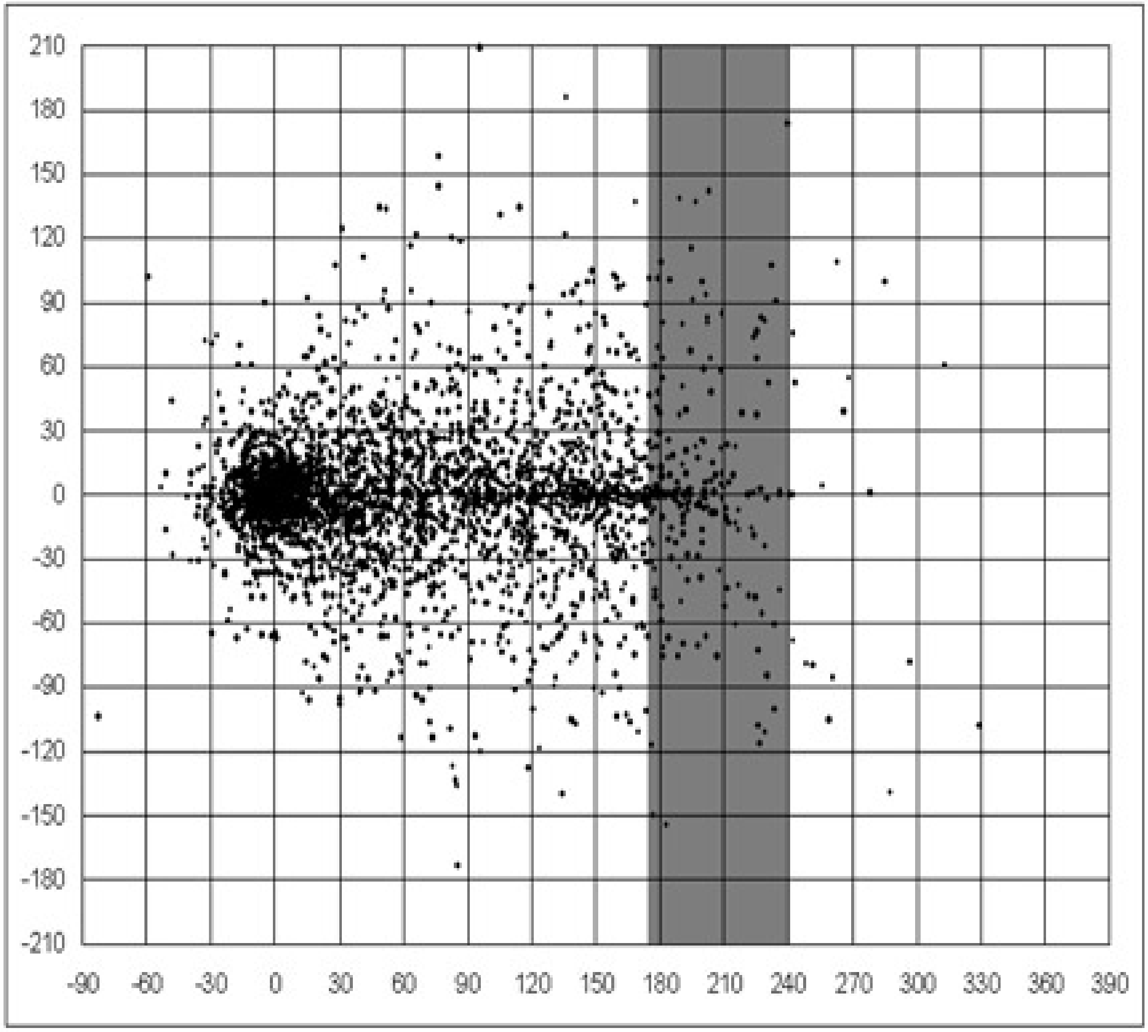
The data was analyzed to find the size of various trouble zones which would put 1/3 of the players in trouble. The model is not yet sophisticated enough to show what would happen if players aimed away from a trouble zone. So, these are the results if players are either unaware of the trouble zone, or make no attempt to avoid it.

In each graph, 333 throws land in the gray area. The tee is at (240,0).

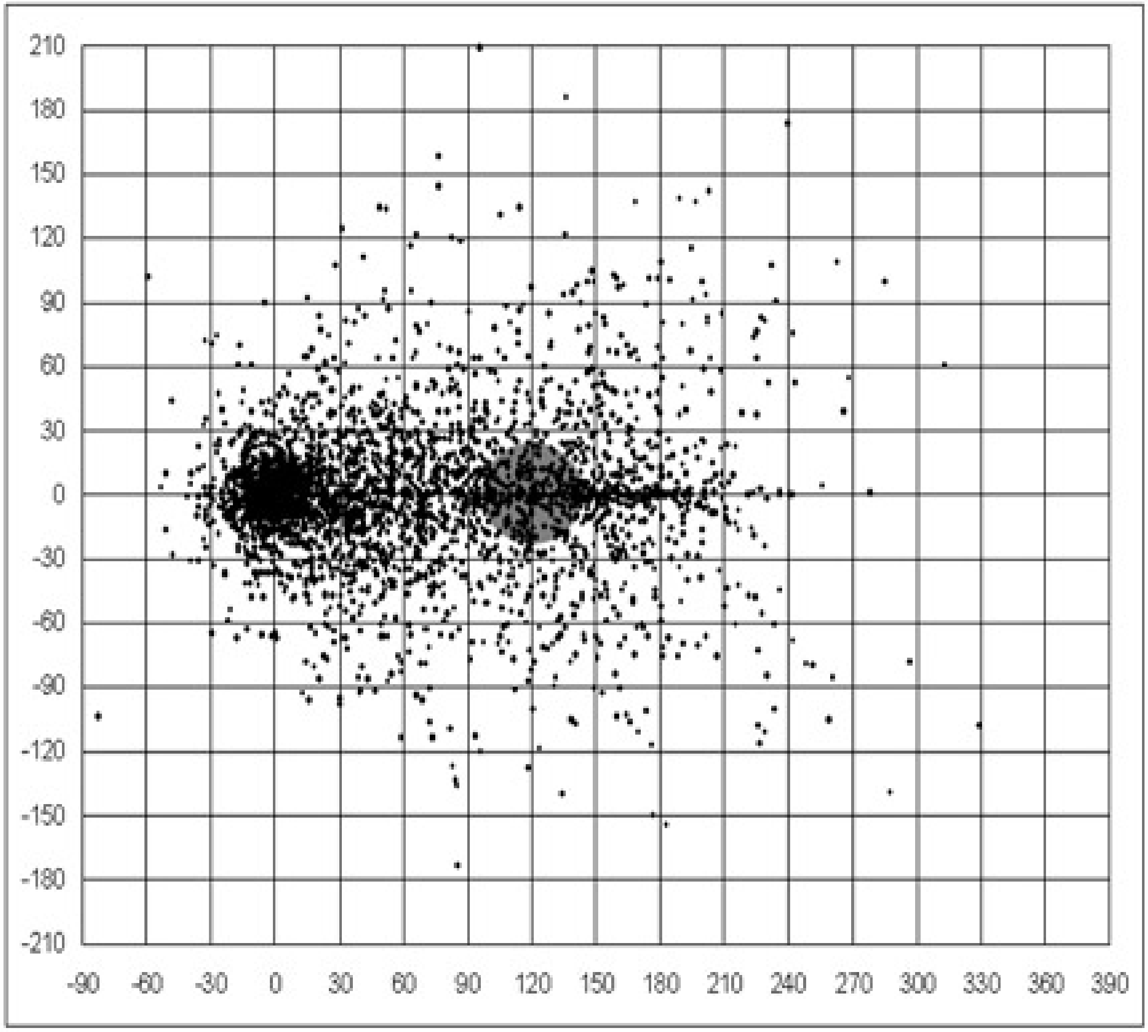
Corridor



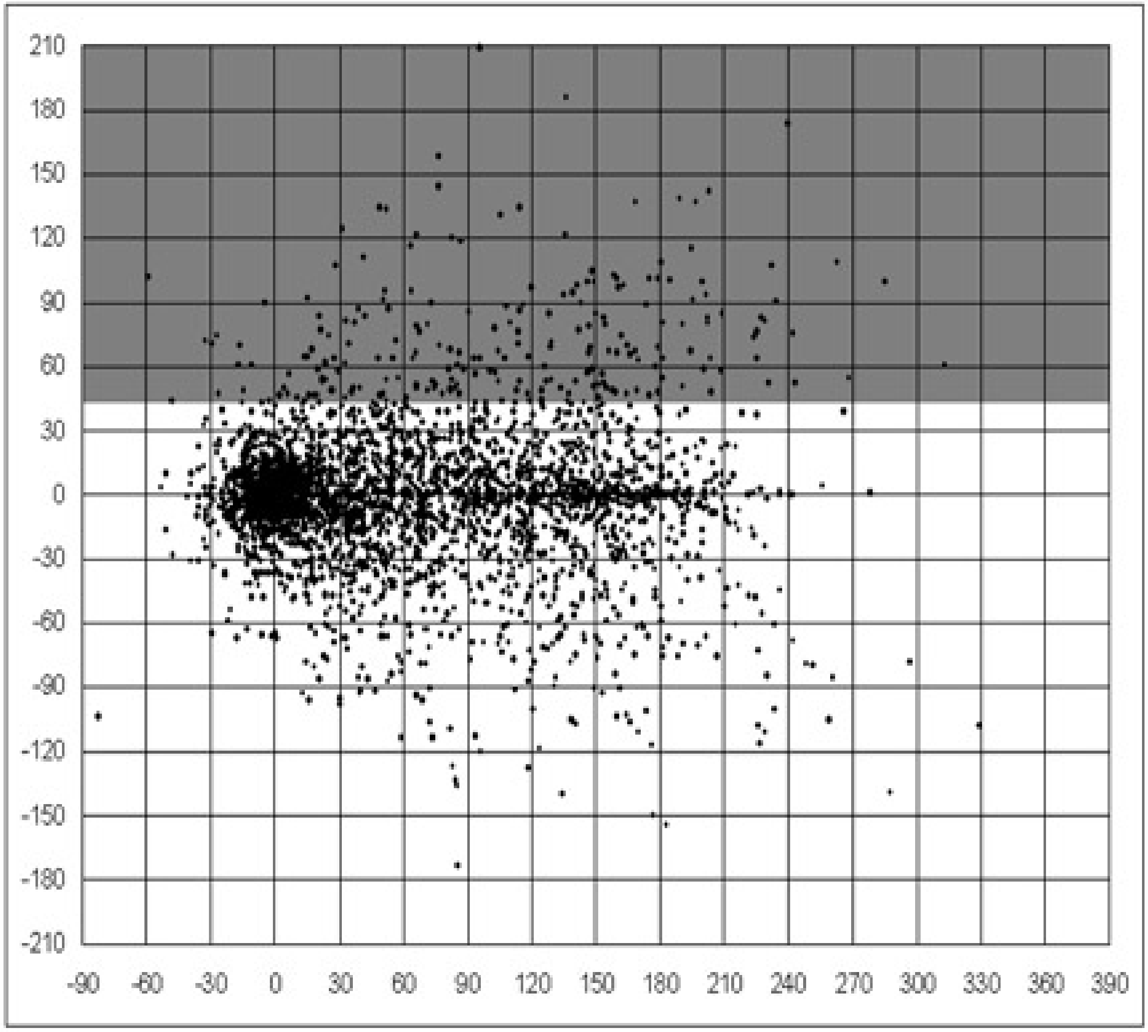
65 foot wide ditch in front of the tee



50 foot diameter pond in the middle of the fairway



Road 40 feet to the right of the fairway



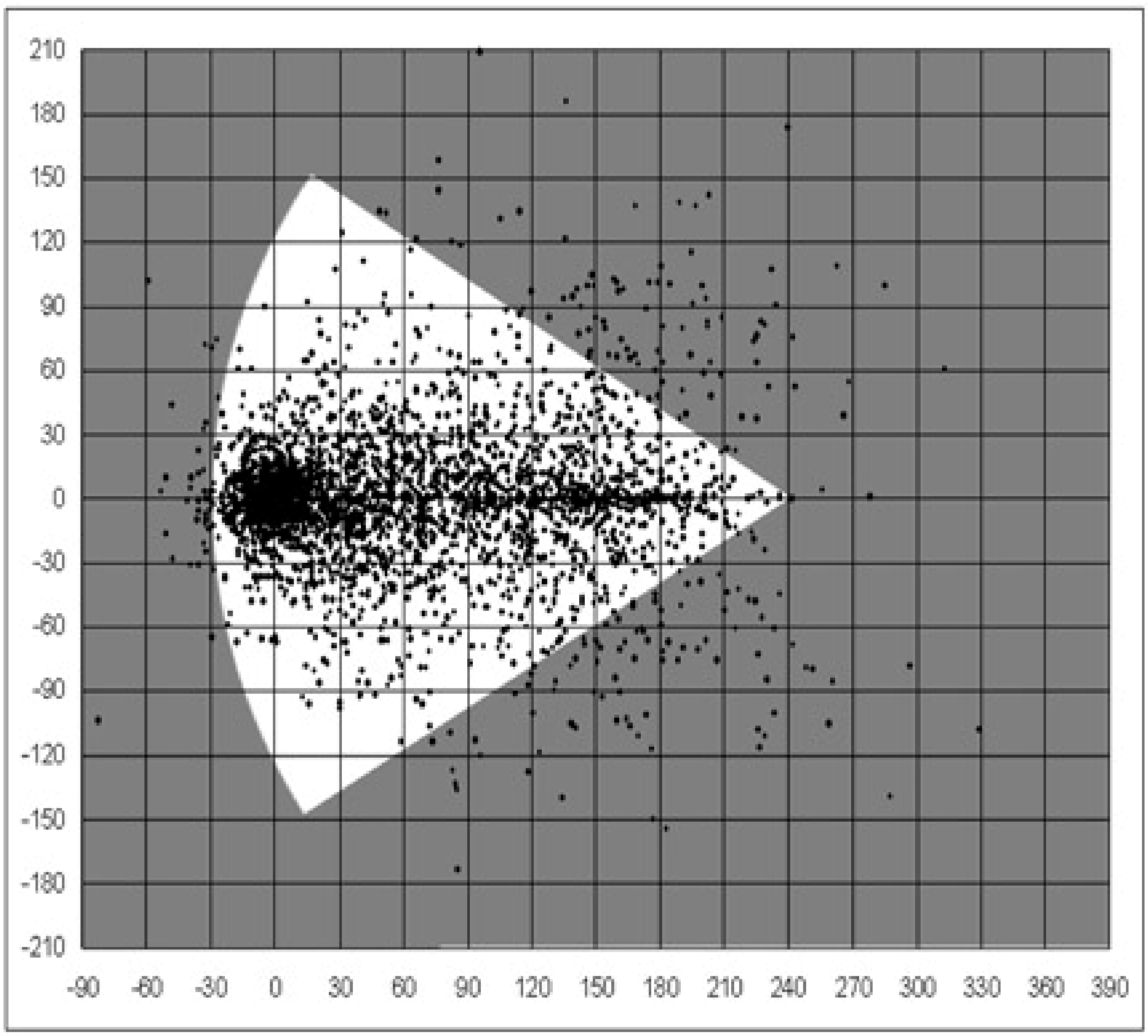
Fairway size and shape.

The data was analyzed to find the most efficient shape a fairway should be, if 2/3 of the players are to have all their throws land on the fairway.

In other words, 333 throws land in the gray area. The hole is 240 feet long.

Wedge shaped fairway

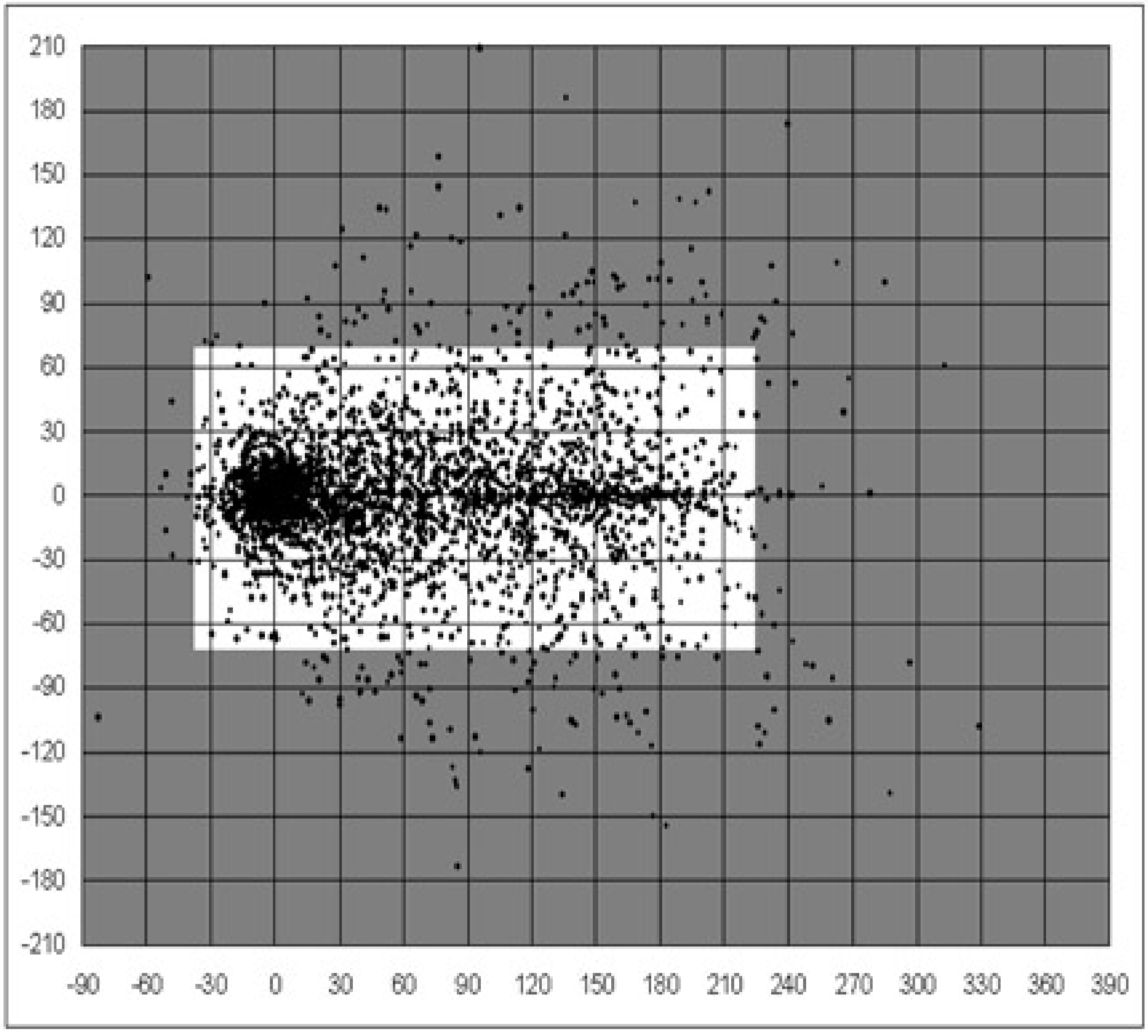
It would seem that a fairway in the shape of a wedge would be an efficient use of mowing resources. This fairway is 0.97 acres. It turns out that other shapes are more efficient.



Rectangular Fairway

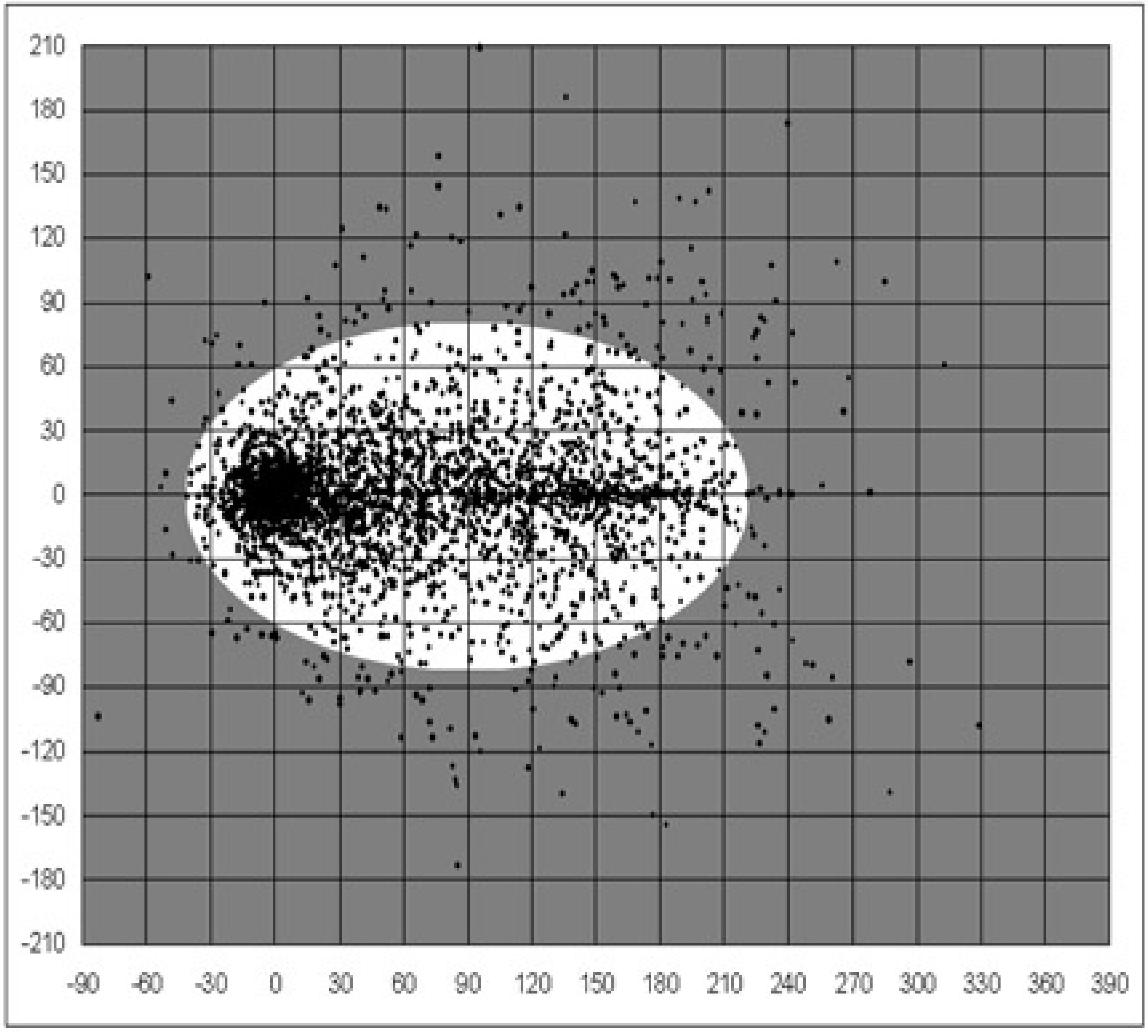
A rectangular shaped fairway is fairly efficient in minimizing the area to be maintained. This fairway is 0.77 acres.

A rule of thumb for a minimal fairway is to clear a rectangle that is at least [40 feet plus 1/3 of the length of the hole] wide, from about 15 feet in front of the tee, to about 40 feet behind the basket.



Ellipse

An ellipse-shaped fairway takes up just slightly less room than a rectangular one. This one is 0.76 acres.



Numerical Data

The following tables present the number of players whose throws land in each 30 by 30 foot square. You can use these in the field to improve your estimates of how many players will land in a trouble zone - the woods, a water feature, or out of bounds.

The numbers add up to more than 100%, because most players make more than one throw.

1. Pick the table that is closest in length of the hole you're working on.

2. Draw the shape of the feature on the table (stretch or squish your drawing along the length of the fairway if the actual hole is shorter or longer than the model).

3. Add the figures for all the boxes entirely within the shape, plus a fraction of each box along the edges.

4. This will give you percent of players who would land in that area, if they made no attempt to avoid it.

120 foot hole chart

120		-90	-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360
		-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360	390
180	210	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
150	180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
120	150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
90	120	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
60	90	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
30	60	0%	0%	3%	6%	7%	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
0	30	0%	1%	86%	102%	20%	12%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
-30	0	0%	1%	86%	102%	20%	12%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%
-60	-30	0%	0%	3%	6%	7%	4%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-90	-60	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-120	-90	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-150	-120	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-180	-150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-210	-180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

240 foot hole chart

240		-90	-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360
		-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360	390
180	210	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
150	180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
120	150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
90	120	0%	0%	0%	0%	1%	1%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
60	90	0%	0%	1%	2%	2%	2%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%
30	60	0%	0%	2%	6%	7%	5%	4%	5%	3%	1%	1%	0%	0%	0%	0%	0%
0	30	0%	2%	52%	58%	20%	15%	14%	14%	12%	6%	2%	0%	0%	0%	0%	0%
-30	0	0%	2%	52%	58%	20%	15%	14%	14%	12%	6%	2%	0%	0%	0%	0%	0%
-60	-30	0%	0%	2%	6%	7%	5%	4%	5%	3%	1%	1%	0%	0%	0%	0%	0%
-90	-60	0%	0%	1%	2%	2%	2%	2%	1%	1%	1%	1%	0%	0%	0%	0%	0%
-120	-90	0%	0%	0%	0%	1%	1%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
-150	-120	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-180	-150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-210	-180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

360 foot hole chart

360		-90	-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360
		-60	-30	0	30	60	90	120	150	180	210	240	270	300	330	360	390
180	210	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
150	180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
120	150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
90	120	0%	0%	0%	0%	0%	0%	1%	2%	1%	1%	1%	1%	1%	1%	1%	0%
60	90	0%	0%	0%	1%	2%	1%	3%	2%	2%	1%	1%	2%	2%	1%	1%	0%
30	60	0%	1%	2%	3%	4%	6%	7%	5%	5%	5%	4%	4%	2%	1%	1%	0%
0	30	0%	1%	23%	33%	17%	13%	13%	10%	10%	10%	11%	12%	9%	5%	1%	0%
-30	0	0%	1%	23%	33%	17%	13%	13%	10%	10%	10%	11%	12%	9%	5%	1%	0%
-60	-30	0%	1%	2%	3%	4%	6%	7%	5%	5%	5%	4%	4%	2%	1%	1%	0%
-90	-60	0%	0%	0%	1%	2%	1%	3%	2%	2%	1%	1%	2%	2%	1%	1%	0%
-120	-90	0%	0%	0%	0%	0%	0%	1%	2%	1%	1%	1%	1%	1%	1%	1%	0%
-150	-120	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-180	-150	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
-210	-180	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Future Improvements

Left or right tendencies

The model is currently completely symmetrical. An improvement would be to add the probability of a player's throw going left of the direction it is aimed.

Other skill levels

The parameters in the formulas could be adjusted to model other skill levels. The best way to do this would be to collect actual data of rated players. Data should be collected on a flat, level hole where the hole length is long enough that no one is expected to reach it on the first throw.

Alternatively, educated guesses could be made, based on estimates of maximum Length of Throw, average Length of Throw, and accuracy.

A third method would be to fiddle with the parameters until an expected scoring average was reached (with an added assumption about putting success at close range). While average length of throw (and maximum throw) should go up, it is not clear whether the standard deviation of the length of throw, or the accuracy of throws should go up or down. In the absence of data, perhaps those parameters should not be adjusted.

Slope

Downhill throws go farther. The model could be adjusted to see what would happen on a sloped fairway. The standard 3 feet of elevation equals 1 foot of distance rule could be used to stretch or shorten the calculated throws in the direction of the slope.

A related question is whether downhill throws are actually less accurate, or do they range wider merely as a result of the extra distance?

Different Aiming Points

The model now assumes every player tries to throw directly at the hole every time. If a mando or trouble zone were in the way, the model should be adjusted so the players are aiming to the side of it.

For shots from the tee, the model could fairly easily be adjusted to aim in a direction different from the direction of the target. However, this would involve some guesses as to how many degrees left or right of a trouble zone players aim, and whether they try to throw as far as possible, or to a specific point.

For later shots from the fairway, the adjustment would be more difficult. The model would need to determine if something is in the way, and set an aiming point to get around it.

Player Track Constraints

If the model were being used to estimate foot traffic, it should be able to divert players onto paths, or around unwalkable zones. Then, it could be used to see the effects of putting up fences, or installing a trail from the tee to the hole.

An even more sophisticated addition would be to calculate heavy traffic areas in an initial run of the model, and divert players to those areas in subsequent iterations. This would model the tendency of players to follow already-worn paths.

Conclusion

When designing courses for Boy Scouts, or for other recreational players, this model can be used to replace guesses about where the discs will land with numbers based on data.