A Comparative Study: The Effectiveness of Various Search Strategies for Finding Critical Evidence in Crime Scene Analysis

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In crime scene investigations, evidence is collected in hopes of establishing probable cause to present in court. There are numerous strategies, but four well-known techniques are spiral, grid, parallel, and wheel (Lothridge, 2014). Many factors like room size, room shape, type of crime, time-sensitivity, available personnel, and more contribute to which search strategy is used. The question is which search strategy is the most effective; meaning it spends a minimal amount of time and collects the most evidence in a square room when compared to other strategies. The purpose of this project was to use mathematical modeling to outline and assess the effectiveness of grid, parallel, spiral, and wheel search strategies in a simple, square crime scene model. It was hypothesized that the parallel search method would be the most effective because it is a consistent repetition that is evenly spaced out. Formulas were created or derived to represent each of the search methods. They were then placed on a coordinate grid with four random points, known as critical points, and assessed for intersection. An intersection would indicate that the critical evidence was discovered by investigators. The hypothesis test results indicated there was sufficient evidence to reject the null hypothesis ($\chi^2(3, N=120) = 45.5, p<.05$). This suggests there is not an equal distribution of critical evidence found when using different crime scene search strategies.

Introduction

Crime scene analysis has been repeatedly studied and improved upon since rules and laws came to be. When a crime is committed there is a series of events that follows. When a crime is committed it is usually called in by a 911 call and the reporting officers will arrive to assess the scene. First, they secure the scene. This is usually done with crime scene tape. Everyone that goes in and out of a secured crime scene must be noted on a timed log to maintain security and preserve the scene. There are a limited number of people allowed in and out of a crime scene but it is imperative that those people are annotated. Before any evidence is taken up or analyzed, photos are taken of anything and everything including disturbed locations, bodies, bodily fluids, and any other location that may aid in investigation of the scene. After all photos are taken and secured, if there is a victim they will be addressed first because of the risk of having a deceased body and maggots that consume the body (Dautartas, 2009). The crime scene personnel will figure out what evidence will be disturbed as a coroner takes the body and they will go ahead and move, file, and store that evidence. In some rare cases, evidence will be removed from the body at the scene but in most cases the evidence is taken off the body at a later time. After the time-sensitive aspects, the crime scene officials get search warrants and employ search strategies at the scene. During the search they will seize all evidence, because even the seemingly irrelevant pieces of evidence can be essential to determining a suspect or a motive. The evidence and data is further analyzed by several departments such as forensics.

Investigators compile results and observations to identify persons of interest. Probable cause, meaning the investigators or prosecutors have developed a set of facts that would leave a reasonable person to believe that the suspect is at fault, is needed to arrest a suspect. Probable cause is tested by presenting the case to a grand jury by whom the case can be dismissed or indicted by (Tracy, 2023). Investigators are very busy so search strategies are put in place so that they can effectively and efficiently search a crime scene. There are numerous strategies but four very common, well-known techniques are spiral, grid, parallel, and wheel (Lothridge, 2014). Generally, many factors contribute to which search strategy is used. These factors can include, room size, room shape, type of crime, time-sensitivity, available personnel, and more.

The question is which search strategy is the most effective; meaning it spends a minimal amount of time and collects the most evidence in a square room when compared to other strategies. The spiral technique (Figure 1A*)* uses a circling technique to analyze the room. To execute this strategy investigators walk in a circular motion that is continuously decreasing in size until they reach the center of the room. This can also be done starting at the middle of the room moving outwards. The grid search strategy (Figure 1B*)* is a series of equidistant lines that run parallel and perpendicular to each other. To have comparable time, lines would have to be spaced further apart causing coverage gaps in the crime scene. Similarly, the parallel search strategy (Figure 1C) is made up of equidistant lines parallel to each other. The parallel search strategy covers the entirety of a room in lines going one direction. The majority of the search strategies are linear or circular in shape. The wheel strategy (Figure 1D) fits the circular shape. Execution of this strategy requires that investigators start at the middle of the room and walk out on several lines towards the edges of the room. These lines can be mathematically measured using the degrees of a circle. This is why, in the end it forms a circle-like shape.

These search strategies were plotted on a coordinate plane using linear and polar equations so that they could be visually and mathematically represented.

Search strategies are used to collect evidence and, ultimately, assign probable cause to a suspect. While all evidence is collected, only certain pieces are essential and yield actual value in the investigation. For the purpose of this research, those essential pieces of evidence are known as critical points, as their discovery is critical for the development of the case. For instance, a case study written by Somnay et al. (2020) details a triple homicide where the suspect was eventually identified by dog feces. The dog feces was found at the crime scene and matched with a boot that had the killer's DNA. This dog feces would be considered a piece of critical evidence as it was crucial in determining who was involved in the homicide. During experimentation the amount of times that the lines or graphs, created to represent each search strategy, intersected with the critical points was measured to determine the effectiveness of each strategy. Because the human eye is able to see much more than what it is directly over, a 2.5 unit long margin was used along the lines to give room for line of sight (Watalingam et al., 2017).

There are several studies that have addressed searching for evidence but few compare them to see which is most effective. There are, however, more modern ways to search a room. With modern technology, it is possible to 3D map a room and make it into models that can allow investigators to see what all happened and help them search for data (Carew et al., 2021). Yet, some investigators are taking it further with 4D tracking and recreation. This type of recreation allows investigators to almost completely replay the crime (Kraus et al., 2020). However, 4D recreation takes a lot of information and is only applicable in certain situations. The majority of the crimes used in most studies have occurred inside and few outdoor crime scenes are studied (Dirkmaat & Cabo, 2016). Outdoor crime scenes must be treated differently, as the environment calls for different procedures (Dirkmaat & Cabo, 2016). One of the easy, high-tech solutions for outdoor crime scenes are unmanned aerial vehicles(UAVs). These vehicles are able to fly above crime scenes and search for evidence. The paths that the UAVs use to search the scene are based on the 4 main search strategies (Georgiou et al., 2022).

The purpose of this project was to use mathematical modeling to outline and assess the effectiveness of grid, parallel, spiral, and wheel search strategies in a simple, square crime scene model. It was hypothesized that the parallel search method would be the most effective because it is a repetitive series of lines that are evenly spaced out so that they cover a large area. Several formulas were created or derived to represent each of the search methods. They were then modeled on a coordinate grid with four random points, known as critical points, and evaluated for points of intersection. These points are all within a hypothetical room 100x100 units long. It is important to consider that this is hypothetical and modeled by computers. The data that was collected was a series of "yes" and "no" that describe when the search strategy intersected with the critical points. The more times that a search strategy intersects with the critical points, the more effective it is.

Methods

In order to accurately model the various search methods, it was necessary to create equations to represent them. It was necessary that these equations be properly written in the Desmos software so that they could be visually graphed. The spiral equation needed to be graphed like a circle but the rate at which it curved needed to change gradually and continuously. To demonstrate this, a polar logarithmic spiral was used. To graph the spiral the polar equation for a Fibonacci spiral was used (Weisstein, 2023). The equation used was

$$r = a^{\theta} \qquad a = 1.1$$

$$0 \leq \theta \leq 15.8\pi$$

In this equation, *r*, is meant to represent the distance from the origin, *a*, is a constant, and, *θ*, is the angle from the x-axis (Weisstein, 2023). The function was centered around the origin, (0,0), and adjusted to fit the expected, hypothetical room size. The space between the rotations in the spiral increases as the spiral approaches the edges of the room.

The parallel search strategy stays true to its name by consisting of a series of parallel lines. These lines can be represented by the equation of a vertical line. That equation looks like this:

$$x = a$$

a is a placeholder for any rational number on the x-axis that the line perpendicularly intersects. The *a* values used for experimentation were multiples of 6.25 where $-50 \leq a \leq 50$. This accounted for 17 lines. Each mathematical representation, apart from spiral, had around 16, 17, or 18 lines so that they would take approximately the same amount of time and could be compared to one another for efficiency.

The grid strategy is very similar to the parallel strategy. The only difference is that it incorporates horizontal lines as well as vertical lines. These equations are:

$$x = a \qquad y = n$$

a and *n* are placeholders for other x and y values to align the lines on different parts of the graph. In order to use the same amount of lines there are half the amount of lines going each direction in comparison to the parallel search strategy. There are nine vertical lines and nine horizontal lines evenly spaced apart. The *a* and *n* values used for experimentation were multiples of 12.5 where $-50 \leq a \leq 50$ and $-50 \leq n \leq 50$. The last mathematical representation was the wheel search strategy. The idea for this was to expand the unit circle and use it togo out on different angles to the outer circumference of the circle. The unit circle was expanded to have a radius of five. A total of sixteen lines went out from the center of the circle located at (0,0). They went out on the angles of 0, π/12, π/4, 5π/12, π/2, 7π/12, 3π/4, 11π/12, π, 13π/12, 5π/4, 17π/12, 3π/2, 19π/12, 7π/4, and 23π/12. This is formatted so that there are three evenly spaced lines in each quadrant with the addition of lines that run on all the axes (Figure 2). The equations to represent the vectors are:

$$(a \cdot t, b \cdot t) \quad \text{Domain: } 0 \leq t \leq 1$$

$$\left(\frac{.6}{\sqrt{a^2 + b^2}}(-.87a - .5b)t, \frac{.6}{\sqrt{a^2 + b^2}}(.5a - .87b)t\right)$$

The top equation is for the line part of the vector and the bottom one is derived from sines, cosines, and coterminal angles so that it takes the shape of a vector and can be specified to exact angles (Picciotto, 2016).

These equations were each placed on a graph with four random coordinate pairs. For instance, the points for the first trial were: (22, -26), (-19, -36), (-2, 47), and (-7,5). The same points were used for each search strategy so that they could be compared to each other. Once the equation and the points were placed on the graph they were evaluated for points of intersection. To be considered an intersection, a point had to come within 2.5 units of the equation(s).

Results

During experimentation, data was recorded in Table A1 (see appendix). The total count of critical points successfully intersected for each trial was recorded. The parallel search method was the most effective method with 97 intersections out of 120 possible intersections. The other data resolved to be 32 intersections for spiral, 41 for wheel, 78 for grid, and 97 for parallel. This means that for spiral 26.7% of the points were intersected, for wheel it resolved to 34.2%, grid was 65%, and parallel ended up at 80.8%.

Figure 4 is a bar chart that demonstrates the number of intersections with critical evidence out of the 120 possible intersections. It reads 32 intersections for spiral, 41 for wheel, 78 for grid, and 97 for parallel. This provides a visual representation of the data so that the search strategies can be compared and analyzed against each other.

There was an average of 62 intersections (table 1). That average equates to a 51.7% intersection rate. Descriptive statistics were used to further analyze the data.

A chi-squared goodness of fit test was used to determine if the difference in frequencies were statistically significant in the data collected (Table 2).

The hypothesis test results indicated there was sufficient evidence to reject the null hypothesis ($\chi^2(3, N{=}120) = 45.5, p<.05$). This suggests there is not an equal distribution of critical evidence found when using different crime scene search strategies.

Discussion

This research was intended to model crime scene search strategies so that they could be compared to each other based on efficiency. These discoveries aimed to further the knowledge of general crime scene investigation and allow investigators to use a time-effective and constructive method. It was hypothesized that the parallel search strategy would be the most effective because it is an evenly spaced, consistent strategy that covers a large portion of the area.The hypothesis test results indicated there was sufficient evidence to reject the null hypothesis ($\square^2$ (3, N = 120) = 45.5, $p < .05$). This suggests there is not an equal distribution of critical evidence found when using different crime scene search strategies. With the visual (Figure 4), it is easy to see that the parallel search strategy has far more intersections than the other strategies.

Table 1 addresses basic descriptive statistics and allows clarity on how likely intersections are in general for any search strategy. This allows for a general expectation for what numbers the data should be between. The mean value was used to determine effectivity rather than comparing the intersection rates with a "perfect" 120 intersections. The mean was used as the expected value in the chi-squared inferential analysis. The range shows that, in general, performing any search strategy will result in the discovery of between 37 and 88 (Q1 and Q3 values) out of 120 pieces of critical evidence. With a small sample size of 4 there were no outliers.

Table 2 is a contingency table for the chi-squared inferential statistics test. The test was performed with a 95% confidence interval meaning that the "a" or alpha value is 0.05. After calculations the p-value resolved to be <0.001. The total combine value for the groups in the chi-squared test was 45.52. This data was calculated with a sample size of 120 ($\square^2$ (3, N = 120) = 45.5, $p < .05$).

It was concluded that there is sufficient evidence to suggest that the parallel search strategy is the most effective search strategy between spiral, wheel, grid, and parallel. The strategies listed in order of least to most effective are spiral, wheel, grid, and parallel. These four were used because they are mentioned in the majority of law enforcement handbooks (Lothridge, 2014). Another search strategy often used, called zone, divides a room where investigators each use various search strategies to search their sections of the room. With new technologies like 3D crime scene mapping (Carew et al., 2021), 4D recreation (Kraus et al., 2020), and UAV drones that can fly above crime scenes (Georgiou et al., 2022) investigators can use technology to be more thorough. However, a large portion of said technology uses the same search strategies to survey a scene. The 3D mapping of a scene requires a lot of work from investigators as they must create the reconstruction. They must use strategies to assess evidence and identify its location so that that information can be used along with photos and other forms of media to recreate the scene (Carew et al., 2021). 4D recreation is more technological than 3D yet still requires some work from the investigators. While this type of recreation is more camera based, there is still a need for someone to conduct the search strategies to assess for evidence to analyze (Kraus et al., 2020). Scenes with the most advanced technology will likely still need the techniques even if it is devices or machines running the search strategies much like the way that drones can be taken over the scene. These drones cannot use arbitrary patterns to assess the scene, they need specific, calculated routes and search strategies are typically used as a model (Georgiou et al., 2022).

Furthermore, outdoor scenes must be treated differently. Due to weather, wildlife, and other factors outdoor scenes are more time-sensitive and require different procedures (Dirkmaat & Cabo, 2016). This research is beneficial for that kind of investigation because using the technique that is most effective and efficient will save time in those time-sensitive situations. To compare the use of these techniques to a real crime, a comparison can be made to a triple homicide involving construction workers working at a home while the homeowners were on vacation (Somnay et al., 2020). This investigation is a fair representation because critical evidence was found both indoors and outdoors. The investigators used search strategies indoors where the body was found which led to evidence like small amounts of DNA yet, the main piece of evidence, that was the key to finding out who was guilty, was found by accident. Smudged dog feces was found in front of the home and matched to dog feces found on the killer's shoes.

It is notable that there are a few limitations within the design of this study. The mathematical representations have concrete stopping points and starting points that could be extended when performed by investigators. Another detail to take notice of is the 2.5 unit margin that was used to account for line of sight. However, real-life scenarios may leave the investigators with obstructed view or other sight issues that were not accounted for. Another limitation is the room shape. Very few rooms have a square shape, like modeled in the data collection, this means the formulas would have to be adjusted to fit different sized/shaped rooms. While this research serves to create a universal model for all room shapes and sizes that is not feasible. The research also does not take into account the chance for human error and the way that novices and experts perform differently in a crime scene (Eeden et al., 2019).

To take this research further, a program could be created that would intake a specific room size and run the mathematical representations in said room and output which strategy would be the most appropriate for that room design. This would require a code to be written and a way for the mathematical representations to change according to the room size. Further research could also include finding a method to increase the effectiveness of these four search methods so that more evidence can be found. This may include further training for investigators. Another suggestion could be a device that is programmable to run these strategies that picks up and properly stores evidence for analysis. These improvements would continue to improve the effectiveness as well as the applicability of these search strategies.

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Tables and Figures

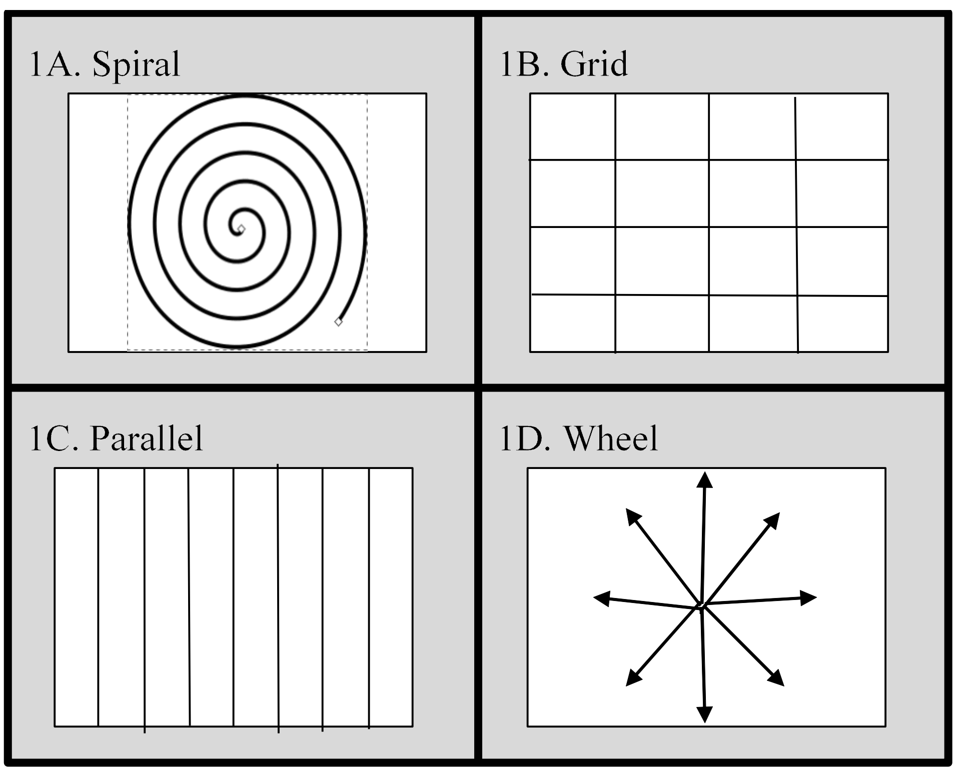
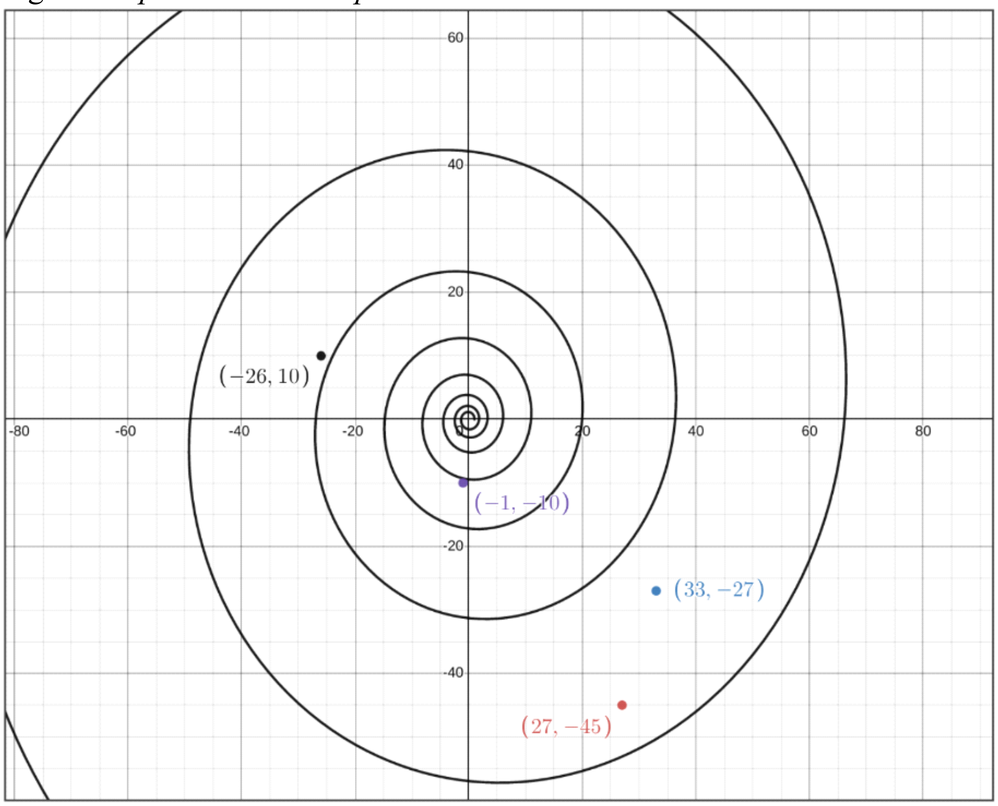


Figure 1 is a visual representation of the different search strategies and what they would look like in a square room. These diagrams are not drawn to the scale used for the study.

Figure 2. *Spiral Trial Example*



This is trial number thirteen in the spiral trials. The critical points can be seen as the colored points that are labeled and found around the spiral. The points (-1,10) and (-26, 10) were considered to be intersections and the points (33, -27) and (27, -15) were not. It is notable that while (-1,10) and (-26, 10) did not directly intersect with the spiral they were still considered intersections because they were less than 2.5 units away.

Figure 3. *Experimental Design Diagram*

ypothesis:

was hypothesized that the parallel search method will be the most effective
:cause it is a consistent repetition that is evenly spaced out so that it covers a large
ırtion of the area.

ıdependent Variable

ype of search method (grid, wheel, spiral, parallel)

.evels of ndependent /ariables	Grid search strategy	Wheel search strategy	Spiral search strategy	Parallel search strategy
Number of Repeated Trials	30 coordinate pair sets	30 coordinate pair sets	30 coordinate pair sets	30 coordinate pair sets

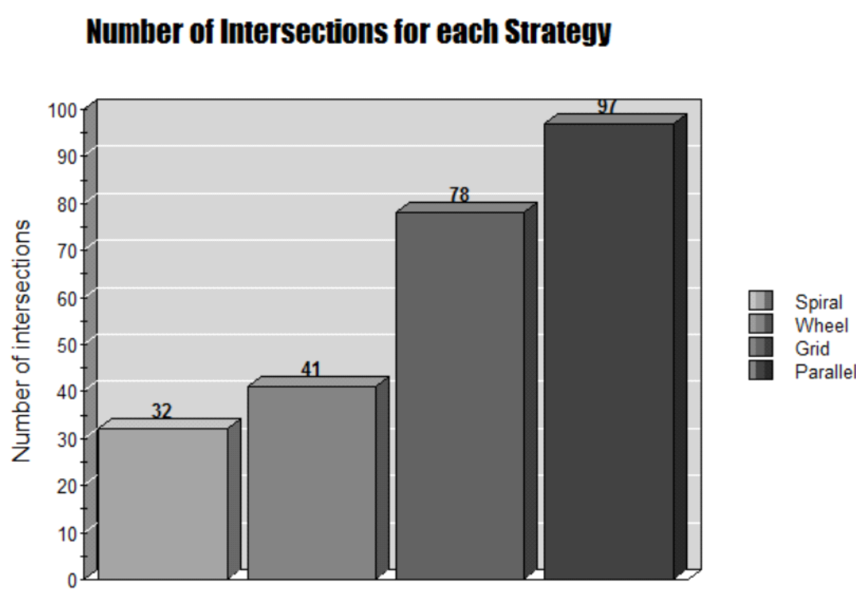
ependent Variable:

ımber of times that the path of the search patterns intersect with the critical points

onstants

- Size of hypothetical room
- Graphing system used (Desmos)
- Standardized coordinate points used on each individual trial
- Device used to test
- Data collection software

Figure 4. *Bar Chart Indicating Number of Intersections for Each Search Strategy*



This is a visual representation of the amount of intersections for each search strategy and the drastic differences between them. It shows a clear representation of the fact that parallel was the maximum frequency (n=97) while spiral was the minimum frequency (n=32).

Table 1. *Descriptive Statistics for Correct Identification of "Yes" Indications in Raw Data*

Mean	Range	Standard Deviation
62	65	26.561

The mean is the measure of the average within the data. This value was used as the expected value in the chi-squared test (Table 2). The range tells how far apart the highest and lowest data points lie. The standard deviation shows the amount of variance in the data. There were no outliers and the sample size was four.

Table 2. *Chi-Squared Contingency Table*

Spiral	Wheel	Grid	Parallel
32(62)	41(62)	78(62)	97(62)

Above are the values that were used in the Chi-Squared test. The observed and expected values can be seen above. The expected found in parenthesis. ⁇^{2} $(3, N = 120) = 45.5$, $p < .05$

Appendix

Table A1. *Experimentation Data Table*

Trial Number	x- value	y value	spiral intersect?	wheel intersect?	grid intersect?	parallel intersect?
1	22	-26	y	y	n	n
	-19	-36	n	n	y	y
	-2	47	n	y	n	n
	-7	5	y	y	y	y
2	-45	18	y	n	n	y
	-4	-16	y	y	n	y
	-34	-3	n	n	n	n
	3	-36	n	n	y	n
3	-24	-4	n	y	y	y
	-38	-19	n	n	y	y
	28	18	n	n	n	n
	44	35	n	n	y	y
4	5	33	n	n	n	y
	-29	-11	n	n	y	y
	-31	-49	n	n	y	y
	15	-7	n	n	y	y
5	20	37	y	n	y	y
	-9	40	y	y	y	n
	-42	-36	n	n	y	y
	20	40	n	n	y	y
6	39	0	n	y	y	y
	-19	-15	n	n	y	y
	17	-13	n	n	y	y

	42	-19	n	n	n	y
7	-14	-45	n	y	y	y
	40	-23	n	n	y	y
	-4	-22	n	y	n	y
	-28	-5	y	y	n	n
8	47	22	n	n	n	n
	-8	-26	y	y	y	y
	-32	-39	n	n	y	y
	25	49	n	n	y	y
9	26	49	n	n	y	y
	-36	41	n	y	y	y
	36	22	n	n	y	y
	-19	-28	n	n	n	y
10	-32	-22	n	n	n	y
	0	-31	y	y	y	y
	-39	-4	n	n	y	y
	10	0	y	y	y	y
11	-40	46	n	n	y	y
	10	-47	n	y	y	y
	17	0	n	y	y	y
	-33	45	n	n	n	y
12	-38	26	y	n	y	y
	1	4	y	y	y	y
	45	2	n	y	y	y
	-7	-4	y	y	n	y
13	-1	-10	y	y	y	y
	-26	10	y	n	y	y

	27	-45	n	n	y	y
	33	-27	n	n	y	y
14	7	-28	n	y	n	y
	27	2	n	y	y	y
	-1	13	y	y	y	y
	-6	-27	n	y	y	y
15	-19	50	n	n	y	y
	-50	19	n	n	y	y
	-20	-22	y	y	n	y
	-27	17	n	n	y	y
16	-7	-19	n	y	n	y
	38	32	n	n	y	y
	-49	-1	y	y	y	y
	32	24	y	n	y	y
17	-26	-31	n	n	y	y
	-41	-3	n	n	n	n
	-11	17	n	n	y	y
	16	40	y	n	y	n
18	4	32	n	n	n	y
	45	28	n	n	n	y
	-13	5	y	y	y	y
	-6	-29	y	y	n	y
19	22	-14	n	n	y	n
	16	30	n	n	n	n
	-1	16	n	y	y	y
	21	-41	n	n	n	y
20	-12	-33	n	n	y	y

	31	22	y	n	n	y
	-11	22	y	n	y	y
	-32	-46	n	n	n	y
21	-39	-13	n	y	y	y
	-41	-50	n	n	y	n
	50	18	n	n	y	y
	-14	36	n	n	y	y
22	-28	17	n	n	n	n
	-8	-9	n	y	n	y
	-22	-33	n	n	n	n
	35	14	y	n	y	y
23	-19	-30	n	n	n	y
	-19	44	n	n	n	y
	5	37	n	n	y	y
	29	3	n	n	n	y
24	34	22	n	n	n	y
	-3	13	y	n	y	n
	42	21	n	n	n	n
	-12	-42	n	y	y	y
25	46	-16	n	n	n	y
	-42	12	n	y	y	y
	47	15	n	y	y	n
	34	-27	n	n	y	n
26	32	28	n	n	n	y
	40	-3	n	n	y	y
	-24	38	y	n	y	y
	23	-41	n	n	y	y

27	-4	19	n	y	n	y
	35	-49	y	n	y	y
	-14	27	n	n	n	y
	-39	25	y	n	y	y
28	-1	-25	n	y	y	y
	38	-18	n	n	y	y
	6	-49	n	n	y	y
	-46	-14	y	y	y	n
29	34	-17	n	n	n	n
	-8	-13	y	n	y	y
	-3	-17	y	y	n	n
	7	-4	n	n	n	y
30	-34	33	n	y	n	n
	-1	38	n	y	y	y
	-19	-31	n	n	n	y
	42	-39	n	n	y	y
Total "Yes"	x	x	32/120	41/120	78/120	97/120