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Probability of Mafia Coming Out on Top

I. Introduction

Mafia is a very popular party social game that can be enjoyed with friends. There is an informed minority (the mafias) versus an uninformed majority (the civilians). At the beginning of the game, everyone is assigned a role. Then when the game starts, there are two phases, a night- and day-phase. During the night phase, the mafias can pick one person to eliminate from the game. During the day-phase all players will try to deduce who are the mafias, and will vote to eliminate one person from the game. The person with the most votes is removed; all remaining players must cast a vote. For the mafias to win the game, they must reach a numerical parity with the civilians; on the other hand, the civilians win the game by eliminating all of the mafias.

Some variations of the game have civilians with special roles, such as the detective or healer. The detective will investigate one player and deduce their identity every round during the night phase, and the healer will protect one person every night to ensure they do not get eliminated from the game.

This is a very complex social game; however, this paper will remove all of the social elements of the game to try to calculate the probability of each team winning the game. First, will be the calculations of just the mafias and civilians. Second, re-doing the calculations with the detective role added, and lastly, re-doing the calculation with the healer role added.

II. Mafia and Civilians

Assume there are n total players in the game during any phase. The number of civilians will be c, and the number of mafias are m. Therefore:

$$n = c + m$$

The probability of winning the game at the start of the night and day phase are:

$$Night\ Phase\text{:}\ N(c,\ m)$$
$$Day\ Phase\text{:}\ D(c,\ m)$$

When

$$\text{Civilian Win: } m = 0 \rightarrow N(c,m) = D(c,m) = 1$$
$$\text{Mafia Win: } m = c \rightarrow N(c,m) = D(c,m) = 0$$

During the night phase, the mafia will randomly select one civilian to be eliminated from the game. All civilians have an equally likely chance to be eliminated from the game; therefore, after the night phase,

$$n = (c - 1) + m$$

During the day, everyone remaining votes uniformly for another random player, and the player with the most votes is removed from the game. The probability of eliminating a player from each role:

$$p(Mafia\ Elimination) = \frac{m}{n}$$
$$p(Civilian\ Elimination) = \frac{c}{n}$$

The situation becomes a recursive problem between the day and night phase. When the game goes from night to day:

$$N(c,m) = D(c - 1,m)$$

Likewise when the game goes from day to night:

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$$D(c, m) \ = \ \frac{m}{n} * N(c,\ m\ -\ 1)\ +* \frac{c}{n} * N(c\ -\ 1,\ m)$$

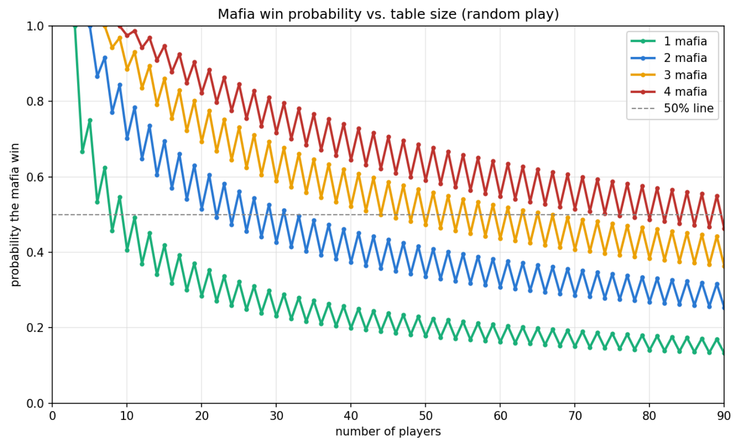

Figure 1. Shows the probability of mafia win (with number of mafias varying) for varying numbers of total players.

Using Python to simulate the results we generated a plot where the x-axis is the number of players while the y-axis is the probability of mafia win (Figure 1). The zig-zag pattern in the scatter plots is due to the parity rule. When there are an odd number of players, the probability favors the mafia because they reach numerical parity during the night phase. For example, let's say there are five players with one mafia. The mafia will eliminate one player at night, someone will be eliminated in the day, and then the mafia will eliminate one more player during the night to win. If there are four players the mafia has to win by the players voting out a civilian randomly instead.

III. Adding Detective

Adding the detective role adds a good amount of complexity to the game. During a game there will be a total of s detectives making the new total:

$$n\ = s\ + c + m$$

Note: usually a game will only have one detective so s = 1.
During the night phase they will investigate one player and the probability of civilian or mafia being investigated are:

$$p(civilian\ investigated)\ \ = \frac{c}{c+m}$$

$$p(mafia\ investigated)\ = \frac{m}{c+m}$$

There is still a chance the mafia randomly pick the detective and remove him from the game:

$$p(detective\ eliminated)\ \ = \ \frac{1}{n}$$

During the day phase, the calculation gets slightly more complicated. In a real game, if the detective finds a mafia and is still alive, they try to convince the other players to eliminate the mafia. For the simulation, if the detective is alive and knows who the mafia is, we will use a Bernoulli distribution to simulate if a mafia will be eliminated or not. There will be a 50% chance the civilians believe the detective and eliminate a mafia and a 50% chance the civilians just play a normal day.

$$D(c, s, m)\ = \frac{1}{2}N(c, s, m\ -\ 1)\ + \frac{1}{2}[normal\ day]$$

Note: even if the detective helps eliminate a mafia, the next evening the mafias still eliminate someone at random.

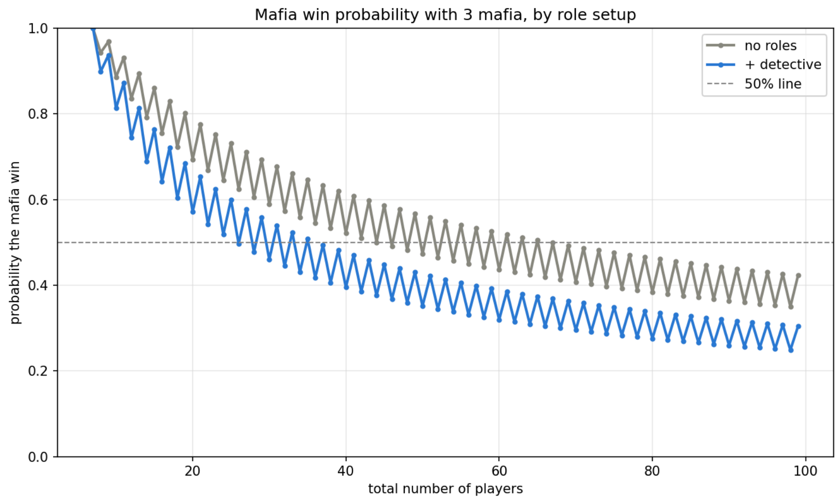

Figure 2. Compare the mafia win probability with three mafias if there is a detective vs no detective.

Overall the detective significantly swings the game in favor of the civilians. The fact that there is a chance they can eliminate a known mafia but it won't result in them being eliminated from the game in the next night cycle is a huge gain for the civilians.

IV. Adding Healer

Adding h healers to the game makes it so:

$$n = s + h + c + m$$

Note: usually a game will have one healer so h = 1.
During the night phase the healer has a slim chance of picking the same person as the mafia. Therefore, there is a very small chance that a night has no elimination.

$$p(block\ mafia) = \frac{1}{n}$$

During the day phase the healer has no effect on the game and will be a normal civilian.

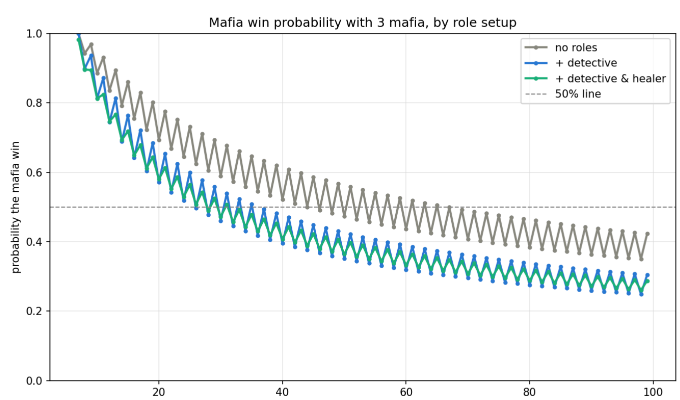

Figure 3. Compare the mafia win probability with three mafias if there is a detective + healer vs detective vs roles.

The healer barely affects the results of the game because it is extremely unlikely the healer will select the same target as the mafias. As the number of players increases the probability of blocking the mafias becomes extremely small and the healer's role becomes obsolete.

V. Discussion

The best way to see the effects of the addition of roles is by asking the question "What is the relation when the probability for a win becomes equal for both sides?"

Table 1. The number of civilians needed for the probability to be 50/50 for both sides.

Mafia	Civilian Only	Adding detective	Adding Healer
1	8	5	5
2	24	14	14
3	51	27	26
4	88	44	43
6	192	90	89
8	336	152	150
12	743	325	322

From the table we can derive the relation to achieve a 0.5 probability for both sides winning:

Civilian Only: $c = 5m^2$

Plus detective: $c = 2.3m^2$

Plus healer: $c = 2.2m^2$

Adding the detective really changes the game for the civilians. It nearly halves the number of civilians needed to reach a fair game; however, the healer does not have much of an effect on the outcome. For the games with smaller parties there is no change in party size.

Finally, I would like to end this short paper by talking about the limitations of this analysis. The simulation treats people as if they are robots and totally removes the social elements of the game. There is no bluffing, manipulation, or deduction in any of the voting processes; therefore, the probabilities shown should be seen as the floor for the civilians, meaning in real life the odds are probably significantly better for the civilians.

VI. LLM Usage

For this optional assignment I used Claude as an assistant to help form my ideas and concepts into a working model. I also had it help me develop the script and help explain the zig zag behavior in the plots.

Youtube Video: https://youtu.be/p2ECMmYj5ls
Note: I really recommend using the paper as the main medium to enjoy this analysis.