Blackjack Simulation

Siddarth Puliyanda

1. Abstract

Gambling has been a part of human history for thousands of years, and its popularity has only continued to grow over time. Among the vast array of games played in casinos worldwide, Blackjack, also known as 21, stands out as one of the most popular and well-known today. This is due in part to two things: first, its relatively simple rules: have a higher hand total than the dealer's hand without going over 21; and second, it has the lowest house edge of any game in the casino. Sounds easy right? Despite the game's popularity, the percentage of players who wind up turning a profit after a long run is likely between just 1-5%, but there is a small group of players who do give the casinos a run for their money.[1] All of the profitable players would agree that the only way one can be successful in Blackjack is to have a solid strategy and stick to it. In this project, I will analyze the effectiveness of different Blackjack strategies, table conditions, and betting systems to see which variations can yield the greatest profit (or the least amount of loss).

I will be creating a Python program which simulates 10,000 hands of Blackjack between the player and dealer for each system. To summarize my findings in the rest of the analysis, I found that the number of decks a table uses does not affect win rate, the stay value that gives the optimal win rate is 16, and that the Martingale betting system, while profitable with the right conditions, is unrealistic given the betting limits placed on each table by the casino.

2. Overview

2.1 Basic game rules

For this analysis, I will be using basic Vegas casino rules to run each simulated hand. There will be only 1 player and 1 dealer, who each start with 2 cards from a standard deck of 52 cards. Aces have a value of 1 or 11, depending on which value results in a higher total without going over 21. The player can either hit and gain a card, or stay and proceed with the dealer's turn. The dealer will either hit a "soft 17," which means they must hit if their hand contains an Ace and is 17 or lower, or stay if their total is higher than 17. Once the dealer's turn is over, whoever has the

[1] 7 Sad Realities of Blackjack

greater total without going over 21 (also known as "busting") is the winner of that hand. Getting a Blackjack, which is when the starting 2 cards total 21, pays the player 6:5 or 1.2x the bet amount.[2] The starting bet amount will be $10, which is the lowest minimum bet I have ever seen at a Blackjack table. There are other table rules when playing in Vegas, such as splitting and doubling, but for the purpose of this study we will not be implementing these rules. We will also not take insurance on any potential blackjack by the dealer.

2.2 Strategies

2.2.1 Number of Decks

One of the table variations that are actively present in Vegas casinos is the number of decks being used at each table. I will be analyzing the winning probability for playing with 1, 2, and 6 decks, which are the typical variations seen in real life. Some regular gamblers swear they have better success when playing with 1 deck vs 6 decks, so I want to see if this is real or by chance.

2.2.2 Stay Value

For all the simulation runs, I will analyze the difference in probability and total profit for automatically staying at a certain hand total, which will range from 11-20. For example, if the stay value is 14 then the player will automatically stay when their hand total is 14 or higher. It seemed logical to choose this range because if the player's total is 11 he/she can safely obtain any additional card without busting, and 20 is the highest total a player can have without having an automatic winning hand at 21. If you stay on an 11 or hit on 20 in real life, people will look at you like you're crazy!

2.2.3 Betting system

Finally, I will be testing out the Martingale betting system, where the player doubles the previous bet after a losing hand and returns back to the original bet amount after a winning hand. One set of runs will use this strategy, while the other will be the control group where the player bets the same $10 amount for every hand. I will further discuss the Martingale system's theory, program output, and limitations in the main findings section. This is a strategy that I have implemented myself in the past, which led to some short-term success but failed in the long run.

[2] How to Play Blackjack in Las Vegas?

2.3 Simulation Program

I created the Monte Carlo simulation from scratch using Python in Jupyter Notebooks. The first part of the code uses OOP (object-oriented programming) to create organized objects used to develop a single game of Blackjack. Some of the key classes here are Card, which assigns each card a rank and suit, Deck, which randomizes the cards into the correct number of decks being used, and Game, which simulates one round of 21 between a player and dealer. The function simulate() takes the inputs of num_hands, stay_value, num_decks, starting_bet, and martingale, and returns a single row of output that displays the percentage of games won, lost, and tied, as well as the net profit. If martingale is set to "True," then the function will run the martingale strategy, and output what the largest bet value was during the simulation. The make_dataframe() function combines the output rows from simulate() into one clean dataframe. I had to split the data frames into Martingale vs. no-Martingale and merge them afterwards because trying to create them at the same time would crash the program. The remaining code involves producing an output that I can analyze. This includes conducting an F-test to compare the Win% between the number of decks, creating line charts to see which stay value is the most optimal/profitable, and finding key values in the output of the Martingale system to analyze.

3. Main Findings

3.1 Number of Decks:

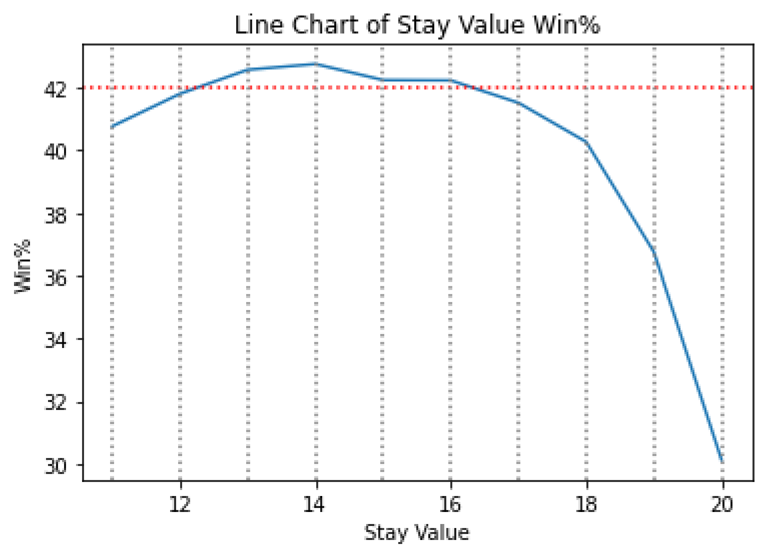
The data frame output after running the full program has columns that have calculated the win, loss, and tie percentage, which I will use to determine whether there is a difference in percentages between playing with 1, 2, and 6 decks. I created 3 new data frames that split up the sample means for the number of decks, and conducted an F-test to test whether there was a significant difference in win percentage between the 2 groups. For the assumptions, since each hand is independent from each other, the variance is the same for each run, and we are running the simulation 10,000 times each row, I will assume that it is ok for us to proceed. Here are the results of the statistical test, using an alpha level of 0.05. The F-statistic and P-value will be slightly different with each new simulation run, but all the values were fairly close so I will go with the results of my most recent simulation.

1. Ho: the win percentages are all equal for 1, 2, and 6 decks

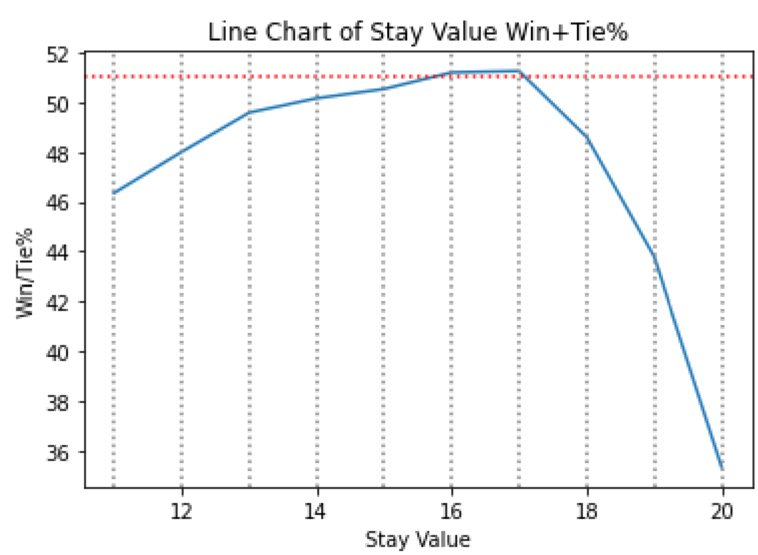
2. Ha: at least one of the groups significantly differs in win percentage
3. F-statistic: 0.00716
4. P-value: 0.99286
5. Conclusion: Since the p-value of 0.99286 is much greater than the alpha level of 0.05, we fail to reject Ho and conclude that there is not a significant difference between the win percentage of 1, 2, and 6 decks.

3.2 Stay Value

In order to determine the most optimal stay value, I created 3 line charts that will help describe the output from the simulation. The first line chart displays the Win% vs Stay Value (see right). The win percentage stays fairly consistent from range 12-16, as all of the values are above 42% (indicated by the dotted red line). From stay values 17-20 there is a significant drop in win percentage, going all the way down to about 30%. The maximum win percentage belongs to stay value 14 at 42.76%, while the lowest percentage is at stay value 20 with 30.13%. While it seems that the win percentage is close for values 12-16, fractions of a percentage point will have large effects on profit when simulated 10,000 times as we will see in the last chart.

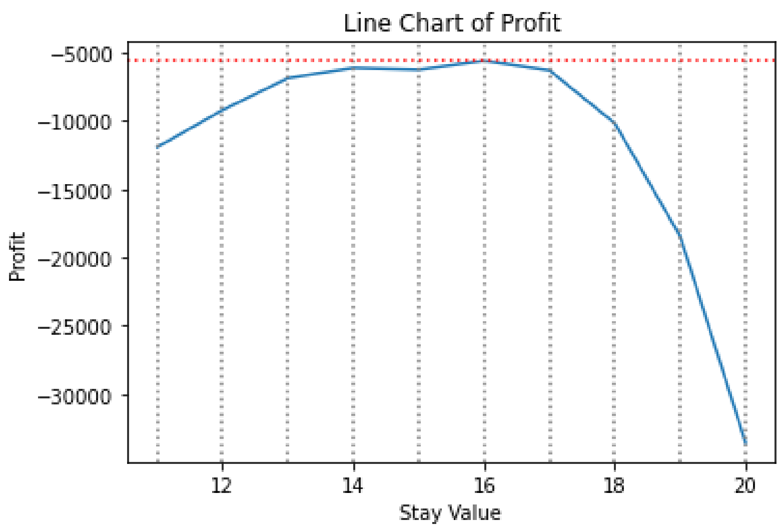


The next line chart (see right) presents the sum of win and tie percentage, which is important because it essentially means the player did not lose money on the given hand. We can see that the maximum percentages lie with stay



values 16 and 17, both of which are over 51%. This makes sense because the higher the stay value, the more likely the player is to tie with the dealer due to the “soft 17” rule. In the first chart we saw that values 12-16 all have similar win percentages, but by including the percentage of ties we are able to see that 16 and even 17 may be more optimal values.

The final line chart displays the Profit vs. Stay Value (see below). It should be noted that all the values are negative, indicating the player lost money no matter what after 10,000 hands. The profit starts increasing until stay value 16, where the loss was $5604, and then sharply decreases until the end of the range at stay value 20. This is consistent with the results in the first two line charts, as both indicate that stay value 16 leads to the highest winning percentage and least amount of loss.



3.3 Martingale System

Finally I created a chart (see right) that displays the largest bet amount and total profit for the Martingale system, taking the average outputs for all the different deck variations. The output shows a positive profit value for all stay values, but this can be misleading. The idea behind Martingale is that you double the previous bet after every loss, with every win bringing the net gain to the amount of the starting bet unit (in this case $10). You could lose 100 hands in a row, but as long as you win the 101st hand and have enough money to make the next bet the net profit will still be positive. However, when

Stay Value	Largest Bet	Profit
11	$ 559786	$ 53872
12	$ 150186	$ 53340
13	$ 44373	$ 53876
14	$ 40960	$ 48664
15	$ 34133	$ 59090
16	$ 75093	$ 52921
17	$ 286720	$ 52706
18	$ 68266	$ 53544
19	$ 7208960	$ 81930
20	$ 38447786	$ 1550557

playing Blackjack in Vegas there are table minimums and maximums that are created carefully to prevent a player from making a near guaranteed profit with this system.[3] A $10 minimum bet table, like in my example, typically has a table maximum of around $1,000. As given in the chart above, all the values for Largest Bet far exceed the table maximum of $1,000, meaning the Martingale strategy would eventually hit its wall quickly. The Martingale system only really works if there is no table maximum and if the player has an unlimited bankroll, conditions that almost never exist in real life.

4. Conclusion

With my Monte Carlo simulation, I was able to test a few variables to see how it affects the win rate for the player. Through the use of an F-test to compare the win rates between 1, 2, and 6 decks, I concluded that there is no significant difference in win rate for the number of decks a table uses. Any success that someone may have seen in real life is likely attributed to short term variability or pure luck. By observing the line charts for stay value vs. win rate and profit vs. win rate, it was shown that the most optimal stay value is 16. This makes sense because the dealer has to hit a "soft 17," which acts as a critical point for the variable. The chance of busting when hitting a 16 is 61.54% because a player will bust with any card 6 or above, so it is safer to stay on the 16s or higher. Finally, by analyzing the output for the Martingale system it is shown that the profit can be made, however this is only true if there is no table limit and the player has an unlimited bankroll. Each individual run of the simulation will produce slightly different results thanks to using the random function in the OOP section. However, since we are running 10,000 simulations for each variation, we can assume the sample mean approaches the true mean through the central limit theorem.

Although we found 16 to be the most optimal stay value, the methods of hitting and staying solely based on the player's own hand are unrealistic in the casinos. In real gameplay, the player will always want to know what the dealer's card is before making a hit/stand decision. Staying on a 16 while the dealer is showing a face card (of value 10) might get you laughed out of the casino. Also, the other actions such as splitting, doubling, surrendering, and insurance can affect how a player's net profit will look. I personally love to split and double at the tables any chance I

[3] Martingale Betting System in Roulette and Blackjack: A Complete Guide

get because the thrill of winning those big hands is unmatched! In the future, I would love to test how these additional actions would affect the win rate.

In reality Blackjack comes down to the randomness of the cards. In the short term, one could turn a small profit with some good luck and strategy; but in the long term, the odds are stacked in the casino's favor which can be seen when running tens of thousands of simulated hands. Unless you are counting cards (which will get you in some serious trouble), it is best to not go to Vegas expecting to become rich from Blackjack. At the end of the day, the house always wins!

5. References

1. 7 Sad Realities of Blackjack
   https://www.gamblingsites.org/blog/7-sad-realities-of-blackjack/
2. How to Play Blackjack in Las Vegas?
   https://www.bachelorvegas.com/casinos/how-to-play-blackjack.html
3. Martingale Betting System in Roulette and Blackjack: A Complete Guide
   https://edge.twinspires.com/casino-news/martingale-betting-system-in-roulette-and-blackjack-a-complete-guide/

6. Appendix

The table above displays the full output from the Monte Carlo simulation after running each variation 10,000 times, combining the basic betting output and the Martingale output into one view. Note that the output will be different each time the simulation is run.

Stay Value	# of Decks	Win%	Loss%	Tie%	Bet Amount	Profit Basic	MG Win%	MG Loss%	MG Tie%	Largest MG Bet	MG Profit
11	1	40.35%	54.12%	5.53%	$ 10	$ -12750	40.86%	53.81%	5.33%	$ 327680	$ 51558
11	2	39.96%	54.48%	5.56%	$ 10	$ -13602	40.6%	53.75%	5.65%	$ 1310720	$ 51954
11	6	41.5%	52.99%	5.51%	$ 10	$ -10550	40.21%	53.9%	5.89%	$ 40960	$ 58104
12	1	41.96%	51.6%	6.44%	$ 10	$ -8694	41.86%	51.69%	6.45%	$ 81920	$ 50532
12	2	41.66%	52.3%	6.04%	$ 10	$ -9722	41.62%	52.14%	6.24%	$ 40960	$ 55324
12	6	42.38%	51.74%	5.88%	$ 10	$ -8326	41.72%	52.28%	6.0%	$ 327680	$ 54166
13	1	41.8%	51.3%	6.9%	$ 10	$ -8560	42.67%	50.76%	6.57%	$ 81920	$ 53942
13	2	41.92%	51.33%	6.75%	$ 10	$ -8424	42.12%	51.2%	6.68%	$ 40960	$ 56674
13	6	42.09%	50.9%	7.01%	$ 10	$ -7882	42.98%	50.03%	6.99%	$ 10240	$ 51012
14	1	42.78%	49.77%	7.45%	$ 10	$ -6038	43.12%	49.59%	7.29%	$ 20480	$ 46604
14	2	42.72%	49.68%	7.6%	$ 10	$ -5950	42.48%	50.22%	7.3%	$ 81920	$ 48306
14	6	41.63%	50.74%	7.63%	$ 10	$ -8194	42.5%	49.85%	7.65%	$ 20480	$ 51084
15	1	43.12%	49.2%	7.68%	$ 10	$ -5084	42.72%	49.11%	8.17%	$ 40960	$ 72328
15	2	41.55%	49.77%	8.68%	$ 10	$ -7292	42.86%	49.62%	7.52%	$ 40960	$ 56214
15	6	42.58%	49.42%	8.0%	$ 10	$ -5980	43.9%	48.15%	7.95%	$ 20480	$ 48728
16	1	42.12%	48.99%	8.89%	$ 10	$ -5866	42.22%	49.18%	8.6%	$ 40960	$ 58348
16	2	42.57%	49.04%	8.39%	$ 10	$ -5494	42.64%	48.79%	8.57%	$ 163840	$ 46880
16	6	42.14%	48.73%	9.13%	$ 10	$ -5610	41.98%	49.16%	8.86%	$ 20480	$ 53536
17	1	41.07%	49.37%	9.56%	$ 10	$ -7402	40.24%	49.49%	10.27%	$ 655360	$ 54636
17	2	41.41%	49.1%	9.49%	$ 10	$ -6758	41.59%	48.72%	9.69%	$ 163840	$ 54322
17	6	42.7%	47.85%	9.45%	$ 10	$ -4162	41.21%	49.1%	9.69%	$ 40960	$ 49160
18	1	39.77%	51.77%	8.46%	$ 10	$ -11050	40.06%	51.16%	8.78%	$ 81920	$ 51050
18	2	40.28%	51.24%	8.48%	$ 10	$ -9892	40.43%	51.06%	8.51%	$ 40960	$ 61358
18	6	40.79%	50.18%	9.03%	$ 10	$ -8476	40.02%	51.75%	8.23%	$ 81920	$ 48226
19	1	36.08%	56.67%	7.25%	$ 10	$ -19688	37.35%	56.0%	6.65%	$ 327680	$ 119950
19	2	36.99%	55.98%	7.03%	$ 10	$ -17980	36.58%	56.16%	7.26%	$ 20971520	$ 67558
19	6	36.98%	56.03%	6.99%	$ 10	$ -17988	36.99%	56.39%	6.62%	$ 327680	$ 58284
20	1	29.62%	65.24%	5.14%	$ 10	$ -34704	30.66%	64.44%	4.9%	$ 83886080	$ 100734
20	2	29.58%	65.49%	4.93%	$ 10	$ -34918	29.57%	65.41%	5.02%	$ 20971520	$ 153030
20	6	30.72%	64.17%	5.11%	$ 10	$ -32540	30.59%	64.09%	5.32%	$ 10485760	$ 4397908