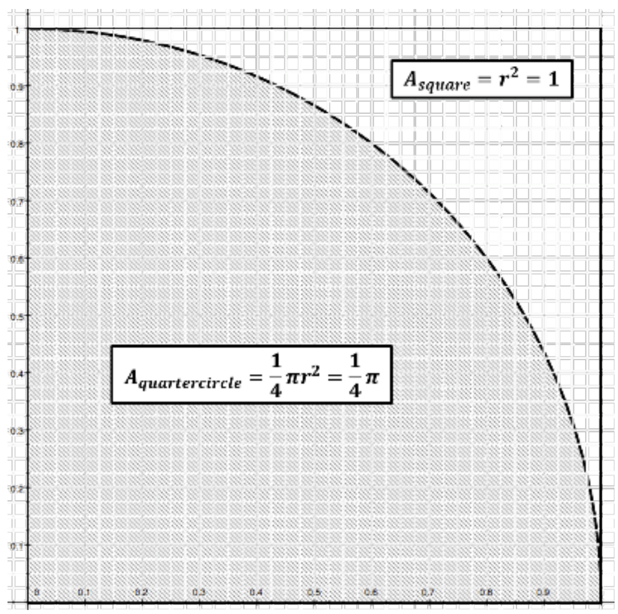
Homework Assignment (Problem Set) 4:

Note, Problem Set 3 directly focuses on Modules 7 and 8: Simulation and Monte Carlo Simulation

3 Questions

Rubric:
All questions worth 50 points
50 Points: Answer and solution are fully correct and detailed professionally.
25-49 Points: Answer and solution are deficient in some manner but mostly correct.
15-24 Points: Answer and solution are missing a key element or two.
1-14 Points: Answer and solution are missing multiple elements are significantly deficient/incomprehensible.
0 Points: No answer provided.

1. Perform Monte Carlo integration using R statistical programming or Python programming to estimate the value of π. To summarize the approach, consider the unit quarter circle illustrated in the figure below:



Generate N pairs of uniform random numbers (x, y), where $x \sim U(0,1)$ and $y \sim U(0,1)$, and each (x, y) pair represents a point in the unit square. To obtain an estimate of π, count the fraction of points that fall inside the unit quarter circle and multiply by 4. Note that the fraction of points that fall inside the quarter circle should tend to the ratio between the area of the unit quarter circle (i.e., ¼ π) as compared to area of the unit square (i.e., 1). We proceed step-by-step:

a) Create a function insidecircle that takes two inputs between 0 and 1 and returns 1 if these points fall within the unit circle.

```
insidecircle <- function(x,y){
  ifelse(x^2 + y^2 < 1,return(1),return(0))
}
```

b) Create a function estimatepi that takes a single input N, generates N pairs of uniform random numbers and uses insidecircle to produce an estimate of π as described above. In addition to the estimate of π, estimatepi should also return the standard error of this estimate, and a 95% confidence interval for the estimate.

```
estimatepi <- function(N){
  x <- runif(N)
  y <- runif(N)
  df <- data.frame(x=x,y=y)
  df$inside <- apply(df,1,function(x) insidecircle(x[1],x[2]))

  mean <- sum(df$inside)/length(df$inside)
  pi_est <- 4*sum(df$inside)/length(df$inside)
  se <- sd(df$inside)
  pi_se <- 4*se
  ci95 <- (1.96*pi_se)/sqrt(length(df$inside))

  return(list(pi=pi_est,standard.error=pi_se,ci95=ci95))
}
```

c) Use estimatepi to estimate π for $N = 1000$ to 10000 in increments of 500 and record the estimate, its standard error and the upper and lower bounds of the 95% CI. How large must N be in order to ensure that your estimate of π is within 0.1 of the true value?

```
results <- data.frame(n=c(),estimate=c(),se=c(),upper=c(),lower=c())
for(n in seq(1000,10000,by=500)){
  pi <- estimatepi(n)
  results <- rbind(results,c(n,pi$pi,pi$standard.error,
                   pi$pi+pi$ci95,pi$pi-pi$ci95))
}

colnames(results) <- c("N","estimate", "se", "upper", "lower")


(results)
```

To get to within 0.1 of the true value, you just need 1000 iterations and do not need to go further than that. It is even possible that fewer iterations can still accomplish this goal.

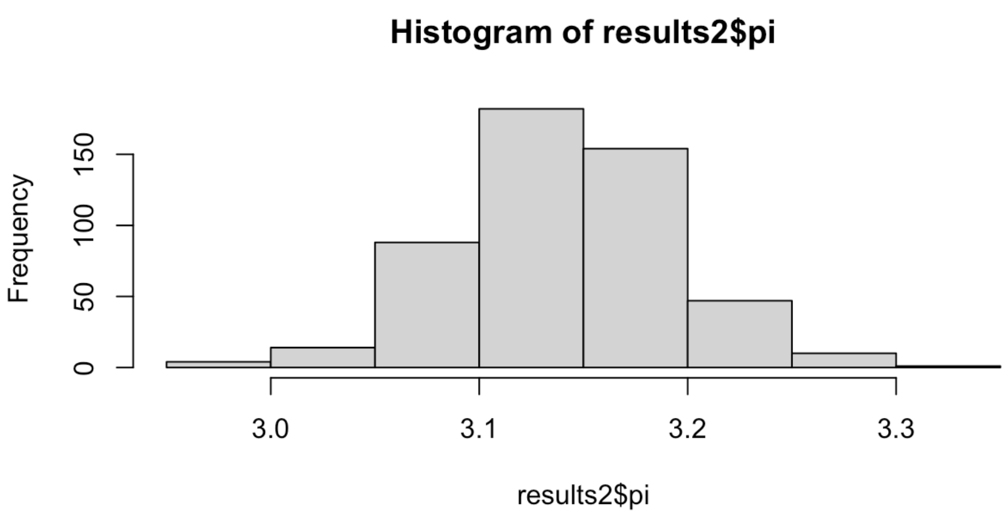
	N	estimate	se	upper	lower
1	1000	3.152000	1.635717	3.253383	3.050617
2	1500	3.109333	1.664700	3.193579	3.025088
3	2000	3.126000	1.653327	3.198460	3.053540
4	2500	3.075200	1.686737	3.141320	3.009080
5	3000	3.152000	1.635172	3.210514	3.093486
6	3500	3.165714	1.625382	3.219563	3.111865
7	4000	3.094000	1.674475	3.145893	3.042107
8	4500	3.160889	1.628781	3.208479	3.113299
9	5000	3.131200	1.649524	3.176922	3.085478
10	5500	3.137455	1.645202	3.180935	3.093974
11	6000	3.098667	1.671346	3.140958	3.056376
12	6500	3.172923	1.620079	3.212309	3.133538
13	7000	3.124571	1.654004	3.163319	3.085824
14	7500	3.174400	1.618992	3.211041	3.137759
15	8000	3.118000	1.658439	3.154342	3.081658
16	8500	3.121882	1.655809	3.157083	3.086681
17	9000	3.130667	1.649817	3.164752	3.096581
18	9500	3.120000	1.657072	3.153322	3.086678
19	10000	3.132400	1.648618	3.164713	3.100087

d) Using the value of N you determined in part c), run estimatepi 500 times and collect 500 different estimates of π. Produce a histogram of the estimates and note the shape of this distribution. Calculate the standard deviation of the estimates – does it match the standard error you obtained in part c)? What percentage of the estimates lies within the 95% CI you obtained in part c)?

```
n = 500
results2 <- data.frame(pi_est=c(), se=c(), lower=c(), upper=c(), n=c())

for(k in 1:500){
  resPi <-estimatepi(n)
  results2 <- rbind(results2, data.frame(pi_est=resPi$pi, se=resPi$standard.error, ci95=resPi$ci95, n=n))
}

hist(results2$pi)

sd(results2$pi_est)
```

The standard deviation is 0.05 which is a little bigger than the one we had previously, but this aligns when we have a smaller sample size. The aspect that remains to look good is the fact that the peak of the histogram is revolving around the true value showing that this is pretty accurate. Given the confidence level of n = 1000, the percentage of estimates within that range is 27%.

```
> sd(results2$pi_est)
[1] 0.05247165
> sd(results$estimate)
[1] 0.03040208
```




```
> ci1000 <- (results %>% filter(n==1000) %>% select(interval))/2
> new_ci<- length(pi[pi>mean(pi)-ci1000 & pi<mean(pi)+ci1000])/length(pi)
> new_ci
[1] 0.266
```

2. A salesperson in a large bicycle shop is paid a bonus if he sells more than 4 bicycles a day. The probability of selling more than 4 bicycles a day is only 0.40. If the number of bicycles sold is greater than 4, the distribution of sales as shown below. The shop has four different models of bicycles. The amount of the bonus paid out varies by type. The bonus for model A is \$10; 40% of the bicycles sold are of this type. Model B accounts for 35% of the sales and pays a bonus of \$15. Model C has a bonus rating of \$20 and makes up 20% of the sales. Finally, a model D pays a bonus of \$25 for each sale but accounts for only 5% of the sales. Develop a simulation model to calculate the bonus a salesperson can expect in a day.

Table

Number of Bicycles Sold	Probability
5	0.35
6	0.45
7	0.15
8	0.05

We saw after running the simulation with 100 iterations that on average, 4.92 bikes were sold. The average bonus was 40.60 with the max being \$116 which is the scenario when 8 bikes are sold. So on a typical day, people can anticipate a bonus around 40.60, but understand that there were days in which 4 or less bikes were sold which meant that no bonus was handed out.

Scenario:

A salesperson in a large bicycle shop is paid a bonus if he sells more than 4 bicycles a day. The probability of selling more than 4 bicycles a day is only 0.40. If the number of bicycles sold is greater than 4, the distribution of sales as shown below. The shop has four different models of bicycles. The amount of the bonus paid out varies by type. The bonus for model A is \$10; 40% of the bicycles sold are of this type. Model B accounts for 35% of the sales and pays a bonus of \$15. Model C has a bonus rating of \$20 and makes up 20% of the sales. Finally, a model D pays a bonus of \$25 for each sale but accounts for only 5% of the sales. Develop a simulation model to calculate the bonus a salesperson can expect in a day. Table

OBJECTIVE:
Estimate Bonus

PARAMETERS

Probability of Selling <4 bikes		60%
Probability of Selling >4 bikes		40%
Probability of Selling 5 bikes		14%
Probability of Selling 6 bikes		18%
Probability of Selling 7 bikes		6%
Probability of Selling 8 bikes		2%
Model A Bonus	\$	10.00
Model A Proportion of Sales		40%
Model B Bonus	\$	15.00
Model B Proportion of Sales		35%
Model C Bonus	\$	20.00
Model C Proportion of Sales		20%
Model D Bonus	\$	25.00
Model D Proportion of Sales		5%

DECISION

Bonus in a day	\$	72.50

Table

Number of Bicycles Sold	Probability		# of Bikes
4	0.6	0.6	5
5	0.14	0.74	
6	0.18	0.92	
7	0.06	0.92	
8	0.02	1	

MODEL

	# of Bikes Sold	Model A Sold	Model A Bonus	Model B Sold	Model B Bonus	Model C Sold	Model C Bonus	Model D Sold	Model D Bonus	Expected Bonus
1	5	2	\$ 20.00	2	\$ 26.25	1	\$ 20.00	0	\$ 6.25	\$ 72.50
2										
3										
4										
5										
6										
7										
8										
9										
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24										
25										

Avg Bikes		4.92
Avg Bonus	\$	40.60
Bonus STD	\$	44.54
Max Bonus	\$	116.00
Min Bonus	\$	-

REPLICATIONS	\$ 72.50	5
1	0	4
2	72.5	5
3	87	6
4	0	4
5	87	6
6	87	6
7	0	4
8	0	4
9	87	6
10	87	6
11	72.5	5
12	87	6
13	0	4
14	0	4
15	0	4
16	72.5	5
17	87	6
18	87	6
19	0	4
20	0	4
21	87	6
22	0	4
23	0	4
24	72.5	5
25	0	4
26	116	8
27	0	4
28	0	4
29	0	4
30	72.5	5
31	0	4
32	116	8
33	87	6
34	72.5	5
35	87	6
36	0	4
37	87	6
38	72.5	5
39	87	6
40	0	4
41	87	6
42	0	4
43	72.5	5
44	0	4
45	0	4
46	0	4
47	116	8
48	0	4
49	0	4
50	87	6
51	0	4
52	87	6
53	0	4
54	116	8
55	0	4
56	0	4
57	72.5	5
58	0	4
59	0	4
60	116	8
61	0	4
62	0	4
63	0	4
64	0	4
65	0	4
66	0	4
67	87	6
68	72.5	5
69	72.5	5
70	0	4
71	87	6
72	72.5	5
73	72.5	5
74	0	4
75	0	4
76	0	4
77	87	6
78	72.5	5
79	0	4
80	72.5	5
81	116	8
82	116	8
83	0	4
84	72.5	5
85	87	6
86	72.5	5
87	0	4
88	72.5	5
89	87	6
90	0	4
91	0	4
92	0	4
93	0	4
94	116	8
95	0	4
96	0	4
97	0	4
98	0	4
99	0	4
100	0	4

3. Michael is 24 years old and has a 401(k) plan through his employer, a large financial institution. His company matches 50% of his contributions up to 6% of his salary. He currently contributes the maximum amount he can (i.e., 6%). In his 401(k), he has three funds. Investment A is a large-cap index fund, which has had an average annual growth over the past 10 years of 6.63% with a standard deviation of 13.46%. Investment B is a mid-cap index fund with a 10-year average annual growth of 9.89% and a standard deviation of 15.28%. Finally, Investment C is a small-cap Index fund with a 10-year average annual growth rate of 8.55% and a standard deviation of 16.90%. Fifty percent of his contribution is directed to Investment A, 25% to Investment B, and 25% to Investment C. His current salary is $48,000 and based on a compensation survey of financial institutions, he expects an average raise of 2.7% with a standard deviation of 0.4% each year. Develop a simulation model to predict his 401(k) balance at age 60.

We found out that the mean balance of the simulation was $1.3 million with a standard deviation of 478K. The max that he reached was $3 million and the min was 471K. This seems to be a fairly accurate solution given the information provided. The only main missing piece is the potential for possible promotions which could increase his salary further.

Scenario: Michael is 24 years old and has a 401(k) plan through his employer, a large financial institution. His company matches 50% of his contributions up to 6% of his salary. He currently contributes the maximum amount he can (i.e., 6%). In his 401(k), he has three funds. Investment A is a large-cap index fund, which has had an average annual growth over the past 10 years of 6.63% with a standard deviation of 13.46%. Investment B is a mid-cap index fund with a 10-year average annual growth of 9.89% and a standard deviation of 15.28%. Finally, Investment C is a small-cap Index fund with a 10-year average annual growth rate of 8.55% and a standard deviation of 16.90%. Fifty percent of his contribution is directed to Investment A, 25% to Investment B, and 25% to Investment C. His current salary is $48,000 and based on a compensation survey of financial institutions, he expects an average raise of 2.7% with a standard deviation of 0.4% each year. Develop a simulation model to predict his 401(k) balance at age 60.

OBJECTIVE:
Maximize 401k returns

PARAMETERS

Company Match	50%
Salary Contribution	6%
Salary	$ 48,000.00
Annual Raise Mean	2.70%
Annual Raise STD	0.40%
Investment A Growth Mean	6.63%
Investment A Growth STD	13.46%
Investment B Growth Mean	9.89%
Investment B Growth STD	15.28%
Investment C Growth Mean	8.55%
Investment C Growth STD	16.90%
Investment A Contribution	50%
Investment B Contribution	25%
Investment C Contribution	25%

DECISION

401k balance at 60 years	$ 737,271.14

MODEL

	Salary	Raise	Contribution	Company Match	Investment A Growth Rate	Investment A	Investment A Net
24	$ 48,000.00	0%	$ 2,880.00	$ 1,440.00	-8%	$ 2,160.00	$ 1,991.37
25	$ 49,060.02	2%	$ 2,943.60	$ 1,471.80	-1%	$ 2,207.70	$ 4,175.92
26	$ 50,257.11	2%	$ 3,015.43	$ 1,507.71	15%	$ 2,261.57	$ 7,382.29
27	$ 51,791.97	3%	$ 3,107.52	$ 1,553.76	5%	$ 2,330.64	$ 10,173.02
28	$ 52,740.61	2%	$ 3,164.44	$ 1,582.22	21%	$ 2,373.33	$ 15,194.52
29	$ 54,137.73	3%	$ 3,248.26	$ 1,624.13	-2%	$ 2,436.20	$ 17,209.52
30	$ 55,512.60	3%	$ 3,330.76	$ 1,665.38	18%	$ 2,498.07	$ 23,345.30
31	$ 57,110.82	3%	$ 3,426.65	$ 1,713.32	1%	$ 2,569.99	$ 26,248.05
32	$ 58,325.22	2%	$ 3,499.51	$ 1,749.76	-13%	$ 2,624.63	$ 25,131.25
33	$ 59,952.89	3%	$ 3,597.17	$ 1,798.59	6%	$ 2,697.88	$ 29,500.93
34	$ 61,710.23	3%	$ 3,702.61	$ 1,851.31	0%	$ 2,776.96	$ 32,216.93
35	$ 63,366.45	3%	$ 3,801.99	$ 1,900.99	-1%	$ 2,851.49	$ 34,837.45
36	$ 64,574.52	2%	$ 3,874.47	$ 1,937.24	-4%	$ 2,905.85	$ 36,368.30
37	$ 66,374.94	3%	$ 3,982.50	$ 1,991.25	-14%	$ 2,986.87	$ 33,821.90
38	$ 67,949.07	2%	$ 4,076.94	$ 2,038.47	17%	$ 3,057.71	$ 43,213.77
39	$ 70,414.68	4%	$ 4,224.88	$ 2,112.44	27%	$ 3,168.66	$ 58,767.85
40	$ 72,104.47	2%	$ 4,326.27	$ 2,163.13	-27%	$ 3,244.70	$ 45,108.83
41	$ 73,855.88	2%	$ 4,431.35	$ 2,215.68	20%	$ 3,323.51	$ 57,968.16
42	$ 75,892.67	3%	$ 4,553.56	$ 2,276.78	-4%	$ 3,415.17	$ 59,056.74
43	$ 77,544.11	2%	$ 4,652.65	$ 2,326.32	9%	$ 3,489.48	$ 68,337.68
44	$ 79,477.80	2%	$ 4,768.67	$ 2,384.33	-1%	$ 3,576.50	$ 71,259.71
45	$ 81,505.89	3%	$ 4,890.35	$ 2,445.18	1%	$ 3,667.77	$ 75,692.77
46	$ 83,490.90	2%	$ 5,009.45	$ 2,504.73	13%	$ 3,757.09	$ 89,694.05
47	$ 85,798.58	3%	$ 5,147.91	$ 2,573.96	0%	$ 3,860.94	$ 93,826.83
48	$ 87,311.03	2%	$ 5,238.66	$ 2,619.33	17%	$ 3,929.00	$ 114,448.77
49	$ 89,668.11	3%	$ 5,380.09	$ 2,690.04	38%	$ 4,035.06	$ 163,662.96
50	$ 92,524.57	3%	$ 5,551.47	$ 2,775.74	-1%	$ 4,163.61	$ 166,809.65
51	$ 94,759.16	2%	$ 5,685.55	$ 2,842.77	10%	$ 4,264.16	$ 188,027.65
52	$ 96,830.16	2%	$ 5,809.81	$ 2,904.90	3%	$ 4,357.36	$ 197,883.65
53	$ 99,886.48	3%	$ 5,993.19	$ 2,996.59	17%	$ 4,494.89	$ 236,004.77
54	$ 102,736.96	3%	$ 6,164.22	$ 3,082.11	7%	$ 4,623.16	$ 256,640.50
55	$ 106,094.81	3%	$ 6,365.69	$ 3,182.84	3%	$ 4,774.27	$ 270,168.21
56	$ 108,797.43	3%	$ 6,527.85	$ 3,263.92	0%	$ 4,895.88	$ 274,492.84
57	$ 111,171.10	2%	$ 6,670.27	$ 3,335.13	15%	$ 5,002.70	$ 321,797.57
58	$ 113,782.02	2%	$ 6,826.92	$ 3,413.46	11%	$ 5,120.19	$ 364,246.24
59	$ 116,962.59	3%	$ 7,017.76	$ 3,508.88	-5%	$ 5,263.32	$ 349,598.20
60	$ 120,948.18	3%	$ 7,256.89	$ 3,628.45	-1%	$ 5,442.67	$ 352,267.00

	Investment B Growth	Investment B	Investment B Net	Investment C Growth	Investment C	Investment C Net	401k Balance
24	-9%	$ 1,080.00	$ 985.99	0%	$ 1,080.00	$ 1,076.30	$ 4,053.66
25	10%	$ 1,103.85	$ 2,304.38	3%	$ 1,103.85	$ 2,240.33	$ 8,720.63
26	10%	$ 1,130.78	$ 3,778.10	7%	$ 1,130.78	$ 3,602.86	$ 14,763.24
27	8%	$ 1,165.32	$ 5,360.79	-3%	$ 1,165.32	$ 4,608.26	$ 20,142.07
28	11%	$ 1,186.66	$ 7,248.23	19%	$ 1,186.66	$ 6,893.41	$ 29,336.16
29	23%	$ 1,218.10	$ 10,377.49	5%	$ 1,218.10	$ 8,503.36	$ 36,090.36
30	20%	$ 1,249.03	$ 13,971.68	19%	$ 1,249.03	$ 11,571.71	$ 48,888.70
31	13%	$ 1,284.99	$ 17,182.63	8%	$ 1,284.99	$ 13,887.16	$ 57,317.83
32	30%	$ 1,312.32	$ 24,123.38	11%	$ 1,312.32	$ 16,896.23	$ 66,150.86
33	24%	$ 1,348.94	$ 31,562.56	-41%	$ 1,348.94	$ 10,711.05	$ 71,774.54
34	-32%	$ 1,388.48	$ 22,571.09	-32%	$ 1,388.48	$ 8,279.20	$ 63,067.22
35	16%	$ 1,425.75	$ 27,932.40	4%	$ 1,425.75	$ 10,126.80	$ 72,896.65
36	2%	$ 1,452.93	$ 29,962.96	16%	$ 1,452.93	$ 13,416.65	$ 79,747.91
37	-1%	$ 1,493.44	$ 31,105.18	-18%	$ 1,493.44	$ 12,187.83	$ 77,114.91
38	12%	$ 1,528.85	$ 36,667.56	13%	$ 1,528.85	$ 15,465.57	$ 95,346.90
39	15%	$ 1,584.33	$ 44,056.60	17%	$ 1,584.33	$ 20,023.51	$ 122,847.96
40	14%	$ 1,622.35	$ 52,276.18	-2%	$ 1,622.35	$ 21,161.09	$ 118,546.11
41	14%	$ 1,661.76	$ 61,569.03	4%	$ 1,661.76	$ 23,627.07	$ 143,164.26
42	33%	$ 1,707.59	$ 84,339.69	13%	$ 1,707.59	$ 28,652.35	$ 172,048.78
43	40%	$ 1,744.74	$ 120,666.97	3%	$ 1,744.74	$ 31,193.20	$ 220,197.85
44	9%	$ 1,788.25	$ 133,094.83	-4%	$ 1,788.25	$ 31,758.62	$ 236,113.16
45	22%	$ 1,833.88	$ 164,721.85	24%	$ 1,833.88	$ 41,752.01	$ 282,166.63
46	-1%	$ 1,878.55	$ 165,662.79	-5%	$ 1,878.55	$ 41,333.54	$ 296,690.37
47	-11%	$ 1,930.47	$ 149,595.34	-5%	$ 1,930.47	$ 41,025.34	$ 284,447.51
48	-10%	$ 1,964.50	$ 136,688.24	-1%	$ 1,964.50	$ 42,347.14	$ 293,484.14
49	3%	$ 2,017.53	$ 142,750.89	7%	$ 2,017.53	$ 47,402.85	$ 353,816.70
50	13%	$ 2,081.80	$ 163,912.50	10%	$ 2,081.80	$ 54,210.88	$ 384,933.02
51	-24%	$ 2,132.08	$ 125,861.16	2%	$ 2,132.08	$ 57,354.65	$ 371,243.46
52	21%	$ 2,178.68	$ 155,169.24	30%	$ 2,178.68	$ 77,506.83	$ 430,559.71
53	-11%	$ 2,247.45	$ 140,022.11	-11%	$ 2,247.45	$ 71,162.08	$ 447,188.96
54	9%	$ 2,311.58	$ 154,907.05	12%	$ 2,311.58	$ 82,016.15	$ 493,563.69
55	4%	$ 2,387.13	$ 163,015.92	26%	$ 2,387.13	$ 106,366.83	$ 539,550.96
56	-2%	$ 2,447.94	$ 162,648.42	15%	$ 2,447.94	$ 125,001.43	$ 562,142.69
57	28%	$ 2,501.35	$ 211,518.09	-2%	$ 2,501.35	$ 124,892.87	$ 658,208.53
58	-15%	$ 2,560.10	$ 181,462.17	22%	$ 2,560.10	$ 154,910.72	$ 700,619.14
59	30%	$ 2,631.66	$ 238,646.85	-14%	$ 2,631.66	$ 134,949.77	$ 723,194.81
60	-6%	$ 2,721.33	$ 227,804.74	14%	$ 2,721.33	$ 157,199.39	$ 737,271.14

Mean 401k Balance	$ 1,385,226.98
STD 401k Balance	$ 478,028.95
Max 401k Balance	$ 3,054,309.50
Min 401k Balance	$ 471,082.83

REPLICATIONS	$ 737,271.14
1	1093850.261
2	1369670.673
3	1206250.256
4	1726372.853
5	965874.9498
6	2556159.112
7	1009495.508
8	2220365.373
9	1052239.429
10	1674509.741
11	1515703.621
12	1778376.884
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