SYSTEM MODELLING AND SIMULATION

TERM PROJECT

Marwan Mohamed Nabil 12/27/22 SYSTEM MODELLING AND SIMULATION

UNDER THE SUPERVISION OF

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PREPARED BY

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SUBJECT

System Modeling and Simulation (DS331)

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PROBLEM 1

PART 1: Problem formulation & Objectives

1. The Problem

We have a bank that serves 2 types of customers (Ordinary & Distinguished), but only has 1 teller to serve both types, where the system gives some sort of privilege to the distinguished customers.

Distinguished customers have a higher priority in service, if a distinguished customer and an ordinary customer both have the same arrival time, the distinguished customer is served first.

2. Objective:

Our objective is to calculate the necessary data and averages to help the bank decide whether a second teller is needed or not, using previously collected probabilities, which will be displayed shortly ahead.

PART 2: System Overview

1. System components:

Let's first look at our system environment:

System	Entity	Attributes	Activities	Events	State Variable
Bank queueing system	Customer	-Type -Arrival time -Service end Time - Service time	-Waiting -Serving -Teller idle	-Arrival -Service begins -Service ends	-Customer waiting -Total ordinary and distinguished customers

2. System Analysis:

Simulation Data

As stated previously, the bank provided previously calculated probabilities for each type of customer, including the probability of arrival time and the probability of service time (Which is how long it will take to serve this customer), for each type.

Here are the tables for each customer:

a. Ordinary Customer's table:

Inter-Arrival times (Minutes)	Probability	Cumulative Probability
0	0.09	0.09
1	0.17	0.26
2	0.27	0.53
3	0.2	0.73
4	0.15	0.88
5	0.12	1

Service times (Minutes)	Probability	Cumulative Probability
1	0.2	0.2
2	0.4	0.6
3	0.28	0.88
4	0.12	1

b. Distinguished Customer's table:

Inter-Arrival times (Minutes)	Probability	Cumulative Probability
1	0.1	0.1
2	0.2	0.3
3	0.3	0.6
4	0.4	1

Service times (Minutes)	Probability	Cumulative Probability
1	0.1	0.1
2	0.3	0.4
3	0.38	0.78
4	0.22	1

Calendar table:

#	IAT	AT	ST	CT	WT	BT	ET	TT	Idle
1	0	0	2	O	0	0	2	2	0
2	2	2	2	O	0	2	4	2	0
3	0	2	1	D	2	4	5	4	0
4	2	4	4	D	1	5	9	5	0
5	2	6	1	O	3	9	10	4	0
6	0	6	4	O	4	10	14	8	0
7	2	8	3	O	6	14	14	9	0
8	2	10	1	O	7	17	18	8	0
9	0	10	3	O	8	18	21	11	0
10	3	13	1	O	8	21	22	9	0

Where: **(# = customer number, IAT = Inter-Arrival time, AT = Arrival time, ST = Service time, WT = Waiting Time, BT = Beginning Time, ET = Ending Time, Total Time in system, Idle = Time Teller spent idle).**

PART 3: Experimentation

1. Experimental parameters:

To determine whether a second teller is needed or not, we need to compute the average waiting time for ordinary and distinguished customers. Also, other factors may weigh in, but we'll leave them for no.

In this problem we have 3 factors affecting the output:

1. Customer arrival time.
2. Customer service time.
3. Type of customer.

2. Justification of experiment parameters values:

We chose these parameters as our controlled inputs because after understanding the problem correctly, we can deduce that they are the attributes that affect most of the other attributes.

For clarification, let’s observe the functions used to generate the calendar table:

- Customer waiting time = End time of previous customer – Arrival time
- Service Begin time = Arrival time + Waiting time
- Service End time = Begin time + Customer Service time
- Total time in system = Service end time – Arrival time
- Teller idle time = Service end time of previous client – Service Begin time of current client

As we can see, (Arrival time and Service time) are an essential part of each of these data calculations.

-Knowing that our initial values are as follows:

- Number of customers to be simulated = 10 customers
- Arrival time of first customer = 0
- Service time of first customer = 1 minute
- Type of first customer = O “Ordinary”.

PART 4: Results and Conclusions

A. Results Analysis:

-In this section we will observe the outputs of this run.

-And then discuss whether they reflect a good system or not.

-And this in turn will help us decide if an additional teller that only serves distinguished customers is needed or not

Here are the results:

1. The Average teller service time

-The average service time of teller equated to <u>2 Minutes</u>

2. The Average waiting time

-Average waiting time for an ordinary customer = 6 minutes

-Average waiting time for a distinguished customer = 1.5 minutes

This here is not a good indication. If we observe the waiting time of the customers approaching the end of the table, we'll find that it's gradually cumulating.

This results in a long waiting line for both customers.

Though it seems as if the average time a distinguished customer waits is 1.5 minutes, this number is only because there were only 2 distinguished customers in this run, and it will be obvious in the following point (The probability of waiting).

This of course can be solved by adding an additional teller.

3. The probability of waiting

-Probability that an ordinary customer will wait = 0.75

-Probability that a distinguished customer will wait = 1

As stated in the previous point, though the average waiting time for a distinguished customer seems low, but this statistic shows the opposite.

It states that there is a 100% chance a distinguished customer will wait, though it's not 100% true, this shows that this number will probably not decrease substantially as the number of customers increase.

Again, this issue could be solved by adding an additional teller.

4. The portion of idle time of the teller.

-Average time teller is idle = 0 minutes

This might be the most extreme indication of this system's flaws.

Although the number of customers is low (10), the teller didn't have any idle time, which shows that eventually a long waiting line will build up since there is no free time between the customer that just ended and the one that will follow.

5. Theoretical vs Experimental values.

ORDINARY CUSTOMERS	Service time	Inter-Arrival time
Theoretical	2.5	2.5
Experimental	1.875	1.375

DISTINGUISHED CUSTOMERS	Service time	Inter-Arrival time
Theoretical	2.5	2.5
Experimental	2.5	1

6. Extra stats.

This run had 10 customers (2 Distinguished, 8 Ordinary)

For which:

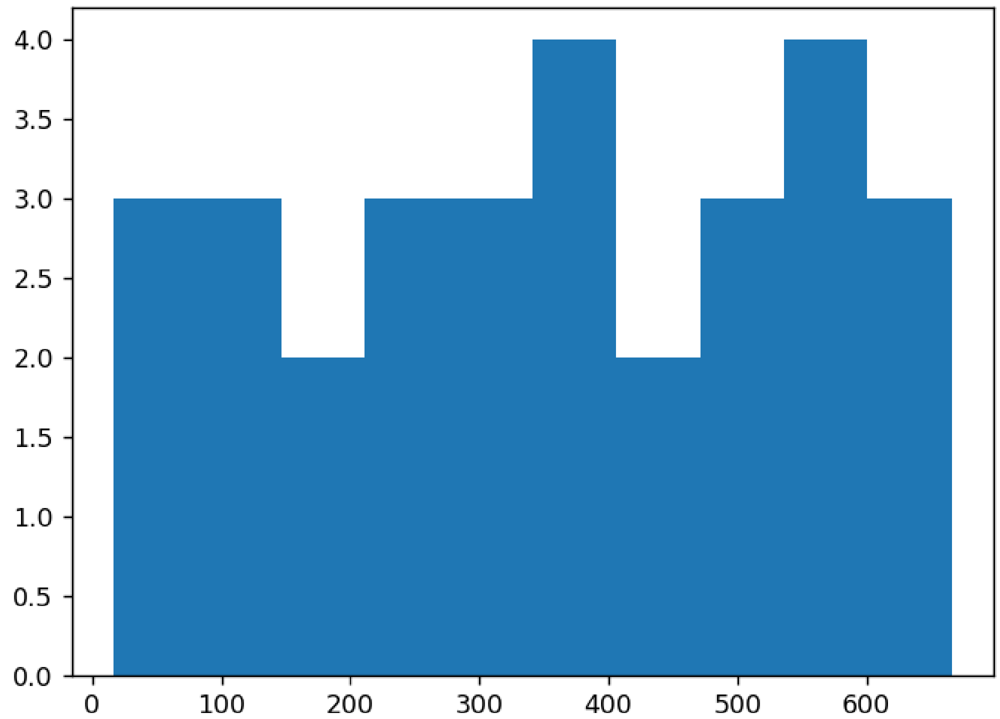
-Average Total time taken in system = 6.1 Minutes.

-Probability that any customer will end up waiting = 0.8 (80% of the customers arrived ended up waiting)

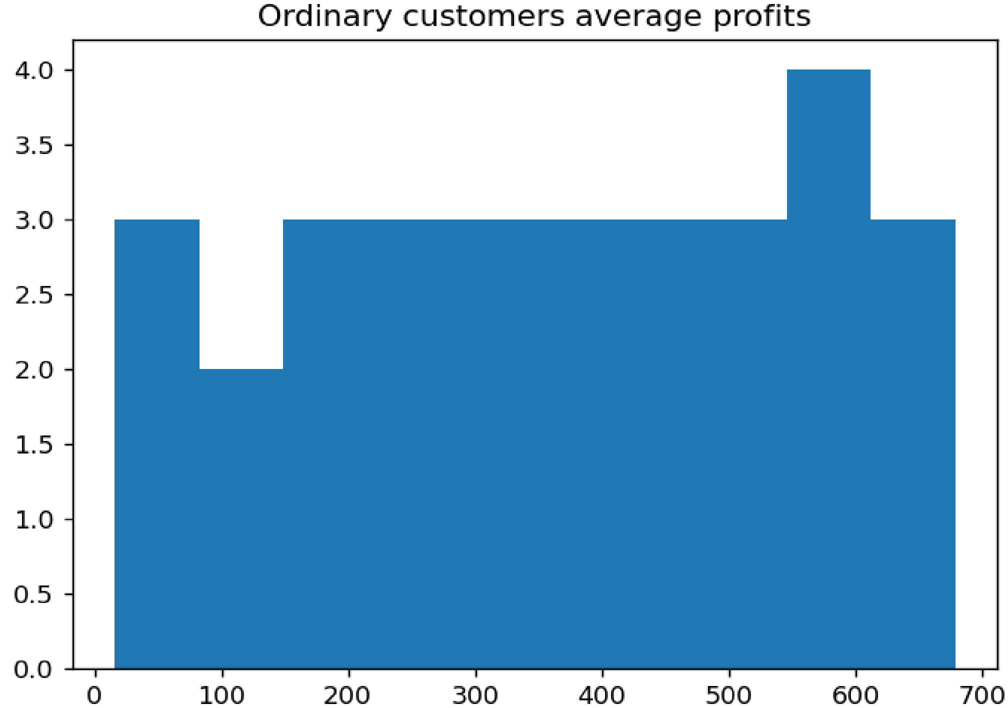
These results give us a huge insight on the system even though it is a small scale (10 customers).

As the number of customers increases, these numbers will be much bigger, which is bad for the teller system.

Distinguished customers average profits



Ordinary customers average profits



B. Conclusion

From the recorded data, it is obvious that this system can't deal with many clients, since the waiting line will gradually increase over time, which increases the time it takes a customer to be served.

Which is why an additional teller is crucial in this case in my opinion.

As:

1. It will decrease the average waiting time of both customers, even though it is meant for the distinguished customers.
2. The load on the first teller will be less.
3. The impact of a long waiting line on a huge number of customers won't be as much as before.
4. Distinguished customers will be treated as they should be, by offering them an additional teller that only serves them if the waiting line is long.

PROBLEM 2

PART1: Problem Formulation and objectives:

a. The Problem:

We have a newspaper seller that buys these papers from a certain agency for 0.5 per paper, where he's obliged to buy a bundle of 20 newspapers only (40, 60, 80, etc.). He sells these papers for 0.7 per paper.

At the end of the day, if he ends up having excess papers, he sells them for 0.15 per paper.

Else, if he ends up running out of papers and the demand was more than he expected, he counts it as a loss for each paper he could've sold.

b. Objective

The seller wants to know what the optimal number of newspapers that he should buy is, which would maximize his profit, using previously collected data, that will be displayed shortly after ahead.

We will perform a run for each possibility.

Since the seller can buy only bundles of 20, so his range is to buy one of the following numbers [{40, 60, 80, 100, 120}.

PART 2: System Overview

a. System Components:

Let's first look at our system environment:

System	Entity	Attributes	Activities	Events	State Variable
Newspaper Simulation for optimal number of papers	Seller	-Revenue -Newsday -Demand -Scrap	-Sells paper -Sells scrap -Calculate loss	-Selling -Buying	-Profit -Paper type

2. System Analysis:

a. Simulation data

As stated before, the seller provided previously recorded data and probabilities that will aid in this simulation system.

This data includes:

-the probability of the type of news in a particular day (Excellent, Good, Fair, Poor)

-The probability of the number of demanded newspapers in a day

We will display the probabilities provided in addition to the cumulative probabilities.

Here is the data:

Type probability Distribution:

Type of Newsday	Probability
Excellent	0.18
Good	0.42
Fair	0.32
Poor	0.08

Demand probability Distribution:

Demand	Excellent	Good	Fair	Poor
40	0	0.06	0.15	0.42
50	0.07	0.09	0.22	0.28
60	0.08	0.16	0.28	0.14
70	0.12	0.19	0.18	0.10
80	0.13	0.28	0.10	0.05
90	0.22	0.12	0.05	0.01
100	0.23	0.07	0.02	0
110	0.08	0.03	0	0
120	0.07	0	0	0

b. Calendar table

Knowing this information, what we need to do next is assign each table it’s random number distribution so we can come up with a calendar table for our first run.

Here are the Random number assignments for each table:

Type Random number distribution:

Type of Newsday	Probability	Cumulative Probability	Random digit
Excellent	0.18	0.18	1-18
Good	0.42	0.6	19-60
Fair	0.32	0.92	61-92
Poor	0.08	1	93-00

Demand Random Number distribution:

	Demand Probability dis.				Cumulative dis.				Random digit Assignment			
Demand	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
40	0.00	0.06	0.15	0.42	0.00	0.06	0.15	0.42	0	1-6	1-15	1-42
50	0.07	0.09	0.22	0.28	0.07	0.15	0.37	0.70	1-7	7-15	16-37	43-70
60	0.08	0.16	0.28	0.14	0.15	0.31	0.65	0.84	8-15	16-31	38-65	71-84
70	0.12	0.19	0.18	0.10	0.27	0.50	0.83	0.94	16-27	32-50	66-83	85-94
80	0.13	0.28	0.10	0.05	0.40	0.78	0.93	0.99	28-40	51-78	84-93	95-99
90	0.22	0.12	0.05	0.01	0.62	0.90	0.98	1	41-62	79-90	94-98	00
100	0.23	0.07	0.02	0.00	0.85	0.97	1	1	63-85	91-97	99-00	00
110	0.08	0.03	0.00	0.00	0.93	1	1	1	86-93	98-00	00	00
120	0.07	0.00	0.00	0.00	1	1	1	1	94-00	00	00	00

After assigning our random numbers, it's time to perform our first run.

We will perform a run for 20 days for each possibility.

So, we will have to determine which number of newspapers is optimal for his profit within these 20 days.

Here is the list of data we are collecting:

1. **Random assigned number for type of news day. (R type)**
2. **Type of news day assigned per day (Type)**
3. **Random assigned number for demand. (R Demand)**
4. **Demand per day (Demand)**
5. **Gross revenue per day (Revenue)**
6. **Money that could've been gained if demand was met (Lost)**
7. **Profit from scrap. (Scrap)**
8. **Net Profit (Profit)**

Here is our calendar table for one run for each possibility:

This is the (40-Newspapers) run:

#	R type	Type	R Demand	Demand	Revenue	Lost	Scrap	Profit
1	80	F	36	50	28.0	7.0	0.0	1.0
2	96	P	87	70	28.0	21.0	0.0	-13.0
3	78	F	95	90	28.0	35.0	0.0	-27.0
4	67	F	91	80	28.0	28.0	0.0	-20.0
5	54	G	38	70	28.0	21.0	0.0	-13.0
6	51	G	5	40	28.0	0.0	0.0	8.0
7	75	F	60	60	28.0	14.0	0.0	-6.0
8	81	F	43	60	28.0	14.0	0.0	-6.0
9	12	E	53	90	28.0	35.0	0.0	-27.0
10	24	G	67	80	28.0	28.0	0.0	-20.0
11	12	E	22	70	28.0	21.0	0.0	-13.0
12	52	G	68	80	28.0	28.0	0.0	-20.0
13	1	E	85	100	28.0	42.0	0.0	-34.0
14	61	F	100	100	28.0	42.0	0.0	-34.0
15	58	G	21	60	28.0	14.0	0.0	-6.0
16	76	F	43	60	28.0	14.0	0.0	-6.0
17	15	E	79	100	28.0	42.0	0.0	-34.0
18	57	G	8	50	28.0	7.0	0.0	1.0
19	91	F	82	70	28.0	21.0	0.0	-13.0
20	20	66	F	63	60	28.0	14.0	0.0

This is the (60-Newspapers) run:

#	R type	Type	R Demand	Demand	Revenue	Lost	Scrap	Profit
1	29	G	7	50	35.0	0.0	1.5	6.5
2	13	E	40	80	42.0	14.0	0.0	-2.0
3	36	G	87	90	42.0	21.0	0.0	-9.0
4	35	G	8	50	35.0	0.0	1.5	6.5
5	85	F	35	50	35.0	0.0	1.5	6.5
6	20	G	81	90	42.0	21.0	0.0	-9.0
7	41	G	68	80	42.0	14.0	0.0	-2.0
8	92	F	49	60	42.0	0.0	0.0	12.0
9	90	F	97	90	42.0	21.0	0.0	-9.0
10	73	F	57	60	42.0	0.0	0.0	12.0
11	31	G	36	70	42.0	7.0	0.0	5.0
12	13	E	67	100	42.0	28.0	0.0	-16.0
13	45	G	15	50	35.0	0.0	1.5	6.5
14	86	F	68	70	42.0	7.0	0.0	5.0
15	61	F	34	50	35.0	0.0	1.5	6.5
16	53	G	52	80	42.0	14.0	0.0	-2.0
17	33	G	2	40	28.0	0.0	3.0	1.0
18	92	F	23	50	35.0	0.0	1.5	6.5
19	53	G	34	70	42.0	7.0	0.0	5.0
20	41	G	100	110	42.0	35.0	0.0	-23.0

This is the (80-Newspapers) run:

#	R type	Type	R Demand	Demand	Revenue	Lost	Scrap	Profit
1	64	F	43	60	42.0	0.0	3.0	5.0
2	80	F	100	100	56.0	14.0	0.0	2.0
3	49	G	72	80	56.0	0.0	0.0	16.0
4	69	F	4	40	28.0	0.0	6.0	-6.0
5	21	G	57	80	56.0	0.0	0.0	16.0
6	55	G	12	50	35.0	0.0	4.5	-0.5
7	42	G	42	70	49.0	0.0	1.5	10.5
8	56	G	38	70	49.0	0.0	1.5	10.5
9	84	F	36	50	35.0	0.0	4.5	-0.5
10	61	F	1	40	28.0	0.0	6.0	-6.0
11	95	P	95	80	56.0	0.0	0.0	16.0
12	82	F	17	50	35.0	0.0	4.5	-0.5
13	22	G	12	50	35.0	0.0	4.5	-0.5
14	25	G	34	70	49.0	0.0	1.5	10.5
15	34	G	13	50	35.0	0.0	4.5	-0.5
16	72	F	16	50	35.0	0.0	4.5	-0.5
17	44	G	28	60	42.0	0.0	3.0	5.0
18	95	P	59	50	35.0	0.0	4.5	-0.5
19	66	F	93	80	56.0	0.0	0.0	16.0
20	9	E	25	70	49.0	0.0	1.5	10.5

This is the (100-Newspapers) run:

#	R type	Type	R Demand	Demand	Revenue	Lost	Scrap	Profit
1	2	E	59	90	63.0	0.0	1.5	14.5
2	89	F	38	60	42.0	0.0	6.0	-2.0
3	76	F	31	50	35.0	0.0	7.5	-7.5
4	53	G	39	70	49.0	0.0	4.5	3.5
5	59	G	87	90	63.0	0.0	1.5	14.5
6	51	G	11	50	35.0	0.0	7.5	-7.5
7	84	F	23	50	35.0	0.0	7.5	-7.5
8	57	G	25	60	42.0	0.0	6.0	-2.0
9	22	G	3	40	28.0	0.0	9.0	-13.0
10	69	F	37	50	35.0	0.0	7.5	-7.5
11	4	E	33	80	56.0	0.0	3.0	9.0
12	76	F	85	80	56.0	0.0	3.0	9.0
13	25	G	28	60	42.0	0.0	6.0	-2.0
14	35	G	44	70	49.0	0.0	4.5	3.5
15	72	F	52	60	42.0	0.0	6.0	-2.0
16	87	F	88	80	56.0	0.0	3.0	9.0
17	99	P	40	40	28.0	0.0	9.0	-13.0
18	96	P	79	60	42.0	0.0	6.0	-2.0
19	48	G	9	50	35.0	0.0	7.5	-7.5
20	77	F	95	90	63.0	0.0	1.5	14.5

This is the (120-Newspapers) run:

#	R type	Type	R Demand	Demand	Revenue	Lost	Scrap	Profit
1	38	G	84	90	63.0	0.0	4.5	7.5
2	72	F	19	50	35.0	0.0	10.5	-14.5
3	90	F	40	60	42.0	0.0	9.0	-9.0
4	54	G	47	70	49.0	0.0	7.5	-3.5
5	65	F	55	60	42.0	0.0	9.0	-9.0
6	46	G	94	100	70.0	0.0	3.0	13.0
7	65	F	12	40	28.0	0.0	12.0	-20.0
8	73	F	16	50	35.0	0.0	10.5	-14.5
9	69	F	27	50	35.0	0.0	10.5	-14.5
10	61	F	23	50	35.0	0.0	10.5	-14.5
11	84	F	36	50	35.0	0.0	10.5	-14.5
12	49	G	65	80	56.0	0.0	6.0	2.0
13	7	E	92	110	77.0	0.0	1.5	18.5
14	73	F	22	50	35.0	0.0	10.5	-14.5
15	21	G	13	50	35.0	0.0	10.5	-14.5
16	64	F	25	50	35.0	0.0	10.5	-14.5
17	43	G	51	80	56.0	0.0	6.0	2.0
18	49	G	47	70	49.0	0.0	7.5	-3.5
19	32	G	85	90	63.0	0.0	4.5	7.5
20	42	G	53	80	56.0	0.0	6.0	2.0

PART 3: Experimentation

1. Experimental Parameters:

To determine the optimal number of newspapers, we need to know the total profit each possibility yearns.

And from several runs, we can estimate which number of newspapers is the most optimal.

To calculate the total profit, we need to know the Type of news day, and the demand in that day, which will help us estimate the profit in that day

So, we have 3 main factors for the output:

1. **The number of bought newspapers**
2. **The Type of news day**
3. **The demand per day**

2. Justification of experiment parameters values:

We chose these inputs as our controllable inputs as after studying the case and formulating the functions, it turns out that these variables are the ones that determine the other factors that weigh into the total profit equation.

For clarification, let's look at some of the main functions that make up our table:

- **Number of sold = Bought - Demand**
- **Cost = Number of bought x 0.5**
- **revenue = Number of sold * 0.7**
- **Profit per day = Revenue - Cost - lost due to excess demand + Scrap Revenue**

As we can see, the 3 main factors we mentioned earlier are at the heart of this process, in fact, they start it.

Now let's begin to discuss the results of our simulation.

Knowing that the following are our starting numbers:

-Selling price per newspaper = 0.7$
-Buying price per Newspaper = 0.5$
-Selling price of scrap = 0.15$
-Profit = 0

PART 4: Results and Conclusions

A. Results Analysis:

-In this section we will observe the outputs of this run.

-And then discuss whether they reflect a good system or not.

-And this in turn will help us decide which number of newspapers is the optimum.

Here are the results:

a. Statistics over 20 days:

Newspapers:	Total Profit ($)	Avg Revenue	Avg Demand	Avg Scrap Revenue	Avg Lost revenue
40	-282	29.6	72.15	0.7	23.1
60	7	69.5	39.2	9.45	0.6
80	102.5	62.5	43.05	0.7	2.78
100	4	64	44.8	0.0	5.4
120	-108.5	66.5	46.55	0.0	8.03

b. What is the best choice?

Obviously, the profit of buying 80 Newspapers is superior to all other options, in every aspect of comparison.

It has the best total profit among the 5 choices without any other competition, as the margin between it and the other choices is large.

It’s also obvious that 40 newspapers are the worst choice

Let’s discuss the different aspects of this choice

c. Validating our choice:

To validate our choice, we need to perform several test runs.

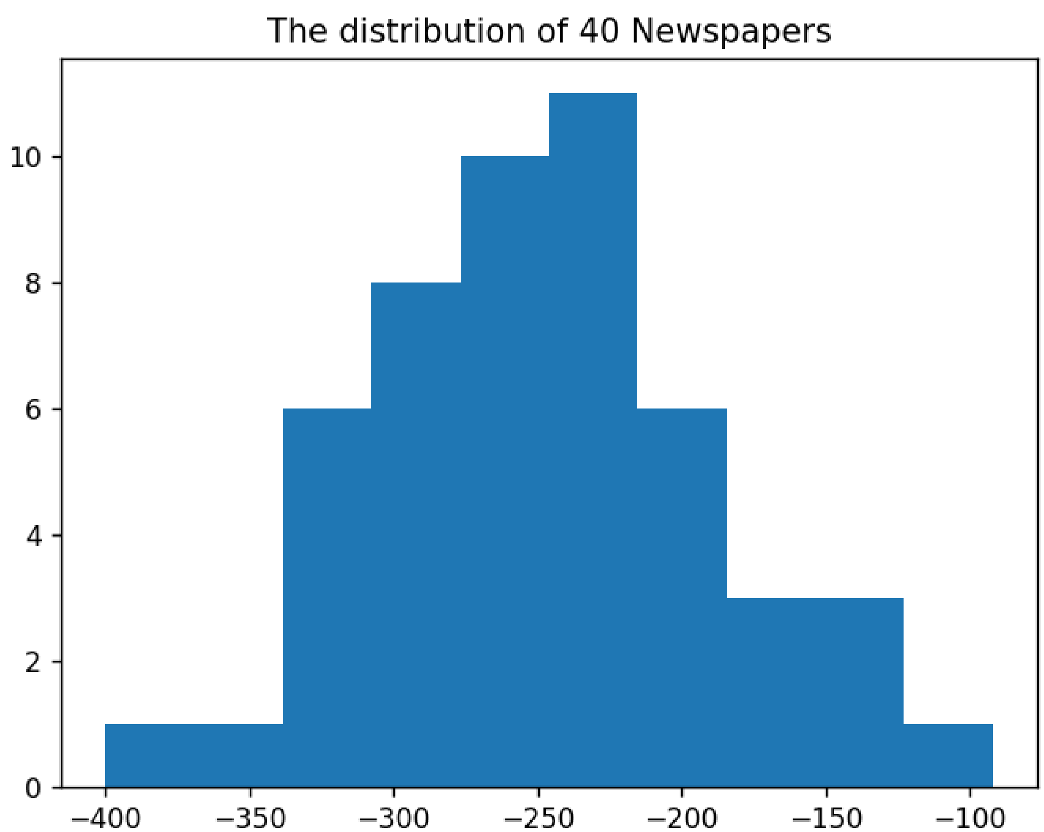
We'll try simulating these 20 days 50 more times and check the data. This will help us solidify our choice.

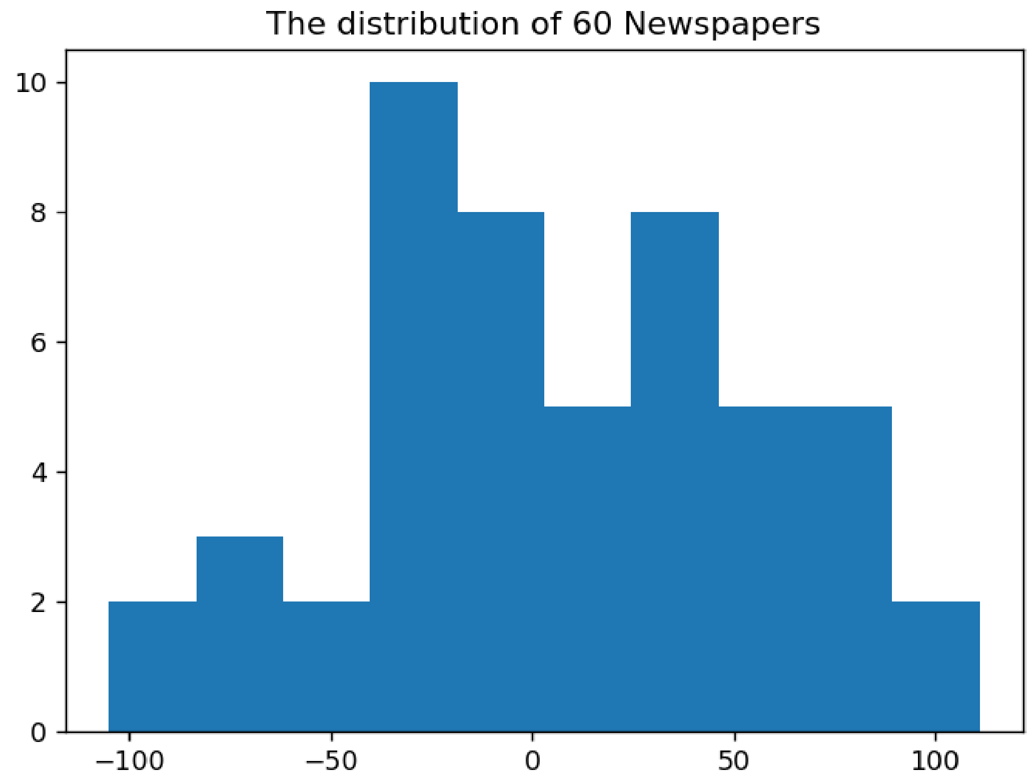
We will be comparing the average total profits of all choices over 50 runs.

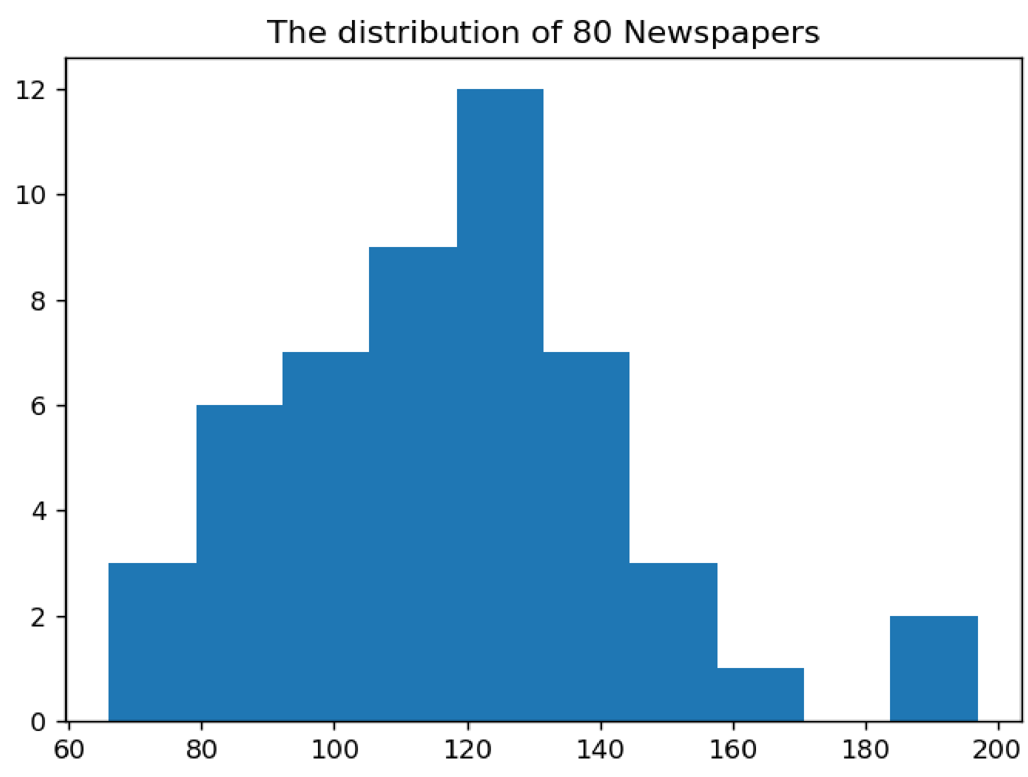
Here are the results:

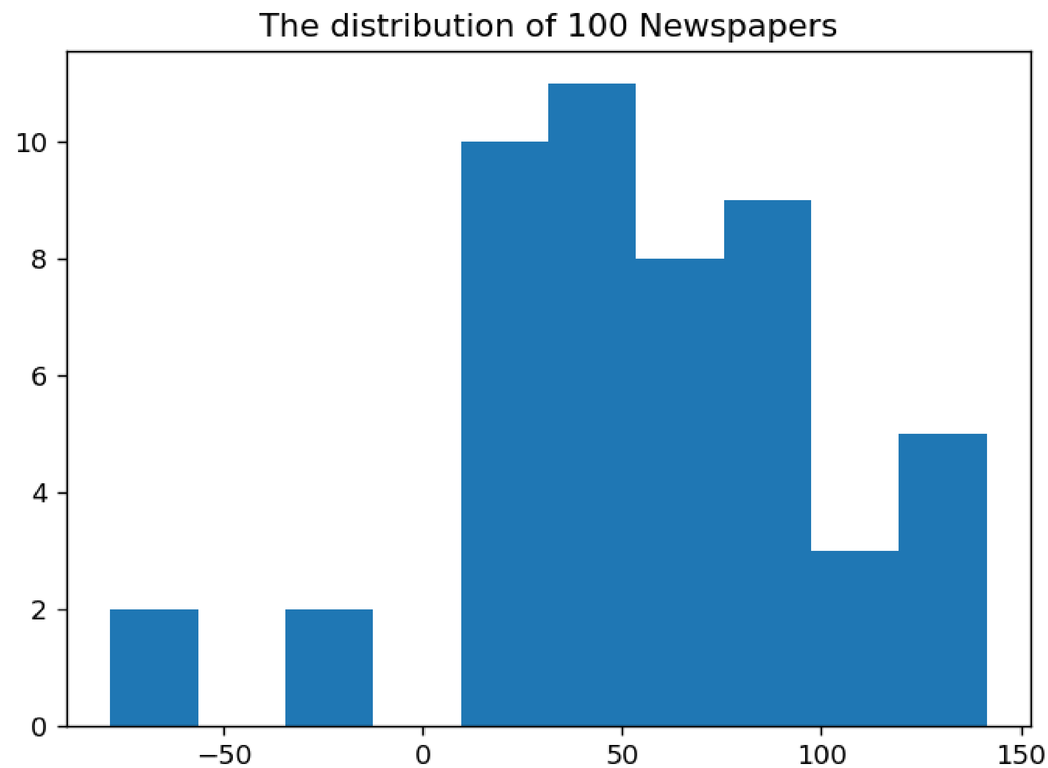
Newspapers	40	60	80	100	120
Average Total Profit	-2604.7	170.85	1164.4	559.7	-761.84

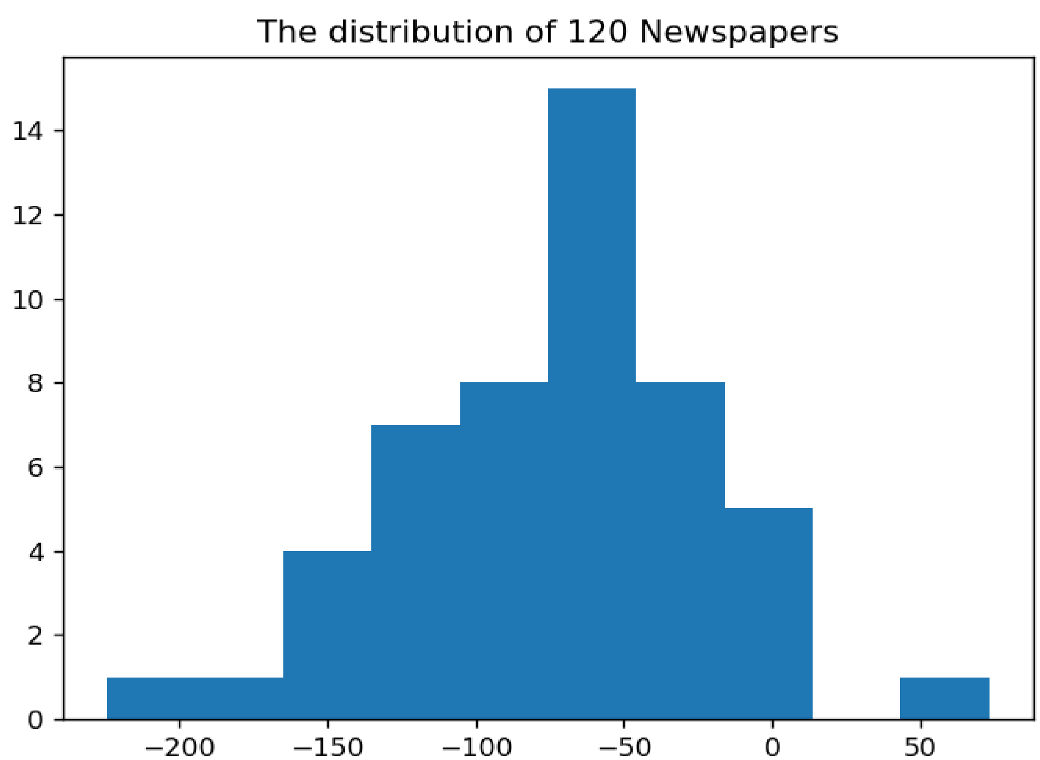
To further validate, let's look at the histogram chart for each possibility:




The distribution of 60 Newspapers
10
8
6
4
2
0
−100
−50
0
50
100


The distribution of 80 Newspapers
12
10
8
6
4
2
0
60
80
100
120
140
160
180
200


The distribution of 100 Newspapers
0
2
4
6
8
10
−50
0
50
100
150


The distribution of 120 Newspapers
0
2
4
6
8
10
12
14
−200
−150
−100
−50
0
50

From the graphs we can deduce that over several runs, buying 80 newspapers should guarantee optimal growth of profit over time.

d. The effect of changing up the constants:

Would changing the selling price the seller sells the newspapers for affect our choice?

What if we change the price of scrap?

We're going to study these effects as follows:

1. Change the selling price of the newspaper and analyze the output.
2. Change the scrap selling price and analyze the output.
3. Changing both together.

PAPER SELLING PRICE CHANGE	New price	Effect on avg profit
Increase by 20%	0.84	Avg profit increased significantly for (80, 100), although still buying 80 newspapers is the optimal option
Decrease by 20%	0.56	Profit always has a negative value for all possibilities which means the seller won't be gaining any profit at all

SCRAP SELLING PRICE	New price	Effect on avg profit
Increase by 20%	0.18	Avg profit increased slightly especially for (60, 80, 100) although 80 newspapers are still the optimal option
Decrease by 20%	0.12	Avg profit slightly decreased for all possibilities although 80 is still the optimal option

So, the answer is:

1. Yes, changing the selling price of a newspaper DOES affect the profit greatly but it doesn't affect the optimal number of newspapers.
2. No, changing the scrap selling price doesn't necessarily reflect hugely on the profit and it doesn't affect the optimal choice at all.

e. Changing the bundle size options:

Changing this input means that the range of options we have increases.

If we choose to make the bundle size = 5, this will give us the following range:

{40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120}

This can make the choosing of the optimal number of newspapers more accurate, that is in the case that the number we have (80) wasn't already the optimal option.

Let us simulate 50 runs of 20 days for each possibility and see the results:

Here are the results:

Newspapers	40	45	50	55	60	65	70	75
Avg Total Profit	-2553.6	-1851.8	-1121.57	-583.695	57.1	477.32	892.56	994.185

Newspapers	80	85	90	95	100	105	110	115	120
Avg Total Profit	1193.21	944.54	950.73	800.5	454.09	170.02	151.84	-361.075	-925.52

Although the results around 80 were surprisingly close to its numbers, over many runs no other option surpassed its average total profit.

Which again, means that:

The optimal number of newspapers to buy is <u>80 Newspapers</u>

B. Conclusion:

From the previously discussed results, we deduced that the optimal number of newspapers the seller should buy from the agency is 80 newspapers, due to many facts:

1. It had the best average total profit over several runs and trials over all other possibilities.
2. Its net profit estimate wasn't affected by any environmental change
3. Its average for other criteria such as (revenue- scrap revenue, etc.) was much more optimal than other possibilities.

The purpose of this technical report was to provide insight on how to simulate a good profit-gaining strategy that the newspaper can use, that would minimize his losses and maximize his profits.

This approach will allow him to minimize the risks of losing profit that could’ve been easy to again

Thank you,
Marwan.