PROBLEM STATEMENT

Background

Catherine Blake, the office manager for the College of Business Administration, has received numerous complaints lately from several department chairpersons. In the past few months, the chairpersons have insisted that something be done about the amount of time their administrative assistants waste waiting in line to make copies. Currently, the college has two photocopy centers dedicated to small copying jobs: copy center A on the third floor and copy center B on the fourth floor. Both centers are self-serve and have identical processing capabilities. The copying machines are not visible to the administrative assistants from their offices. When copying is required, the administrative assistant goes to the copy room and waits in line to make the necessary copies. Catherine's assistant, Brian, was assigned to investigate the problem.

Background Information

Brian reported that, on average, administrative assistants arrive at copy center A at the rate of 10 per hour and at copy center B at the rate of 14 per hour. Each of the copy centers can service 15 jobs per hour. The administrative assistants' arrivals essentially follow a Poisson distribution, and the service times are approximated by a negative exponential distribution. Brian has proposed that the two copy centers be combined into a single copy center with either two (A&B) or three identical copy machines (A&B&C). He estimates that the arrival rate would be 24 per hour. Each machine would still service 15 jobs per hour.

Tasks

(a) Examine the current situation by determining the average waiting time of each of the copy centers.
(b) Determine the average waiting time at the combined copy center A&B and combined copy center A, B & C.
(c) What would you recommend to Catherine?

(d) College of Infrastructure and IT Services has decided to open a new copy center near "Business Analytics Center" outside the campus, which would serve the Business Analytics Center as well as the nearby Commercial Center. The arrival rate and service time can be considered 24/hour and 15/hour as before with an annual demand growth rate of 0.02 percent. The new center would open for 6 hours a day and 270 days a year. Price per page is $0.15. The cost of a new copy machine is $1500. Cartridge cost per year is $800 and Service Cost per year is $200 for a single copier machine.

They want a detailed analysis and reporting on how many copy machines should the new center have? The analysis should be over 5 years.

(e) The new copy center is switching to a high-quality paper. This paper is very good for reports and business documents. This paper is one of the popular choices by various commercial offices. A high average demand of 100 assistants per hour is expected. The demand essentially follows a Poisson distribution. Fulfilling one unit of demand generates a revenue of $3. Each assistant on an average copies two pages.

Paper for copier machines will be supplied by a supplier. The supplier charges the following cost, a fixed ordering cost of $10 and a wholesale price of $1 per unit. The time taken by an order to arrive is 3 days. Unused inventory is stored for future use with a holding cost $0.005 per unit, per day. Unmet demand is backlogged and needs to be satisfied in future. Each unit of unmet demand has a backlogging cost of $0.025 per day.

What ordering policy maximizes the expected average daily profit? What will be the maximum expected average daily profit using this policy?

ANALYSIS AND SIMULATION STUDY

Part A

The complaints received by Catherine are due to the high waiting time of assistants at copy centers. The current situation was examined by computing the average waiting time of an assistant at copy center A and copy center B. Since both, the copy centers are at different floors, they form two separate single server models.

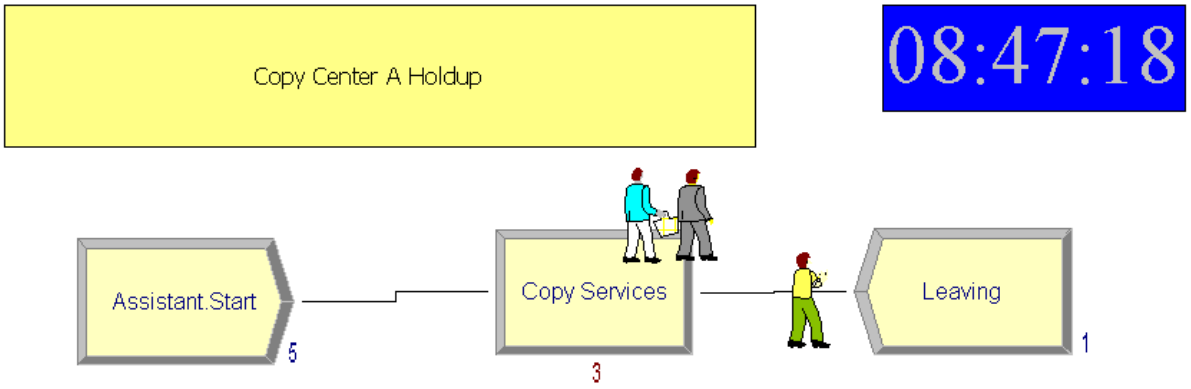

Figure: Snapshot of Copy Center A Holdup using Arena

Following variables were defined for each Copy Center to generate the respective queuing models.

Interarrival Time	Inter arrival Time between two assistants
Service Time	Service Time for each assistant using Service Rate
Arrival Time	Arrival Time of each assistant using Arrival Rate
Waiting Time	Waiting Time in the queue for each assistant
Exit Time	Time at which the assistant exits the system

Monte Carlo Simulation for a size of 1000 was done to compute the Average Waiting Time for both Copy Center A and B. These were significantly high and much higher for Copy Center B.

- **Expected Waiting Time Copy Center A:** **6.971 minutes**
- **Expected Waiting Time Copy Center B:** **14.344 minutes**

The waiting time for copy center B is quite high close to ~15 minutes.

Part B

Brian proposed to combine the copy centers with 2 or 3 printing machines. To study whether the the efficiency of the system will be improved by this combination we conduct a simulation study for two scenarios

- Combine A and B and compute its average waiting time
- Combine A, B and C and compute its average waiting time

Following variables were defined for each Copy Center to generate the respective queuing models.

Interarrival Time	Inter arrival Time between two assistants
Service Time	Service Time for each assistant using Service Rate
Arrival Time	Arrival Time of each assistant using Arrival Rate
Waiting Time	Waiting Time in the queue for each assistant
Copier	Copier Number (1 or 2 or 3)
Exit Time 1	Time at which the assistant exits the copier 1
Exit Time 2	Time at which the assistant exits the copier 2
Exit Time 3	Time at which the assistant exits the copier 3

Monte Carlo Simulation for a size of 1000 was done to compute the Average Waiting Time for both combinations i.e. Copy Center A&B and Copy Center A&B&C.

- **Expected Waiting Time Copy Center A&B: 8.127 minutes**
- **Expected Waiting Time Copy Center A&B&C: 3.637 minutes**

The waiting time for combined copy center A&B&C is significantly low from the original average time of 14.3 mins. Thus, combining the copy centers and using 3 copiers will significantly reduce the average waiting time to 3.637 mins. While for copy center with two copiers the average waiting time is still 8.127 mins which is higher than the average waiting time of copy center A alone i.e. 6.971 mins.

Part C

I would recommend Catherine to go ahead with the combining of both the copy centers and utilizing the three copiers (i.e. A&B&C) in the center. Using 3 copiers will significantly reduce the average waiting time for an assistant whereas using just 2 copiers in a combined center is not a good option as it does not significantly reduce the average waiting time.

Thus, combining copy centers and setting up three copy machines is a good option and Catherine should utilize this option.

Part D

To determine the number of copy machines/copiers which should be utilized in the new copy center, an effective NPV analysis is conducted. The number of copiers which maximizes the average Net Present Value will be the result.

To compute the NPV, various cost and revenue streams were considered, and the cash flow was computed for each year in the five-year time span.

Then, the NPV was computed from the cash flow per year data. The optimal number of copiers which provides maximum average Net Present Value, was computed using Risk Optimizer with 100 trials and 1000 iterations each.

Trial	Elapsed Time	Iterations	Result	Goal Cell Statistics				Adjustable Cells
				Mean	Std. Dev.	Min.	Max.	C19
2	0:02:24	1000	$ (4,332.19)	$ (4,332.19)	$ 9,350.70	$(32,975.23)	$ 28,154.40	6
3	0:02:25	1000	$ 5,456.09	$ 5,456.09	$ -	$ 5,456.09	$ 5,456.09	1
5	0:02:25	1000	$ 11,525.06	$ 11,525.06	$ 7,915.00	$(16,252.58)	$ 21,824.37	4
7	0:02:25	1000	$ 14,451.91	$ 14,451.91	$ 3,711.75	$ (7,891.26)	$ 16,368.28	3

Figure: Log of Process Steps

The above process steps log shows, that 3 is the optimal number of copiers which should be installed in the new copy center.

- **Optimal Number of Copiers at the new copy center: 3**
- **Expected Net Present Value: $14,451.91**

Thus, I would recommend College of Infrastructure and IT Services to go ahead with establishing a new copy center with 3 copiers as that would maximize their Net Present Value.

Part E

The most optimum r/Q policy will be determined in this part.

- r is the quantity threshold which determines whether an order needs to be placed from supplier or not. If the inventory position is less than the 'r' value, and there is no order in transit, it indicates that an order needs to be placed
- Q is number of units ordered from supplier

To determine the optimum ordering policy, we computed the optimal r and Q that maximizes the expected average daily profit. To compute this, different cost and revenue streams were considered, and the profit was computed for each day. Mean of the daily profit was computed and then maximized using the Risk Optimizer with 500 trials and 1000 iterations each.

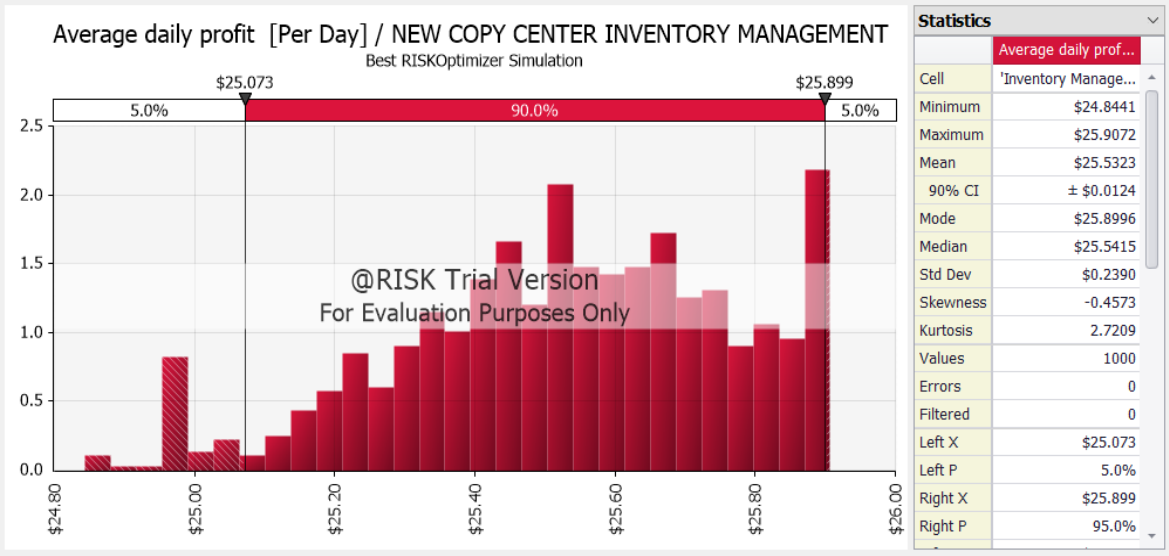

Figure: Daily Profit Distribution

The above plot shows that the distribution of Average daily profit. The distribution looks somewhat normal with mean of $25.53. Then we plot the distribution of inventory per day across different days of the year

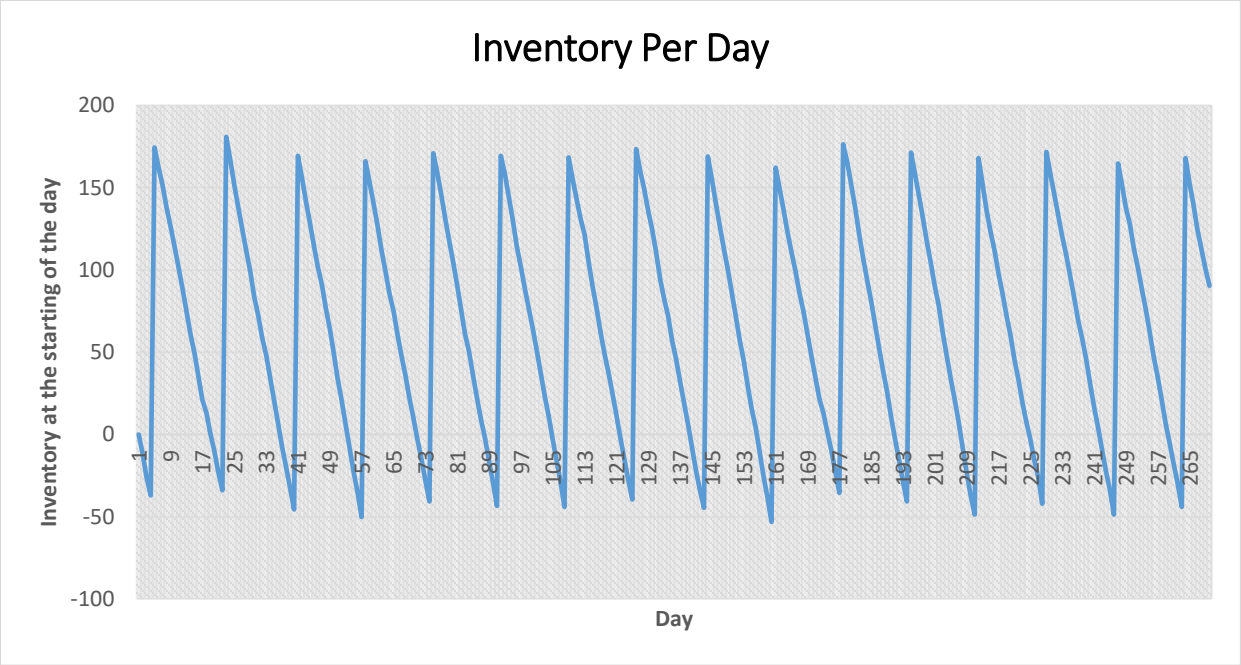

Figure: Inventory Distribution Per Day

The above plot shows that the inventory distribution is not always consistent. It keeps on changing from day to day. Inventory at the beginning of the day ranges between -50 to 200.

The optimal optimum ordering policy and the maximum expected average daily profit using this policy, is as follows:

- **Optimal Ordering Policy:** **r = 3, Q = 242**
- **Expected Net Present Value:** **$25.53**

CONCLUSION

College of Business Administration were receiving numerous complaints lately from several department chairpersons regarding high waiting time at copy centers. The problem was examined by computing average waiting time in different scenarios and recommendations were provided to the same. Combining copy centers with 3 copy machines turns out to be most optimal setup.

Secondly, College of Infrastructure and IT Services were facing issue in deciding the number of copiers they should install in a new copy center. Data was analyzed and optimal model which maximized the Net Present Value was provided. The optimal model suggested to use 3 copy machines as that maximized the Net Present value.

Thirdly, the new copy center was replacing existing papers with a new high-quality paper which was supplied by the third-party supplier. The best ordering policy which maximized the expected average daily profit was identified. The best r/Q policy was r = 3, Q = 242 and the expected average daily profit was $25.53

References:

1. Problem Statement is inspired by the Case mentioned in Sec 22 in Operations Management: An Integrated Approach, 5th Edition by Nada R. Sanders; R. Dan Reid ; Published by Wiley, 2012

   Link: *https://learning.oreilly.com/library/view/operations management-an/9781118122679/suplec-sec022.html*

2. Figures and Numbers relating to demand and cost price were taken from website: *https://www.statista.com*