BAN – 403
Simulation of Business Processes
Spring 2024

Project 1 (100 points total)

Read the lines below carefully to ensure that your report fulfills the expectations:

- The main report must be a pdf file named Assig1-BAN403.pdf, all the attachments must come in a zip file and have the prefix att-, for example, "att-proj1.zip".
- You must deliver all the simulation and calculation files that you used to obtain any numerical result. Failing to do so will render those numerical results invalid, and they will be assessed as missing.
- The main body of the report must be limited to a maximum of 5 pages, and it has to be self-contained, failing to comply will be penalized. Appendices may be used as support, but they should not be essential for the flow and understanding of the main body of the report.
- All answers provided in the report must be properly documented and justified. Answers with single numbers without any explanation will be considered incomplete. It is your responsibility that the interpretation by the reader of your answers may be clear and unambiguous.
- For this project, the work must be entirely the result of the team credited with in the report. No collaboration is allowed between groups. Any use of generative AI must be acknowledged and explained. It is your responsibility to explain to what extent it was use as a support and to what extent the solution is copied literally.

Montecarlo simulation: (20 Points)

Your task is to use Monte Carlo simulation to find the best investment proportions in five different assets you are considering for your portfolio. You may assume you have an arbitrary amount of money if that helps.
Select data for the daily close or adjusted close prices for 5 assets of your choice for the past 5 years, one source could be Yahoo finance. Simulate different portfolio compositions, compute the expected return, the expected variance, and use the Sharpe ratio to decide which portfolio composition is the best choice. This is a fairly common problem, and you will find plenty of references online. For your submission you must clearly document and explain the procedure you decided to implement, and explain the role of Monte Carlo simulation. Don't forget to cite any references used, including generative AI. The assessment will be based on how clear and precise is your report explaining your simulation, not only on the numerical result.

Response assessment guide:
(10 points) The solution have to provide a clear explanation for the implementation. It could be pseudocode or an explanation of the steps taken for doing the implementation. The key element here is that they have the loop generating the different proportions for each of the assets summing to 1 and then compute the returns. Finally, they need to select the portfolio that performed better among the ones simulated using the Sharpe ratio. They can assume a return of zero for the free risk rate to simplify, or clearly explain where is the rate coming from.

(10 points) An implementation that runs gives a reasonable explicit result and is consistent with the documented explanation of the procedure. A good example with and implementation is at https://github.com/akashprem12/Portfolio-Optimisation-using-Monte-Carlo-Simulation.

Queuing theory: (25 Points)

Use JaamSim to create a simulation of the process described in example 6.7 in the book "Business Process Modeling, Simulation and Design". This is an example of a $M/M/c/\infty/N$ queue. Your job is to compare the analytical approach with the simulation approach. We are particularly interested in the remark made just before the example 6.7 is presented, which says:
Remark: The $M/M/c/\infty/N$ model is based on the assumption that the time an individual job or customer spends in the calling population outside the queuing system is exponentially distributed. However, it has been shown (see Bunday and Scraton, 1980) that the expressions for P_0 and P_n (and consequently, those for L, L_q, W, and W_q) also hold in more general situations. More precisely, the time that a job or customer spends outside the system is allowed to have any probability distribution as long as this distribution is the same for each job or customer and the average time is $1/\lambda$. Note that these situations fall outside the class of birth-and-death processes into a $G/M/c/\infty/N$ model.
Use your Jaamsim simulation model to verify this remark with the data of example 6.7. You must do it at least with three general distributions for the interarrival times. You must clearly explain and justify your results, just numerical values without any explanation will be considered as an empty answer. Also, you must document your implementation in JaamSim.

Response assessment guide:

- (7 points) The solution has to explain clearly the model implementation. Any assumptions have to be explicit. The model itself has to be documented and explained properly.

  For example, the first model M_M_C_Inf_N-with-servers.cfg provided with this guide uses a circular flow where the transient entities never leave the system. In that model one uses three servers to model the failure times for the three machines in the book's example, and they process the entities following a distribution governing the time to failure of the machines. They have to clearly explain that those three servers are modeling the arrival process to the system. Once the entities are processed, they are release and send to the queue of the service teams which are modeled as two servers. In other words, that is the moment they enter the system. In a model like that one they have to clearly identify and state that the cycle time goes from the moment they enter the queue of the service teams until they are served by any of the service teams.

The other example M_M_C_Inf_N-with-arrivals.cfg shows the system modeled with three entity generators mimicking the three different machines in the example working in parallel. This system is more straight because the boundaries of the system are defined by the entity generator and the sink. However, they have to identify and clearly state the condition that at most one entity of each type may be in the system and any time.

- (8 points) The model has to match the explanation, and it must run. It has to be clearly identifiable that at most one entity of each type can be in the system. Also, the distribution for the arrival process (exponential with mean 8h) and the repair service time (exponential with mean 4 h) have to be properly assigned to the corresponding entities. Moreover, the corresponding models with the three general distributions for the arrivals to test the remark have to be provided and must run in a meaningful way. Important to notice is that the assumption that the three machines are identical must be kept. That means that the new general distribution must be the same for modeling the three working machines.
- (5 points) To verify the correctness of the reference model they must use the results in the book and match. The average number of machines in reparation process in steady state should be 1.04 machines. The average number of machines waiting to be repaired in steady state should be 0.05 machines. They need to be able to estimate the effective arrival rate, which in this case is determined by the rate of failure times the number of machines up working. The value in steady state is 0,2454625 failures per hour. They can use little's law to compute the cycle time or compute it directly from the simulation. In steady state the average cycle time is 4 hours and 13.3 minutes.
- (5 points) Those values should also hold when they change the distribution of failure to a general distribution to their choice. They must test that with three different distribution.

General analytical models: (20 Points)

Consider a drive-through restaurant illustrated in class. The model presented in class is reproduced in Figure 1.
After an extensive analysis of the data the following distributions were found reasonable:

- The service time at the microphone ordering the food follows an exponential distribution with a parameter $\mu_1 = 30\frac{orders}{hour}$
- The service time for food preparation and pay follows an exponential distribution with a parameter $\mu_2 = 40\frac{orders}{hour}$.
- The time between the arrival of two different clients follows an exponential distribution with a parameter $\lambda = 50\frac{clients}{hour}$.

The space at the drive-through only allows having 3 clients in the system. When all the space is used any arriving client has to leave immediately. The microphone station is a machine taking orders. Then, the orders are printed in the kitchen for the one employee

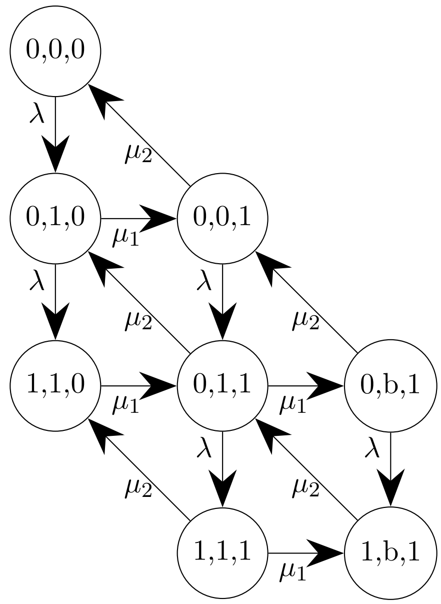

Figure 1: Transition diagram drive-through

working there to prepare them. When a client finishes ordering at the microphone it moves to the pickup window if there is space. If a previous customer is still waiting for an order when the client at the microphone finishes ordering, that client must stay at the microphone waiting to move to the pickup window. When a client receives the food it leaves the window immediately and any client behind can move immediately to the next step.

- (4/20 points) Compute the steady-state probabilities for the different states of this system using the balance of flow equations.

  Response assessment guide:

  Following the example in class, we can characterize the state of the system with a vector with three positions (q, m, w). The first position q describes the length of the queue, which in this case can be 0 or 1. The second position m describes the status of the microphone, which can be empty (0), ordering (1), and blocked (b). The third position w describes the status of the pickup window, which can be empty (0), and waiting for food (1). Using this notation one can find that the following 8 states describe the different states of the system:

  $$\{(0,0,0),(0,1,0),(1,1,0),(0,0,1),(0,1,1),(1,1,1),(0,b,1),(1,b,1)\}$$

  Now, one can build the equations to find the steady state probabilities using the balance of flow principle to obtain:

$$\begin{aligned}
\lambda p_{(0,0,0)} &= \mu_2 p_{(0,0,1)} \\
(\lambda + \mu_1) p_{(0,1,0)} &= \lambda p_{(0,0,0)} + \mu_2 p_{(0,1,1)} \\
\mu_1 p_{(1,1,0)} &= \lambda p_{(0,1,0)} + \mu_2 p_{(1,1,1)} \\
(\lambda + \mu_2) p_{(0,0,1)} &= \mu_1 p_{(0,1,0)} + \mu_2 p_{(0,b,1)} \\
(\lambda + \mu_1 + \mu_2) p_{(0,1,1)} &= \lambda p_{(0,0,1)} + \mu_1 p_{(1,1,0)} + \mu_2 p_{(1,b,1)} \\
(\mu_1 + \mu_2) p_{(1,1,1)} &= \lambda p_{(0,1,1)} \\
(\lambda + \mu_2) p_{(0,b,1)} &= \mu_1 p_{(0,1,1)} \\
\mu_2 p_{(1,b,1)} &= \lambda p_{(0,b,1)} + \mu_1 p_{(1,1,1)}.
\end{aligned}$$

Additionally, one need the equation for the probabilities to add up to 1:

$$p_{(0,0,0)} + p_{(0,1,0)} + p_{(1,1,0)} + p_{(0,0,1)} + p_{(0,1,1)} + p_{(1,1,1)} + p_{(0,b,1)} + p_{(1,b,1)} = 1.$$

Solving this system of equations one finds the following steady probabilities:

$$\begin{aligned}
&p_{(0,0,0)} = 0.04671552,\ p_{(0,1,0)} = 0.10648390,\ \ p_{(1,1,0)} = 0.32468595 \\
&p_{(0,0,1)} = 0.05839440,\ p_{(0,1,1)} = 0.15457341,\ \ p_{(1,1,1)} = 0.11040958 \\
&p_{(0,b,1)} = 0.05152447,\ p_{(1,b,1)} = 0.14721277.
\end{aligned}$$

- (4/20 points) Using the steady state probabilities, compute the average number of clients in the system, the average rate of clients entering the drive-through, and the average time a client spends in the system.

  Response assessment guide:

  To compute the average number of clients L in the system we may use the definition of expected value computing the number of clients in each state. That way, with some rounding, we obtain:

  $$\begin{aligned}
  L = 0p_{(0,0,0)} + 1p_{(0,1,0)} + 2p_{(1,1,0)} + 1p_{(0,0,1)} + 2p_{(0,1,1)} +& \\
  3p_{(1,1,1)} + 2p_{(0,b,1)} + 3p_{(1,b,1)} &\approx 1.9993 \text{ customers.}
  \end{aligned}$$

  The average rate of clients entering to the system is computed using the fact that when in states $p_{(1,1,0)}, p_{(1,1,1)}, p_{(1,b,a)}$ the arrival rate drops to 0. Hence the average arrival rate in steady state is (with some rounding):

  $$\bar{\lambda} = \lambda(1 - p_{(1,1,0)} - p_{(1,1,1)} - p_{(1,b,a)}) \approx 20.8846\ \frac{\text{customers}}{\text{hour}}.$$

  Finally, to obtain the average time W a client spends in the system one can use little's law. Hence, we obtain:

  $$W = \frac{L}{\bar{\lambda}} \approx 5.7439 \text{ minutes}$$

- (4/20 points) Is this system stable? Justify your answer.

  Response assessment guide:

  This system has finite capacity. As such there is no stability issue.

- (4/20 points) Build a simulation model with JaamSim and compare your analytical results with the simulation results. Are there any differences or do they match exactly? Explain your answer.

  Response assessment guide:

  A possible simulation model build in Jaamsim is provided in the file driveThru.cfg. It is important to pay attention to the use of the threshold, because the wrong set up may lead for example to problems modeling the limited capacity in the window or to have an overestimation of the time the microphone is blocked. Using the provided model and running the simulation for 1000 hours one obtains the following:

$$
\begin{aligned}
\bar{\lambda} &= 21.18 \frac{\text{customers}}{\text{hour}} \\
W &= 5.75 minutes \\
L &= 1.99 clients.
\end{aligned}
$$

  Note that the values are not fully precise, but they show that the simulation converges to what is expected from the analytical model. If they have problems making it converge, they should realize that the transient period may be influencing the final result and more simulation time is needed.

- (4/20 points) What happens if the food preparation time is not Exponential, but instead, it follows a normal distribution with the same mean. How does it compare with the previous model?

  Response assessment guide:

  Note that the variance was not specified here. Now we have that the average time for the food preparation is 1.5 minutes. If we take the same standard deviation to define the normal, one has to deal with the possibility to obtain negative values. One way is to truncate the normal to provide only positive values. One can use the fact that around 68% of the values in a Normal distribution are within one standard deviation of the normal and truncate the distribution at 3. With that truncation the W does not increase much. Now, if the decision is not to truncate the distribution above, there is a slight increase in the W and that is due to the increase in variability in the food preparation time. The implications of truncation should be discussed here.

Airline Ticket Counter (Excersice 5, chapter 8, textbook) (35 Points)

At an airline ticket counter, the current practice is to allow queues to form before each ticket agent. Time between arrivals to the agents lines is exponentially distributed with a mean of 5 minutes. Customers join the shortest queue at the time of their arrival. The service time for the ticket agents is uniformly distributed between 2 and 10 minutes.

(a) (9 points) Develop a JaamSim model to determine the minimum number of agents that will result in an average waiting time of 5 minutes or less.

Response assessment guide:

The model for this bullet is provided in Airport1.cfg. The main elements here are:

- One essential observation here is that customers are not allowed to change queues when they move, this has to be stated for their model as an assumption since that is not explicit in the statement.
- They need to create a branch to specify the selection of the shortest queue.
- They need to define how to measure the waiting time. Furthermore, they have to explain how they measure that. One way to do it is to set the state waiting in the queue. A possible mistake there is to forget to change the state after they leave the queue which will result on the waiting time being the cycle time.
- Using the simulation in Airport1.cfg the average waiting time in steady state is approximately 2,37 minutes, and the number of agents needed to achieve this time is be 2. They need to discuss and document the process to reach the answer, a single number is not enough. It doesn't take many models, but they must realize that if there were to use only one server the system in unstable.

(b) (8.5 points) The airline has decided to change the procedure involved in processing customers by the ticket agents. A single line is formed, and customers are routed to the ticket agent who becomes free next. Modify the simulation model in Part (a) to simulate the process change. Determine the number of agents needed to achieve an average waiting time of 5 minutes or less.

Response assessment guide:

The model for this bullet is provided in Airport2.cfg. The main elements here are:

- They need to define how to measure the waiting time. Furthermore, they have to explain how they measure that. One way to do it is to set the state waiting in the queue. A possible mistake there is to forget to change the state after they leave the queue which will result on the waiting time being the cycle time.
- Using the simulation in Airport2.cfg the average waiting time in steady state is approximately 2,09 minutes, and the number of agents needed to achieve this time is be 2. Again, they need to discuss and document the process to reach the answer, a single number is not enough. It doesn't take many models, but they must realize that if there were to use only one server the system in unstable.

(c) (9 points) Compare the systems in Parts (a) and (b) in terms of the number of agents needed to achieve a maximum waiting time of 5 minutes.

Response assessment guide:

The discussion should be in terms of the number of agents. They must discuss if they think the two systems are the same or not. Hence, the response has to discuss the difference in waiting time, since both system achieve the target with two servers. The second model results in a lower waiting time with just one line. They must notice here why this difference. The main point is that customers are not allowed to switch to the next available server once they select to join a queue in the first model. That makes the main difference between the two and helps the second model to perform better.

(d) (8.5 points) It has been found that a subset of the customers purchasing tickets is taking a long period of time. By separating ticket holders from non-ticket holders, management believes that improvements can be made in the processing of customers. The time needed to check in a person is uniformly distributed between 2 and 4 minutes. The time to purchase a ticket is uniformly distributed between 12 and 18 minutes. Assume that 15 percent of the customers will purchase tickets, and develop a model to simulate this situation. As before, the time between all arrivals is exponentially distributed with a mean of 5 minutes. Suggest staffing levels for both counters, assuming that the average waiting time should not exceed 5 minutes.

Response assessment guide:
For this problem they may assume that buying the ticket also includes check in (Airport3.cfg). If this is the case, then a two M/M/1 queues model is needed where 15% is directly to the queue of buying and checking and 85% of the clients are directed to the Check In only queue. Another assumption is to have the buying ticket clients go to the buying window, buy the ticket and then go to the Check In (Airport4.cfg).
The assumptions made have to be state explicitly and clearly in order to document and discuss the models.