Module Code: AQ052-3-M-ORO

Module Name: Operational Research and Optimisation

Project Assignment

Student Name: Muhammad Yousouf Ali Budullah
TP Number: TP086704
Programme: MSc Data Science & Business Analytics
Intake Code: APDMF2501DSBA(BI)(PR)
Module Lecturer: Dr. Ryan Ho Ming Kang

Date of Submission: 11 January 2026

Contents

1 Question A1(a)

1.1 Model Formulation (a)(i)

Decision Variables

Let

$$x_{ij} = \begin{cases} 1; & \text{if task } i \text{ is assigned to staff member } j, \\ 0; & \text{otherwise,} \end{cases}$$

where

$$i = 1, 2, \ldots, 8 \quad \text{represent Tasks T1 to T8,}$$

$$j = 1, 2, 3, 4 \quad \text{represent Yousouf, Jared, Zuhayr, and Sacha respectively.}$$

Objective Function

The objective is to minimise the total time (in days) needed to complete all tasks.

$$\min \ Z = \sum_{i=1}^{8} \sum_{j=1}^{4} t_{ij} x_{ij}$$

where

$$t_{ij} \text{ is the number of days required for staff member } j \text{ to complete task } i.$$

Constraints

Each task must be assigned to exactly one staff member

$$\sum_{j=1}^{4} x_{ij} = 1 \qquad \forall i = 1, 2, \ldots, 8$$

Each staff member may be assigned at most two tasks

$$\sum_{i=1}^{8} x_{ij} \leq 2 \qquad \forall j = 1, 2, 3, 4$$

The total time allocated to each staff member must not exceed their available working days

$$\sum_{i=1}^{8} t_{ij} x_{ij} \leq D_j \qquad \forall j = 1, 2, 3, 4$$

where D_j is the maximum number of days available for staff member j.

$$D_j \text{ is the maximum number of days available for staff member} j.$$

The total completion time must not exceed the two-week (14 days) period

$$Z \leq 14$$

Binary Constraints

$$x_{ij} \in \{0, 1\} \qquad \forall i, j$$

1.2 Model Solution (a)(ii)

Task	Task Name	Staff			
		Yousouf	Jared	Zuhayr	Sacha
T1	Write social media posts highlighting menu items	1	5	5	2
T2	Design Instagram and Facebook promotional graphics	5	2	2	4
T3	Film a restaurant tour / promotional video	5	2	3	4
T4	Edit and produce the promotional video	2	1	4	5
T5	Write a blog post about the chef and restaurant story	2	1	3	4
T6	Create an email newsletter for the marketing campaign	5	4	2	2
T7	Photograph menu items for digital platforms	1	5	5	4
T8	Write online food advertisement copy (Google / blogs)	4	1	2	1

Task	Task Name	Staff				Staff Assigned	Required Staff
		Yousouf	Jared	Zuhayr	Sacha		
T1	Write social media posts highlighting menu items	1	0	0	0	1	1
T2	Design Instagram and Facebook promotional graphics	0	0	1	0	1	1
T3	Film a restaurant tour / promotional video	0	0	1	0	1	1
T4	Edit and produce the promotional video	0	1	0	0	1	1
T5	Write a blog post about the chef and restaurant story	0	1	0	0	1	1
T6	Create an email newsletter for the marketing campaign	0	0	0	1	1	1
T7	Photograph menu items for digital platforms	1	0	0	0	1	1
T8	Write online food advertisement copy (Google / blogs)	0	0	0	1	1	1
	Number of Tasks Assigned	2	2	2	2		
	Maximum Tasks Allowed	2	2	2	2		
	Total Time (Days)	2	2	5	3		
	Maximum Days Allowed	8	10	11	7		
	Objective Function	**12**					

Figure 1: Excel Solver Output for the Optimal Task Assignment Model

1.3 Interpretation of Results (a)(iii)

The minimum total completion time is 12 days which satisfies the deadline of two-weeks (14 days). Each task is assigned to exactly one staff member, and each staff member is assigned no more than two tasks. Furthermore all staff members complete their assigned tasks within their available working days.

2 Question A1(b)

2.1 Model Formulation and Expected Return (b)(i)

Decision Variables

Let

$$x_i = \text{proportion of total investment allocated to menu item } i,$$

where

$$i = 1, 2, 3, 4 \quad \text{correspond to Items A, B, C, and D respectively.}$$

Objective Function

The objective is to minimise the total portfolio risk S, measured by the variance of returns.

$$\min \; S = \sum_{i=1}^{4} x_i^2 s_i^2 + \sum x_i x_j r_{ij}$$

where

$$s_i^2 \text{ is the variance of returns for menu item} i$$

$$r_j \text{ is the covariance between returns on menu items } i \text{ and } j.$$

Constraints

Minimum Expected Return Constraint

$$3.95x_1 + 3.79x_2 + 4.68x_3 + 4.26x_4 \geq 3.5$$

Budget Constraint

$$x_1 + x_2 + x_3 + x_4 = 1$$

Non-Negativity Constraints

$$x_1, \; x_2, \; x_3, \; x_4 \geq 0$$

Expected Return and Optimal Allocation

Table 1: Expected Returns and Optimal Investment Allocation

Menu Item	Expected Return (%)	Optimal Allocation
Item A	3.95	0.856
Item B	3.79	0.000
Item C	4.68	0.000
Item D	4.26	0.144
Portfolio Expected Return	**3.99**	**1.000**

Excel Solver Output

Year	Annual Return for Each Menu Items (in %)			
	Item A	Item B	Item C	Item D
1	5.01	8.03	6.12	8.31
2	5.35	3.31	6.41	4.97
3	3.12	2.11	4.03	1.05
4	8.04	6.67	8.03	7.55
5	1.67	1.00	2.03	2.12
6	-0.20	0.44	-0.12	3.33
7	4.70	3.06	3.22	2.12
8	1.21	-0.06	2.88	-1.02
9	7.03	9.10	9.11	8.05
10	3.55	4.24	5.08	6.11
Expected Return	3.95	3.79	4.68	4.26

	Investment Weights (Decision Variables)			
	A	B	C	D
Optimal Allocation	0.85592427	0	0	0.14407573

Portfolio Risk	5.96731598

	Item A	*Item B*	*Item C*	*Item D*
Item A	6.063796			
Item B	6.3436	9.20854		
Item C	6.147278	7.11878	7.193049	
Item D	5.394148	8.36329	6.046139	9.372389

A,B	6.3436	0
A,C	6.147278	0
A,D	5.394148	0.12331791
B,C	7.11878	0
B,D	8.36329	0
C,D	6.046139	0

	Model Constraints	
Total Weight	1	1
Minimum Expected Return	3.99280755	3.5

	Lower	Upper
95% Confidence Interval	-0.80	8.78

Figure 2: Excel Solver Model for Portfolio Risk Minimisation

2.2 Confidence Interval (b)(ii)

Table 2: 95% Confidence Interval for Mean Annual Return (Assuming Normally Distributed Returns)

	Lower	Upper
95% Confidence Interval	-0.80	8.78

3 Question A2(a)

3.1 Transition Matrix Formulation (a)(i)

Let the daily number of customers visiting the restaurant be modeled as a discrete-time Markov chain with the following state space.

$$S = \{50,\ 80,\ 100,\ 120\}$$

where each state represents the total number of customers on a given day.

The transition probability matrix P after simulating 90 day, is given as,

$$P = \begin{pmatrix} 0.21 & 0.25 & 0.38 & 0.17 \\ 0.36 & 0.23 & 0.36 & 0.05 \\ 0.30 & 0.15 & 0.22 & 0.33 \\ 0.25 & 0.44 & 0.19 & 0.13 \end{pmatrix}$$

where each entry p_{ij} represents the probability of transitioning from state i to state j on the following day, and each row sums to 1 up to rounding error.

3.2 Steady-State Probabilities and Interpretation (a)(ii)

The steady-state probabilities represent the long-run probability of having a given number of customers on any given day. Based on the transition matrix P, the steady-state distribution returns.

$$\boldsymbol{\pi} = \begin{pmatrix} 0.28 & 0.25 & 0.29 & 0.18 \end{pmatrix}$$

Therefore, the probabilities of having a given number of customers on any given day is,

$$P(50) = 0.28, \quad P(80) = 0.25, \quad P(100) = 0.29, \quad P(120) = 0.18.$$

From the steady state distribution, the restaurant is more likely to experience busy days as demand levels of 80 and 100 customers ($P(80) = 0.25$, $P(100) = 0.29$). Lower demand of 50 customers ($P(50) = 0.28$) occurs just as often as 80 and 100. While a high demand of 120 customers $P(120) = 0.18$), occurs less often. However, promotions could be used to increase the number of customer and improve demand.

4 Question A2(b)

4.1 Transition Matrix Formulation (b)(i)

Customer movement within the shopping mall is modelled as an absorbing Markov chain. States B (booth) and G (cafe) are absorbing states, while states A, C, D, E, and F are transient.

Table 3: Transition Probability Matrix P

	B	G	A	C	D	E	F
B	1	0	0	0	0	0	0
G	0	1	0	0	0	0	0
A	$\frac{1}{2}$	0	0	0	0	$\frac{1}{2}$	0
C	$\frac{1}{2}$	0	0	0	$\frac{1}{2}$	0	0
D	0	$\frac{1}{3}$	0	$\frac{1}{3}$	0	$\frac{1}{3}$	0
E	$\frac{1}{3}$	0	0	0	$\frac{1}{3}$	0	$\frac{1}{3}$
F	0	$\frac{1}{2}$	0	0	0	$\frac{1}{2}$	0

Figure 3 shows the layout of the restaurant, including booth (B), cafe (G), and surrounding areas (A, C, D, E, F) used to construct the transition matrix.

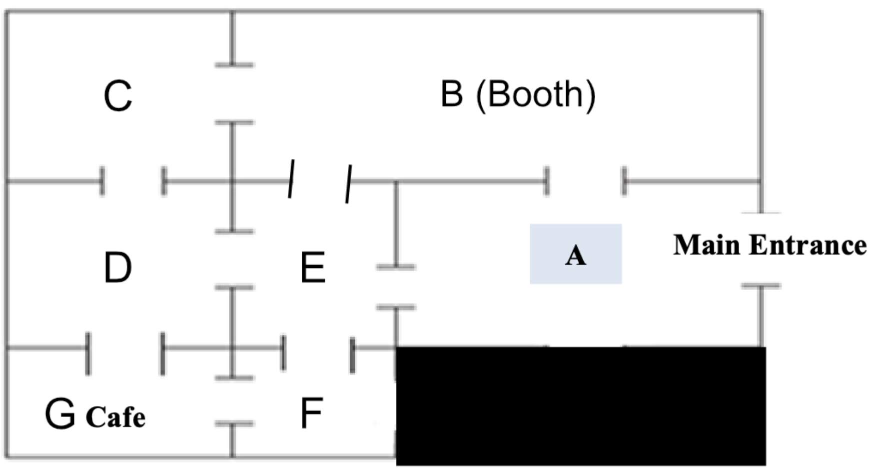

Figure 3: Restaurant layout showing booth (B), cafe (G), and surrounding areas

4.2 Probability of Visiting the Booth (b)(ii)

The following absorption probabilities for a customer to visit the booth, found by solving the transition matrix P are given as follows.

Starting Area	Probability of Visiting Booth (B)
A	0.79
C	0.71
D	0.43
E	0.57
F	0.29

Table 4: Probability of Visiting the Booth from Each Area

The booth location performs well, as customers starting in Area A have a high probability of visiting the booth (79%), followed by Area C (71%) and E (57%). However, customers starting in Areas D (43%) and F (29%) are less likely to visit the booth. The foot traffic of customers to the booth could be improved by providing clearer directions to the booth or relocating it closer to Areas D and F.

5 Question A3

5.1 Activity Details and Time Estimates (a)

Table 5 summarises the activities required for the event setup, including the immediate predecessors and optimistic (a), most probable (m), and pessimistic time (b) estimates.

Table 5: Event Setup Activities and Time Estimates

ID	Activity Description	Predecessor(s)	a	m	b
A	Finalise seasonal menu	–	2	3	5
B	Order ingredients	A	1	2	4
C	Design marketing materials	A	2	4	6
D	Promote event	C	2	3	5
E	Arrange tables and decorations	B	1	2	3
F	Final setup and rehearsal	D, E	1	2	4

5.2 Gantt Chart Using Most Probable Time (b)

A Gantt chart (Figure 11) was created to visualise the project schedule by using the most probable time estimates (m).

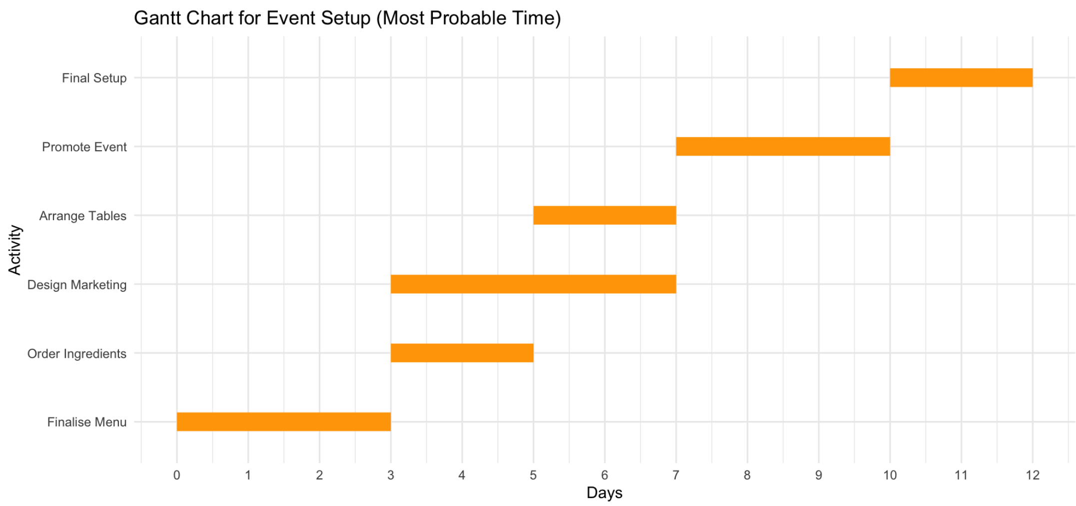

Figure 4: Gantt Chart for Event Setup Using Most Probable Time

5.3 Project Completion Time and Critical Path (c)

The estimated project completion time is 12.5 days.

The critical path is as follows.

$$A \rightarrow C \rightarrow D \rightarrow F$$

Where activities B and E have positive slack and can both be delayed by up to 3 days without affecting the project completion time.

5.4 Project Feasibility and Discussion (d)

The estimated project completion time of 12.5 days indicates that the special event can be completed within the 2 weeks (14 days) given. Furthermore, the probability of completing the project in 14 days is approximately 91.5%, suggesting a high chance to complete the project on time.

Since the project can be completed in the given time, it is not necessary to alter the schedule. However, critical activities should still be monitored closely to avoid any delays.

6 Question B1(a)

6.1 Model Formulation (a)(i)

Decision Variables

Let

FT_i = number of full-time staff starting at time i, $\quad i \in \{10\text{AM},\ 11\text{AM},\ 12\text{PM},\ 1\text{PM},\ 2\text{PM}\}$

$PT_i^{(3)}$ = number of part-time staff starting at time i (3-hour shift), $\quad i \in \{10\text{AM},\ 11\text{AM},\ \ldots,\ 7\text{PM}\}$

$PT_i^{(4)}$ = number of part-time staff starting at time i (4-hour shift), $\quad i \in \{10\text{AM},\ 11\text{AM},\ \ldots,\ 6\text{PM}\}$

Objective Function

Model A: 3-hour part-time shifts

$$\min Z = 280 \sum FT_i + 75 \sum PT_i^{(3)}$$

Model B: 4-hour part-time shifts

$$\min Z = 280 \sum FT_i + 100 \sum PT_i^{(4)}$$

Constraints

Let h denote an operating hour, where

$$h \in \{10\text{AM}, 11\text{AM}, \ldots, 9\text{PM}\}.$$

Let i denote a staff start time.

$$f(h,i) = \begin{cases} 1, & \text{if a full-time staff member starting at time } i \text{ works during hour } h, \\ 0, & \text{otherwise,} \end{cases}$$

$$p(h,i) = \begin{cases} 1, & \text{if a part-time staff member starting at time } i \text{ works during hour } h, \\ 0, & \text{otherwise.} \end{cases}$$

The values of $f(h,i)$ and $p(h,i)$ are from the work schedule shown in Figure 5 and Figure 6 where full-time staff work a 4-hour shift followed by a 1-hour break and then a further 3-hour shift, while part-time staff work 3-hour or 4-hour shifts depending on the model.

Total staff on duty, for each hour h, the total number of staff working is given by,

$$\sum_i FT_i \, f(h,i) + \sum_i PT_i \, p(h,i)$$

For all off-peak hours h, the total number of staff on duty must be at least three

$$\sum_i FT_i \, f(h,i) + \sum_i PT_i \, p(h,i) \;\geq\; 3$$

For each peak hour between 12PM and 3PM, the total number of staff on duty must be at least five

For $h \in \{12\text{PM}, 1\text{PM}, 2\text{PM}\}$,

$$\sum_i FT_i \, f(h,i) + \sum_i PT_i \, p(h,i) \;\geq\; 5$$

At least two full-time staff must be working during every operating hour

$$\sum_i FT_i \, f(h,i) \;\geq\; 2$$

The total number of full-time staff employed during the event must be at least four and no more than ten

$$4 \;\leq\; \sum_i FT_i \;\leq\; 10$$

The total number of part-time staff employed during the event must not be more than ten

$$\sum_i PT_i \;\leq\; 10$$

6.2 Model Solution (a)(ii)

						3 Hour Shift														
Time	FT1	FT2	FT3	FT4	FT5	PT1	PT2	PT3	PT4	PT5	PT6	PT7	PT8	PT9	PT10	FT Staff	PT Staff	Total Staff Assigned		Total Required Staff
10-11am	1					1										2	1	3	≥	3
11-12am	1	1				1	1									2	1	3	≥	3
12-1pm	1	1	1			1	1	1								3	2	5	≥	5
1-2pm	1	1	1	1			1	1	1							4	1	5	≥	5
2-3pm		1	1	1	1			1	1	1						4	1	5	≥	5
3-4pm	1		1	1	1				1	1	1					6	0	6	≥	3
4-5pm	1	1		1	1					1	1	1				5	0	5	≥	3
5-6pm	1	1	1		1						1	1	1			5	0	5	≥	3
6-7pm		1	1	1								1	1	1		2	1	3	≥	3
7-8pm			1	1	1								1	1	1	4	2	6	≥	3
8-9pm				1	1									1	1	3	2	5	≥	3
9-10pm					1										1	2	1	3	≥	3
Solution	2	0	1	1	2	1	0	1	0	0	0	0	0	1	1					

Cost	1980

Additional Requirements			
Total of FT	6	≥	4
Total of FT	6	≤	10
Total of PT	4	≤	10

Figure 5: Excel Solver output for the staffing model with 3-hour part-time shifts

						4 Hour Shift													
Time	FT1	FT2	FT3	FT4	FT5	PT1	PT2	PT3	PT4	PT5	PT6	PT7	PT8	PT9	FT Staff	PT Staff	Total Staff Assigned		Total Required Staff
10-11am	1					1									2	1	3	≥	3
11-12am	1	1				1	1								3	2	5	≥	3
12-1pm	1	1	1			1	1	1							3	2	5	≥	5
1-2pm	1	1	1	1		1	1	1	1						4	2	6	≥	5
2-3pm		1	1	1	1		1	1	1	1					4	1	5	≥	5
3-4pm	1		1	1	1			1	1	1	1				5	0	5	≥	3
4-5pm	1	1		1	1				1	1	1	1			6	0	6	≥	3
5-6pm	1	1	1		1					1	1	1	1		5	0	5	≥	3
6-7pm		1	1	1							1	1	1	1	2	1	3	≥	3
7-8pm			1	1	1							1	1	1	3	1	4	≥	3
8-9pm				1	1								1	1	3	1	4	≥	3
9-10pm					1									1	2	1	3	≥	3
Solution	2	1	0	1	2	1	1	0	0	0	0	0	0	1					

Cost	1980

Additional Requirements			
Total of FT	6	≥	4
Total of FT	6	≤	10
Total of PT	3	≤	10

Figure 6: Excel Solver output for the staffing model with 4-hour part-time shifts

6.3 Model Recommendation (a)(iii)

Table 6: Comparison of 3-hour and 4-hour Part-Time Staffing Models

Model	Total Cost (RM)	Number of FT Staff	Number of PT Staff
3-hour part-time shift	1980	6	4
4-hour part-time shift	1980	6	3

Both the 3-hour and 4-hour part-time shift models have the same total cost of RM1980. However, the 4-hour shift uses fewer part-time staff than the 3-hour shift. If the manager prefers to manage fewer staff during the event and simplify scheduling, the 4-hour part-time shift would be the better choice, while still meeting all staffing requirements.

6.4 Optimal Schedule Diagram (b)

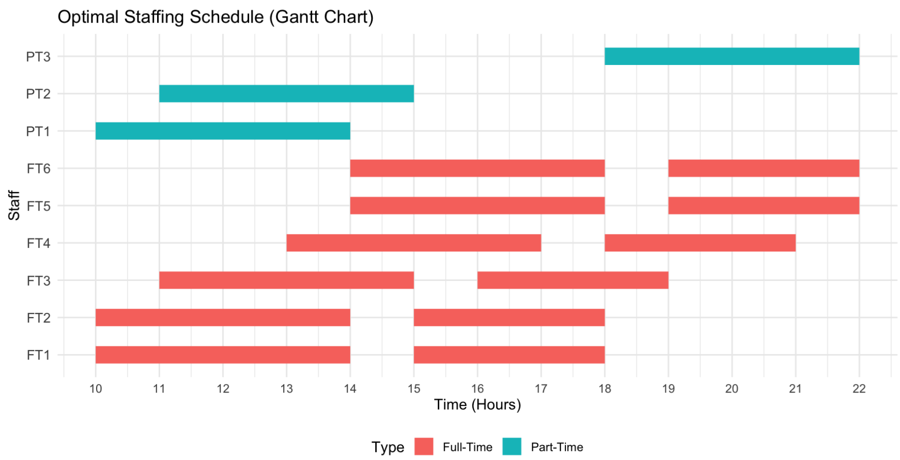

Figure 7: Optimal staffing schedule for the promotional event

The Gantt chart shows the optimal staffing schedule using 6 full-time staff and 3 4-hour part-time staff. The chart shows how full-time and part-time working hours are distributed throughout the day to ensure that staffing requirements are met throughout the event.

7 Question B2(a)

7.1 Decision Tree

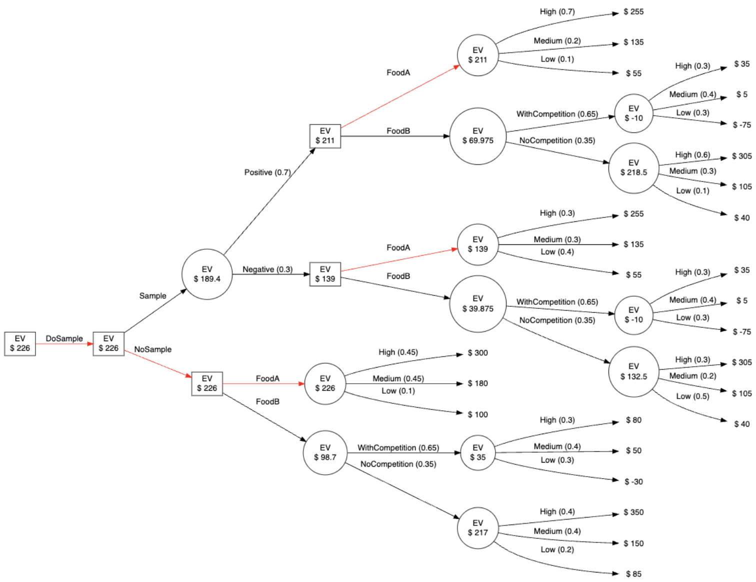

Figure 8: Decision Tree for Food Selection With and Without Sample Testing

The best decision is to not conduct the sampling and sell Food A straight away. Not sampling gives a higher expected value of RM226, compared to RM189.4 when sampling is conducted. Since Food A is still the better option regardless of whether the test result is positive or negative, the sample test does not affect the final decision and therefore does not justify the RM45 cost to sample.

8 Question B2(b)

8.1 Network Construction (b)(i)

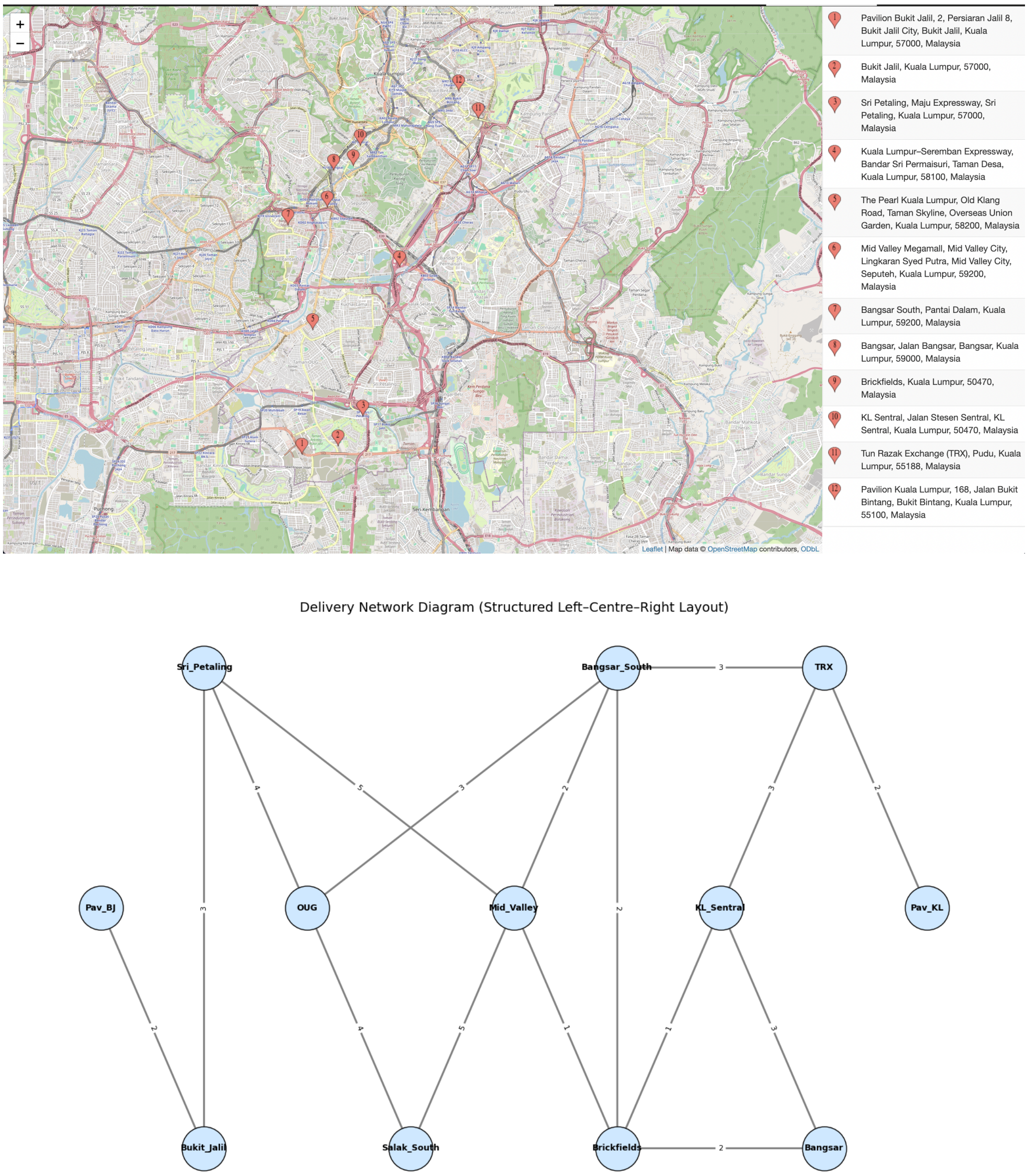

Figure 9: Map of locations between Pavilion Bukit Jalil and Pavilion Kuala Lumpur (top) and the corresponding network representation used for analysis (bottom)

Figure 9 shows a map of locations between Pavilion Bukit Jalil and Pavilion Kuala Lumpur and the corresponding network representation. Each location is represented as a node and each route as an edge, allowing shortest-path algorithms to be used to find travel routes between the two malls.

8.2 Shortest Distance Algorithm Comparison (b)(ii)

The network between Pavilion Bukit Jalil and Pavilion Kuala Lumpur is modeled as an undirected, weighted graph, where nodes are areas and edge weights represent distances in kilometres. The Dijkstra and the Bellman–Ford algorithms, are used to find the shortest distance to the shopping mall.

Both algorithms return the same shortest distance of 17 km and identify the same shortest route. This is due to the edge weights in the network being non-negative, so both algorithms are guaranteed to give the same shortest path and distance.

The shortest path passes through the follwoing locations in the network.

$$\text{Pavilion Bukit Jalil} \rightarrow \text{Bukit Jalil} \rightarrow \text{Sri Petaling} \rightarrow \text{Mid Valley}$$
$$\rightarrow \text{Brickfields} \rightarrow \text{KL Sentral} \rightarrow \text{TRX} \rightarrow \text{Pavilion Kuala Lumpur}$$

Dijkstras is the better choice for this network as its algorithm is more efficient with non-negative edge weights.

9 Question B3

9.1 Interarrival Time Distribution (a)

Based on the sample and assuming normal distribution, the minimum and maximum interarrival times are shown in Table 7.

Table 7: Interarrival Time Parameters (Normal Distribution)

Parameter	Time (mm:ss)
Minimum interarrival time	00:00
Maximum interarrival time	23:00

9.2 Service Time Distribution (b)

Assuming normal distribution the mean service time and standard deviation obtained from the sample are shown in Table 8.

Table 8: Service Time Parameters (Normal Distribution)

Parameter	Time (mm:ss)
Mean service time	05:04
Standard deviation	02:11

9.3 Simulation of the Single-Server System (c)

Using the values from (a) and (b), a simulation is performed (Figure 10. and three graphs are generated to evaluate the system performance.

Interarrival Time (Uniform Distribution)	
Smallest	00:00
Largest	23:00
Service Time (Normal Distribution)	
Mean	05:04
Standard Deviation	02:11
Summary	
Average Waiting Time	0:00
Average Service Time	0:05
Probability of Waiting	0.21
Average Interarrival time	0:13
Average Waiting Time for those Who Wait	0:03
Average Time in System	0:06
starttime	14:00

Customer	Interarrival Time	Arrival Time	Service Start	Service Time	Service Ends	Waiting Time	Total Time
1	13:54	14:13:54	14:13:54	0:07:41	14:21:35		0:07:41
2	10:13	14:24:07	14:24:07	0:06:59	14:31:07	0:00:00	0:06:59
3	16:39	14:40:46	14:40:46	0:05:11	14:45:57	0:00:00	0:05:11
4	06:28	14:47:14	14:47:14	0:08:11	14:55:26	0:00:00	0:08:11
5	18:42	15:05:56	15:05:56	0:04:31	15:10:27	0:00:00	0:04:31
6	03:09	15:09:05	15:10:27	0:08:04	15:18:31	0:01:22	0:09:26
7	05:57	15:15:03	15:18:31	0:10:00	15:28:31	0:03:29	0:13:29
8	20:25	15:35:27	15:35:27	0:02:19	15:37:47	0:00:00	0:02:19
9	19:53	15:55:20	15:55:20	0:06:21	16:01:40	0:00:00	0:06:21
10	00:21	15:55:41	16:01:40	0:01:19	16:02:59	0:05:59	0:07:18
11	18:23	16:14:04	16:14:04	0:05:49	16:19:53	0:00:00	0:05:49
12	16:29	16:30:33	16:30:33	0:06:44	16:37:17	0:00:00	0:06:44
13	05:43	16:36:16	16:37:17	0:05:01	16:42:18	0:01:01	0:06:02
14	20:34	16:56:50	16:56:50	0:04:19	17:01:09	0:00:00	0:04:19
15	22:29	17:19:19	17:19:19	0:05:30	17:24:49	0:00:00	0:05:30
16	06:28	17:25:47	17:25:47	0:11:17	17:37:04	0:00:00	0:11:17
17	17:22	17:43:09	17:43:09	0:07:01	17:50:10	0:00:00	0:07:01
18	00:38	17:43:47	17:50:10	0:05:29	17:55:39	0:06:23	0:11:52
19	20:35	18:04:22	18:04:22	0:01:07	18:05:28	0:00:00	0:01:07
20	18:09	18:22:31	18:22:31	0:06:42	18:29:13	0:00:00	0:06:42
21	15:32	18:38:03	18:38:03	0:02:54	18:40:57	0:00:00	0:02:54
22	14:01	18:52:04	18:52:04	0:05:26	18:57:30	0:00:00	0:05:26
23	18:54	19:10:58	19:10:58	0:01:37	19:12:35	0:00:00	0:01:37
24	17:12	19:28:10	19:28:10	0:07:01	19:35:12	0:00:00	0:07:01
25	07:26	19:35:37	19:35:37	0:05:04	19:40:41	0:00:00	0:05:04
26	21:26	19:57:02	19:57:02	0:05:10	20:02:12	0:00:00	0:05:10
27	15:40	20:12:42	20:12:42	0:05:43	20:18:25	0:00:00	0:05:43
28	09:48	20:22:30	20:22:30	0:04:33	20:27:03	0:00:00	0:04:33
29	04:17	20:26:47	20:27:03	0:04:36	20:31:39	0:00:16	0:04:52
30	15:51	20:42:38	20:42:38	0:02:54	20:45:32	0:00:00	0:02:54

Figure 10: Excel Simulation Output

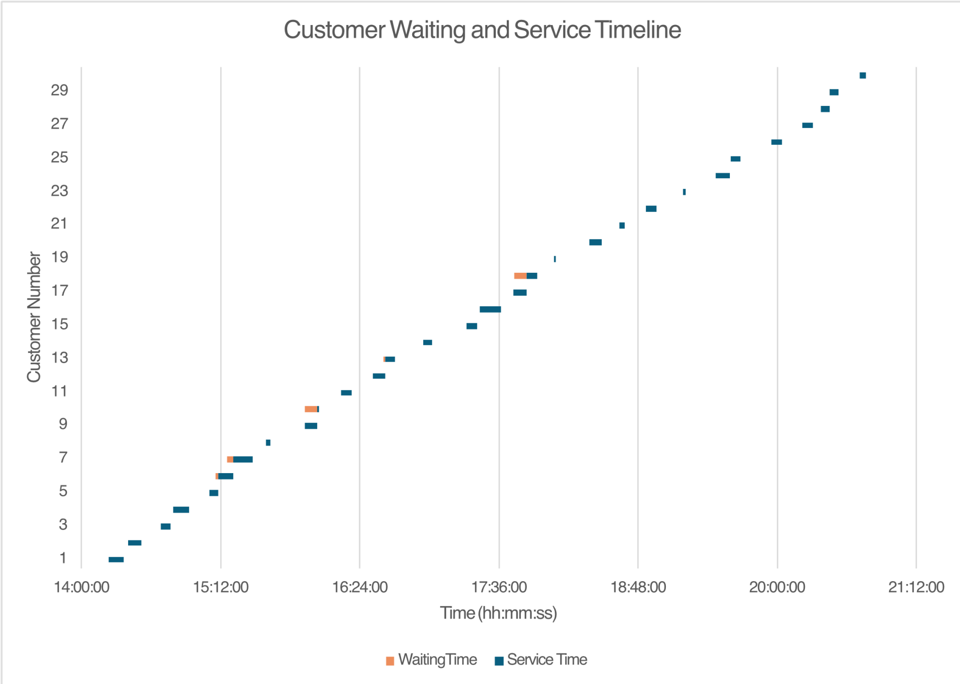

Figure 11: Customer Waiting and Service Timeline

Figure 11 shows the waiting time and service time for each customer during the simulation. It is clear most customers begin service shortly after arrival, while a small number experience short waiting periods, indicating occasional congestion.

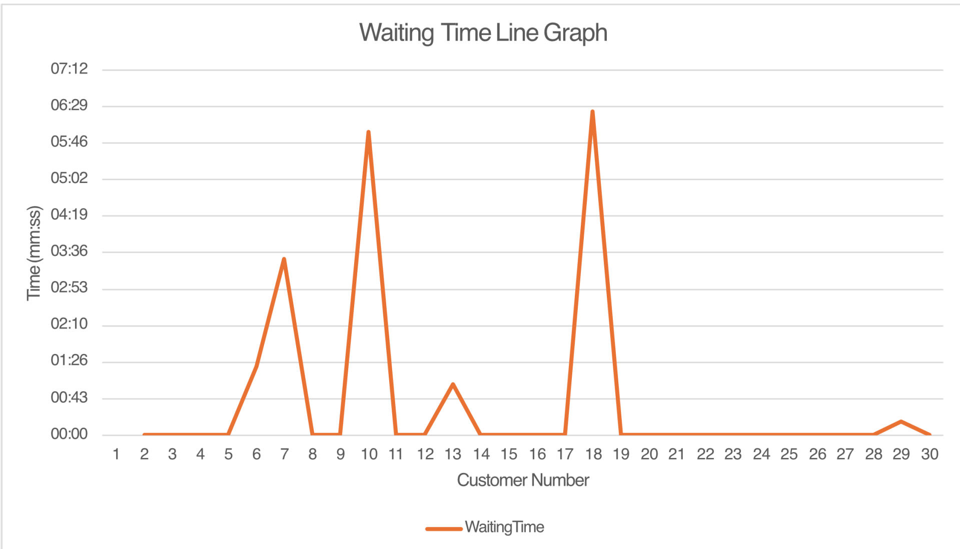

Figure 12: Waiting Time per Customer

Figure 12 shows that majority of customers experience no waiting time, while a few customers experience long waiting times, shown by the isolated spikes. Overall, waiting is uncommon which suggests efficient system performance.

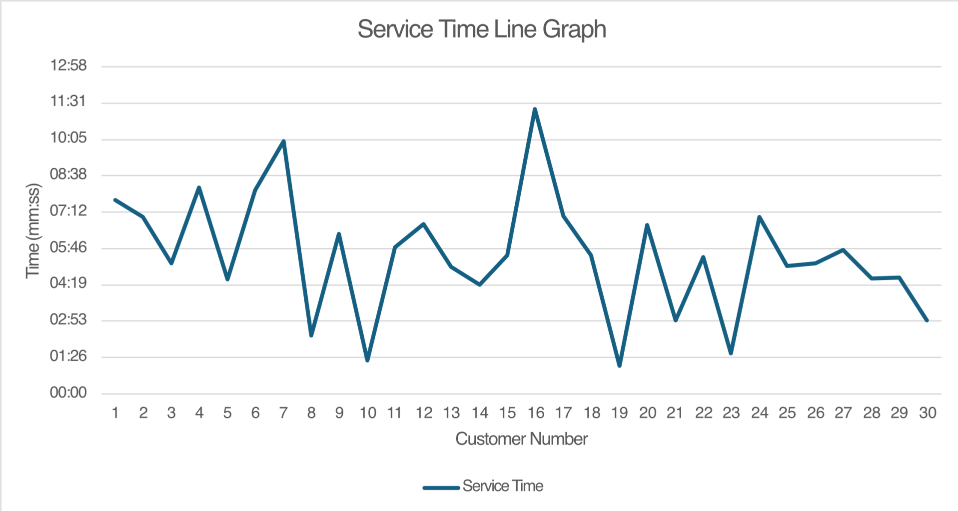

Figure 13: Service Time per Customer

Figure 13 shows variation across customers, with most values clustered around the average service time (5 minutes). This suggests that service performance is consistent throughout the simulation.

9.4 Performance Measures (d)

Based on the simulation results (Figure 10), the performance measures of the waiting line system are summarised in Table 9 where time is mm:ss.

Table 9: Summary of Waiting Line Performance Measures

Performance Measure	Value
Average waiting time	00:00
Average service time	05:00
Probability of waiting	21%
Average interarrival time	13:00
Average waiting time (customers who wait)	03:00
Average time in system	06:00

9.5 Suggestions for Improvement (e)

The restaurants waiting line system performs well overall. The performance measures show an average waiting time close to zero, a low waiting probability of 21%, and an average service time of about 5 minutes. The simulation graphs support these results by showing that waiting occurs only occasionally while service times are generally consistent across customers. However, some waiting can still be observed during busier periods and there is noticeable variation in service times. To further improve performance, the restaurant could add extra staff during peak times or reduce service time variability through better scheduling and training.

Figure 14: Sampled Restaurant