NATIONAL UNIVERSITY OF SCIENCE AND TECHNOLOGY

FACULTY OF ENGINEERING

DEPARTMENT OF INDUSTRIAL AND MANUFACTURING ENGINEERING

BENG HONS INDUSTRIAL & MANUFACTURING ENGINEERING

SIMULATION & MODELLING OF MANUFACTURING SYSTEMS

EIE 3221 / TIE 5215

SECOND SEMESTER MAIN EXAMINATION

MARCH 2025

This examination paper consists of **8** printed pages

Time Allowed: **3 HOURS**

Total Marks: **100**

Examiner's Name: **TAKUDZWA MACDONALD MUHLA**

INSTRUCTIONS AND INFORMATION TO CANDIDATE

1. Answer **QUESTION 1, QUESTION 3** and Any Other three **(3)** Questions.
2. Each Question carries a total of **20** Marks.
3. Start the answer to each full question on a fresh page.
4. Ensure neatness and legibility of work.
5. Use of calculators is permissible

QUESTION 1

Read the Case Study titled **"Assembly Line Delays at Gweru Electronics Ltd"** and answer the following questions.

a) Identify the most suitable queuing model that can be applied to this scenario. Justify your choice by explaining how the model aligns with the characteristics of the assembly line delays. **[6]**

b) Propose two strategies to enhance the efficiency of the Assembly line using queuing theory principles. Explain how each strategy would help reduce delays and improve workflow within the organization. **[8]**

c) Discuss the potential limitations of using queuing models in this real-world scenario. What external factors or operational challenges might limit the effectiveness of queuing theory in fully optimizing the assembly process? **[6]**

QUESTION 2

Following the restructuring exercise undertaken by CBZ Holdings, one of its branches in the City of Bulawayo now makes use of a single Teller for its operations. The Teller can serve customers at an average rate of 15 customers per hour, while the customers arrive at a rate of 10 per hour, following a Poisson process. Assuming that the Teller follows an exponential service time distribution, determine:

a) The average number of customers in the queue. **[4]**

b) The average time customer spends in the queue. **[4]**

c) The average number of customers in the system. **[4]**

d) Probability that there are no customers in the system at any given time. **[4]**

e) The utilisation factor of the Teller. **[4]**

QUESTION 3

a) Explain what is meant by steady state and provide reasons why this is an important concept in the analysis of queuing models. **[6]**

b) Bob's Garage is a Service station located along Gwanda Road, having a single fuel attendant serving all customers. The inter-arrival times and service distributions, and the random digits are shown in Table Q3a, Q3b and Table Q3c respectively.

Table Q3a: Inter-arrival times distributions

Inter-Arrival Time (mins)	1	2	3	4	5	6	7	8
Probability	0.05	0.10	0.15	0.15	0.30	0.10	0.10	0.05

Table Q3b: Service Times Distributions

Service Time (mins)	1	2	3	4	5	6
Probability	0.05	0.15	0.25	0.25	0.25	0.05

Table Q3c: Random Digits for Arrival and Service

Customer	1	2	3	4	5	6	7	8	9	10
Random Digit for arrival	-	26	98	90	26	42	74	80	68	22
Random Digits for Service	95	21	51	92	89	38	13	61	50	49

i) Develop the simulation table and analysis for the first 10 customers. **[12]**

ii) What is the average waiting time for a customer? **[1]**

iii) What is the utilization of the attendant? **[1]**

QUESTION 4

NUST Canteen has recently introduced Steak Pies to its menu and needs to determine the optimal number of pies to prepare each morning so as to maximise profitability while minimising waste. As an Operations Specialist, the Canteen has hired you to assist them in this regard. The probability distribution for the number of customers per day is outlined in Table 4a below:

Table 4a: Customers Probability Distribution

Number of Customers per Day	20	25	30	35
Probability	0.25	0.30	0.30	0.15

Each customer orders either 1, 2 or 3 cups of coffee with the following probability distribution

Table 4b: Probability distribution for Customer Orders

Pies Ordered per Customer	1	2	3
Probability	0.45	0.45	0.10

The canteen sells Pies for \$1.00 per pie and incurs a production cost of \$0.50 per pie. In compliance with health and safety regulations, all unsold pies are discarded at the end of the working day. Using the random digit assignments in Table 4c, simulate the Canteen's demand for 5 days and determine the optimal number of cups to prepare each day.

Table 4c: Random Digits for Customers and Orders

DAY	Random Digits for Customers	Random Digits for Orders (One per Customer)
1	27	12, 78, 05, 47, 39, 89, 55, 23, 64, 91
2	83	31, 70, 25, 60, 95, 81, 10, 59, 44, 77
3	44	09, 33, 18, 21, 56, 67, 98, 85, 29, 72
4	19	66, 43, 12, 81, 93, 54, 22, 74, 90, 37
5	68	14, 52, 31, 88, 20, 61, 79, 48, 36, 55

Also determine how many pies should be prepared daily in order to maximise profit.

QUESTION 5

a) With the aid of relevant examples, explain the difference between Discrete Event Simulation (DES) and Continuous Simulation. **[6]**

b) A manufacturing system has two processing stations. Each entity (job) arrives every 5 minutes on average and takes an exponentially distributed time of 8 minutes at Station 1 and 6 minutes at Station 2. With the aid of properly labelled sketches, describe how you would model this system in Arena Simulation Software. **[14]**

QUESTION 6

a) Describe the concept of Little's Law and demonstrate its application in queuing analysis using a relevant example. **[6]**

b) With the aid of valid queuing theory examples, differentiate between jockeying and reneging with respect to queuing situations. **[6]**

c) Explain the key differences between finite and infinite queue models in Queuing Theory and provide practical examples of each. **[8]**

QUESTION 7

a) Explain the assumptions underlying Jackson's Theorem and discuss its significance in analyzing queuing networks. **[4]**

b) A two-node Jackson network consists of two service nodes, each with a single server. External arrivals occur at Node 1 according to a Poisson process with rate λ. After service at node 1, customers may proceed to Node 2 with probability p or leave the system with probability $(1 - p)$. After service at Node 2, customers may return to Node 1 with probability q or leave the system with probability $(1 - q)$ Service times at both nodes are exponentially distributed with rates μ_1 and μ_2, respectively.

  i) Write the traffic equations for the network. **[4]**

  ii) Solve for the arrival rates of each node. **[4]**

  iii) Compute the utilization of each server in both nodes **[4]**

  iv) Using Jackson's Theorem, determine the average number of customers in the system. **[4]**

APPENDIX A: List of Formulae

	M/M/1	M/D/1	M/M/m
L	$\frac{\lambda}{\mu-\lambda}$	$L_q+\frac{\lambda}{\mu}$	$\frac{\lambda\mu(\lambda/\mu)^m}{(m-1)!\,(m\mu-\lambda)^2}P_0+\frac{\lambda}{\mu}$
W	$\frac{1}{\mu-\lambda}$	$W_q+\frac{1}{\mu}$	$\frac{\mu(\lambda/\mu)^m}{(m-1)!\,(m\mu-\lambda)^2}P_0+\frac{1}{\mu}=\frac{L}{\lambda}$
L_q	$\frac{\lambda^2}{\mu(\mu-\lambda)}$	$\frac{\lambda^2}{2\mu(\mu-\lambda)}$	$L-\frac{\lambda}{\mu}$
W_q	$\frac{\lambda}{\mu(\mu-\lambda)}$	$\frac{\lambda}{2\mu(\mu-\lambda)}$	$W-\frac{1}{\mu}=\frac{L_q}{\lambda}$
ρ	$\frac{\lambda}{\mu}$		$\frac{\lambda}{m\mu}$
P_0	$1-\frac{\lambda}{\mu}$		$\frac{1}{\left[\sum_{n=0}^{n=m-1}\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right]+\frac{1}{m!}\left(\frac{\lambda}{\mu}\right)^m\frac{m\mu}{m\mu-\lambda}}$ $for\ m\mu>\lambda$

CASE STUDY: ASSEMBLY LINE DELAYS AT GWERU ELECTRONICS (PVT) LTD

Gweru Electronics (Pvt) Ltd is a medium sized electronics manufacturing company based in the Midlands capital of Gweru, Zimbabwe, specializes in the production of circuit boards and consumer electronic devices. The company has over the years been facing persistent delays in its assembly line due to varying service times for complex components. Some of the components manufactured by the company require intricate assembly steps, leading to unpredictable processing times and bottlenecks. As a result, production output has been rather inconsistent, and customer order fulfilment times have been negatively affected.

The company's Production Manager has observed that some workstations experience long queues of partially assembled products waiting for processing, while others remain underutilized. To address this, the company is considering the application of Queuing Theory to analyse and optimize its assembly line operations.

Customer	Inter-Arrival Time	Arrival Time	Service Time	Time Service Begins	Waiting Time in Queue	Time Service Ends	Time Customer Spends in System	Idle Time of Server
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								