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Business School

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CMSE11426 Simulation Modelling and Analysis

Conceptual Modelling Document

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1. Introduction

The report aims to conceptualise the current operations of a coffee shop in Edinburgh, to effectively identify, analyse and improve inefficient functioning within the daily routine operations, namely customer arrival and order mechanism, queueing and crowd management, food preparation and delivery, sojourn service and revenue management. It is crucial for the coffee shop to continually adapt to changing customer preferences, seasonal demand, and other disruptions to maintain a competitive edge in the market. A simplified representation of the current scenario, as presented in this document, will aid in constructing effective alternative configurations to strategically improve customer satisfaction and service, and subsequently increase sales revenue.

2. Problem Definition

STJ Coffee Shop is a small cafe located in the centre of Edinburgh, near the central University Campus attracting many university students. The coffee shop is co-owned by three friends and business partners, Sam, Tom and Jane, who work between 8 am and 8 pm on weekdays. While the shop is open every day of the week, it attracts most of its customers during the peak tea time of weekdays. Currently, a full-time employee, David, works as a barista between 12 pm and 8 pm on weekdays. An additional part-time employee assists during the 4-6 pm slot, and this position has a high turnover rate.

Each owner takes a day off during the week, and only two owners work during the weekend based on a rota. Due to limited indoor capacity of the shop, the shop currently offers 2 two-seater tables and 1 four-seater table. An additional two-seater table can be accommodated within the cafe. If there is further requirement for seating, the external space outside the coffee shop can be rented from QRmile Estate.

Customers tend to arrive either individually or within groups of four. The occurrence of larger group customers is highly infrequent. Each customer tends to order one drink, and may get one or two snacks along with their beverage. The owners have noticed that customers tend to leave the coffee shop straightaway before entering if they notice a queue size of larger than 10. The owners are concerned about the steep decline in sales revenue and reduced customer satisfaction resulting from overcrowding, long queues and unavailable seating. The owners seek strategic assistance to analyse areas of mismanagement to improve their revenues and ensure customer retention and expansion.

3. Business Process Modelling

Conceptual Modelling is an essential step in Simulation Modelling and involves the development of a high-level representation of the system under evaluation to establish the basic structure and behaviour of the model. A clear understanding of the system's key features and relationships is crucial to lay foundation for rest of the modelling process. The AS-IS system refers to the current state of the system or process. It involves documenting and analysing the existing process, identifying bottlenecks and inefficiencies where improvements can be introduced. This forms a baseline for comparison against proposed changes or improvements. The four prominent phases are identified as below:

- Customer Arrival and Till Order
- Order Preparation and Delivery

- Order Collection and Sojourn
- Customer Departure

Business Process Model and Notation (BPMN) enables effective differentiation between the different phases (sections) of operations within the system architecture (Law, 2013). Each phase is further represented using Business Process Model and Notation (BPMN), which is a standardised way to present complex business processes. This helps in illustrating the current functioning of the coffee shop to effectively communicate inefficiencies and bottlenecks to business stakeholders.

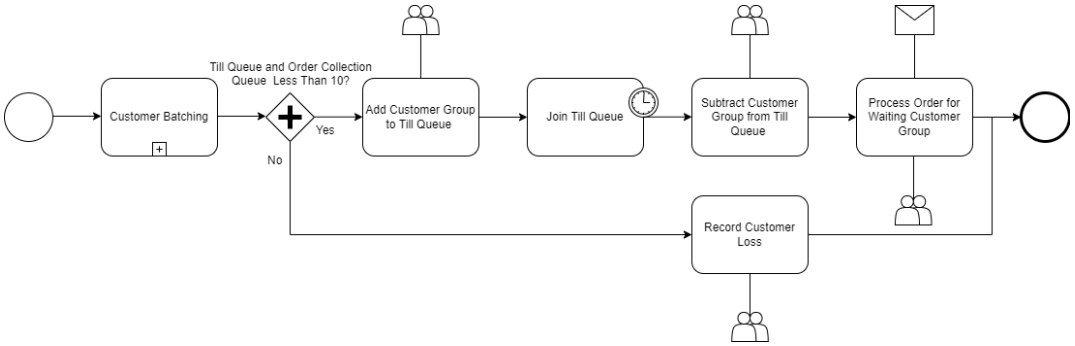

Figure 1. Customer Arrival and Till Order (Phase I) BPMN

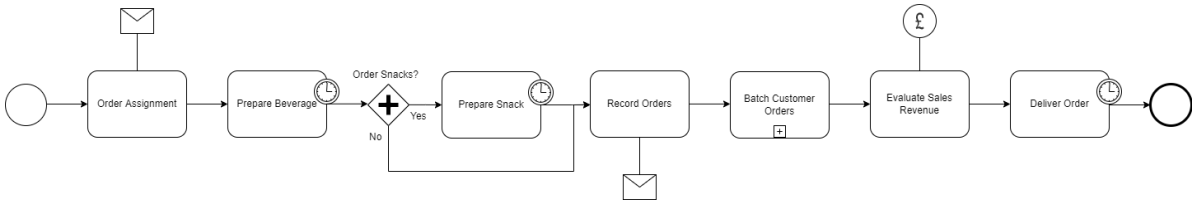

Figure 2. Order Preparation and Delivery (Phase II) BPMN

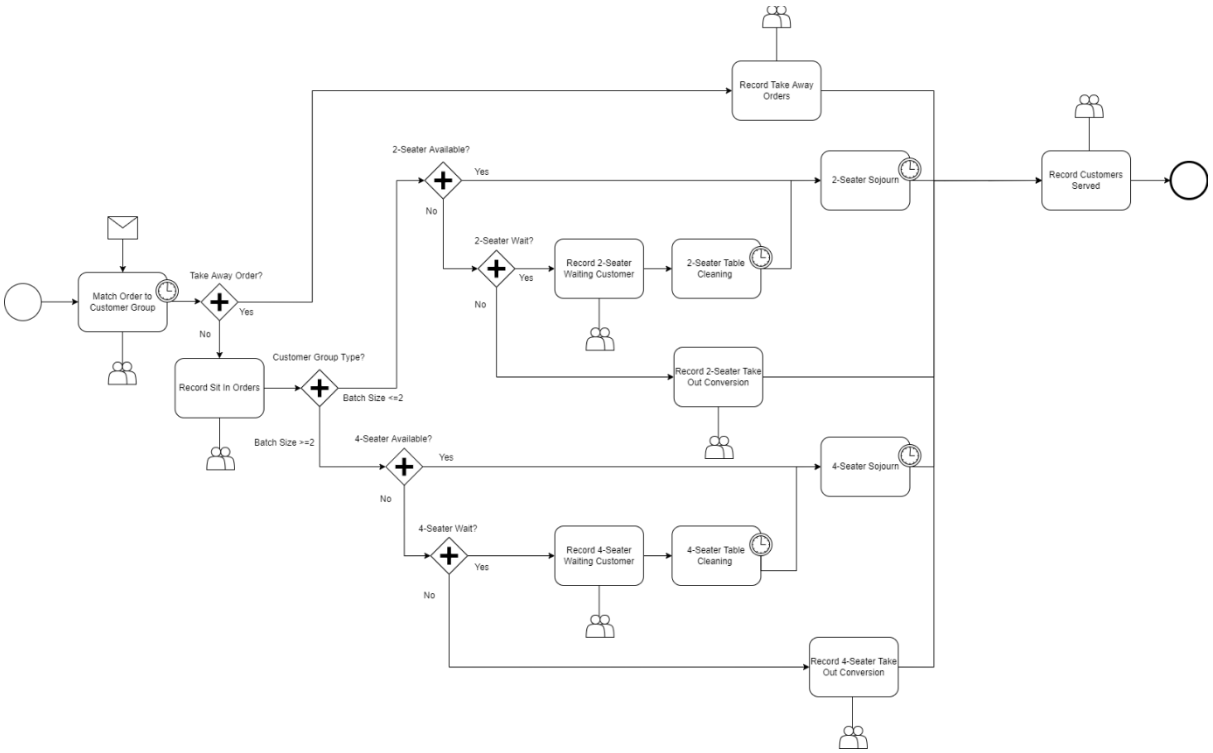

Figure 3. Order Collection and Sojourn (Phase III) BPMN

4. Model Assumptions

The assumptions considered in this coffee shop simulation are enlisted below, which will serve as the assumptions document for this conceptual model:

1. It is assumed that the five-day data collected pertaining to customer behaviour and trend is from 2nd January (Monday) to 6th January (Friday).
2. The flow of customers into the coffee shop is consistent and follows the trend documented during data collection phase averaged over five days of a single week.
3. The prices of the beverages and snacks sold in the coffee shop are fixed, and do not change over the time period of complete development of the model.
4. The number of seating arrangements available remain consistent in the coffee shop, unless the business owners purchase additional furniture.
5. The behaviour of customers in terms of ordering beverages and snacks, and preferences pertaining to seating and take-out follows documented trend, and does not vary throughout the period of development of the simulation model.
6. The staff, both full-time and part-time, have all the necessary skills to perform responsibilities of baristas during their working hours, and will not have any hindrance to their ability to perform necessary tasks within the documented time.
7. The turnover rate for the part-time staffing is high, and such an employee is readily available should there be a requirement for such staffing by the owners.
8. The three owners follow the agreed rota for taking a day off on weekdays.
9. Prospective customers shall always leave the shop, should there be a till queue or order collection queue of larger than ten people (excluding the current customer being served).
10. The external space outside the coffee shop is readily available to be rented by the owners, should they decide to utilise the space to expand their seating arrangements.
11. Customers often arrive at the coffee shop either individually, in pairs, or groups of three/four.
12. It is assumed that there are no significant outliers in any of the data trends presented in this model.
13. The coffee shop shall have a consistent supply of all necessary ingredients for making any beverage or snack, at any time, and never face a shortage to meet customer's order.
14. The coffee shop offers a standard menu with limited items, and does not entertain sale of any additional, or seasonal item requiring additional resource, preparation, or equipment.
15. The coffee shop never experiences unexpected events impacting sales or operations, such as power outages, severe weather, labour strikes, or nearby construction work affecting operations.
16. The coffee shop is not affected by any major competitors in close proximity suddenly impacting customer arrival patterns.
17. The coffee shop houses a point-of-sale system accurately tracking all transactions and inventory levels in real-time.
18. The coffee shop operates on a standard business schedule, opening and closing at the same time each day, with no unexpected closure or extended hours.
19. It is assumed that tables are dirty every time customer(s) leave(s) post sojourn, and the table has to be cleaned and prepared for the next sit-in customer(s) in line every time a sojourn table has been made available. This requires the services of any of the baristas.

20. It is assumed that no customer waits for the coffee shop to open by arriving before the specified opening time, and therefore no large queues exist outside or inside the cafe before this time.
21. It is assumed that the customer(s) immediately occupy a cleaned table on a first come first serve (FIFO) basis for sojourn once it has been cleaned and prepared by the staff.
22. Customers follow the general rule of occupying the two-seater tables if present as an individual, or a pair, and occupying the four-seater when present in groups of three or four.
23. For each order, the beverage is prepared, post which the preparation of snack, if ordered by the customer, takes place.
24. It is assumed that sit-in customers queue to collect their orders, and only after order collection proceed to search for available seating for their sojourn.
25. It is mentioned that 37% customer orders are cakes, the distribution of homemade and outsourced cake has been assumed to be 25% and 12% respectively (it is mentioned that homemade cakes are more popular than outsourced cakes).
26. It is mentioned that 28% customers order either one or two snack(s), it is assumed that 20% customers order one snack item and 8% of customers order two snack items.
27. It is assumed that 20% customers wish to wait for sojourn tables to be available, and remaining 80% customers convert to take-out behaviour.
28. The analysis conducted on the ten-seater sojourn considers the seating arrangement as an individual bar table, where any customer group is able to occupy, and does not require any particular seating requirements. Each customer is independently provided a seat in such a seating arrangement.
29. It is assumed that a delay of 30 seconds to 1 minute occurs between the time the order is ready to be collected and the time it is claimed by the customer(s).
30. It is assumed that in general table cleaning process takes 1 to 2 minutes for two-seater tables and 2 to 4 minutes for four-seater tables.

5. Model Simplification

An important step of conceptual model is model simplifications. In this step, certain components and interconnections that have little to no effect on the overall execution of the model are removed. This leads to a reduction in the level of detail that complicates the process. This step involves excluding infrequent events and occurrences.

The simplifications adopted in this project are as below:

1. A simplification to exclude consideration of an additional owner working on any two of the five weekdays simulated has been levied to ensure consistent evaluation of daily operations (Reference: Assumption 8).
2. The infrequent occasion of bigger groups of customers (larger than four) arriving at the coffee shop (five times a week at most) has been excluded (Reference: Assumption 11).
3. The customers served, lost, and orders accounted for at the time of the coffee shop closing is analysed, and the system discards consideration of customers currently being catered to from the model evaluation metrics (Reference: Assumptions 17, 18).
4. The occasional instance of groups splitting to check table availability at the till order, or order collection phase, has been excluded (Reference: Assumptions 24).

The impact of the above simplifications are as below:

Table 1. Model Simplifications and its impact on the model if violated

Model Simplification	Impact
Simplification I: Exclusion of additional barista (owner) on 2/5 weekdays	Low: The impact is low on base case, where customer loss is occurring mainly due to overcrowding and long queues, rather than unavailability of baristas (as evidenced from resource utilisation statistics). This could have medium impact on modified alternative configurations involving additional seating and customers.
Simplification II: Exclusion of infrequent large groups	Low: Since such an occurrence is infrequent, and current seating cannot accommodate larger groups, this assumption does not play a significant effect neither on the AS-IS nor on the TO-BE model.
Simplification III: Discard entities currently being processed in the system at the closing time	Medium: The customers currently in system are crucial towards evaluation of metrics. However, since comparative analysis occurs relatively between the AS-IS and TO-BE configurations, such cases have been excluded for simplified analysis. The simplification can be avoided by considering a 'last call' functionality permitting new customers to only choose take-out. Since this fix would affect statistics of customer preference, it is not implemented in the scope of this project.
Simplification IV: Customer groups check table availability before joining any queue	Low: The removal of this customer behaviour is assumed to not drastically impact analysis conducted. If this assumption were to be violated in the real-world scenario, this could lead to medium impact specifically on results pertaining to table availability and inconveniences documented for sit-in customers

6. Module Definition

6.1. Phase I: Customer Arrival and Till Order

Customer Arrival: Customers arrive at the coffee shop following the trends documented during the five days of data collection. It is observed that the customer rate peaks during tea time.

Customer Batching into Groups Sub Model: Consists of batching of customers based on Batch Size, an attribute which reflects a discrete distribution for the probabilistic distribution of customers based on observations made during data collection.

Decision to Join the Queue: The customer group joins the queue if the size of the queue, excluding the current customer being served, is larger than 10. If the size of either the till or order collection queue is larger than this cut-off, customers leave without entering the coffee shop.

Till Order: Customers mention their order preferences to the available Barista. The process follows a uniform distribution and could take between 30 seconds to 3 minutes.

Process Order for Waiting Customers: The customer having completed the ordering process now proceeds to join the Order Collection Queue (Phase III), while the individual orders of the customer group are prepared by the baristas behind the counter (Phase II).

6.2. Phase II: Order Preparation and Delivery

Order Drink/ Food Decision: Customer's chosen beverage and snack is prepared by the barista. The preparation time and probabilities pertaining to beverage and snack preparation is tabularised in the mathematical modelling section.

Customer Order Batching: The completed orders of customer groups are batched together and are ready to be collected by the customer groups.

Order Value: The Sales generated from completed orders is evaluated in real-time by multiplying the number of beverage and snack units sold against their unit prices.

Order Delivery: A minor delay of 30 seconds to 1 minute is considered by the model to account for inadvertent delays between the instance order is ready to be collected to the time it is actually collected by the customer group.

6.3. Phase III: Order Collection and Sojourn

Match Order to Customers: The customer group wait for their group orders to be available, and once the batched order is available to be collected, the order is matched to the customer based on their Customer ID.

Decision to Check Order Type: The customer group's preferred order type is evaluated, if it is a sit-in order or take-away order. The orders are sit-in with a probability of 40% and take-away with a probability of 60%.

Customer Group Type Check: Check the customer group size, to forward individual customers, and pairs to two-seater tables, and allow groups of three and four to proceed to four-seater tables.

2-Seater and 4-Seater Sojourn: The customer groups proceed to respective tables to begin their sojourn.

2-Seater and 4-Seater Table Cleaning: The tables must be cleaned by the staff upon the customers leaving the table, to make it available for the waiting customer group next in line to dine at the coffee shop. The table cleaning process could take between 1 to 2 minutes for two-seaters and 2 to 4 minutes for four-seaters.

6.4. Phase IV: Customer Departure

The customers successfully served at the coffee shop, both sit-in and take away, are recorded, and the customers lost due to overcrowding and long queues is also recorded.

7. Mathematical Modelling

The number of customers arriving at the coffee shop and respective number of staff available to conduct operations is assumed to be consistent with observed trends from the five-day average as illustrated below:

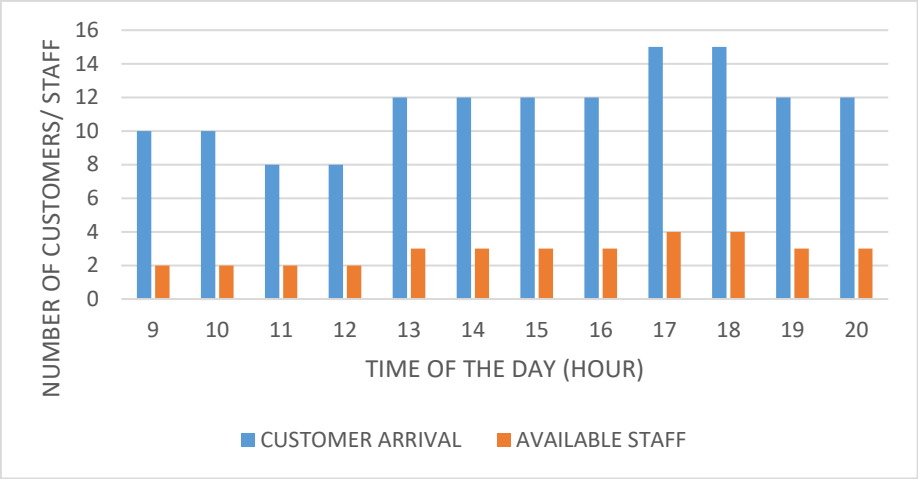

Figure 4. Ratio of Customer Arrival to Available Barista Staff

A majority of the customers arriving at the cafe are individuals or couples. The distribution of customer group type is visualised with the below bar plot:

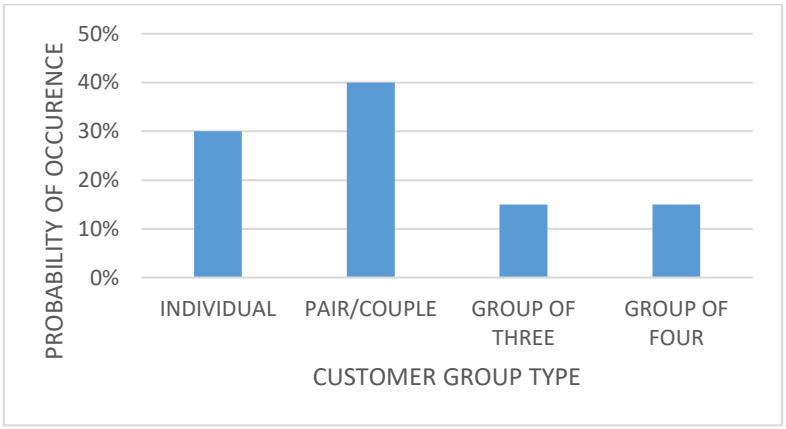

Figure 5. Distribution of customer groups based on observed data of five-day average

The forecasted probabilities of beverages and snacks orders, their preparation times, and prices are documented in the table below:

Table 2. Customer order behaviour, price and preparation time of beverages and snacks sold by the coffee shop

BEVERAGE / SNACK	PRICE PER UNIT	PREP TIME	PROBABILITY
Coffee	£2.00	UNIF(2,4)	50%
Tea	£1.00	TRIA(1,2,3)	30%
Soft Drink	£1.50	0.5	20%
Homemade Cake	£2.50	UNIF(0.5,0.75)	25%
Outsourced Cake	£2.80	UNIF(0.5,0.75)	12%
Fruit	£1.00	UNIF(0.5,0.75)	25%
Other Item (Snack)	£1.50	UNIF(0.5,0.75)	20%
Two Other Items (Snacks)	£3.00	UNIF(1,1.5)	8%

With α value as 0.05 and relative error (γ) of 0.15 at most (percentage error of 15%), making replications until half-width of the 95% confidence interval divided by the estimate of the actual relative error is less than or equal to the relative error. An approximate expression for the total number of replications required to obtain the relative error agreed upon is given by:

$$n_r{}^*(\gamma) = \min\{i \geq n: \frac{t_{i-1,1-\frac{\alpha}{2}}\sqrt{\frac{S^2(n)}{i}}}{|\bar{x}_t(n)|} \leq \gamma'\}$$

$$\text{where, } \gamma' = \frac{\gamma}{(1+\gamma)} = 0.1304$$

It is assumed that the samples taken in this experimental verification is independent of each other. To achieve this, the AS-IS model is run for 780 replications, and divided into experimental dataset of varying n (n = 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120) to ensure that the samples collected are independent and random. Conducting independent verification on selected parameters, namely, the sales revenue, customers served and lost, two-seater and four-seater table wait and take out instances against the maximum value calculated, it is observed that the chosen number of replications meeting the condition is 120.

For this purpose, further experimentation on the AS-IS system and improvements to the TO-BE configurations is performed on n = 120 replications. A summary of the relative errors obtained for varying number of replications is summarised in the graph below:

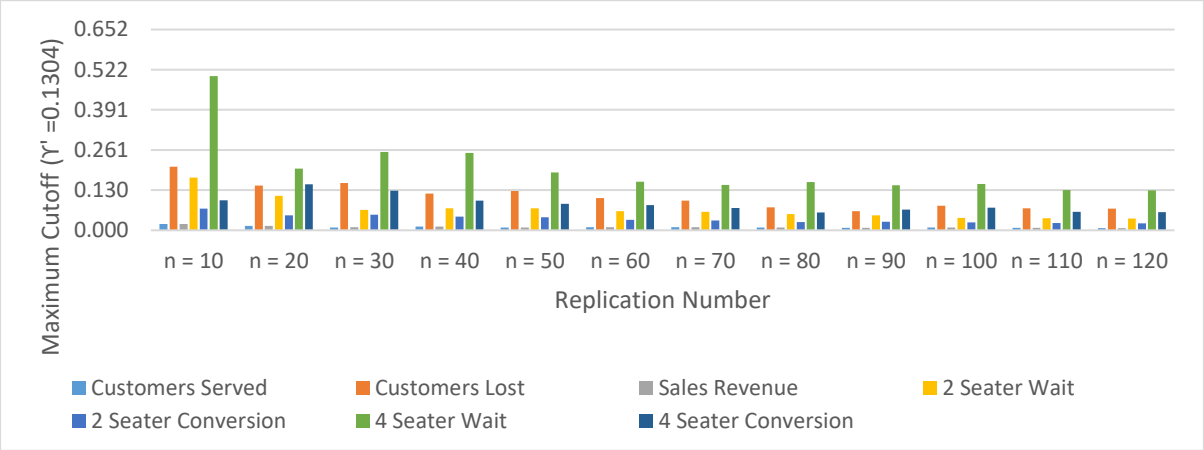

Figure 6. Maximum cut-off for permissible relative standard error in estimation of response parameters

8. References

Law, A.M. (2013) *Simulation modeling and analysis*. Fifth edition. Dubuque: McGraw-Hill Education (McGraw-Hill series in industrial engineering and management science).