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CMSE11426 Simulation Modelling and Analysis

Final Business Insights Report

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1. Introduction

The owners of STF Coffee Shop are concerned about the mismanagement of operations in their coffee shop pertaining to customer order mechanism, queueing and crowd management. The purpose of this report is to be build and compare an alternative configuration to possibly reduce, or potentially eliminate these issues. The report shall address the following research questions:

RQ1. How can the current flow of operations be optimised?
RQ2. How can overcrowding be avoided?
RQ3. How can customer satisfaction be improved?
RQ4. What capital investments (machinery, equipment, labour) can guarantee increase in weekly sales revenue and reduction in customer loss?

2. Problem Summary

The coffee shop currently has provision for 2 two-seater tables and 1 four-seater table. There are prominent issues in queuing and crowd management. There exists an observed mismanagement in operations within the coffee preparation time, an order that is ordered by 50% of customers. Customers often have to wait for a long time to have a good sojourn experience at the coffee shop and are often left distraught at the wait time, oftentimes opting to convert to take-out. This is believed to have left many customers unwilling to revisit the coffee shop, leading to poor customer retention.

Table 1. Issues classified according to their presence in each phase of the coffee shop operations

Operational Phase	Current Issues
Phase I: Customer Arrival and Till Order	Overcrowding, Long Queues, Slow Order Intake
Phase II: Order Preparation and Delivery	Significant delay in preparation of coffee, accounting for 50% of orders based on customer purchase behaviour
Phase III: Order Collection and Sojourn	Unavailability of seating, Long waiting time for vacant sojourn space

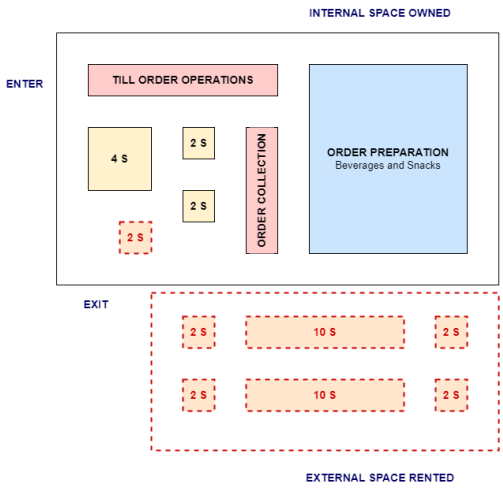


Figure 1. The current layout of the coffee shop (AS-IS Model)

3. Statistical Metrics for Performance Measurements

The simulation implemented in this report belongs to the discrete-event type (DES), where the occurrence of discrete events trigger state changes in the system (White, 2019). Customer arrival is generally modelled as a Normal or Poisson distribution (Rosetti, 2015). The Poisson

distribution assumes that events occur independently at a constant rate over time. Since the customer arrival trend observed during the five days of data collection depict a hike in customers during teatime, this simulation project rather models it as an arrival schedule. A standard relative error of 0.15 has been permitted in the model, and the calculations pertaining to the ideal number of replications for this model is given by the equation below (Law, 2013), discussed in detail in the Conceptual Model Report.

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

Utilising this threshold, 780 samples were extracted to be distributed into independent samples in the range of 10 (10, 20, 30…120). The equation was satisfied using number of replications (n value) as 120, which guarantees a good balance between accuracy and computational efficiency.

It is important to identify key performance indicators (KPIs) for any system, to validate improvements (if any) in the system against its base case counterpart (Tomasella *et al.*, 2017). In this report the comparison between the current model to the suggested model is performed on the below KPIs:

- Net Sales Revenue: Income from successfully serving customers at the coffee shop post deduction of all capital investments.
- Lost Customers Count: Customers leaving due to overcrowding and long queues (Till, Order Collection)
- Customer Satisfaction: This metric is built on the assumption that an inverse relation exists between customer satisfaction and number of instances a table is unavailable to be occupied by customer(s), leading to the sit-in customers either waiting in queue for the sojourn, or forced to consider and convert to take-out behaviour.

4. Business Process Modelling

The alternative system configuration has been represented using BPMN to reflect the recommendations in each of the phases. The decision flow post customer batching checks the availability of a self-checkout kiosk instead of ordering from a barista at the till. This ensures a quicker service and proves its prominence in crowd management.

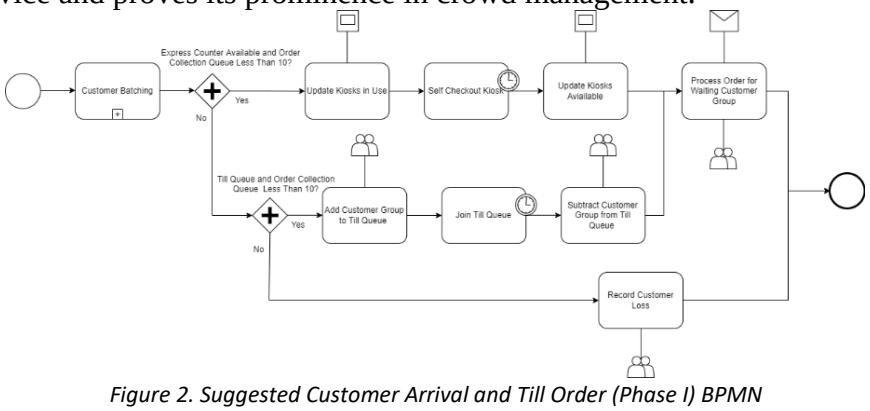


Figure 2. Suggested Customer Arrival and Till Order (Phase I) BPMN

For the order preparation phase, an automatic espresso machine can be used to prepare coffee in the absence of a barista, an approach adopted by many coffee shops. This will ensure that coffee, accounting for 50% of customer orders, is prepared in a shorter time.

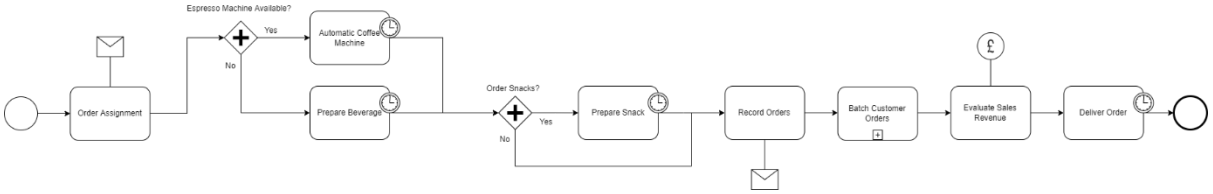


Figure 3. Suggested Order Preparation and Delivery (Phase II) BPMN

In the final and crucial stage of improvement, the entire logic of outdoor seating expansion, (both two-seaters and ten-seaters) has been constructed. The seating availability can be arranged based on the optimal configuration in response to current customer inflow, and further seating additions can be made should customers arriving at the coffee shop increase.

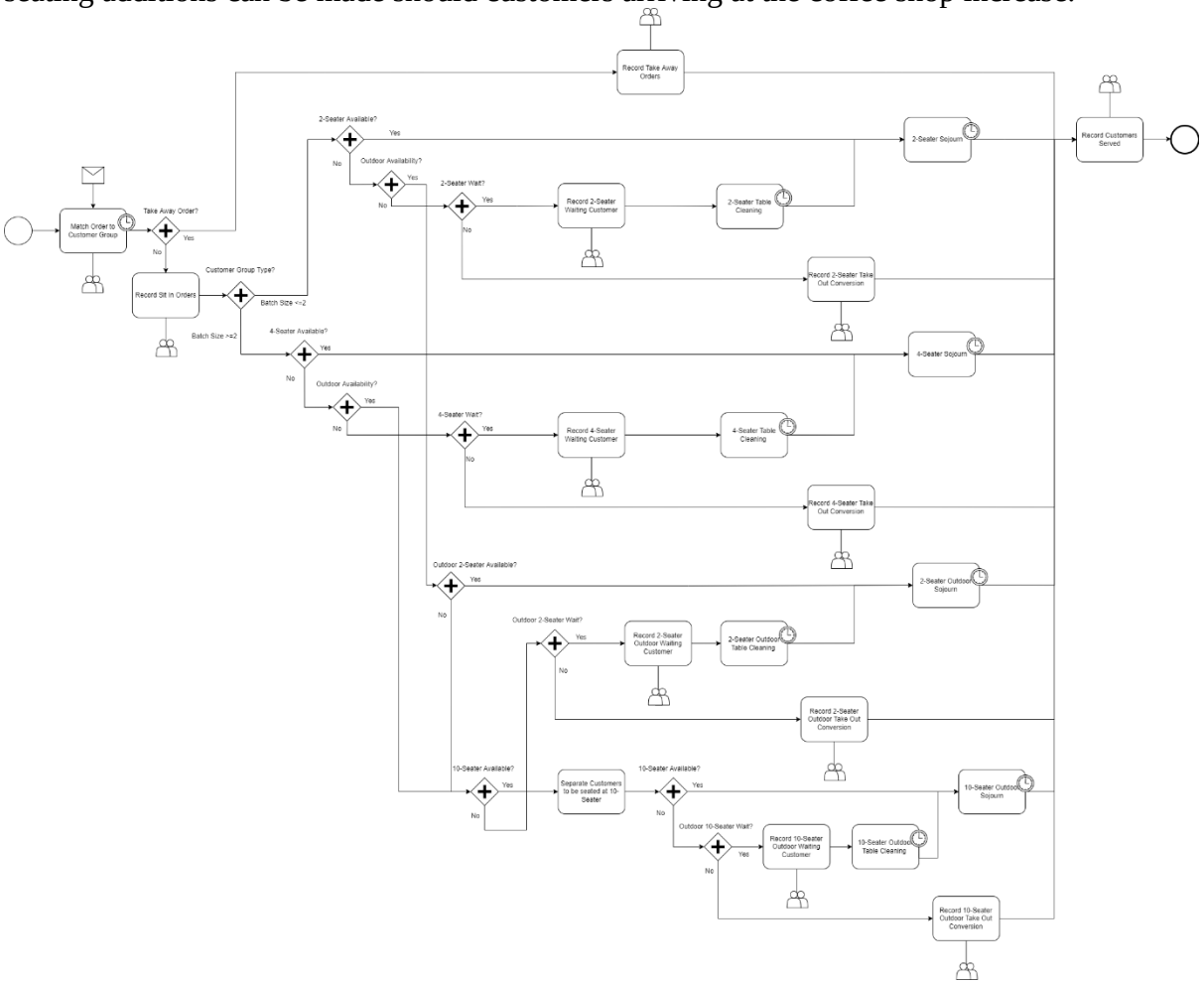


Figure 4. Order Collection and Sojourn (Phase III) BPMN

5. Model Enhancements

5.1. Process Analyser

The addition of a self-checkout express counter and an automatic espresso machine provided highest return on investments (ROI) as evidenced by the sensitivity analysis conducted on Process Analyser. The weekly sales generated from this improvement showed an increase of up to £130 pounds from its base case, and the net sales after deducting the expenses incurred showed an increase of up to 1.96% using the proposed solution. Furthermore, the issue of customer loss due to long queues and overcrowding was reduced by around 50% with suggested solution.

Table 2. Process Analyser Sensitivity Analysis on Control Variable Combinations

Scenario	Sales	2S Wait	2S Take Out	4S Wait	4S Take Out	Customer Loss	Expenses	Net Income
Base Case	4752	47	59	331	6	77	0	4752
Kiosk	4823	44	60	339	6	80	21	4802
Espresso Machine	4855	26	60	339	6	78	3	4852
Indoor Expansion	4780	47	41	234	6	80	6	4774
Indoor and Outdoor Expansion (2 Seater)	4794	50	0	0	0	0	106	4688
Indoor and Outdoor Expansion (10 Seater)	4790	45	0	0	0	0	93	4697
Additional Full Time	4782	46	0	0	0	0	107	4674
Kiosk Espresso Machine	4861	25	60	341	6	80	24	4837
Kiosk Espresso Machine Indoor Expansion	4875	24	43	244	6	84	30	4845
Kiosk Espresso Machine Indoor and Outdoor Expansion (2 Seater)	4878	24	0	0	0	0	130	4747
Kiosk Espresso Machine Indoor and Outdoor Expansion (10 Seater)	4886	23	0	0	0	0	117	4769

Additional analysis was conducted by varying the number of full-time and part-time staff, however, it was noted that this did not yield significant improvements on neither the sales generated nor the customer loss reduced. This is documented in the Appendix Section, and no further sensitivity analysis was conducted on staff variations.

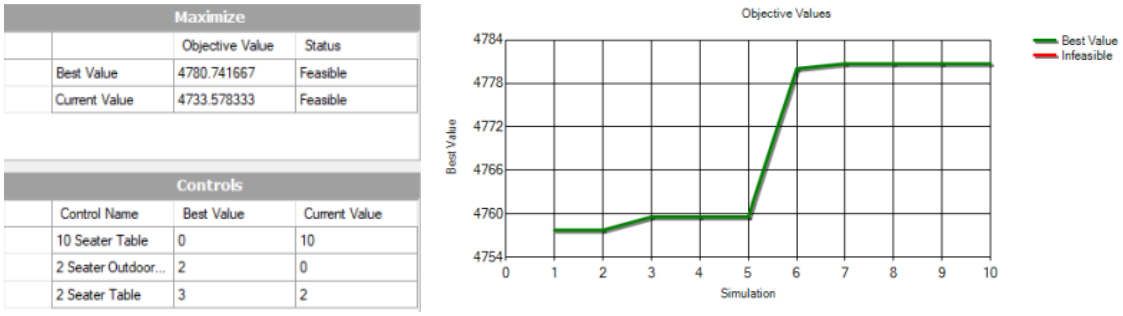
5.2. Opt Quest Optimisation

The advances and applications of combining simulation and optimisation techniques are tremendous and often highly rewarding, improving the decision-making process efficiently by reducing costs and time (Glover, Kelly and Laguna, 1996). The effectiveness of this combinatorial technique has been leveraged to enforce customer retention and ensure that the customer satisfaction is further improved by reducing the instances of customer(s) waiting for a sojourn table to be vacant. It is important to analyse and consider the scenario where seating availability is expanded, which can be achieved by either indoor expansion, outdoor expansion, or both. The objective function formulated for this model is given below:

$$Objective: Maximise\ Net\ Income$$

$$Net\ Income = Sales - (Additional\ two\ seater\ units * Unit\ cost\ of\ two\ seaters) - (Additional\ four\ seater\ units * Unit\ cost\ of\ four\ seaters) - (Additional\ full\ time\ staff * Unit\ compensation\ of\ full\ time\ employee) - (Additional\ part\ time\ staff * Unit\ compensation\ of\ part\ time\ employee)$$

To optimise this objective, Opt Quest was used to iterate through multiple scenarios to suggest the optimal configuration of two-seater tables, two-seater outdoor tables, and ten-seater long benches. The system showed that investing in a ten-seater table was not profitable, and that the expansion of two-seater tables from 2 to 5 yielded maximum returns.



Maximize

	Objective Value	Status
Best Value	4780.741667	Feasible
Current Value	4733.578333	Feasible

Controls

Control Name	Best Value	Current Value
10 Seater Table	0	10
2 Seater Outdoor...	2	0
2 Seater Table	3	2

Figure 5. Optimisation of Sales by considering the seating configuration possibilities as the control variables

6. Alternate System Configuration (TO-BE Model)

Incorporating the suggestions from Process Analyser, and OptQuest, an alternative system configuration was constructed that accounted for the issues discussed earlier. The solutions to the underlying issues present in each phase, and an illustration of the alternative system configuration has been documented below:

Table 3. Solutions to the Issues identified in each phase of the coffee shop operations

Operational Phase	Current Issues	Solution
Phase I: Customer Arrival and Till Order	Overcrowding, Long Queues, Slow Order Intake	Self-Checkout Kiosk
Phase II: Order Preparation and Delivery	Significant delay in preparation of coffee, accounting for 50% of orders based on customer purchase behaviour	Espresso Machine
Phase III: Order Collection and Sojourn	Unavailability of seating, Long waiting time for vacant sojourn space	Indoor and Outdoor Expansion (2 Seaters)

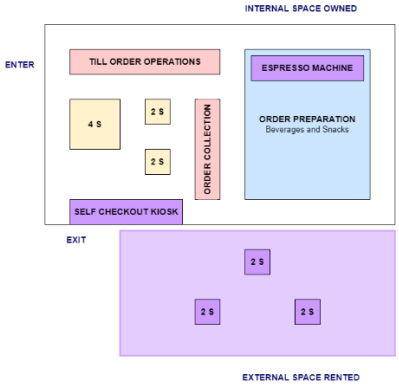


Figure 6. The alternative layout of the coffee shop (TO-BE Model)

7. Results and Analysis

The proposed architecture ensures an increase of 16.82% in weekly sales generated from selling beverages and snacks in the coffee shop (AS-IS Sales: £4,813.84, TO-BE Sales: £5,623.47). However, to achieve this increase in Sales, an additional expense of £712.58 for furniture and equipment is required. Assuming the impact of this additional expense is on weekly basis over the year, the proposed architecture corresponds to an increased net sales (2.02% higher than estimated weekly net sales of the AS-IS configuration), which promises a 6% increase in net sales monthly.

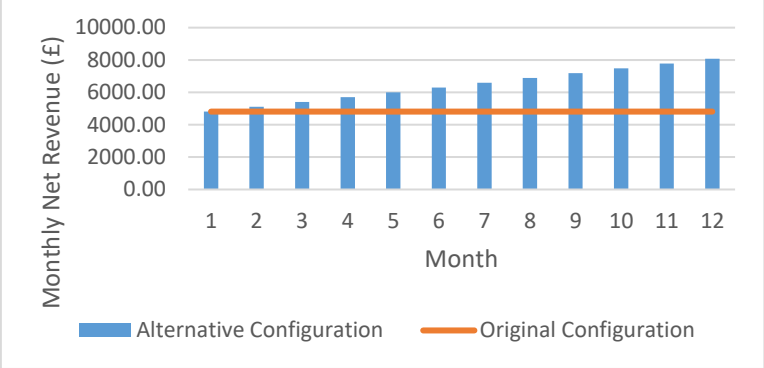


Figure 7. Comparison of monthly net sales (post deductions) of the Original and Alternative Configurations

The recommendations also illustrate their impact on decreasing customer(s) inconveniences due to seating unavailability, i.e. customer(s) leaving the coffee shop with an unsatisfied experience. The lower the occurrence of such occasions, the better the customer retention, and ultimately the customer satisfaction. As illustrated below, this issue is entirely resolved for two-seaters and partially resolved for four-seaters using the alternative configuration.

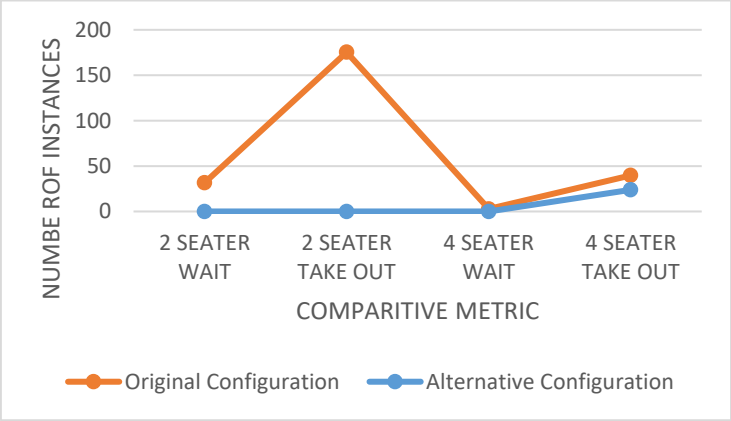


Figure 8. Comparison of customer inconvenience due to unavailability of seating in Original and Alternative Configurations

Table 4. Number of instances customers faced an inconvenience due to table unavailability

Scenario	Original Architecture	Proposed Architecture
Sit-in customer(s) wait for a two-seater table to be available	32	0
Sit-in customer(s) convert to take-out due to lack of two-seater table vacancy	175	0
Sit-in customer(s) wait for a four-seater table to be available	3	0
Sit-in customer(s) convert to take-out due to lack of four-seater table vacancy	40	24

The proposed configuration has further established a 47.68% reduction in customer loss, bringing down the average customer loss from 46 to an average customer loss of 24.

8. Recommendation Validation

A crucial step in simulation modelling and analysis is conducting the formal verification to prove or disprove the correctness of a system through mathematical techniques (Spoletini *et al.*, no date). In this report, the proposed model was validated for its statistical significance in operational improvements by considering the sales and customer loss KPIs. For this purpose, Minitab was utilised to conduct a Paired t-test, which requires the normality assumption to be satisfied. The KPIs show a normal distribution, with the exception of a certain outlier in the simulation results, which is discarded. The p-values obtained from the paired t-test for these KPIs were both 0.0000 (less than chosen significance level of 0.05) and therefore the proposed recommendation is deemed to be statistically significant to be considered. Additionally, a white-box validation was performed by verifying the statistics recorded from KPIs (Customer Loss and Sales), which were in agreement with expectations.

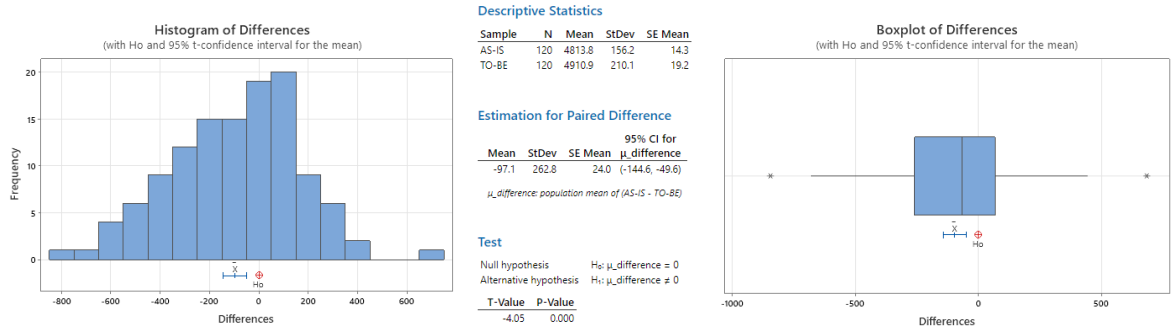


Figure 9. Histogram, Paired t-test statistic, and Boxplot for Sales (Original and Alternative Configuration)

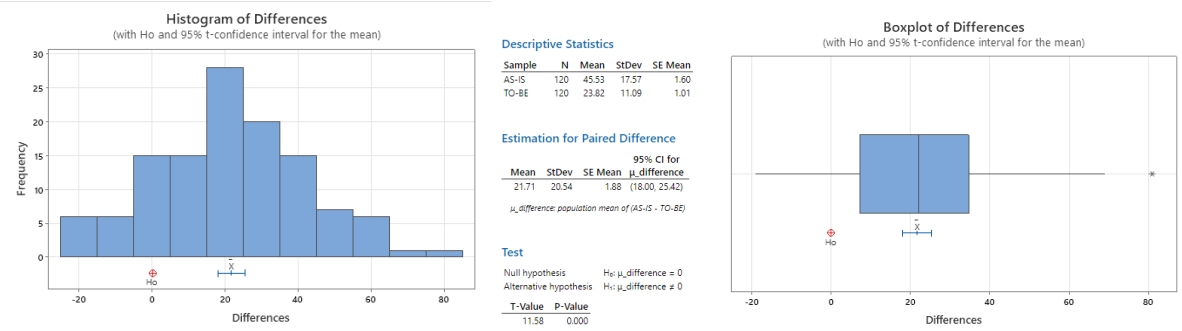


Figure 10. Histogram, Paired t-test statistic, and Boxplot for Customer Loss (Original and Alternative Configuration)

9. Limitations

The proposed system has several limitations due to the simplifications of formal assumptions undertaken during Conceptual Modeling:

1. Oversimplification: The assumptions in the model may oversimplify the dynamic real-world scenario. For example, an assumption of customer compulsorily ordering a drink may not accurately reflect the actual customer behaviour, leading to inaccurate results
2. Lack of variability: The model assumes that all customers reflect the same behaviour, and that all beverages and snack categories cost the same (Cost can vary for homemade cakes based on flavour, for example). In reality, the model reflects rigidity in adapting to these variabilities.
3. Fixed costs: The model assumes fixed costs, disregarding seasonal variability in prices, and demand supply relations.

4. Limited scope: The coffee shop's financial situation may not fully be reflected in the model's limited scope of not considering other sources of income or expenditure, such as merchandising and catering events, or unforeseen expenses.
5. Lack of external factors: The model disregards external factors influencing or affecting the forecasted revenue and predicted operations of the coffee shop.

10. Conclusion and Future Work

The current flow of operations of the coffee shop was simulated, and an alternative configuration was developed using optimisation and simulation. This followed a sensitivity analysis by varying the seating configurations, staff availability, additional machinery and equipment to improve the speed of certain operations.

The proposed system architecture improved crowd and queue management, operational and resource optimisation, and showed significant reduction in customer loss and inconveniences caused by table unavailability.

For future research and development, this simulation project can be extended by diversifying the limited menu items currently offered to include more options. The owners can consider investing in additional outdoor seating if there is significant increase in customer arrivals in the future, or alternatively if they wish to further decrease customer inconvenience faced due to unavailability of four-seaters. Such outdoor rental arrangements could also be specifically made available only during seasonal demand from university students. Provision to order online and collect it from the coffee shop can be also implemented to avoid overcrowding at the till during peak hours.

11. References

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