IB320 ASSIGNMENT

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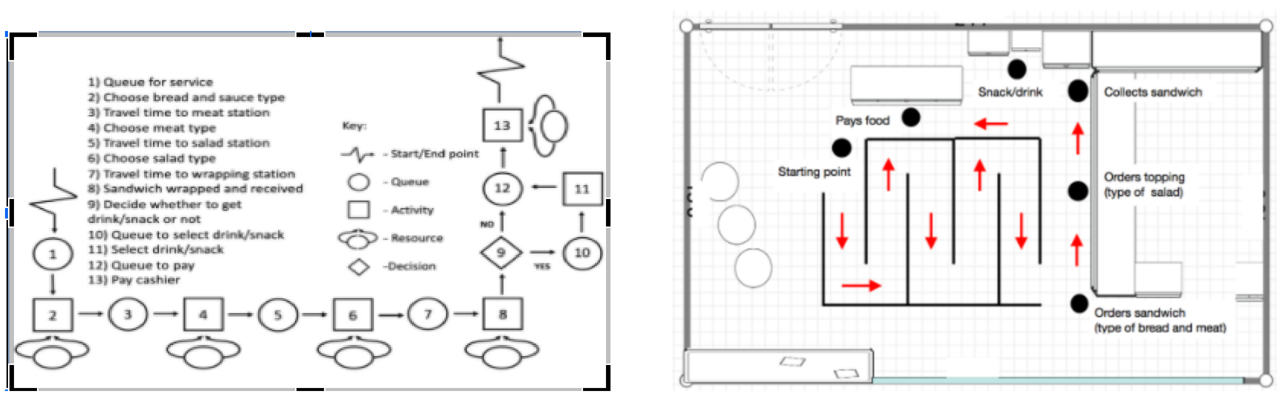
1 Introduction

In the previous report, an investigation into Breadoven, a takeaway service providing sandwiches primarily, was conducted. We have identified that there was a clear need for improvement, specifically in its queuing management. After digitizing the data collected, We carried out appropriate exploratory data analysis to identify trends of waiting times and arrivals count in time intervals. We identified that their biggest dilemma was the size of queues at peak times. We contrived a simulation model to run different experimental procedures that would have been inefficient and expensive to run in real life. We successfully presented an alternative strategy to fix the worker's position to improve efficiency and cut time in the manufacturing process, which reduced average queue sizes by 11%. After completing the model, We conducted visual checks to test the validity of the model. Furthermore, we conducted a chi-squared test with our simulation data and its real data counterpart. We concluded that there was insufficient evidence to reject this model to represent the real-life system.

My team and I identified that their biggest dilemma was the size of queues at peak times. We contrived a simulation model to run different experimental procedures that would have been inefficient and expensive to run in real life and successfully presented an alternative strategy to fix worker's position to improve efficiency and cut time in the manufacturing process, which reduced average queue sizes by 11%.



(a) label 1

(b) label 2

Figure 1: Structure of queue and process

This report will explore the simulation and report on different system scenarios to suggest a viable strategy to bolster their capabilities. Additionally, the client further enquired about the model and to justify chosen run lengths, methods, and critically discuss any limitations, strengths, and weaknesses of the modeling and experimentation process that has been implemented.

2 Modelling objectives and key experimental factors (Task 1)

2.1 Problem and modelling objectives

From our perspective, there was a definite problem in the sizes of the queue during peak and at other times. Not only were some customers waiting for over 15 minutes, but the magnitude of these queues also deterred potential customers from ordering. Evidence of this problem is shown in figure 6 in the appendix.

My modelling objectives are as follows:

What client wants to achieve:

- Reduce average waiting times in order to increase customer satisfaction and decrease the likelihood of customers reneging.
- Improve efficiency of workers to reduce waiting times of consumers

Performance: Reduce waiting times for customers waiting to be served and pay so that 95% of customers spend no more than 9 minute to finish the process .

2.2 Experimental Factors

Component	Detail	Include/exclude	comments
Customer	Inter arrival times	Include	represented by probability distributions over time intervals
servers	service times	Include	represented by probability distribution
cashiers	service times	Include	represented by probability distribution
stations	service times	(+) Include	represented by probability distribution
staff for preparation of food	maintain resources for servers	exclude	irrelevant for queuing purposes
transaction type	sandwich/ salad/ wrap	exclude	does not impact service times
absenteeism of workers	cashiers/servers	exclude	not a significant problem
stock of food and materials	vegetables/ meat	Exclude	irrelevant for this investigation, assume infinite

experimental variables	reason
Servers	may improve service times and utilisation which has an aftereffect on queue times
Cashiers	may improve queuing times at the end of service
Stations	provides an alternative route for customer service and different queues
Queue rules	may improve customer utilisation

Constraints	Options
Budget	currently 5 staff in one shift, the maximum this can be increased to is 10 in a shift
space	a maximum of two stations and 3 paying tills

Quantitative inputs	Range
number of Servers	1,10
number of Cashier staff and cash tills	1,3
Stations	1,2

Output	Reason
Waiting times for each customer	identify whether objective has been reached
service time at each stage (meat, bread etc)	observe where improvements can be made
Utilisation of staff	improve Server utilization
queue sizes	measure to conclude whether objective targets have been reached

Assumptions:

- Cashiers and servers are paid the same salary and are trained for their assignment.
- It is cheaper to build a new station than to hire new people, justification for this is in appendix
- Second customer will not receive his sandwich before the first customer
- Payment denotes end of the run
- wraps/sandwiches/salad all take the same time and are perfect substitutes to each other
- 5 same servers work for the whole working duration while in reality there are shifts with many workers
- arrivals follow the same distributions as identified from the data, this was identified in the previous team report

Simplification:

- All staff and customer arrivals follow relevant distribution
- Time taken for service by workers is independent of queue sizes and time of day
- Queues have no capacity

The experimental factors that are considered for the experiment are the number of servers, the size of cashiers and tills, and the number of service stations. The above factors were chosen because they are quantitative inputs, and we can define explicit ranges and figures to the factors mentioned earlier.

The outputs that will be explicitly measured in the Simul8 model are waiting times and queue sizes for this experiment because they relate to the objective of reducing queue sizes to prevent customers from reneging.

Each of these factors is expected to make an impact on the outputs; an increasing number of staff members available should cut service times, and the construction of a new station should provide an alternative route for queues. All these are foreseen to reduce queue sizes and overall waiting times for customers as calculated by the simul8 model.

3 Task 2

3.1 Run length and initial bias

This model is an example of a transient output because the output is constantly changing in random sized cycles as evidenced in the graph below. This is because the input distribution is changed over every one hour time interval in the model and it has a natural termination point (close of restaurant at 15:30). There is a command in our simulation model which resets the queue back to zero and the start of new day.

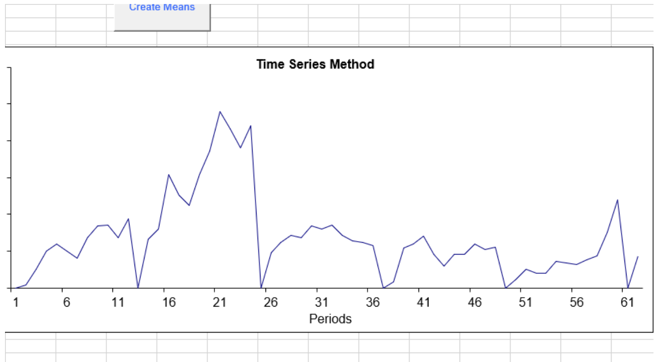


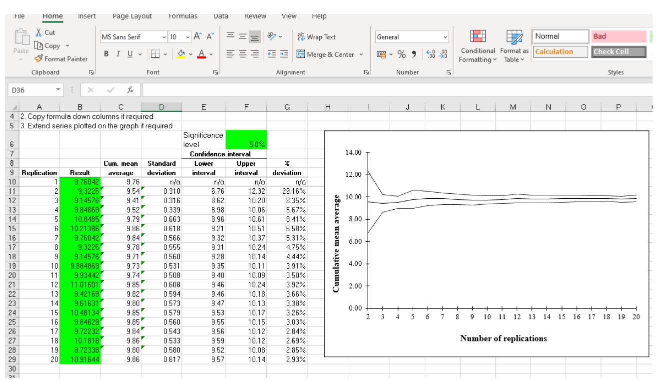
Figure 2: Time series graph from data collected by simulation

This is a service system that starts empty of customers; this matches the empty start-up state of our model by default, and therefore there is no initialization bias. Furthermore, it is not a steady-state or a steady-state cycle; therefore, there is no convergence in the data, as witnessed by figure 1.

for this analysis, a 5% precision (95% range) is enforced. Within this confidence interval, we can be confident that we have captured the population mean. The process will reduce the number of replications needed to save time and money, but they still come up with consistent results. It is crucial to replicate the correct amount to run because running too few could lead to inaccurate results, which leads to incorrect decision making, and running too many is costly both financially and time-wise.

The DES model recommended the number of trials to be 17 for a 5% precision. This is computed from the simul8 trial run calculator. We must get the information for the correct amount of replications needed to make sound decisions; this is a terminating system; therefore, it is impossible to run this for one long run since visual logic commands predetermine the endpoint in the simulation, so replications are the only options. This is to ensure we do not get abnormal results since we are using random distributions to capture variations in the system.

To further test this, the cumulative average for each added replication is calculated to see where it converges to a satisfactory amount. Please refer to the graph below to identify convergence around 9.86 as x tends to infinity.



2. Copy formula down columns if required
3. Extend series plotted on the graph if required

Significance level: 5.0%

Replication	Result	Cum. mean average	Standard deviation	Confidence interval Lower interval	Upper interval	% deviation
1	9.76042	9.76	n/a	n/a	n/a	n/a
2	9.3225	9.54	0.310	6.76	12.32	29.16%
3	9.14576	9.41	0.316	8.62	10.20	8.35%
4	9.84869	9.52	0.339	8.98	10.06	5.67%
5	10.8485	9.79	0.663	8.96	10.61	8.41%
6	10.21386	9.86	0.618	9.21	10.51	6.58%
7	9.76042	9.84	0.566	9.32	10.37	5.31%
8	9.3225	9.78	0.555	9.31	10.24	4.75%
9	9.14576	9.71	0.560	9.28	10.14	4.44%
10	9.884869	9.73	0.531	9.35	10.11	3.91%
11	9.93442	9.74	0.508	9.40	10.09	3.50%
12	11.01601	9.85	0.608	9.46	10.24	3.92%
13	9.42169	9.82	0.594	9.46	10.18	3.66%
14	9.61631	9.80	0.573	9.47	10.13	3.38%
15	10.48134	9.85	0.579	9.53	10.17	3.26%
16	9.84629	9.85	0.560	9.55	10.15	3.03%
17	9.72232	9.84	0.543	9.56	10.12	2.84%
18	10.1818	9.86	0.533	9.59	10.12	2.69%
19	8.72338	9.80	0.580	9.52	10.08	2.85%
20	10.91644	9.86	0.617	9.57	10.14	2.93%

Figure 3: cumulative mean vs number of replications graph with data used and confidence interval calculated, Data calculated from simul8

For further testing I carried out the MSER-5 test statistics and plotted the data against its output data and concluded that there is no need for a warm up period.

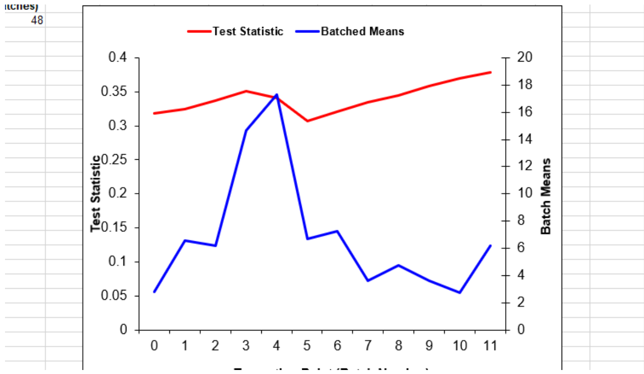


Figure 4: cumulative mean vs number of replications graph with data used and confidence interval calculated, Data calculated from simul8

The data does not follow a steady state trend hence this test will not be sufficient on its own but considering other factors mentioned in this simulation model it is safe to conclude that there is no initial bias therefore a warm up period is not needed to boost the accuracy of the model.

3.2 Accuracy of the model

After conducting these tests in figures 3 and 4, it is apparent that there is no initialization bias. Hence, there is no problem with accuracy at the start of each simulation run.

Due to the random nature of the simul8 model and to ensure that this run is not an outlier, multiple replications of the model for reach scenario were performed. Using the trials run calculator in the program, it was reckoned that 17 replicas of the model would be sufficient for each experimental scenario. I was able to achieve a 5% significance test to ensure 95% of the data is accurate for my modeling objectives. Using cumulative mean queue times, it is clear to see in figure 2 that this converges to a number as the number of replications is increased, and this number is then used in my calculations.

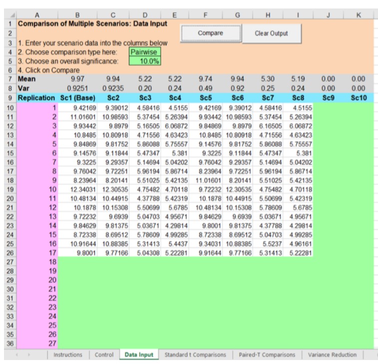
I have tested the validity of the simul8 model for each experimental factor by conducting visual comparisons on the original data and the original simulation and using knowledge to identify which factors should have the biggest impact.

4 Task 3

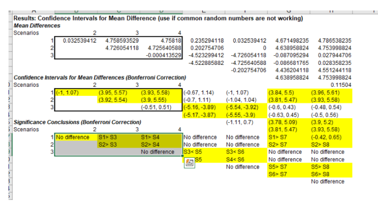
In my factorial design approach I will be considering the first three factors outlined above.

Scenario	server	cashier	stations
1	(-) 5	(-) 1	(-) 1
2	(+) 10	(+) 3	(-) 1
3	(+) 10	(-) 1	(+) 2
4	(-) 5	(+) 3	(+) 2
5	(+) 10	(-) 1	(-) 1
6	(-) 5	(+) 3	(-) 1
7	(-) 5	(-) 1	(+) 2
8	(+) 10	(+) 3	(+) 2

I recreated these scenarios in simul8 simulation program and ran 17 replicas of each scenario using the trial's run calculator and recorded these in an excel file. I was clear from these results that the more staff and station you have, the less the customers have to wait but this fails to account for risk and confidence intervals for mean difference. to rectify this I carried out further statistical tests including paired t test, Bonferroni correction and variance reduction to justify which scenario is the optimum choice. Please refer to the tables below for the tests conducted with the 8 scenarios using scenario one as a base.

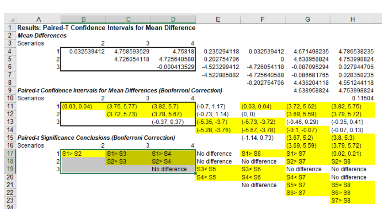


(a) Data and means

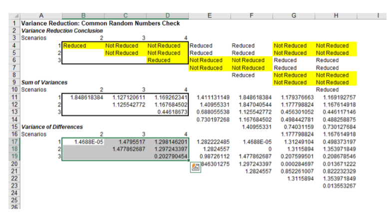


(b) t test

Figure 5



(a) paired t test



(b) variance

Figure 6

There are more than two scenarios thus Bonferroni Inequality is applied. With 8 scenarios, 17 comparisons are needed to be made with each of the SI significance levels set to 100-$\frac{5}{17}$ which is equal to 99.82% approximately for the Bonferroni inequality.

To read the figures above please refer to the variance comparison first. If the variance has been reduced, go to paired t comparison's figure. Else, use the standard t comparisons test. At the bottom of these figures, the significance conclusions are shown which tells us which scenarios have the larger sample mean. Our objective is to minimise the waiting times therefore we pick the values for least means, in our case the least is clearly scenario 8 which is the optimal solution.

4.1 Conclusions

These scenarios are statistically the best since each has a lower sample means than the original. Unfortunately, better scenarios involve hiring more staff and investment into more equipment, which can be exorbitant. Assuming it is cheaper to have another station and that it costs more to hire and train more staff, I would recommend scenario 7 to be the best because station numbers have more exceptional waiting times. Otherwise, with an enormous budget, scenario 8 is a better proposition. There is no significant statistical difference between these two scenarios' results, but since S8 uses more staff resources, I would recommend Scenario 7.

4.2 Strengths

The motivation for this task was to reduce queuing times for most customers after experiencing their queuing system, and this was achieved. We have achieved clear results from our experimentation where we have decreased output total system lengths in each run; hence we have achieved our modeling objectives. The targets have been bet wherein our best scenarios, 95% of total customers, now wait less than 9 minutes; in some scenarios, even lower. Adding another station was identified to have the most impact on queuing times, and thanks to research, it is shown that this is a cheaper alternative than hiring more staff.

This model is valid since the Chi-squared tests between the simulation output data and real data suggest that there is insufficient evidence to reject this model according to 5% significance tests. This implies that the input data in all my experimental models would be accurate.

4.3 Weaknesses/Limitations

To further improve my testing, I could have carried out tests for actual mean results plus confidence intervals of each scenario rather than differences to see which of these scenarios hit the 99.82% target.

Furthermore, it would have been helpful to monitor the utilization of staff and possibly identify whether servers and cashiers can act as perfect substitutes for each other. I would have been useful to record how many total staff members there are at each shift instead of assuming five servers at each time interval.

However, the most prominent complication was that I had to make many assumptions on the costs of service stations and to hire extra staff. If it is costlier to have more stations, then scenario six would have been the better solution. I have tried to mitigate this risk by conducting online research on this matter and managed to confirm that it is cheaper to build another station in the long term than hire more staff.

In these tests, we are also not considering manager utilities and preferences; they are our clients, and it is important to consult them on these solutions so that they can pick the best one. Otherwise, it would have been better to ask the manager beforehand their preferences on these matters and include this in our calculations.

The final complication arises from the fact that we have no detailed record of their floor plan, and therefore we had to assume that the maximum number of possible stations is two. In reality, it may be the case that we could have had more stations, further decreasing queue sizes, or we could have a scenario that it is impossible to build another; this causes the solutions to change.

We also need to consider the extra revenue vs. cost to justify the implementation of these strategies. This is to ensure the client makes significant gains my implementing our chosen strategy, and if it does not, then it may be illogical to implement this approach. Smaller queue sizes do not necessarily imply a more significant profit is made; it improves customer satisfaction by reducing queue times. It may prevent customers from departing, but an advertisement for a higher tally of customers may be needed to reap the full benefits of schemes produced to handle a more considerable amount of customers.

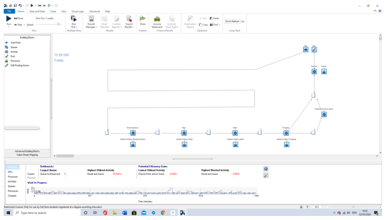
We also could carry out experimentation with further scenarios to try and improve upon the current results to identify whether there is a better, low-cost alternative.

5 Appendix

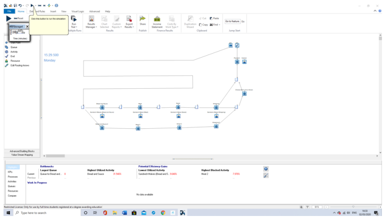
5.1 My changes to the original simulation model

For this evaluation I wanted to use a weeks worth of simulation data and I noticed that queues seem to pause at the end of working day and the customers remain there until the next working day. This is obviously a fault within the system so I used a time logic check command to empty the simulation queues at close of day.

For each Scenario I had to make changes to the simulation model. In scenarios where the number of servers were doubled, I simply created more resources to showcase this. For the scheme where another. working station was added, I added an alternative route from the first initial queue. When increasing the number of cashiers, I added two more staff designated to this role and created two alternative cash tills in the simulation model which customers can go to. These can be found in the figures below



(a) scenario 1



(b) scenario 7

Figure 7

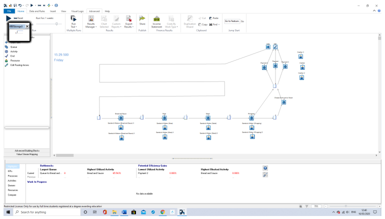


Figure 8: Scenario 2

5.2 Justification for my assumptions

When recommending my solution, I had to make an assumption that a service station is cheaper than hiring new staff. This restaurant follows a similar model to subway and on subways website it is mentioned that a equipment and stations have a cost of $65,000 dollars. Hiring 5 more full time staff and providing them with training will cost around $100,000. This is recurrent per year while the station is a one time investment.

Furthermore it is clear from the differences of means that adding another station which provides an other pathway has a greater effect on waiting and queue times than any other experimental factor so in our objective, utilising this would be a priority.

From observations on Bread Oven and the floor plan from figure 1, it is clear that it is improbable to have more than two service stations. Moreover when hiring more staff, you would expect them to be utilised efficiently. With increasing staff members, each individual is utilised less at non peak times consequently wasting the firms capital. Please refer to the figures below for each resources utilisation. (test for utilisation, reject if below ...)

Component	visual check	result
Distributions	Checked against raw data	Yes
Resources	do resources meet expected utilisation	yes
queues	are total queue sizes reasonable	no
routes	when there are more routes present i.e. station or cashier, are they being utilised sufficiently	yes

After completing the model, We conducted visual checks to test the validity of the model. Furthermore, we conducted a chi-squared test with our simulation data and its real data counterpart. We concluded that there was insufficient evidence to reject this model to represent the real-life system.

5.3 Proof of problem

Figure 9: large queue

5.4 Nature of Model use

Time scale: I am using one weeks worth of data for each scenario to achieve sufficient amount of data for analysis. This is to improve my accuracy. I am not running this longer because this is unnecessary as the means converge very quickly and it save time in project.

Flexibility: no need for model to be changed except varying the experimental factors.

Run speed: Use the fastest available run speed to save time as there are a large number of scenarios.

Visual display: 2D model adequate because the system is modeled similar to that of a floor plan and a flowchart which is usually 2d. The Client will see and use model to approximate waiting times by changing factors.

The model is easy to use; all activities, resources and routes are predefined so the manager is able to run the simulation and make quantitative changes. For other types of changes, for example role assignments, further instruction will be required.

It is also important to note that this is just a simulation and that it should be used to make major decisions basing only this as evidence; it should be used only to support your objectives.

5.4.1 Further simplifications

I used a Black-box modelling approach where I represented a section of the operation as a time delay. This is dome in each activity and the queues before it.

I assumed that resources were always available and full time but in reality they have shifts with multiple different workers.

I made two different models, one where the customers waits and gets his sandwich and another system where he waits and pays for this. The output of this first model became the input of the next.

5.4.2 Replications

Replications are random runs of the model each using different streams of random numbers. Multiple replications are needed to make accurate estimates of the KPIs as the original run may have extreme results. Furthermore this is a terminating system so it is not possible to run one long run and is transient therefore the results are always changing.

It is recommended to create a confidence Interval around the mean to identify the ranges the average waiting times can fall in.

5.4.3 Initialisation bias

If the date was steady state and non terminating I would use the MSER-5 to find the truncation state where I would find the point where it is acceptable to accept the data. This is shown in figure 4 in the main report.

This process works by batching the output data points into batches of 5,then calculating the MSER-5 test statistic (standard error) for the batch means data. Then the first batched data point is removed and the test statistic recalculated. This step is then repeated with the next first data point until there are no more values.

The warm-up period would then be 5 x the number of data points that were removed in order to produce the smallest test statistic value.

I have considered the fact that at peak times the data can be steady state at peak times at bread oven. But when visualising the data it is clear that the peaks are very short in duration and only occur at the start of each hour. This can be explained by the realisation that students arrive when a lecture ends. I plotted a time graph on arrivals count using python and realised that each of these peaks is different in size therefore considering this as steady state is wrong. In the group report a chi squared analysis was conducted which proved that the model is valid so there is no need to account for initial bias.

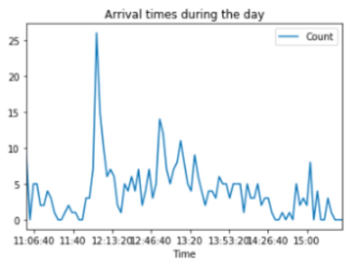


Figure 10

5.5 Conclusions of Experimentation

In figures 5 and 6 comparisons were made to see which data sets were the best. In this investigation because I am looking to minimise the total times spend in this system, I will take the least values. From these tables we can conclude that scenarios 4, 7 and 8 are the best solutions with 8 being the most effective. This is worked out by reading off the table and using the inequalities to identify the least variables.

According to this analysis, number of counters have the greatest effect on waiting times (scenarios 3,4,7, and 8 are amongst those that have the least mean times as shown by left table on figure 5) . This can be explained by the fact that there is an alternative route for the queue so customers wait less in the initial queue which has the greatest waiting times. This is further enhanced in scenarios 8 where there are more staff members and cashiers on standby to serve customers. Therefore if the constraints such as budget and space permit, an additional counter would be the best solution.

In my model I consider staff to be full time members but in reality most are part time workers so when considering scenarios with more workers, you may have to hire more than the recommended range. I also assumed based on my floor plans and visuals that the maximum number of counters can only be two but this may give impression that the restaurant is overfilled and not spacious so the manager may my against this idea.

There were other ways to improve service times such as better utilisation of staff but this was not considered as this is not a quantitative experimental factor. In the previous report it was concluded that fixing servers position reduced waiting times by 11% so if the budget proves to be little then these ideas must be further explored. It may be that better utilisation of staff in scenarios may reduce times ever further and may have a greater effect on scenarios with more servers where scenarios 2 and 3 may be more effective than the recommended scenarios.