Title: Case study of Simulation of Supermarket Operation

Module Name: Simulation for Managerial Decision making (BNM802).

Table of content

1. Introduction:

The aim of this report is to optimize staff allocation and minimize customer waiting time in the queue for checking out in a hypothetical supermarket. Here we will be using discrete event simulation modelling for the as-is along with to-be situation using arena software. The main goal is to increase customer satisfaction based on comparison of these two scenarios.

In a world where customer satisfaction has been a predominant factor in determining the quality of an establishment, it is of fundamental importance to offer quality services, and in addition, to have better products and services to attract more customers. (Pereira Junior et al., 2020).

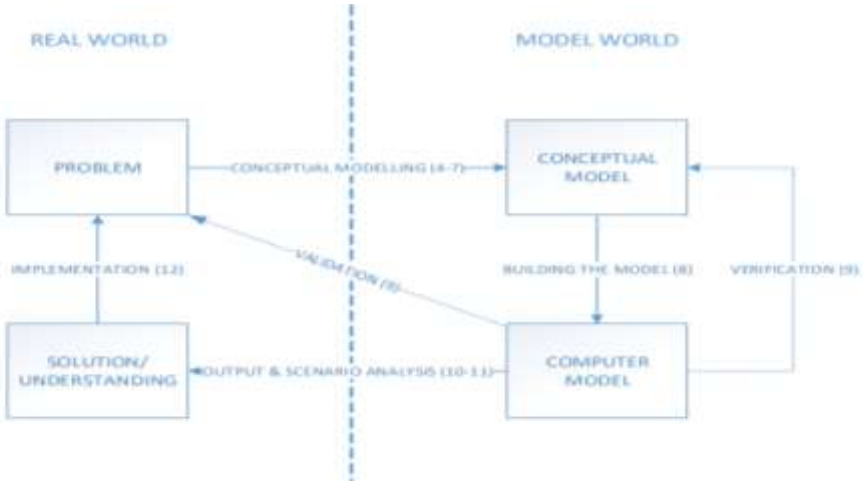


Figure 1 Simulation Modelling (from module content on blackboard)

2. Conceptual Model Development:

Conceptual modelling is the abstraction of a simulation model from the real-world system that is being modelled; in other words, choosing what to model, and what not to model (Robinson, 2013).

a) Elements of Conceptual Model Development are discussed as follows:

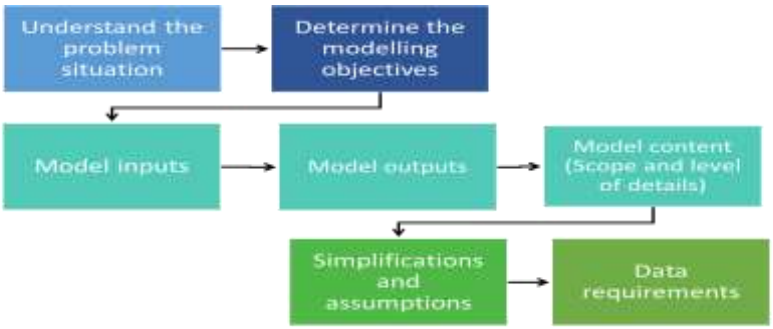


Figure 2Conceptual Model Development

Objectives:

To review and simulate the typical supermarket operation to optimize staff allocation and minimize customer waiting time in the checkout queue. Here we are using a discrete-event simulation (DES) models because in DES, the operation of a system as a (discrete) sequence of events in time. (*Discrete-event simulation*, Wikipedia, 2024)

Inputs:

Customer Arrival Rate: The customers arrive at the supermarket at a steady rate of 100 per hour (given).

Customer Service Times:

Time spent by customer in supermarket- Minimum 20 minutes, most likely 30 minutes and maximum 40 minutes (Lake, 2020).

Waiting time spend by customer in Manual checkout line is having triangular distribution with values (Minimum 5 minutes, most likely 6 minutes and maximum 8 minutes) (Pereira Junior et al., 2020).

Waiting time spend by customer in Self-checkout line is maximum 4 minutes so we assume it as triangular distribution (Minimum 2 minutes, most likely 3 minutes and maximum 4 minutes) (Team, 2023).

Percentage of customer choosing self-checkout process = 58% (Team, 2023).

Assign staff Allocation: 10 cashiers available to operate the manual cash counters (given).

Layout of Supermarket: Supermarket has of 25 cash/checkout counters.10 of the total 25 are self-checkout counters. This supermarket operates 24 hours (given).

Outputs:

1. Number of customers in and out of the supermarket.
2. The average time that customers spend in each queue.
3. Staff Utilization outputs.
4. Number of customers who used Manual Checkout counters and self-checkout counters.

Content:

Entities: Individual Customers

Checkout Counters- This are discrete entities shown as the place where customer queues for checkout (Manual checkout counter and Self-checkout counter)

Queues: Checkout queues at both manual and self-checkout counters

Resources: Staff members operating the checkout counters.

Record: Module used for recording the number of customers using checkout counters.

Service time: The total time that customers spend in the supermarket including selection of their items and in the checkout queue before leaving the supermarket.

Assumptions:

Here we are investigating a hypothetical supermarket, so we need to consider some of the following assumptions before simulating the supermarket.

- Supermarket runs 24 hours.
- Customer arrives independently at steady rate of 100 per hour.
- Customers follow a typical pattern of shopping their goods. They stay in the same queue until billing and checkout.
- Service time is considered based on typical supermarket operation.
- 10 people are available to operate manual cash counters while running the simulation model.
- Supermarket follow first come first served rule throughout the operation.

Simplifications:

Number of checkout counters stays constant during simulation model.

All manual checkout counters provide same service time to all the customers.

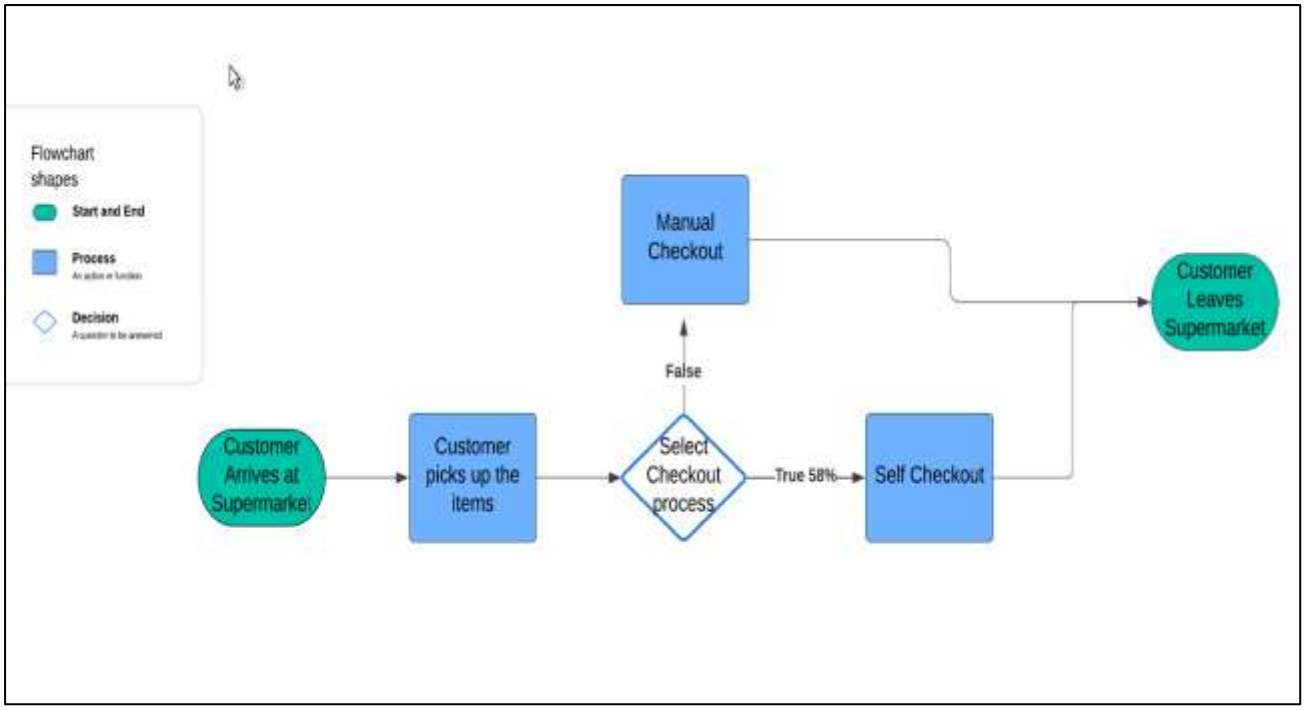
Factors like peak hours, Holidays, weather conditions are not considered because they can cause complexity for modelling.

Data Requirements:

- Number of both manual and self-checkout counters.
- Customer data: Number of customers coming to supermarket.
- Service time for each Customer.
- Staff availability throughout the simulation period.
- Number of days and replication to run the model.

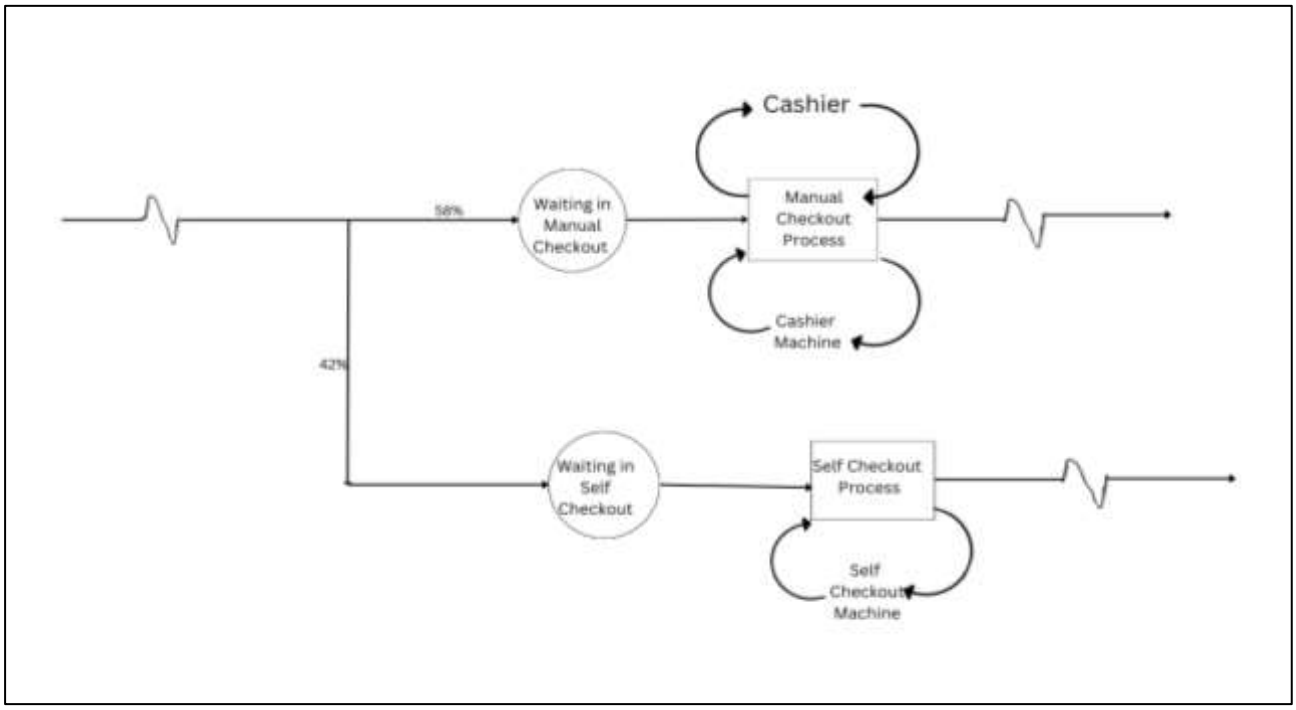
b) Process Flow Map:

Process flow map shows the flow of activities throughout the operation.



c) **Activity Cycle Diagram:**

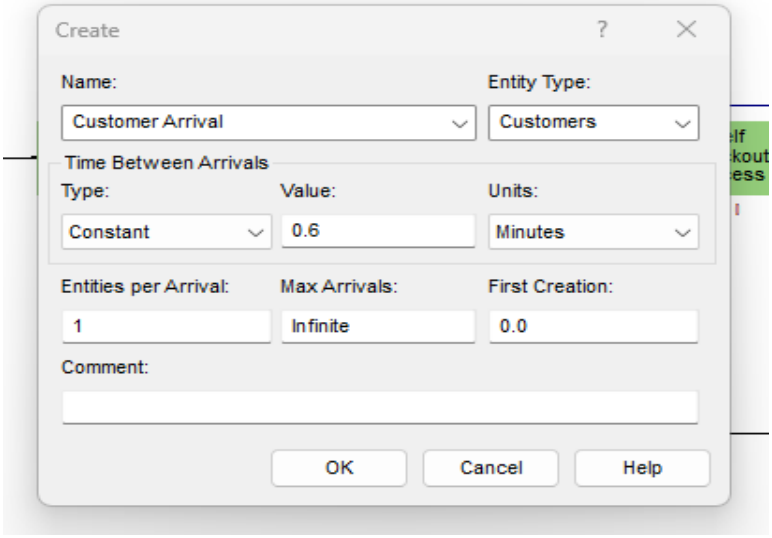
Activity cycle diagram shows the resources used at each process and outlines the queues.



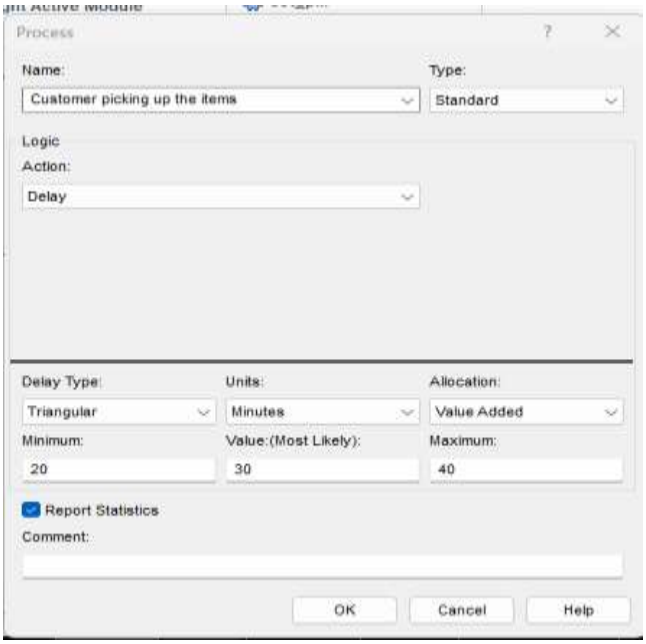
3. Simulation Model Development:

To model the operation of supermarket, Rockwell software Arena is used.

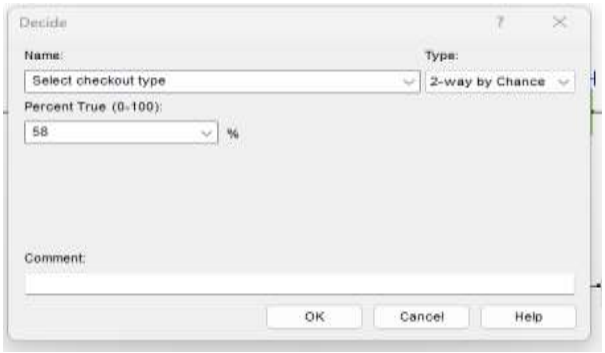
To describe the customer arrival at the supermarket, “Create” is used and named it as “customer arrival”. Entity type as customer and Inter arrival time is set as 0.6 minutes since it is given that there are 100 customers per hour coming into the supermarket at constant rate. Refer to the image.



After entering the supermarket, customer picks up the needed items. It is represented by “Process” module. Here customer spends time with triangular distribution (minimum, most likely, maximum) = (20 min, 30 min, 40 min). Here we use delay because each customer does individual shopping and spends time before he reaches the checkout line. Refer the image.



Now customer heads towards the checkout area. Here customer have to select between Manual checkout process and self-checkout process. To represent this, we introduce “Decide” Module. We name it as “select checkout process” and type as 2-way by chance because customer selects checkout process randomly and it is different for every customer. The percentage for true are entered from the input data. Refer image.

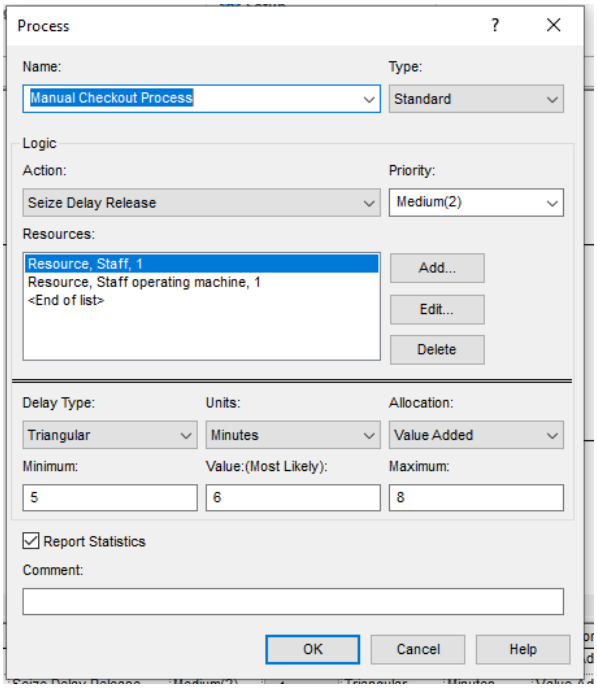


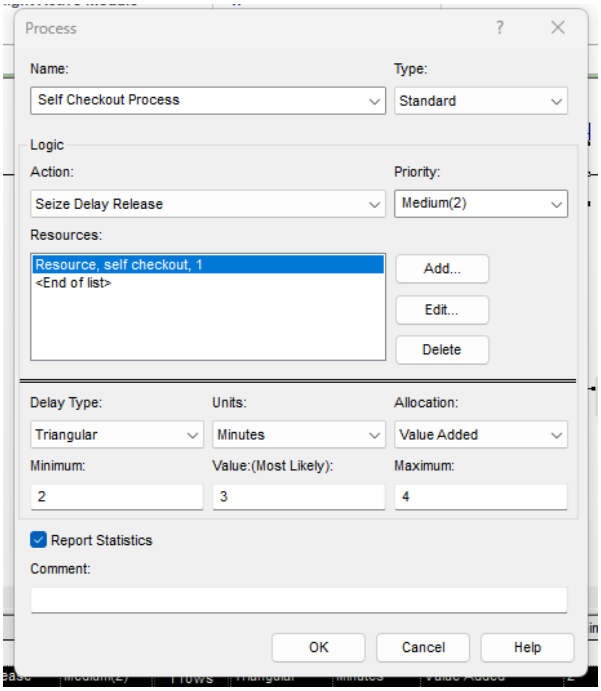
So, there are 58% chances that customer will choose self-checkout process. We create two process modules for each self-checkout and manual checkout process.

For Manual checkout Module, we have set the action of logic as “seize delay release” because we are using resources – cashier and cashier machine. We need to seize the cashier machine and the cashier until they complete billing process for individual customer. Billing process

cause delay and then after completing billing process, cashier can start billing for the next customer. The parameters are entered from the input data. Refer the image given below.

For self-checkout process, customer serves themselves by scanning the item and paying so here we just need one resource as self-checkout machine. Also, the logic of action will be seizing delay release because every customer does individual billing and in that process, we need to seize that particular machine. The parameters are entered from the input data.

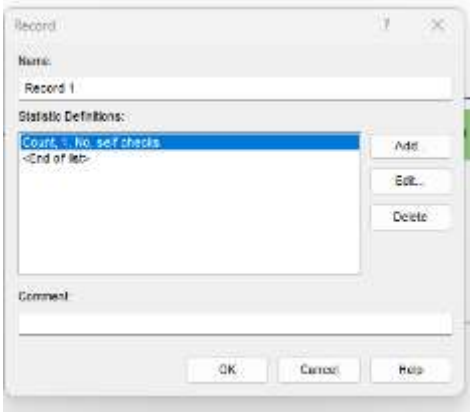




Now, we need to the record the number of customers for each type of checkout process. It is represented by record module in model.

For Self-checkout process, we represent it as Record 1 and set static definition as count. We do the same for Manual checkout process by naming it as Record 2.

At the end we represent customer departure by dispose module.



Now, we have given the resource capacity for each resource that needs to be entered by selecting resource module on the left panel, we can see the table at the bottom of the window. We set the capacity according to the given input data.

	Name	Type	Capacity	Busy / Hour	Idle / Hour	Per Use	StateSet Name	Failures	Report Statistics	Comment
1	self checkout	Fixed Capacity	10	0.0	0.0	0.0		0 rows	☑	
2	cashier	Fixed Capacity	10	0.0	0.0	0.0		0 rows	☑	
3	cashier machine	Fixed Capacity	10	0.0	0.0	0.0		0 rows	☑	

Double-click here to add a new row.

Since, we need to reduce customer waiting time and optimize the staff, we record the average waiting time in queue for customer. To do this in arena, we select output module and enter the following equations as follows:

TAVG (self. Queue.WaitingTime)

TAVG (manual. Queue.WaitingTime)

Also, we save both the output files as self.dat for self-checkout queue and staff.dat for manual checkout queue.

	Expression	Name/Report Label	Output File	Comment
1	TAVG(self.Queue.WaitingTime)	average self	C:\Users\LENOVO\OneDrive\Desktop\self.dat	
2	TAVG(manual.Queue.WaitingTime)	staff	C:\Users\LENOVO\OneDrive\Desktop\staff.dat	
	Double-click here to add a new row.			

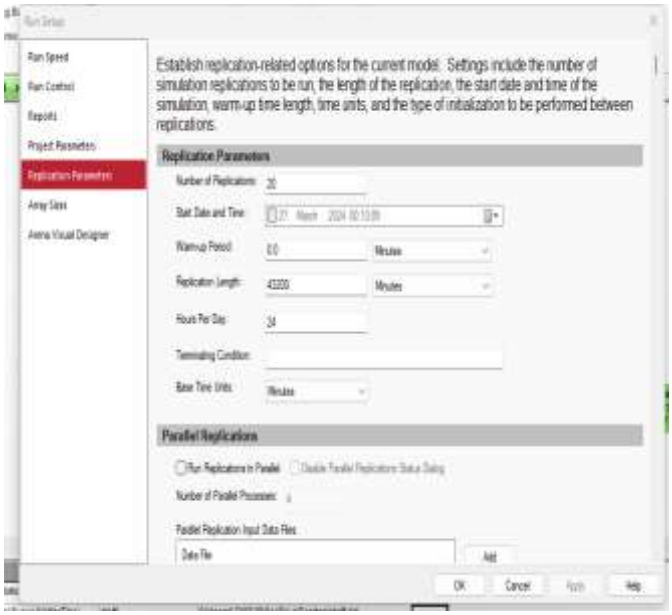
We finish modelling by setting up the parameters in the run tab from the toolbar.

Given supermarket operates 24 hours per day and we have asked to run the simulation model for 30 days with 20 replications. So, we set,

Replication length =30*20*60=43200 minutes.

For reports, we select SIMAN summary report. And click apply > Ok.

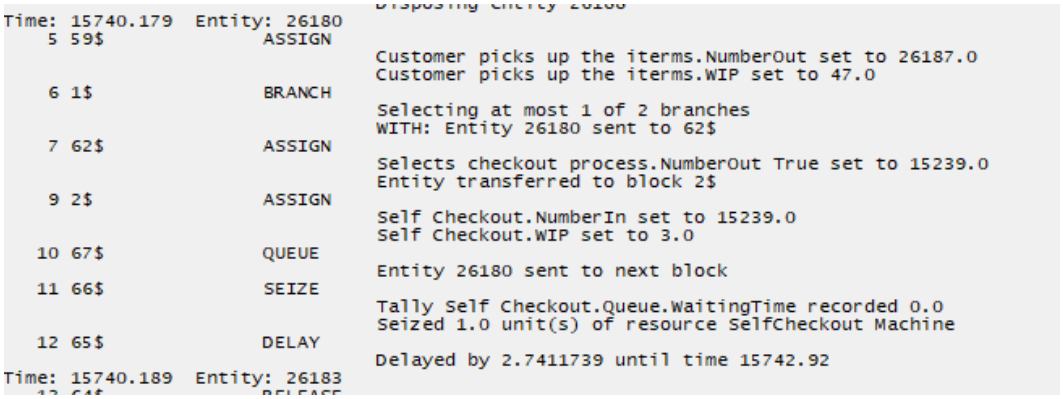
We finally check all the time units and set it as in minutes and finish modelling.



4. Verification and validation:

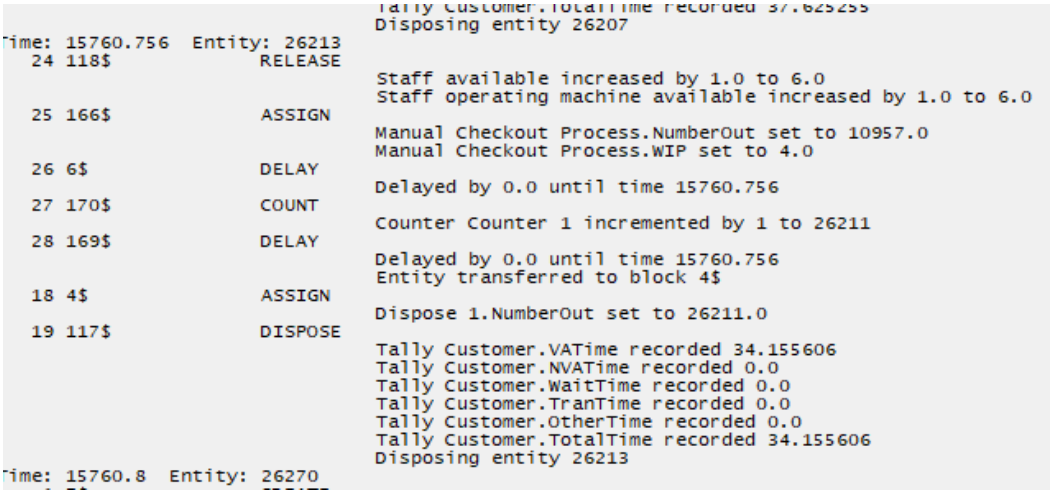
   Given supermarket is hypothetical so we will only verify our model since validation is done for the real-life examples. The techniques commonly used in dynamic testing are traces, investigations of input-output relations using different validation techniques, internal consistency checks, and reprogramming critical components to determine if the same results are obtained (Sargent, 2010).

   To do this, we give command “Set Trace” before running the simulation model. Then after completion of run time we get the following summary of activities:



Here it shows entity number = 26180

We can see the customer picking up the items and after that selecting the checkout process. Also, we can see that the self-checkout waiting time is being recorded. It is following the correct order of actions according to the input data.



From the screenshots above, the entities are getting disposed which shows that customers are leaving from the supermarket.

We verified our model by using trace analysis.

Validation:

Validation compares the simulation model outputs with the real-world system based on the assumptions and simplifications. Here, we are modelling a hypothetical supermarket system, therefore we cannot validate our model.

5. <u>Output Analysis:</u>
   For given hypothetical supermarket, we get the following report from simulation model:

ARENA Simulation Results
Digital Services - License: STUDENT

Output Summary for 20 Replications

Project: Unnamed Project
Analyst: Digital Services

Run execution date : 3/28/2024
Model revision date: 3/28/2024

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Manual checkout queue waiting time	.00472	3.2361E-4	.00348	.00612	20
Self checkout queue avg wait time	7.1805E-5	2.1671E-5	3.2009E-6	1.6926E-4	20
Customer.NumberIn	72001.	.00000	72001.	72001.	20
Customer.NumberOut	71943.	1.0351	71940.	71948.	20
Staff.NumberSeized	30205.	65.307	29983.	30491.	20
Staff.ScheduledUtilization	.44286	9.6839E-4	.43932	.44689	20
SelfCheckout Machine.NumberSeized	41744.	65.280	41461.	41968.	20
SelfCheckout Machine.ScheduledUtilization	.28991	4.6539E-4	.28783	.29144	20
Staff operating machine.NumberSeized	30205.	65.307	29983.	30491.	20
Staff operating machine.ScheduledUtilizat1	.44286	9.6839E-4	.43932	.44689	20
System.NumberOut	71943.	1.0351	71940.	71948.	20

Simulation run time: 0.20 minutes.
Simulation run complete.

Here, we can see that the total number of customers visited the supermarket are 72001 customers, but the number of customers left supermarket is 71943. This indicates that some customers entered supermarket but did not buy anything.

Number of customers used Self-checkout process =41744 customers and there is around 28% utilization of self-checkout machines throughout the operation.

Number of customers used Manual checkout process= 30250 customers and there is 44% utilisation of the Manual Checkout counters.

The average time spent in manual checkout queue is 0.0047305 minute and average time spent in self-checkout line is very low 7.18055E-5 minutes.

Our aim is to reduce waiting time and optimize the staff, so we try running simulation by reducing the resources. We get the following results:

Staff resources	Machines operated by staff	Self-checkout machines	Results
7	6	10	Error
8	7	10	Error
6	7	5	No error
5	6	4	No error

The output is shown below:

ARENA Simulation Results
Digital Services - License: STUDENT

Output Summary for 20 Replications

Project: Unnamed Project
Analyst: Digital Services

Run execution date : 3/28/2024
Model revision date: 3/28/2024

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Manual checkout queue waiting time	2.5626	.07897	2.3101	2.8184	20
Self checkout queue avg wait time	.00787	2.7783E-4	.00705	.00915	20
Customer.NumberIn	72001.	.00000	72001.	72001.	20
Customer.NumberOut	71941.	1.1301	71938.	71946.	20
Staff.NumberSeized	30234.	72.648	29995.	30468.	20
Staff.ScheduledUtilization	.73866	.00176	.73262	.74434	20
SelfCheckout Machine.NumberSeized	41714.	72.312	41479.	41949.	20
SelfCheckout Machine.ScheduledUtilization	.41382	7.2219E-4	.41132	.41608	20
Staff operating machine.NumberSeized	30234.	72.648	29995.	30468.	20
Staff operating machine.ScheduledUtilizati	.88640	.00212	.87914	.89321	20
System.NumberOut	71941.	1.1301	71938.	71946.	20

Simulation run time: 0.20 minutes.
Simulation run complete.

From the output summary, we can see that, although the waiting time in manual checkout line is increased but staff is utilised up to 73% and self-checkout machines are used up to 41%. After reducing the resources further, we ger the following output summary:

ARENA Simulation Results
Digital Services - License: STUDENT

Output Summary for 20 Replications

Project: Unnamed Project
Analyst: Digital Services

Run execution date : 3/28/2024
Model revision date: 3/28/2024

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Manual checkout queue waiting time	.53221	.00969	.49263	.57295	20
Self checkout queue avg wait time	.11283	.00178	.10530	.12080	20
Customer.NumberIn	72001.	.00000	72001.	72001.	20
Customer.NumberOut	71942.	1.0766	71938.	71948.	20
Staff.NumberSeized	30214.	62.781	30004.	30487.	20
Staff.ScheduledUtilization	.73813	.00160	.73300	.74497	20
SelfCheckout Machine.NumberSeized	41734.	62.511	41464.	41945.	20
SelfCheckout Machine.ScheduledUtilization	.57961	9.0435E-4	.57599	.58236	20
Staff operating machine.NumberSeized	30214.	62.781	30004.	30487.	20
Staff operating machine.ScheduledUtilizati	.63268	.00137	.62828	.63855	20
System.NumberOut	71942.	1.0766	71938.	71948.	20

Simulation run time: 0.20 minutes.

Here we can see that, average waiting time in manual checkout queue is reduced to 0.53 minutes, the staff utilisation is about 73% and self-checkout machine utilisation is 63%. Therefore, we will consider this is optimized system of supermarket with following resources:

Staff = 5

Machine operated by staff = 6

Self-checkout machines =4

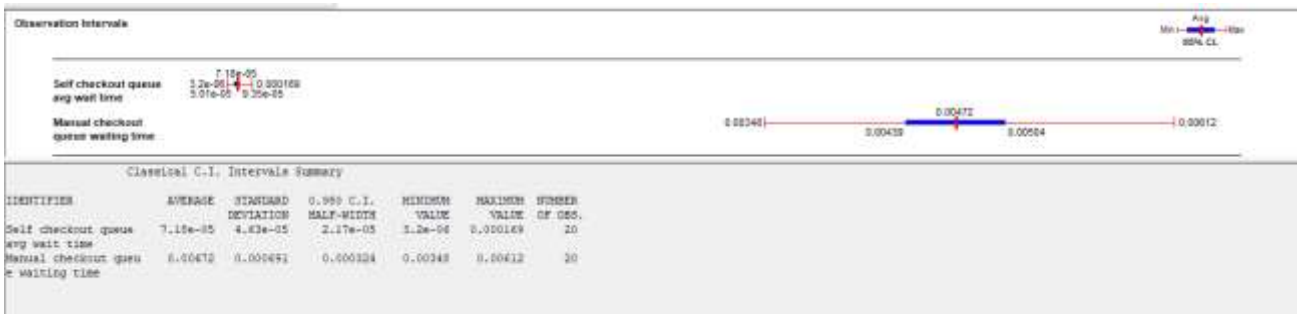
6. Scenario Analysis:

In the as-is scenario, the supermarket had 10 people operating manual checkout machines, 10 self-checkout machines and the supermarket was running 24 hours for 30 days. We observed that the resource utilization was comparatively low.

In to-be scenario, we reduced the resources and got high percentage of utilisation of the resources. The comparison of both these scenarios are done on basis of confidence interval. It is shown below:

From the images, we can see that the confidence intervals are not overlapping. It shows that these two processes are statistically independent, and they are producing statistically significant outputs. For both the queues, 95% confidence interval is considered.

As-is scenario:



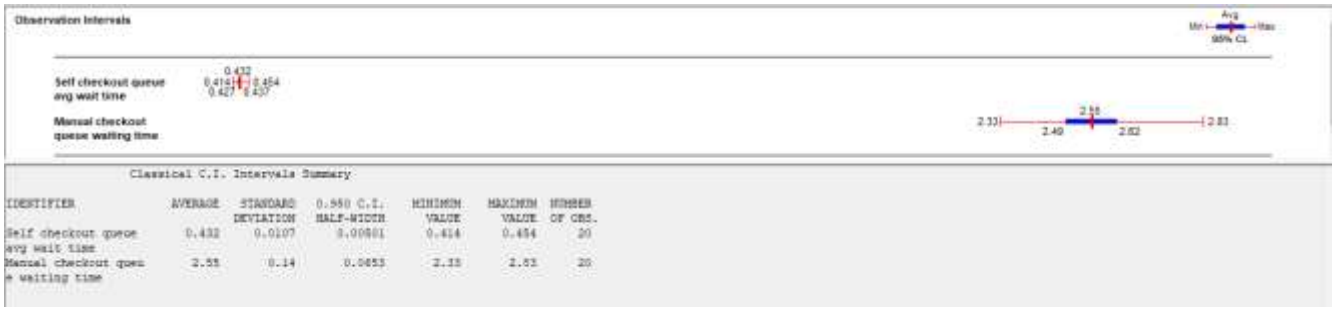
Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Self checkout queue avg wait time	7.18e-05	4.63e-05	2.17e-05	3.2e-06	0.000169	20
Manual checkout queue waiting time	0.00472	0.000491	0.000324	0.00348	0.00612	20

Confidence intervals gives estimate of where the true average wait times for the entire population might lie, with a 95% level of confidence.

The short confidence interval for self-checkout queue shows high accuracy for average wait time estimate. The average wait time in self-checkout queue is approximately 0.0000718 minutes. The average wait time in manual checkout queue is approximately 0.00472 minutes.

To-be scenario analysis:



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
Self checkout queue avg wait time	0.432	0.0107	0.00501	0.414	0.454	20
Manual checkout queue waiting time	2.55	0.14	0.0653	2.33	2.83	20

The average waiting time for manual checkout queue is estimated at 2.55 minutes. The confidence interval for manual checkout is wider than the self-checkout, indicates that less accuracy in estimation of average waiting time for manual checkout.

7. Conclusion:

In conclusion, we analysed the hypothetical supermarket to optimize their staff and increase customer satisfaction. The input data was taken from research papers. Model is verified with trace analysis, and they are compared on basis of confidence intervals. We optimized the operation by reducing the resources. It is suggested that supermarket should keep both manual and self-checkout process because 42% customer prefer manual checkout process.

8. Reflection

In this course, we learnt how to simulate real business processes using Arena and do statistical analysis to make managerial decisions. These skills will help us to do data analysis more effectively and precisely.

9. References:

1) Pereira Junior, J.V., Silva, A.M. and Moraes, D.G. (2020) 'Discrete simulation applied to queue management in a supermarket', Independent Journal of Management & Production, 11(5), p. 1667. doi:10.14807/ijmp. v11i5.1296.
2) Robinson, S. (2013) 'CONCEPTUAL MODELING FOR SIMULATION', School of Business and Economics Loughborough University Loughborough, LE11 3TU, UNITED KINGDO, p. 377. Proceedings of the 2013 Winter Simulation Conference
3) Lake, R. (2020) *Grocery shopping statistics: 23 fun size facts to know*, *CreditDonkey*. Available at: https://www.creditdonkey.com/grocery-shopping-statistics.html (Accessed: 26 March 2024).
4) Team, S. (2023) *18 Self-Checkout Statistics You have been waiting for (2024)*, *Soocial*. Available at: https://www.soocial.com/self-checkout-statistics/ (Accessed: 26 March 2024)
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6) WikiPedia (2024) *Discrete-event simulation*, *Wikipedia*. Available at: https://en.wikipedia.org/wiki/Discrete-event_simulation (Accessed: 26 March 2024).