Joseph Barrett, Kenneth Ehete,
Sean Quinney, Yuhui Liu, Jiayuan
Zhang

MAT021 Group Project – Group 21

Joe Barrett, Kenneth Ehete, Sean Quinney, Yuhui Liu, Jiayuan Zhang

Purpose of the model

Our research explored the simulation of a local petrol station (Excelsior Tesco). Tesco offers 16 petrol pumps. Four pumps of which are pay at pump, and 12 pumps of which are cash only. Tesco offers both Unleaded and Diesel fuel in their supply (combined in many of the pumps). The Tesco Station also offers a small market where drivers can walk inside, buy a quick snack, and continue their drive.

To address this question, three types of customers were identified. First, those who buy petrol and visit the store. Second, those who only buy petrol. Lastly, those who only visit the store.

Experimentation Aims

The goals of this project were to complete a simulation optimisation project. Our model aimed to answer the question: **How many pumps are needed to maximize throughput of the busiest hour of a day when customers both do and do not go into the convenient store?**

Data

Data Sources

Methods of data collection involved timing cars as they entered the petrol station, lapping the time spent, and keeping detailed records in a shared excel notebook. Data was collected from 12:00-13:00 on November 3, 2022. The sample size was 173 observations.

1. *Time of Entry*
2. *Time of Arrival at Pump*
3. *Time of Car Finishing at Pump*
4. *Time of Exit*
5. *Type of Customer*
6. *Time Spent in Store*

From the above collection, the following variables were calculated:

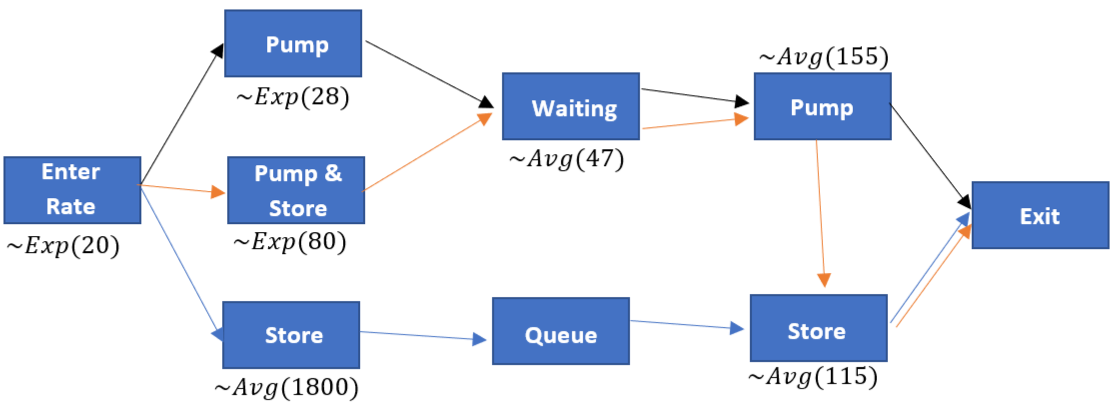
1. *Total Time on Property =* Time of Exit – Time of Entry
2. *Time in Queue =* (Time of Arrival at Pump – Time of Entry) - average time to pump with 0 queue
3. *Time Spent at Pump =* Time of Car Finishing at Pump – Time of Arrival at Pump

Pre-Processing

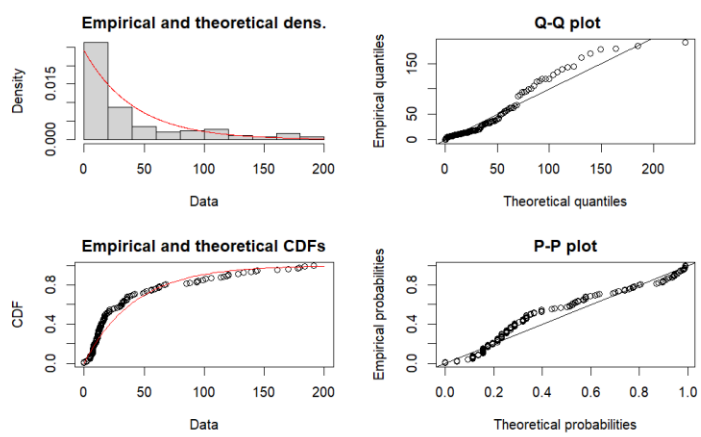
One outlier was identified. We chose not to exclude the outlier as exit time did not vary significantly from the max value's exit time. To identify distributions of data, collections were filtered by customer type. All time was converted into seconds allowing for integer processing.

Input Parameters

Customer types are defined to be Exponential input variables. Our model must also consider the entire time a customer is on property. The model has tracked the type of customer moving through the simulation, graphically represented in the red, blue, and green model below with corresponding distributions. Since driving conditions are stochastic time-varying sequences, their changing rule is nonlinear and irregular. It follows that since most customers of a petrol station arrive by car, the data collected were stochastic time-varying continuous sequences. The calculations for achieving these distributions are below, the package *fitdistrplus* in R was used for distribution fitting. The rate of customer intake was subset to each input variable below.

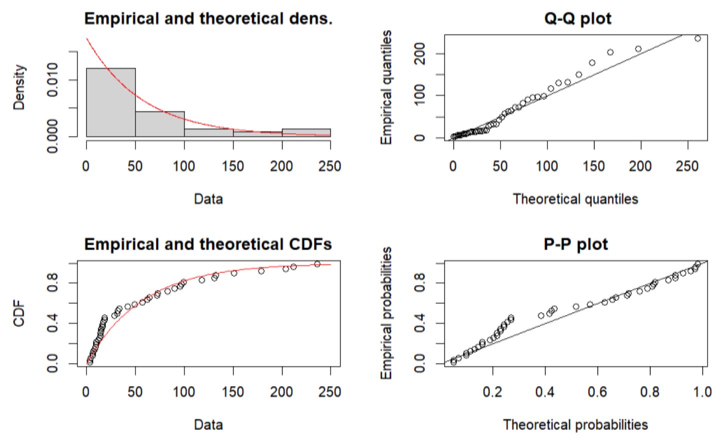


- Pump Only (126 customers)
  - Data for customers only using the pump was used as input for waiting times the petrol queue. be used to calculate queuing times, The graphical representation below further confirms customer input distributions are exponential.



  - Parameter Calculation: $\frac{60 \cdot 60}{126} = 28 \sim \exp(28)$
- Pump and Store (45 Customers)

- Similarly, data for customers only using both pump and store will be immediately used in the creation of the waiting list for the gas pump. These customers will be tracked as they follow a path through to the store.



- Parameter Calculation: $\frac{60 \cdot 60}{45} = 80 \sim \exp(80)$

- Store Only (2 customers)
  - Store only input will be used to send an average distribution of customers directly to the store. Due to few customers shopping in only the store, and average distribution of 30 minutes (or 1800) seconds was chosen such that Store Only ~ avg(1800).
- Waiting Line (variable number of customers)
  - The waiting line provides a place for customers to queue prior to pumping gas after entering the property. The average time in queue was 47 seconds, thus Waiting Line ~ Avg(47).

Assumptions

Parameter Values

A key assumption was developed from individual experiences, and location of the petrol station stating that only drivers would be the ones to visit the petrol station. Although there are rare cases, we feel confident a person walking would not walk to the petrol station store.

Distributions

An assumption of number of people in the store was made to be 1 person/30 mins.

Routing Logic

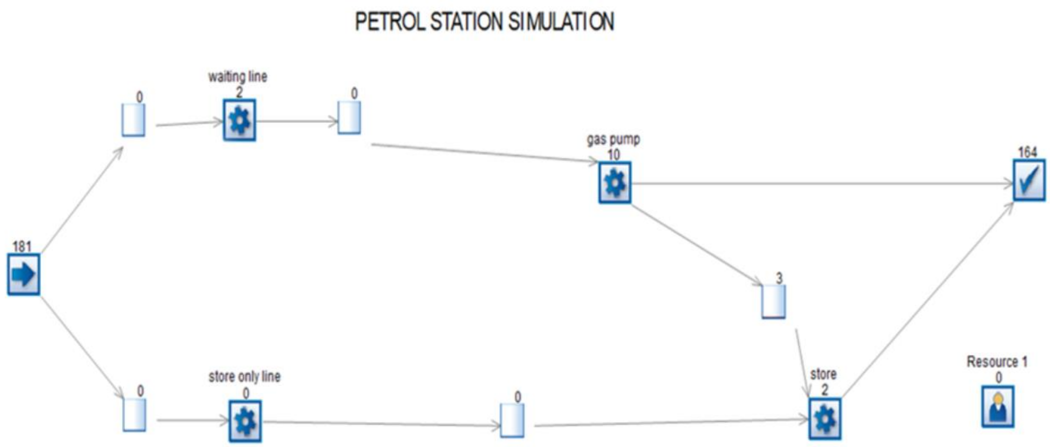
One may argue that six customers should be identified. As many pumps are connected, for purposes of this project, unleaded and diesel gasoline were considered to simply be the receival of petrol. Secondly, an assumption was made that there will only be eight queues based on real world situations (lines typically only form from one side of the pump).

Regarding the flow of our model, an assumption was made stating that a customer who both buys petrol and shops in the store will first park and fill up their car/truck. Although this could vary from different individuals, we felt this is a common practise observed within the petrol station.

Model Description

Base Model Overview Diagram

Below is a visual representation of the base petrol station model used in our simulation. Our model takes into consideration 3 types of customers namely, customers that would only require the pump facilities, customers that would require both the pump and store services and customers that would only require the store services.



Base Model Logic

As mentioned above, our model considers 3 types of customers:

1. Pump only customers
2. Pump and store customers
3. Store only customers

Once a particular customer crosses the entry threshold, their journey from waiting in the queue till they finally leave the petrol station is tracked and timed. On crossing the entry threshold, the pump only customer is going to have to queue initially as they wait for a gas pump to become available for use. Once a gas pump is available, they head towards it and fill their car, pay for the fuel once completed and finally leave the petrol station. The pump and store customer will also be subjected to a queue before getting to the gas pump, however, this type of customer while filling up their vehicle will visit the store as well and make some purchases before paying for the fuel and then leaving the petrol station. The final type of customer frequents the petrol station to only make use of the store facilities. That being the case, this type of customer crosses the entry threshold and is also subjected to a queue. The reason is there is no direct route to the store without passing through the gas pumps, so this customer will have to be subject to a queue until they can find a space pass through to get to the store. They purchase whatever brought them to the store and eventually leave the premises. The store as an activity has two physical staff working on alternating shifts throughout the day to ensure sales are made.

Scenario Logic

While we run the model as is, in its current state, it assumes that there is 100% efficiency across all the elements of the model. This in theory provides us with a perfect environment for the model to run without any type of interruption at any stage. However, from a practical and realistic point of view, having 100% efficiency across the board is something that is simply not attainable. Regardless of the type of system in place, there are always factors that hinder efficiency from being at 100%.

That being the case, some experiments we did with our model included varying the model's efficiency levels from 50% efficient, which is the case when a petrol station is undergoing maintenance and topping up of the fuel reserves, up to 90% efficiency. The reason for having this range is based on the normal functioning and operations of a petrol station, any interruptions to business activities would hinder efficiency by that range given the different circumstances of interruption.

Components

Entities

At the start point in the model, we have 3 types of customers that come to the petrol station. They are divided into: pump only customers, pump and store customers, store only customers.

- Pump only customers are those who come to the petrol station only to fill up their cars.
- Pump and store needed are customers who come to the petrol station to fill up and then go to the store to make a purchase before leaving.
- Store only customers are customers who come to the petrol station only to go to the store and leave once done.

From the data analysis carried out, the start point has an exponential distribution with an average of 20.

The waiting line activity represents the actual queue a customer would experience once they cross into the petrol station's entry threshold. This activity from analysis carried out has an exponential distribution with an average of 47.

The store-only line represents the queue customers would have to wait in before they can get to the store. This store only line has an average distribution with an average of 10.

The gas pump activity represents the physical pumps present at the petrol station. We replicated the activity 16 times to give an accurate representation of the petrol station that has 16 pumps available to customers.

The store activity assumes the role of the physical store at the petrol station. Customers interact with it, make purchases, and exit the store. The store makes use of the store staff resources who have alternating shifts as the day goes by. This activity is represented by an average distribution with an average of 115.

Activities

The model has four activities:

1. **Waiting line**

This activity involves pump only and pump and store needed customers waiting for a free pump.

2. **Store only line**

This activity involves store only customers waiting to enter the store.

3. **Gas pump**

This activity involves customers filling their car with gas.

4. **Store**

This activity involves customers going into the store physically and making a purchase.

Resources

The model has only one main resource that is utilized by the store activity. This resource is:

- Store staff – These staff members are located inside of the store and are the points of contact for any purchases inside the store.

Queues

The model has six queues:

- The two queues routing out from the start point refer to the time required from entering the gas station to the pump.
- The queue routing out from pump only activity refers to the waiting time for those customers to get a free pump.
- The queue routing out from pump and store activity refers to the waiting time for those customers to get a free pump.
- The queue routing out from store only activity refers to the time for those customers required to enter the store
- The queue routing out from gas pump activity refers to the time for pump and store needed customers required to enter the store.

Entry/Exit Point

There is an entrance and an exit on either side of the petrol station. So, we set one start point and one end point for customers to enter and leave.

Verification and Validation

Verification

To verify our model, we spent multiple sessions working in smaller groups to brainstorm how we felt the model should look and operate, by doing this, we were able to gain multiple perspectives and identify aspects one may not consider if working alone. Furthermore, we created logic flow diagrams to ensure we were not making broad assumptions, and we considered each logical decision an entity might have during the system.

Validation

To validate our model, we used the collected data on customer type inter-arrival time and average time spent at pump to inform the system, and then looked at the results from SIMUL8. We found that the proportion of customer types closely replicated what we observed during our data collection. This finding was consistent across multiple different random number streams.

Experimentation

Initialisation

The petrol station we have decided to model is a terminating system due to the well-defined operating times, namely, 06:00-22:00. In our system, we have only modelled the busiest one-hour period, therefore our model is terminating, and the terminating condition of the system is one hour elapsing from the start of the system. As we are modelling the busiest one-hour period, we have implemented a warm-up period to ensure the model represents the real-world petrol station. This is important as the busiest one-hour period is not at the start of operation, therefore we must run a warm-up period to 'fill' the petrol station with customers before we can start our simulation. We decided to run our warm-up period for one hour and modelled it using the same data we collected for the busiest hour. This is because we found that the busiest hour is not fixed every day and the flow of customers that arrive either hour around the busiest hour is of a similar amount.

Run length

The run length of our model is one hour as this provides the necessary data to answer the question, we are interested in. The time units we have used are seconds, the rationale behind this decision was our inter-arrival times during data collection were recorded in seconds.

Implementation

Software or Programming Language

Our model was created using SIMUL8, version 28, build number 4060.

Data analysis on our collected data was performed using R studio, Version: 2022.07.2+576, R, Version 4.2.1 along with the package *fitdistrplus, Version 1.1-8.*

Random Sampling

SIMUL8 uses random number streams to create random numbers which are then used in conjunction with the distributions we set to; populate the system with entities, determine times to fill a vehicle with gas and how long a customer takes in the store. By default, SIMUL8 keeps the random stream set number constant, this means every run of the simulation will yield the same results. One can set SIMUL8 to auto change the random number set on every restart of the simulation, which adds a level of stochasticity to the simulation.

Model Execution

In our model, there are no shared resources, therefore there are no priority rules for resources to be allocated to resources. Our model assumes that customers entering the waiting line follow a 'First in First out' rule and therefore there is no way for a customer to 'queue jump.'

System Specification

The specification of the machine used to run the simulation is as follows; Intel i7-1165G7 2.80GHz processor, 16GB RAM, 64-bit OS and simulation run time was less than 1 second.

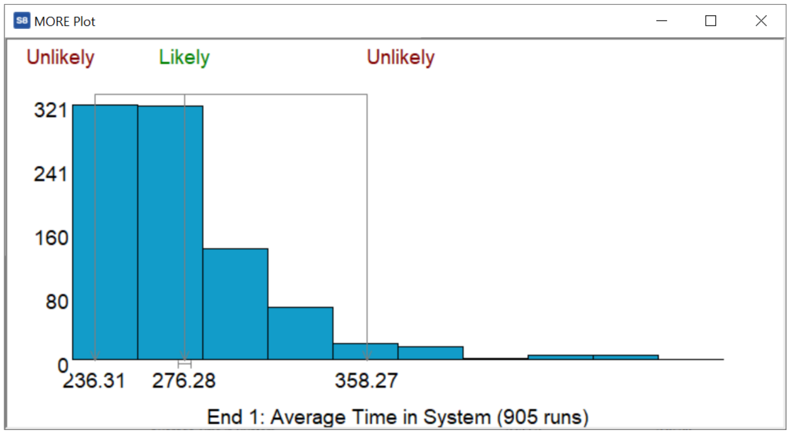
Experiments and Key Findings

The first trial we conduct is to understand how the most important key performance indicators (KPI) behave with the current petrol station setup. We are interested in KPIs (Key Performance Indicators) that are going to help us identify how many pumps are necessary to maximise throughput of the petrol station on the busiest hour of a given day. The KPIs we initially observe are;

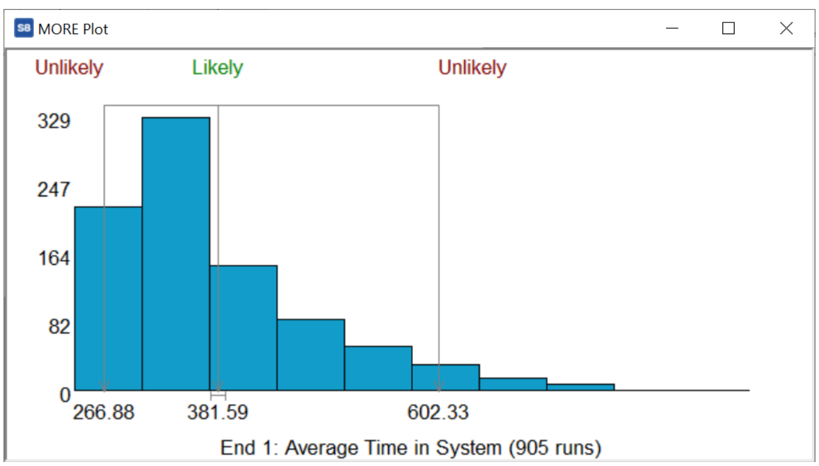
- Time spent in system
- Gas pump usage (average, maximum)
- Waiting line usage (average, maximum)
- Store staff utilisation

By observing these KPIs we will gain an understanding of the system over the hour period and insight into bottlenecks that are affecting throughput. Using the trial calculator on SIMUL8 and setting the confidence interval to 1% with the KPIs listed above, we are recommended to perform 905 runs to achieve our desired confidence interval.

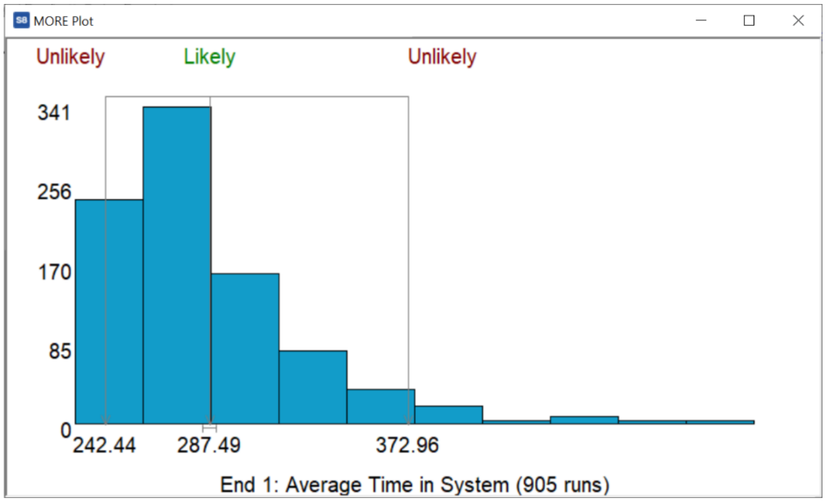
The scenario for the first trial is as follows; 16 pumps, 8 waiting lines, 2 members of staff. We set this as our initial scenario as this is the setup we first observed when collecting data. The results of the trial indicate on average 173 customers passed through and spent 276 seconds in the system. Furthermore, at any given moment during the one-hour period the average number of pumps being used was 7 and the maximum was 15. From the results, we also notice that on average only 2 customers are waiting in the waiting line at any given moment, and a maximum of 8 customers was observed during the one-hour period (This did not line up with our observations and is discussed later in the 'Limitations' subsection).



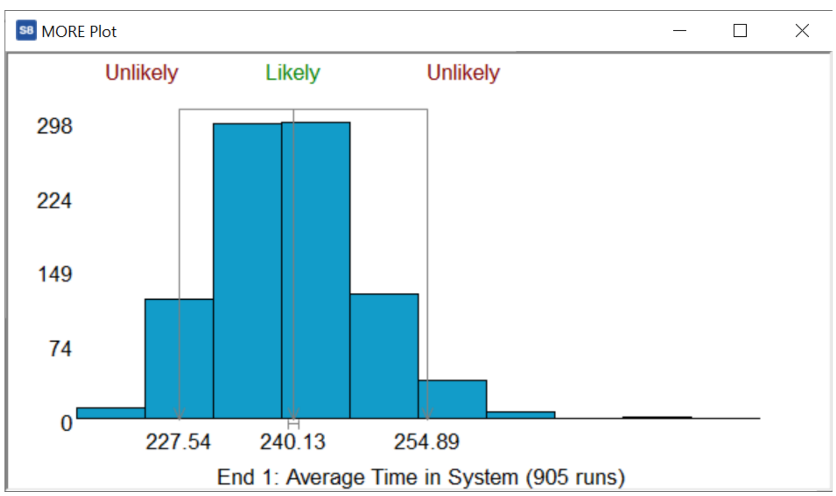
The first trial shed some interesting data on the number of pumps at the petrol station, namely, at any given moment on average only half the pumps are utilised. For our second trial, we set the number of pumps to 8, waiting lines to 4 and keep 2 members of staff in the store. Similarly, to the first trial, on average 173 customers passed through the system and spent 381 seconds in the system. From the data we can state that despite only having half the pumps available the same number of customers passed through the system in the one-hour period, however, on average it took them 72% longer to reach the end, this increase of time was waiting for a pump to become available.



For our third trial we were interested in trying to minimise the average time spent in the system by increasing the number of pumps by as little as possible. We initiated the trial with 10 pumps and 5 waiting lines and found the following data. On average 172 customers passed through the system and spent 287 seconds in the system. With this setup the petrol station was able to achieve similar average time spent in system with 6 less pumps and 3 less waiting lines than the 16-pump setup.



Finally, we conducted a trial to investigate to what extent does the number of staff members working in the store have on the average time spent in the system. For this trial, we used the first trial setup, but this time increased the number of staff members in the store to 3. From the results we observe a 36 second decrease in average time spent in system. This change has a greater impact than that of adding 6 pumps to a 10-pump petrol station as seen by the simulation results above. It is worth noting that adding another member of staff to the store, making the total members of staff equal to 4, does not yield such returns as before, instead this time only a 4 second reduction can be observed. This seems to indicate that 3 members of staff operating the store is beneficial to the business to maximise throughput of the petrol station.



Limitations

Limitations of our model are twofold. Firstly, a customer of the type ‘pump and store’ will leave the gas pump to enter the store and allow the next customer in the waiting line to occupy their space at the gas pump.

This is not observed in the real world, most commonly, a customer’s vehicle will occupy the gas pump until they have finished using the store facilities. This allows for customers to move through the simulation must faster than expected and explains why the waiting line average use is typically much lower than what we observed during our data collection.

Another limitation of our system is that it does not take into consideration nuance situations that we observed during data collection. Obscure situations such as a car wanting to enter from a different angle (I.e., creating n-number of queues, for n cars). A large vehicle occupying two gas pump spaces at one given time