Project Freight’s Data Analysis

In this simulation, we want to answer the question of how different variables, such as varying the number of trucks with no cars produced, varying the number of cars produced at each of the 5 *cargenerator* entity while fixing the number of delivery trucks, and varying the distribution of cars on horizontal roads, affect the production rate of a warehouse. We define production rate to be the number of parcels received at the warehouse over the time taken (hour) for trucks to reach the warehouse. To achieve our objective, we ran multiple simulations while varying one independent variable and fixing the rest of the variables. Our dependent variable will be production time, a measure of system performance that can be estimated in our simulation.

1) Data Manipulation

To obtain more accurate results, we conducted data cleaning to present our data clearly. Subsequently, we picked data points, which were steady-state averages from each simulation to ensure that data was not affected by initialization bias.

Data Cleaning

Some data cleaning is conducted in Excel. In Jaamsim, the data recorded by the ExpressionLogger entity outputs the data in a txt file format. When we imported this txt file into Excel, the raw data looks like Figure A as shown below *(refer to Figure 1)*. It was important to remove unnecessary information, from the SoftwareName to the Simulation PresentSimulation Time, as they were redundant for our data analysis. Columns with duplicate data from previous columns were removed too.

A	B	C	D	E	F	G
Simulatior	SoftwareName	JaamSim	-			
Simulatior	SoftwareVersion	2022-07	-			
Simulatior	ConfigurationFile	C:\SMA\SMA projec\project_freigh	-			
Simulatior	ScenarioNumber	1	-			
Simulatior	ScenarioIndex	{ 1 }	-			
Simulatior	ReplicationNumber	1	-			
Simulatior	RunNumber	1	-			
Simulatior	RunIndex	{ 1 }	-			
Simulatior	PresentTimeAndDate	Apr 11, 2023 16:41	-			
Simulatior	InitializationDuration	0	h			
Simulatior	RunDuration	8760	h			
Simulatior	PresentSimulationTime	0	h			
this.SimTi	([EntitySink4].NumberProcesse	[Simulation].SimTime)	([EntitySink4].NumberProcessed)/([Simulation].SimTi	[Simulation].SimTime)		
0	NaN[/s]	[Simulation].SimTime)	NaN[/s]	[Simulation].SimTime)		
0	NaN[/s]	[Simulation].SimTime)	NaN[/s]	[Simulation].SimTime)		
7.41E-05	0.0[/s]	[Simulation].SimTime)	0.0[/s]	[Simulation].SimTime)		
0.145278	0.0019120458891013384[/s]	[Simulation].SimTime)	0.0019120458891013384[/s]	[Simulation].SimTime)		
0.14541	0.0019103092937649392[/s]	[Simulation].SimTime)	0.0019103092937649392[/s]	[Simulation].SimTime)		
0.145566	0.0019082657569358247[/s]	[Simulation].SimTime)	0.0019082657569358247[/s]	[Simulation].SimTime)		
0.145605	0.0019077431622550344[/s]	[Simulation].SimTime)	0.0019077431622550344[/s]	[Simulation].SimTime)		

__Figure 1__: Raw Data of JaamSim output from txt format converted into Excel's xlsx format

Finally, units in the dataset such as [/s] were removed using the 'replace' command in Excel. We then obtained a cleaned datasheet such as Figure 2.

B	C
([EntitySink4].NumberProcessed)/([Simulation].SimTime)[/s]	([EntitySink4].NumberProcessed)/([Simulation].SimTime)[/h]
0	0
0	0
0	0
0.001879699248	6.766917293
0.001878502758	6.76260993
0.001876493583	6.7553769
0.001876172608	6.754221388
0.001874621385	6.748636986
0.001874206702	6.747144128
0.001872659176	6.741573034
0.0018709071	6.735265558

__Figure 2__: Example of Cleaned Data presented in Excel's xlsx format

Sensitivity Analysis (select steady-state average for each simulation)

Sensitivity analysis is used to assess how changes in one or more input variables affect the output of a simulation model. Sensitivity analysis was used to investigate the impact of three independent variables on the production rate of a car manufacturing plant respectively:

2a) Varying the number of trucks with no cars produced.
2b) Varying the number of cars produced at each of the 5 *cargenerator* entities while fixing the number of delivery trucks.
2c) Varying the distribution of cars on horizontal roads.

To obtain accurate and reliable results, we consider the steady-state of the system, which occurred when the production rate reached a constant average over time.

Determining Steady State Data

We first excluded the burn-in period where the production rate fluctuates widely due to the initial conditions of the system. We then identified the time point at which the production rate reached an approximated plateau, indicating that the system had stabilized. This point was selected as the steady-state average of the production rate for each simulation.

By analyzing the steady-state averages of the production rate for each simulation, we identified a reliable value of the production rate for us to conduct data analysis.

For instance, in Figure 3 below, the mean production rate was set to 180 seconds per car (mean production rate of 20 cars/hr), and steady-state was achieved 6 hours into the simulation. The burn-in period is from 0 to 2 hours, whereas the production rate started to stabilize at the 2 hours mark. We selected the data point at time= 6 hr as the steady-state average of the production rate. We followed the same procedure for the other simulations where we varied one of the following three independent variables:

- The number of trucks with no cars produced,
- The number of cars with a fixed number of delivery trucks
- The distribution of cars on horizontal roads.

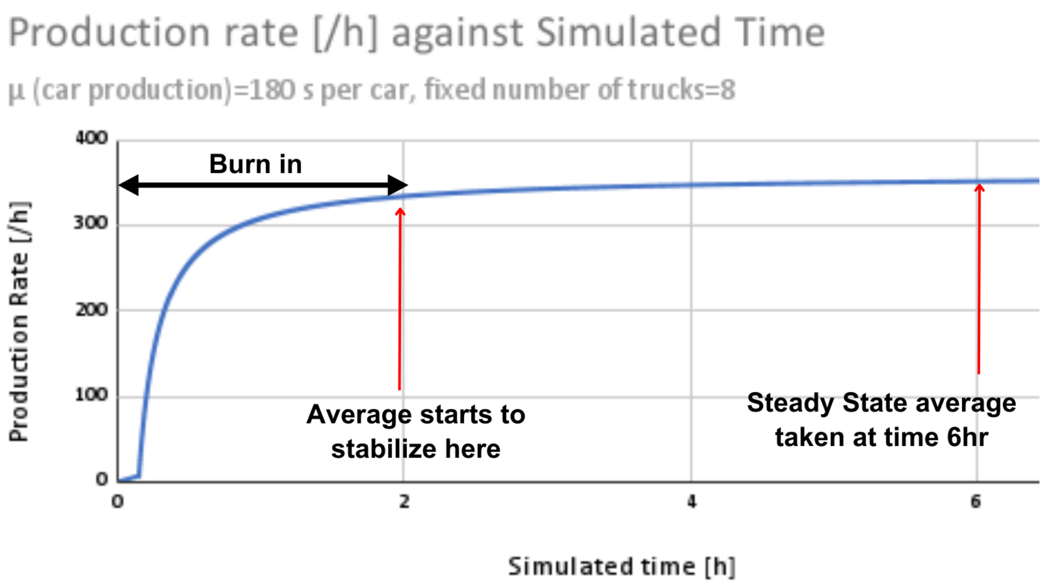

***Figure 3** : Demonstration of determining steady-state average and burn-in period in the simulation, where mean of car production is set at 180s per car and number of trucks=8*

2a) Varying the Number of Trucks, No Cars are Produced

To find out if varying the number of trucks on the road affects the production rate which is determined by the following formula in Jaamsim:

[EntitySink4].NumberProcessed)/([Simulation].SimTime [/h].

We changed the number of maximum trucks generated by Truck Generator entity. We hypothesize varying the number of trucks that will go on these roads will affect the volume of traffic on the horizontal and vertical roads, and as a result, affect the production rate at the warehouse.

Fixed Parameters

These are the parameters fixed in this simulation as shown in Figure 4 below. It is important to note we set the generation of cars at each CARtrafficgenerator to be 0 by setting the maximum number of entities to be generated to 0 in Jaamsim.

Time taken for each traffic light to turn red or green	200s
Number of trucks in the system	**Varying from 1 truck to 20 trucks**
Number of parcels per truck	10
Car production	
Number of cars on the road (By setting max number of cars at each CARtrafficgenerator to 0)	0
Parcel arrival	
Mean	1s
Standard deviation	2s
Distribution of truck arrival	
Mean	15s
Standard Deviation	10s

***Figure 4**: Table of parameters fixed in the “Varying the Number of Trucks, No Cars are Produced” Simulation*

Tabular summary: Varying the Number of Trucks, No Cars are Produced

We set the maximum number of trucks generated by the TruckGenerator entity to vary Truck numbers between 1 to 20 and ran the simulation. We then took the steady state averages of the production rate, which occurs at approximately time= 6 hr, and plotted these production rates. The table of the number of trucks and the production rate is shown in Figure 5.

No of trucks	([EntitySink4].NumberProcessed)/([Simulation].SimTime) [Per Hour]
1	43.33333333
3	132.0000012
5	220
8	351.3333333
11	351.3333333
20	351.3333333

Figure 5: *Table showing the varying the Number of Trucks against the production rate*

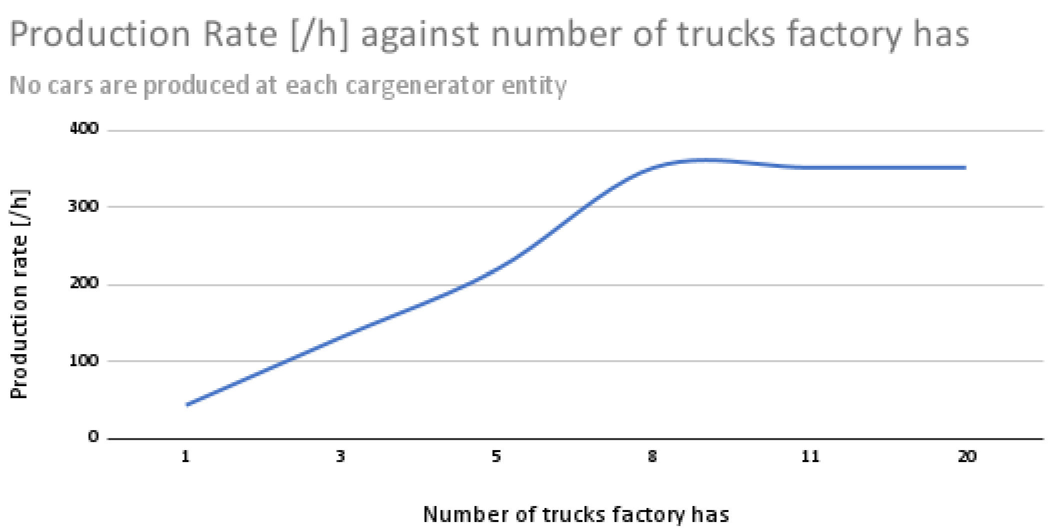

Figure 6: *Graph showing production rate against the total Number of trucks truckgenerator entity generates throughout the entire simulation*

Based on the graph, we noticed that the number of trucks is directly proportional to the production rate from 0 to approximately 8 trucks the factory (TruckGenerator) has. For values after 8, the production rate stabilises which suggests that the number of trucks the factory has far exceeds the rate of release of goods from the airport. This result is what we expect as beyond a certain point, the rate of trucks arriving at the airport to collect the goods far exceeds the rate of trucks leaving the airport to transport the goods to the factory warehouse.

2b) Varying the Number of Cars Per Hour, Fixed Number of Trucks

We want to find out if varying the number of cars per hour on the road affects the production rate which is determined by this formula in Jaamsim:

[EntitySink4].NumberProcessed)/([Simulation].SimTime [/h]

As such, we varied the mean number of cars produced at each traffic generator per hour. We hypothesized that increasing the number of cars per hour that will go on these horizontal roads will increase the traffic, and as such, reduce the production rate at the factory warehouse.

Fixed Parameters

These are the parameters we fixed in this simulation as shown in Figure 7 below.

Time taken for each traffic light to turn red or green	200s
Number of trucks in the system (optimum number of trucks determined earlier)	8
Number of parcels per truck	10
Car production	
Mean number of cars produced at each traffic generator in 1 hour	**Varying from 20 to 328 cars per hour**
Standard deviation for time taken for 1 car to be produced	2s
Parcel arrival	
Mean	1s
Standard deviation	2s
Distribution of truck arrival	
Mean	15s
Standard Deviation	10s

Figure 7: *Table of parameters fixed in the "Varying the Number of Cars Per Hour, Fixed Number of Trucks" Simulation*

Tabular summary: Varying the Number of Cars Per Hour, Fixed Number of Trucks
We vary the number of cars produced to simulate the traffic congestion according to the following values of 20, 30, 40, 60, 180, 240, and 328 cars per hour to obtain 7 different production rates as seen in Figure 8 below.

No. of cars per hour	([EntitySink4].NumberProcessed)/([Simulation].SimTime) [Per Hour]
20	351.3333333
30	351.3333333
40	351.3333333
60	351.1666667
180	351
240	351
328	335.6666667

Figure 8: *Table showing production rate against the Number of cars per hour at each CARtrafficgenerator entity*

Based on the graph (refer to Figure 9), we noticed that the number of cars generated at each CARtrafficgenerator entity is inversely proportional to the production rate from approximately 240 cars per hour generated at each car generator entity (to simulate the flow of traffic) onwards. For values before 240 the production rate stabilises, suggesting that below 240, the number of cars on the road is not significant enough to affect the production rate. This result is expected as beyond a certain threshold (approximately 240 cars per hour generated at each car generator entity), the number of cars on the road starts to become a hindrance to how fast the trucks are able to reach the factory warehouse.

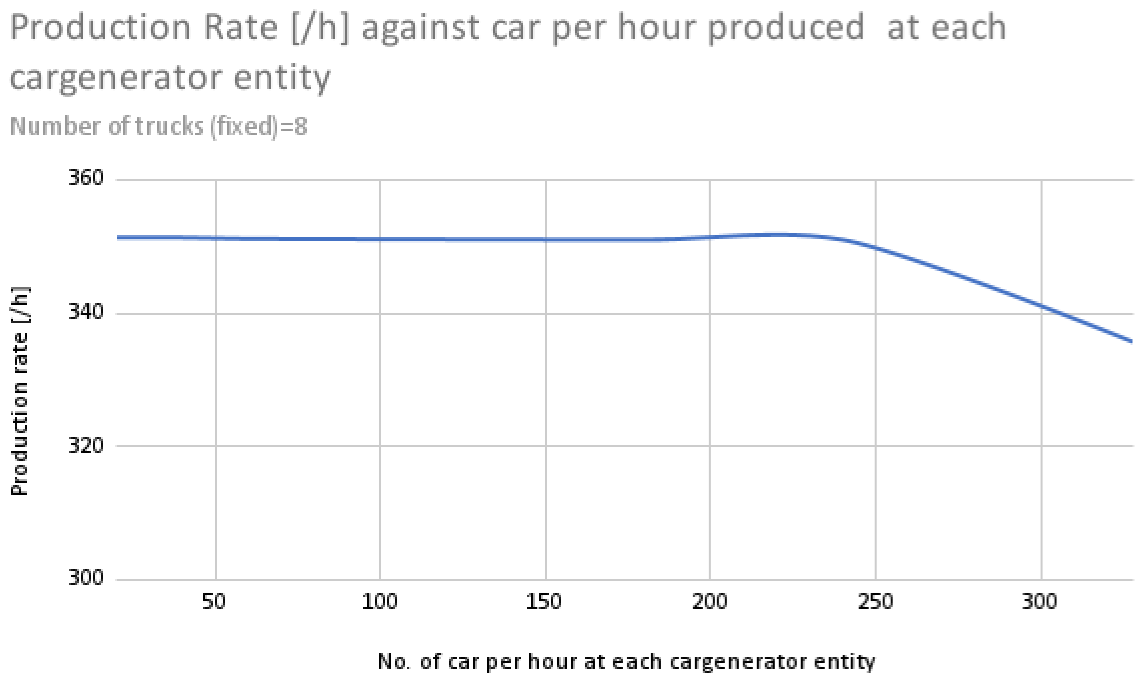

Figure 9: *Graph showing production rate against the Number of car per hour at each cargenerator entity*

2c) Varying the Distribution of Cars on Horizontal Roads

It is important to note that we set a rule where the cars have 2 options of going a certain route after reaching a junction: either along the vertical road or horizontal roads EntityConveyor6 or EntityConveyor16. This is determined by the DiscreteDistribution1 entity *(refer to the PowerPoint presentation for the rules of simulation).*

We want to find out if varying the distribution of cars on the horizontal road, EntityConveryor6 and Entity Conveyor16, affects the production rate [EntitySink4].NumberProcessed)/([Simulation].SimTime [/h]. Hence, we are going to vary the distribution of cars on the horizontal road by varying the probability of the DiscreteDistribution1 entity.

The horizontal roads (EntityConveryor6 and Entity Conveyor16) at the 2 junctions are also the route that the truck takes to the warehouse *(refer to Figure 10)*. We hypothesize varying the distribution of cars that will go on these horizontal roads will affect the traffic, and as a result, affect the production rate at the warehouse.

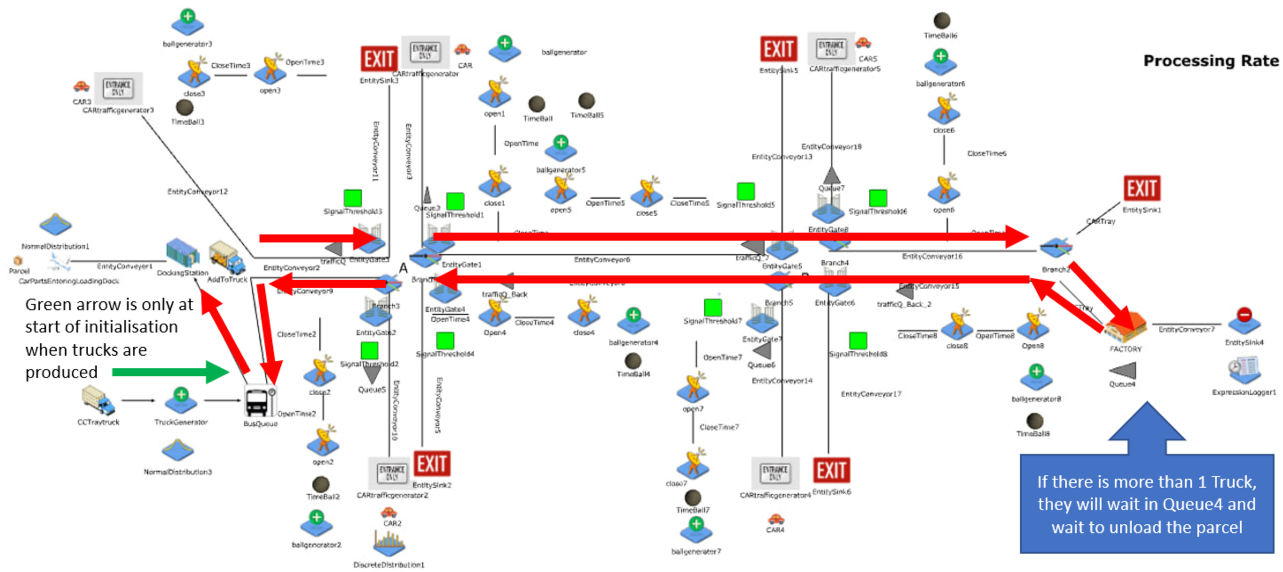

Figure 10: *Route of Truck in JaamSim Simulation*

Fixed Parameters

These are the parameters we fixed in this simulation as shown in *Figure 4*:

Time taken for each traffic light to turn red or green	200s
Number of trucks in the system (optimum number of trucks determined earlier)	8
Number of parcels per truck	10
Car production	
Mean number of cars produced at each traffic generator in 1 hour	Fixed (60 cars/328 cars)
Standard deviation for time taken for 1 car to be produced	2s
Parcel arrival	
Mean	1s
Standard deviation	2s
Distribution of truck arrival	
Mean	15s
Standard Deviation	10s

Figure 11: *parameters fixed while running simulations varying distribution of cars on horizontal roads*

Mean number of cars produced at each CARtrafficgenerator in 1 hour=60 cars

Tabular Summary: Mean number of cars produced at each CARtrafficgenerator in 1 hour=60 cars

Initially, we wanted to set the mean for the time taken for car production to be 60s/car for each of the 5 cargenerator entities, while varying the distribution of cars on the horizontal road to 0.20, 0.30, 0.40, 0.50, 0.60 and 0.70 respectively. However, after running the simulations while varying the distribution of cars on horizontal roads, we realized that the mean car production of 60 cars/hr (equivalent to the mean time taken for the production of 1 car: 60s for *each cargeneration entity*) does not affect the production rate regardless of the varying distribution of cars on the horizontal road as shown in Figure 9 below.

distribution of cars on horizontal road	Production Rate [/h]
0.2	351.1666667
0.3	351.1666667
0.4	351.1666667
0.5	351.1666667
0.6	351.1666667
0.7	351.1666656
0.8	351.1666667
0.9	351.1666667
0.99	351.1666667

Figure 9: Table showing the varying distribution of cars on horizontal roads against production rate with mean of car production= 60s per car

We plotted the production rates of each simulation at the timestamp, 6h, as production rate data would have reached a steady state in each simulation *(refer to "combined 60s mean for car data, varying dist on road" excel).*

As seen in Figure 10, the graph shows a horizontal line, with a trendline of y= -1.52*10E-6 x+351 with R=-0.003≈0 to the graph. With a small and negative correlation close to 0 of the trendline to the graph, this shows that there is no correlation of the distribution of cars on horizontal road to the production rate when the mean car production is fixed at 60 cars produced/hr (equivalent to mean for 1 car to be produced= 60s/car) for the simulations.

This emphasizes the point that setting the mean car production of 60 cars produced /hr does not affect the production rate, while varying the distribution of cars on the horizontal road. Hence, we must use another value of the mean of car production. The new mean of car production fixed should result in a notable change in production rate when the distribution of cars on horizontal road is varied and the mean of car production is fixed in each simulation.

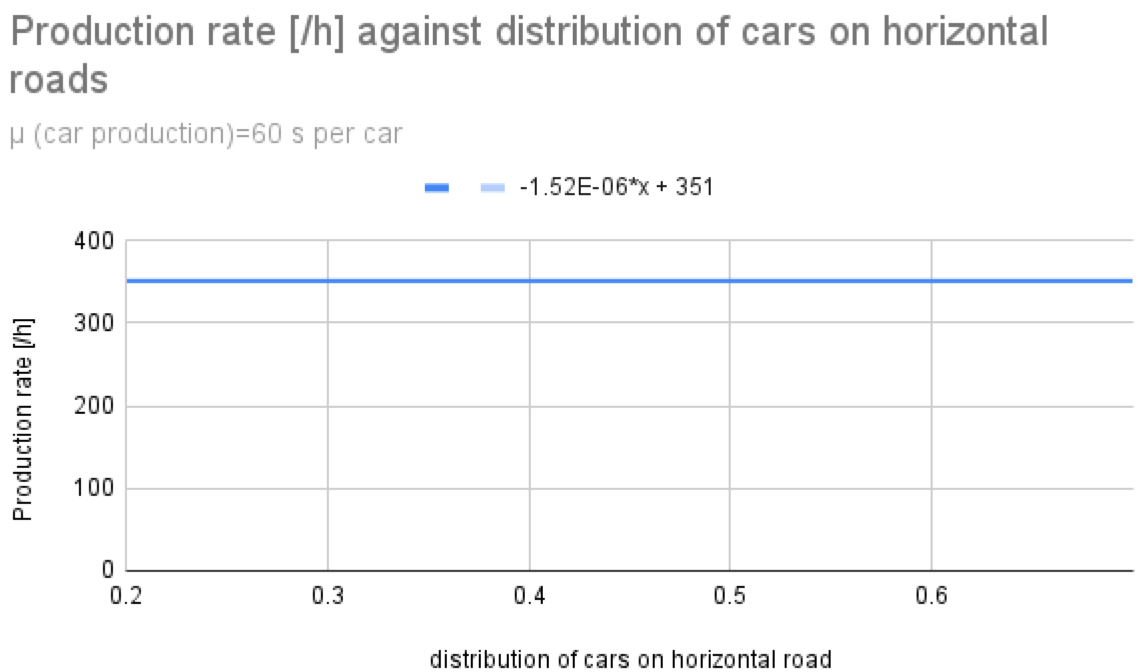

Figure 10: Graph showing production rate against the distribution along the horizontal road with mean of car production=60s

Mean number of cars produced at each CARtrafficgenerator in 1 hour=328 cars

Tabular Summary: Mean for Time Taken for Production of 1 car: 328cars for *each CARtrafficgeneration entity*

As shown in the "Varying number of Cars, fixed number of trucks" section, the mean of car production=328 cars per hour for each *cargenerator* entity results in a notable change in production rate. Hence, we set the mean number of cars produced at each CARtrafficgenerator to be 328 cars per hour (mean of the time taken for one car to be produced=11s) at each of the 5 cargenerator entities.

Varying the distribution of cars along the horizontal road to ratios of 0.20, 0.30, 0.40, 0.50, 0.60 ,and 0.70, we obtained the production rate against the distribution of cars along the horizontal road *(refer to Figure 11)*. We then plotted the production rates of each simulation at the timestamp, 6h, as production rate data would have reached a steady state in each simulation .

distribution of cars on horizontal road	production rate
0.2	335.6666667
0.3	333.8333333
0.4	333.8333333
0.5	332.3333333
0.6	332
0.7	330.6666667

Figure 11: Table showing the varying distribution of cars on horizontal roads against production rate with mean of car production = 328 cars per hour

In Figure 12 below, we see that as the distribution of cars on the horizontal road increase, the production rate decreases at fluctuating rates from the distribution of cars, where the production rate graph concave downwards.

The production rate decreases as the distribution of cars on the horizontal road increase, as such the amount of congestion along the route of trucks increases, and more time is spent in traffic. This shows that the distribution of cars on the horizontal road is inversely proportional to the production rate as expected. More time is spent in traffic to queue at *traffic junction B* as more cars are processed at the traffic light before the truck, allowing less time for the trucks to pass through before the light turns from green to red again due to the increased distribution of cars at to *entityconveryor6* located right before *traffic junction B*. At *entityconveyor16,* another horizontal road with varying distribution of cars located near the warehouse, there would be more cars that would be able to pass through the traffic before the trucks given the order of vehicles in the traffic queue, hence, this leads to more accumulated time for the truck to reach the factory warehouse. Hence, the production rate decreases due to increased time taken for trucks to reach the warehouse with the increasing distribution of cars on the horizontal road.

Hence, we can conclude that the distribution of cars on the horizontal road is significant to the production rate, where the production rate decreases with increasing distribution of cars on horizontal road.

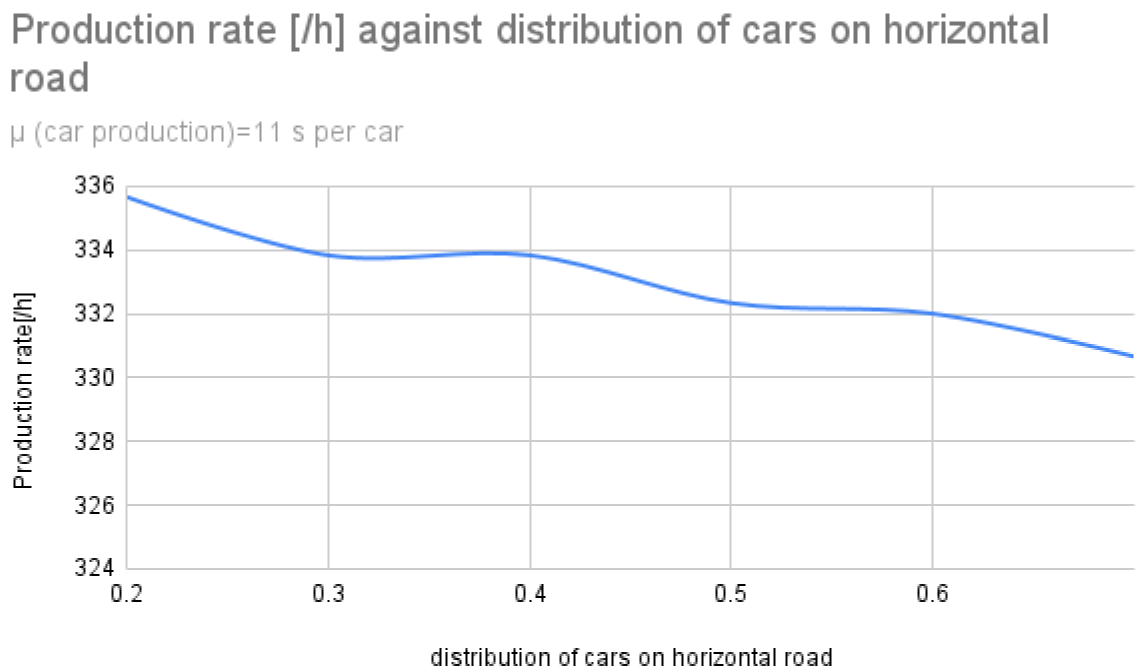

Figure 12: production rate against the distribution along the horizontal road, with mean of car production= 328 cars/hr (11s / car production)

Lessons Learnt

Firstly, we found that the production rate data is sensitive to the mean of car production for each *cargenerator* entity. Specifically, when the mean of car production for each *cargenerator* entity exceeds 328 cars per hour. This suggests that the production rate is only affected by a high enough volume of traffic of cars beyond this threshold.

Car Distribution

Additionally, we discovered that there is a relationship between the production rate and the distribution of cars on the horizontal road. We found that the production rate decreases as the time taken for a truck to reach the warehouse increases with an increasing distribution of cars on the horizontal road. This is because more time is spent in traffic, queuing at traffic junctions as more cars are processed at the traffic light before the truck, allowing less time for the trucks to pass through before the light turns from green to red again. This is because more cars will be able to pass through the traffic before the trucks, given the order of vehicles in the traffic queue. Consequently, this leads to more accumulated time for the truck to reach the factory warehouse, resulting in a decrease in production rate. Therefore, it is essential to consider the traffic conditions on the roads when trying to optimize production rates.

Number of Trucks

From this simulation, the factory can have an idea of how many trucks they should employ in order to reach the maximum production rate. From our simulation, 8 trucks should be employed. This can be used in a real-world context, where the number of trucks employed can be considered by factories in order to reduce transport costs.

Importance of considering traffic flow in production rate analysis

The report highlights the importance of considering traffic flow when analyzing production rates in transportation systems. The traffic flow affects the time taken for a truck to reach the warehouse and, therefore, affects the production rate. This insight can be used to optimize traffic flow in transportation systems to improve production rates.

Need for simulations in transportation system planning

The report demonstrates the value of simulations in transportation system planning. Simulations can be used to model various scenarios and identify potential issues before implementing changes in the real world. By simulating traffic flow and analyzing production rates, researchers can identify areas of concern and make recommendations for improvements. For example, if there is a high volume of traffic on a certain route, recommendations, such as implementing ERP (Electronic Road Pricing) on that route, can reduce the volume of traffic.

Importance of understanding system constraints

The report highlights the importance of understanding system constraints in transportation systems. System constraints can limit the production rate and affect the efficiency of transportation systems. By understanding system constraints, we were able to identify areas of improvement and make recommendations for optimizing the system.

A crucial system constraint we identified is the distribution of parcel arrival times. In our simulation,we set our parcel arrival to be 1s per parcel. In reality, this is not the case. Since parcels arrive at the dock based on the number of flights, it is important to consider factors that could impact flight or parcel arrivals. For instance, adverse weather conditions could hinder flights, causing parcels to arrive later or at a slower rate than anticipated compared to favorable weather conditions.

Overall, the report demonstrates the complexity of transportation systems and the importance of analyzing various factors that affect production rates. By understanding these factors, transportation system planners and operators can make informed decisions to optimize production rates and improve system efficiency.

Conclusion

In conclusion, we have investigated how different variables affect the production rate of a car manufacturing plant through simulation. We manipulated the data to obtain more accurate results and performed a sensitivity analysis to investigate the impact of three independent variables: varying the number of trucks and no cars produced, varying the number of cars produced at each of the 5 CARtrafficgenerator entities while fixing the number of delivery trucks, and varying the distribution of cars on horizontal roads. By analyzing the steady-state averages of the production rate for each simulation, we were able to identify a reliable value of the production rate. Our findings showed that increasing the number of trucks increases the production rate up to a certain point, after which the production rate stabilizes while increasing the number of cars generated at each car generator entity decreases the production rate. The distribution of cars on horizontal roads did not show a significant impact on the production rate. Overall, our results provide insights into how different variables affect the production rate of a car manufacturing plant, which can help improve efficiency and optimize the production process.