Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

ISE 4100 Spring 2020 Stochastic Modeling and Simulation
FINAL PROJECT (Group 15)

Introduction

The purpose of this report is to summarize Group 15's approach to the Last Mile Transportation System (LMTS) problem posed in the ISE 4100 final project. In this system, two types of passengers - ordinary and "special" - exit their train at the local train station and walk to the local LMTS. There, they are separated depending on their passenger type; special passengers go to the discount line and regular passengers must decide to wait in line or take a taxi home, depending on the expected wait time. Should they choose to utilize the LMTS, both groups are sorted into 1 and 2 passenger cars to be taken to their final destination. The local train station is looking to build a system in order to optimize their LMTS. Due to the complex nature of mapping these constantly moving parts and the goal of minimizing wait times, the train station would like to develop a simulation using previous data to better understand and predict future traffic and wait times. The following report will summarize Group 15's methodology to develop this simulation using previous arrival time distributions as well as historical travel time data to predict future behavior of this system.

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

Planning

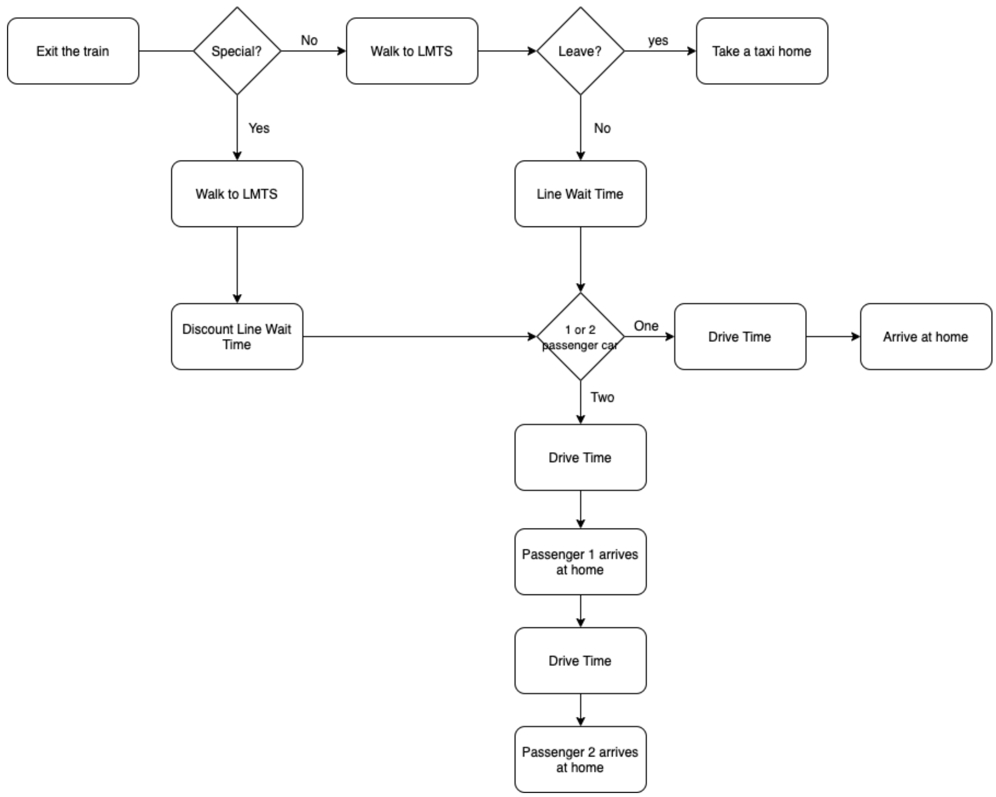

Figure 1 - LMTS Flow Chart

There are two components of our model: ordinary people and special people. Special people are given priority with discounted tickets and the opportunity to wait in a shorter line. This is with the expectation that they will have a good experience and will increase in value. During rush hour, half of our fleet of cars will be 2 passenger vehicles, the other half will be 1 passenger. We designed it this way in order to move people quickly out of the station and not have people waiting as long as if the fleet were all 2 passenger vehicles. 2 passenger vehicles must make two stops before returning to the station, thus they would take longer than 1 passenger vehicle. During off-peak hours, all the vehicles will be 2 passenger vehicles since demand is not as high. Assignment of vehicles is on a first come first serve basis.

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

Table 1 - *Parameters*

Parameters	
Number of drivers	Number of different types of vehicles
Number of queues	

Table 2 - *Input Variables*

Input Variables	
Number of passengers exiting the train	Train arrival time
Time for ordinary passengers to walk from the train to the LMTS Service	Time for special passengers to walk from the train to the LMTS Service
Travel times for a trip from the station to a passenger destination	Travel times for a trip from one passenger destination to another passenger destination
Number of passengers waiting in each queue.	

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Input Analysis

<u>One-Way Drop Off Time</u>

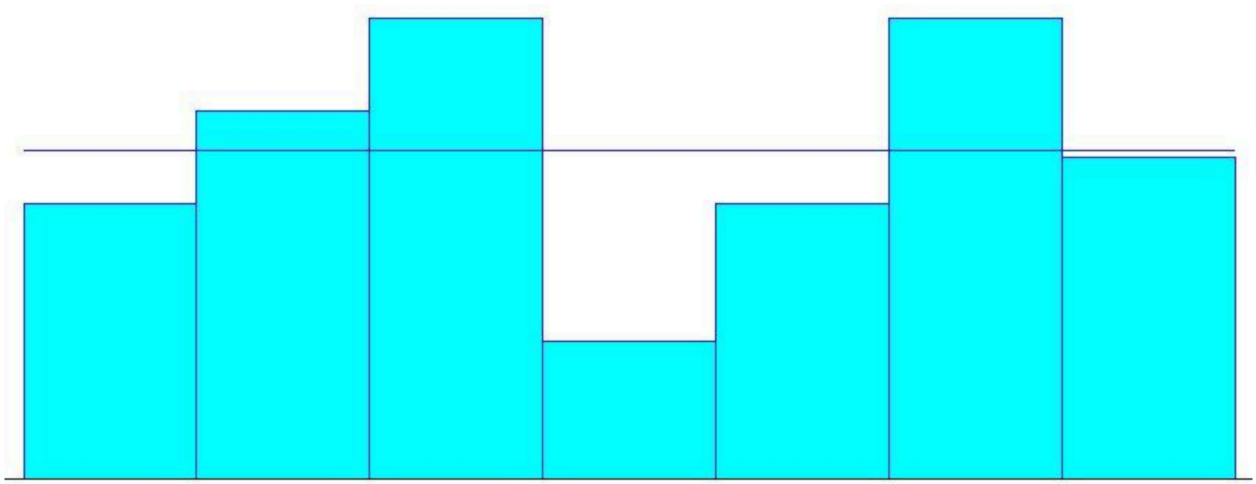

Figure 2 - One-Way Drop Off Time Distribution

Distribution Summary

Distribution: Uniform
Expression: UNIF(5, 10)
Square Error: 0.014743

Chi Square Test
Number of intervals = 7
Degrees of freedom = 6
Test Statistic = 5.16
Corresponding p-value = 0.525

Kolmogorov-Smirnov Test
Test Statistic = 0.0767
Corresponding p-value > 0.15

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Passenger House to Passenger House Time

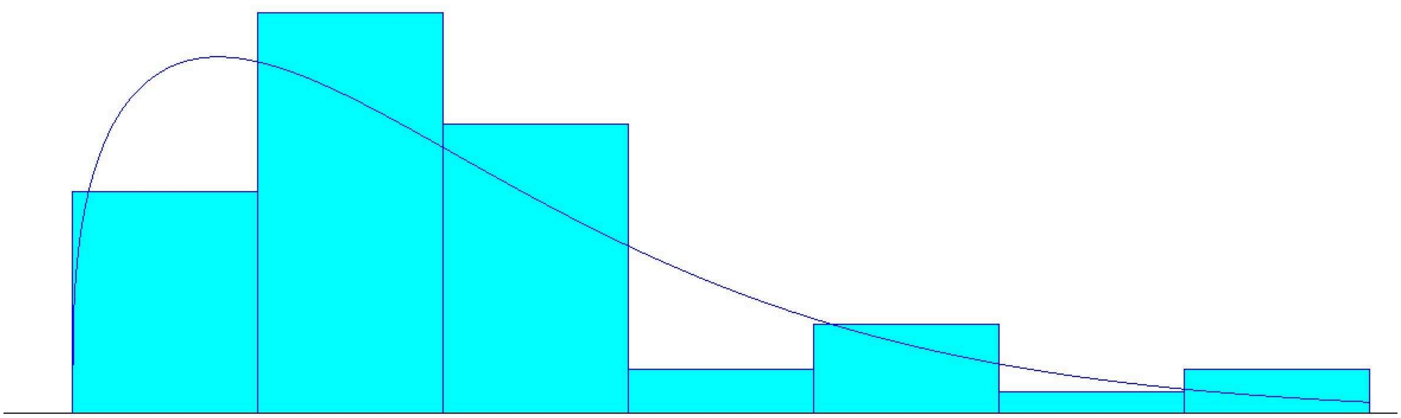

Figure 3 - Passenger House to Passenger House Time Distribution

Distribution Summary

Distribution: Weibull
Expression: 5 + WEIB(3.6, 1.32)
Square Error: 0.024301

Chi Square Test
Number of intervals = 5
Degrees of freedom = 2
Test Statistic = 6.31
Corresponding p-value = 0.0443

Kolmogorov-Smirnov Test
Test Statistic = 0.11
Corresponding p-value > 0.15

Total Driving Time

The total driving time (TDT) to drive to a passenger's destination and return to the station (depending on the type of car) is based on the two above distributions.

For a single-passenger car:

TDT = 2 * (UNIF(5, 10))

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Jake Langermeier.4
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Luyang Wang.11850

For a two-passenger car:

TDT = UNIF(5,10) + (5 + WEIB(3.6, 1.32)) + UNIF(5,10)

This equation represents the time needed to drive to the first passenger destination, drive to the next passenger destination, and then return to the station.

Arrivals

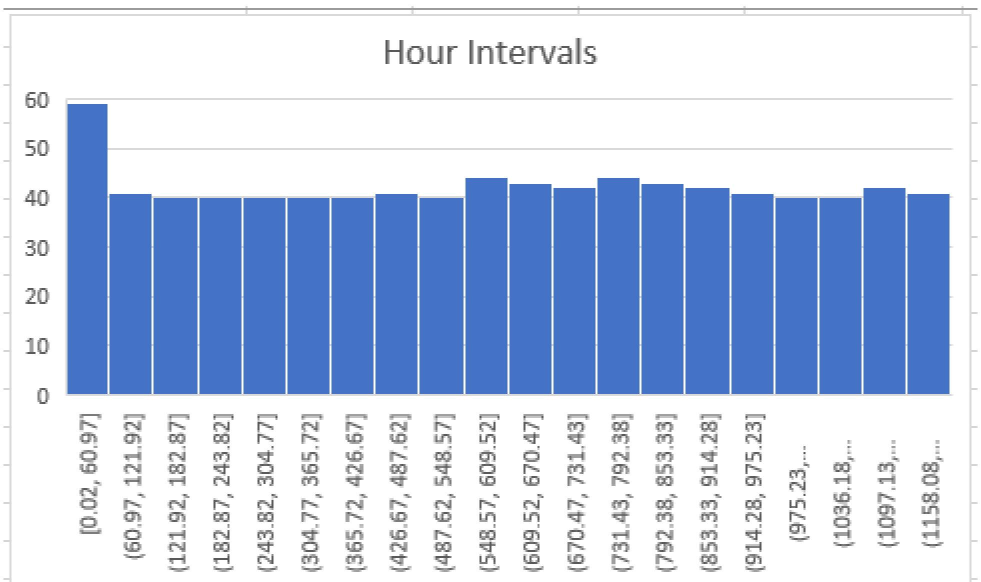

Figure 4 - Train Arrivals by Hour

From the above plot, it is clear that the train arrivals are at a stationary rate throughout the day. Therefore, the average interarrival time (approximately 29 minutes) will be used as the arrival rate for the model.

Next, it was necessary to plot the volume of passengers by hour to discover the trends of passenger volume throughout the day. Based on the operating hours of the system, the day was broken into 21 separate intervals, one hour in length, as summarized in the following image:

Melissa Holland.428
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Allison Spicer.135
Luyang Wang.11850

i	Passenger in Interval i
1	575
2	450
3	407
4	794
5	751
6	429
7	419
8	424
9	373
10	394
11	391
12	389
13	902
14	818
15	395
16	435
17	401
18	456
19	428
20	404
21	69

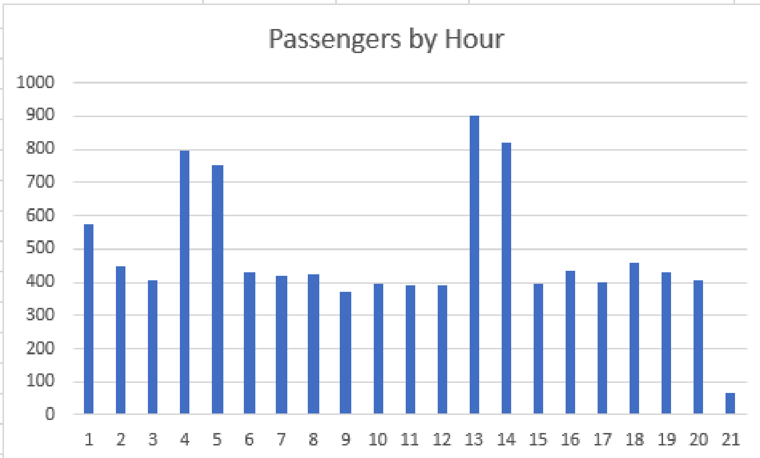


Figure 5 - Passenger Arrivals

Based on the above data, the colors represent the five different blocks of the day, indicating large differences in volume. The red block is the first hour of the shift, with slightly higher volume than off-peak. Orange is off-peak, or not rush hour, times in which volume is similar. Yellow and green are two separate rush hour blocks, with green (afternoon rush) having slightly higher volume than the morning rush. Lastly, the blue block indicates passengers after midnight. Each block was put into Input Analyzer and resulted in the following distributions:

Table 3 - *Block Distribution Results*

Block #	Corresponding i Values	Distribution
1	1	POIS(10.5)
2	2-3, 6-12, 15-20	POIS(10.1)
3	4-5	TRIA(8.5, 17, 33.5)
4	13-14	11.5 + 17*BETA(2.03,1.9)

5	21	NORM(8.63, 2.12)

In conclusion, train arrival times will be based on the stationary rate provided above and passenger volume will come from 1 of 5 distributions depending on the hour of the day.

Assumptions and Additional Data

In modeling this system, our team did make some assumptions in order to assure that our model was as accurate as possible while also reflecting a realistic outcome. We made the assumption that the drivers will finish any drive they start, even if it goes overtime. This assumption is built into their salary. Also for drawing conclusions and making recommendations, we assumed that the mean for the values outputted from the arena report were good representations of our model.

Modeling

The ‘create’ module controls the rate at which trains arrive as well as the number of entities (passengers) that are included in each train using boolean logic based on the simulation time. The two attached ‘decide’ modules first filter out the 25% of passengers who choose not to use the LMTS, followed by splitting the remaining passengers into ordinary and special passengers. The ‘station’ and ‘route’ modules have no direct impact on the model itself and are used for the purpose of animation only.

For both types of passengers, there is a ‘delay’ module for their time to walk to the LMTS station. For special passengers, their time is recorded before and after their travel in order to test whether or not the additional social welfare bonus is included in the sales. Finally, their sales are added to the running total and they leave the system.

Ordinary passengers follow similar steps, with an initial ‘delay’ module to represent their walk to the LMTS station. Per the project instructions, ordinary passengers will choose to not use the LMTS if their line has 10 or more passengers already waiting. This is represented by the ‘decide’ module, sending passengers out of the system if the queue in the following process module is 10 or higher. Finally, their sales are added to the system and the passengers leave the system.

The drivers are scheduled based on the time ‘blocks’ found in the Input Analysis section above. The number of drivers in each interval was decided based on passenger volume in that interval and the upper constraint that the total daily operating cost must be no greater than $2000.

Sales for both types of passengers, as well as the operating costs and calculated revenue, are all displayed to the screen as the model runs.

Output Validation & Verification System

Verification

In order to verify and validate the above system, our team utilized a multi-step approach to prove to our client that our system is accurate and reliable all the while satisfying given requirements.

Our first method of verification was completed through performing various common sense techniques. As can be seen in *Figure 1*, our flow chart follows the complete process as it is stated in the problem description: the riders, both special and ordinary, enter the system, wait in queues depending on their choice of ride, and exit the system by leaving on their own or taking one LMTS ride options as they become available. Using this as our baseline for future decisions as well as a max operating budget of $2,000 for paying drivers, our system showed that we should incur a profit within the range of $2,300 to $2,400 after operating costs. The system showed that our overall income comes from an average of approximately 563 passengers passing through the system each day (or each “run”), paying us anywhere from $7-$12 per ride depending on their passenger status. Assuming that 75% of the passengers pay $12 and 25% pay $7, it is reasonable to expect a theoretical revenue of $6,052. After subtracting a max $2,000 operating budget, we should expect a theoretical maximum profit of $4,052. After ten replications of our system, we observed a daily average income around $4,593 (Ordinary Passenger Sales + Special Passenger Sales). This value, minus the observed operating cost of $1,970, shows a profit of approximately $2,623 for an average day. This can be assumed to be within reasonable limits when accounting for variation in passenger numbers, types, as well as their respective priorities within the LMTS system and decision to utilize the system or not. One way to test how the system will work is to test it using a slow and a stressed model to make observations. A slow model can be created by following a single entity (person) through the system at a reduced speed to see how the system models their experience. A

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

stressed model was created by functioning with 1000 people - double the average entity - to see how the system would perform at the upper limits of its capabilities. Looking at the system functioning at a reduced pace using ‘Slow’ and stressed animation, it is clear to see that there is a potential for bottlenecks at each queue which can be expected for most systems involving limited resources, such as available cars. These bottlenecks will not be of major concern during off-peak hours however, in order to mitigate this issue, our team chose to bring on more riders during those peak hours. Since these periods of concern are infrequent and easy to track our team finds it reasonable to believe that no further action is required.

The next technique that we used for verification throughout this process was assuring the use of thorough and complete documentation. In doing so, each member of our team was able to understand the model well enough to examine it for errors, check for accuracy at each stage of creation, and make necessary corrections to assure that we were putting forward the highest quality model possible. At this time, the four members of our team see no errors in variable identification or inputs.

The final technique our team utilized for verification was debugging by tracing the simulation. While a fairly straight-forward and reasonable method, verifying that the system has no “bugs” or errors has proven to be an important step to verifying that the system works as a whole. This approach has allowed us to identify potential errors and address error messages to put forward our current state. After this was completed we performed a single entity release and followed that single entity through the system to make sure that the route and decisions being made were reasonable and worked as expected for the model. What we saw was that the entity successfully exited their train, sorted themselves into their respective passenger category, and successfully used the LMTS in a way that was reasonable for this system.

Validation

The team also did a multi-step validation for the model. The first step we did was proving the model satisfied face validity, which means the model appears to measure what it claims to measure. The model successfully simulated the entire process of the LMTS system. In addition, since the sales for both types of passengers, as well as the operating costs and calculated revenue were all derived from the model, the measurements of the model were consistent with the purpose of the project. Therefore, the model subjectively appeared to measure the construct it claimed and met the face validity.

Secondly, we did a sensitivity analysis for the number of passengers and the relative percentage of ordinary passenger based on our theoretical assumptions, as was shown in table 4:

Table 4 - *Sensitivity Analysis Results*

Sensitivity Analysis		Passenger Number				
		543	553	563	573	583
Ordinary Percentage	65%	$ 3,566	$ 3,668	$ 3,771	$ 3,873	$ 3,976
	70%	$ 3,702	$ 3,807	$ 3,912	$ 4,017	$ 4,122
	75%	$ 3,837	$ 3,945	$ 4,052	$ 4,160	$ 4,267
	80%	$ 3,973	$ 4,083	$ 4,193	$ 4,303	$ 4,413
	85%	$ 4,109	$ 4,221	$ 4,334	$ 4,446	$ 4,559

According to the table, when the number of passengers increases and the percentage of ordinary passengers increases, the total profit will also increase, which is in line with both the reality and our model results.

The third step we did was the data validation. Due to lack of real-world data for drivers, the only data validation we could do was to compare the daily number of passengers derived from our model and from the given data. The result was shown in table 5 below:

Table 5 - *Passenger Number Comparison*

Total # Passengers	Average	Model	Error
504	505	563	0.114410135
500			
505			
490			
504			

According to the table, the average number of passengers is about 505 in reality, and 563 for our model. The approximate error is 0.11, which is relatively small. Thus, the model was a good representation of the real-world train station system.

Recommendation & Decision Support

After simulating multiple models, our team found that a model that prioritizes special passengers and only uses one-passenger vehicles produces the most profit while not sacrificing high quality service. This model produces a profit of $2,623.60 with a wait time of 4 mins and 26 mins for special and ordinary passengers, respectively. This end model was contrary to our initial model design where we used 2 passenger cars as well.

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

We considered a model where we used solely 2 passenger cars however we noticed a significant drop in profit ($1953.80 drop) because of the lack of throughout due to the extra time needed to drop off both passengers. Our service quality also decreased because while wait time was decreased to under a minute, passengers were required to ride with strangers and their trips home were longer than they would have been had they been driven in a one passenger car. Most special passengers' trips were longer than 30 mins which means we did not receive the 5$ satisfaction bonus, which decreased our revenue.

We also considered the model where neither ordinary nor special passengers received any priority. This model accumulated $10.60 more profit than a special passenger priority model, however wait times increased to 25 mins and 29.5 mins for special and ordinary passengers, respectively. This model's increase in profit is not worth the sacrifice of quality of service for special passengers.

Conclusion

It is our recommendation that the train station move forward with the one-passenger LMTS structure as detailed in this project. In creating this simulation and model our team learned many valuable lessons as it pertains to collaboration, simulation, and remote work. While it was unintentional, our group found that creating multiple simulations for each potential option allowed us to better understand the situation and real-life implications to make more well-informed decisions. It was through comparing the model with no priorities to the model with one-person passengers that prioritized special passengers that a higher profit of $10 was not worth the extra wait time for our special passengers. Our next takeaway was that efficient project management is key, especially when working remotely. While this was not the intended platform for conducting this project, our team did a good job of communicating regularly and putting forward detailed documentation that allowed for better cross-collaboration in each section of the project. Finally, by the end of the project we walked away with a better understanding of how to proceed with our next simulated scenario. At the beginning of this project we tried to delve too deep into detail before we had a high-level visualization of the system and this caused many setbacks. Moving forward we now understand that it would benefit us to start at a high level, going into greater detail as the phases move forward.

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

Appendix

5:57:32PM **Category Overview** April 21, 2020

Values Across All Replications

Special Priority

Replications: 10 Time Units: Minutes

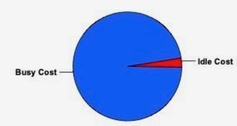
Key Performance Indicators

All Entities

	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	1,913
Wait Cost	0
Total Cost	1,913

All Resources

	Average
Busy Cost	1,913 *
Idle Cost	57
Usage Cost	0
Total Cost	1,970



* *these costs are included in Entity Costs above.*

System

	Average
Total Cost	1,970
Number Out	563

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Figure 6 - KPI, Special Priority Model

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

5:57:32PM **Category Overview** April 21, 2020

Values Across All Replications

Special Priority

Replications: 10 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	14.9778	0.13	14.7818	15.2510	10.0010	19.9966
Special One Passenger	15.0214	0.16	14.6141	15.3448	10.0039	19.9999

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	26.0434	3.54	20.0301	35.0181	0.00	86.7058
Special One Passenger	4.3357	0.51	2.7637	5.4385	0.00	26.0915

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	41.0212	3.60	34.9289	50.2588	10.0250	103.00
Special One Passenger	19.3571	0.61	17.4802	20.3101	10.1056	42.8471

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Ordinary One Passenger	3854.71	112.06	3606.71	4134.53
Special One Passenger	1884.63	160.30	1486.36	2212.35

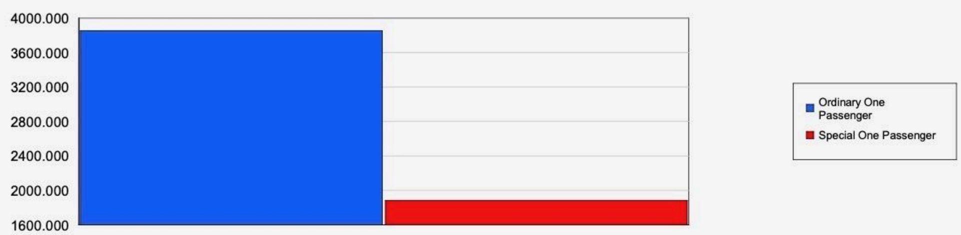

Figure 7 - Time, Special Priority Model

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Jake Langermeier.4
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5:57:32PM **Category Overview** April 21, 2020

Values Across All Replications

Special Priority

Replications: 10 Time Units: Minutes

Station

Other

Number Entities Transferring	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Station 1	0.00	0.00	0.00	0.00	0.00	0.00
Station 2	0.6724	0.04	0.6095	0.7667	0.00	12.0000
Station 3	0.6507	0.06	0.5126	0.8067	0.00	10.0000
Station 4	0.3660	0.01	0.3410	0.3860	0.00	18.0000

User Specified

Tally

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Special Total Time	625.18	15.31	590.19	657.43	20.6720	1259.83

Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary Sales	1583.17	53.96	1472.60	1687.86	0.00	3348.00
Special Sales	759.47	73.15	596.59	924.98	0.00	1740.00

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Ordinary Passenger Sales	3088.80	94.74	2892.00	3348.00
Special Passenger Sales	1504.80	121.88	1212.00	1740.00

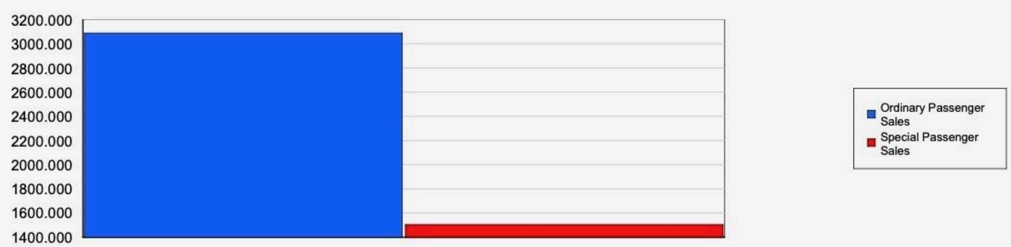

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Figure 8 - Sales, Special Priority Model

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Luyang Wang.11850

10:36:21AM **Category Overview** April 22, 2020

Values Across All Replications

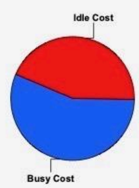
Two-Passenger Car

Replications: 10 Time Units: Minutes

Key Performance Indicators

All Entities	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	1,099
Wait Cost	0
Total Cost	1,099

All Resources	Average
Busy Cost	1,099 *
Idle Cost	858
Usage Cost	0
Total Cost	1,957



* *these costs are included in Entity Costs above.*

System	Average
Total Cost	1,957
Number Out	363

Model Filename: C:\Users\jacob\OneDrive\SP20\4100 - Simulations\Final Project Two Passenge Page 1 of 15

Figure 9 - KPI, Two Passenger Model

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

10:36:21AM **Category Overview** April 22, 2020

Values Across All Replications

Two-Passenger Car

Replications: 10 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	15.0647	0.18	14.5526	15.4006	10.0036	19.9834
Special One Passenger	15.0405	0.24	14.5089	15.6114	10.0028	19.9947

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	0.6871	0.27	0.2358	1.5307	0.00	24.9628
Special One Passenger	0.7505	0.22	0.3843	1.4800	0.00	9.6435

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	15.7518	0.35	15.2503	16.9223	10.0036	41.7101
Special One Passenger	15.7910	0.23	15.2736	16.2684	10.0028	26.0026

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Ordinary One Passenger	2325.91	92.38	2150.26	2514.16
Special One Passenger	969.70	76.68	822.41	1140.89

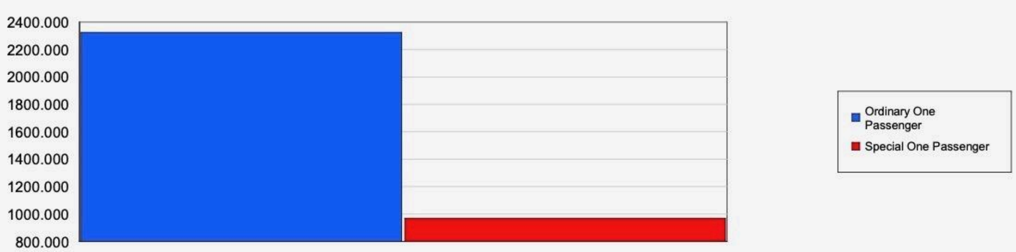


Figure 10 - Time, Two Passenger Model

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

10:36:21AM **Category Overview** April 22, 2020

Values Across All Replications

Two-Passenger Car

Replications: 10 Time Units: Minutes

Station

Other

Number Entities Transferring	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Station 1	0.00	0.00	0.00	0.00	0.00	0.00
Station 2	0.6843	0.03	0.5952	0.7286	0.00	11.0000
Station 3	0.6833	0.06	0.5856	0.8377	0.00	10.0000
Station 4	0.3731	0.01	0.3429	0.4071	0.00	19.0000

User Specified

Tally

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Special Total Time	621.79	17.96	591.99	677.38	28.0394	1257.99

Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary Sales	936.75	40.25	839.65	1024.47	0.00	2028.00
Special Sales	392.10	33.99	331.89	473.96	0.00	924.00

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Ordinary Passenger Sales	1852.80	70.92	1704.00	2028.00
Special Passenger Sales	774.00	62.72	660.00	924.00

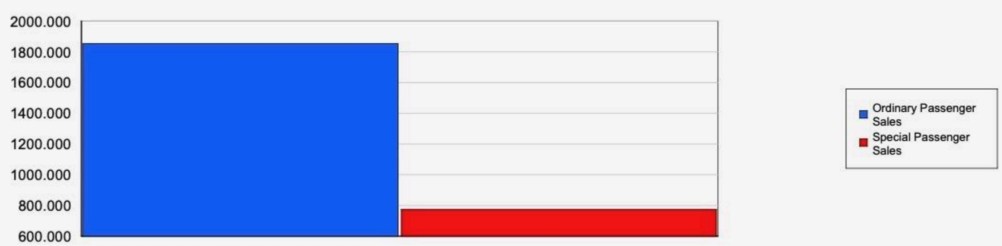


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Figure 11 - Sales, Two Passenger Model

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

5:54:39PM **Category Overview** April 21, 2020

Values Across All Replications

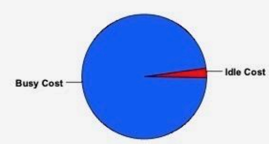
Even Priority

Replications: 10 Time Units: Minutes

Key Performance Indicators

All Entities	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	1,918
Wait Cost	0
Total Cost	1,918

All Resources	Average
Busy Cost	1,918 *
Idle Cost	50
Usage Cost	0
Total Cost	1,969



* *these costs are included in Entity Costs above.*

System	Average
Total Cost	1,969
Number Out	562

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Figure 12 - KPI, Even Priority Model

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

5:54:39PM **Category Overview** April 21, 2020

Values Across All Replications

Even Priority

Replications: 10 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	15.0155	0.10	14.8372	15.2703	10.0036	19.9999
Special One Passenger	14.9609	0.25	14.3295	15.4618	10.0010	19.9884

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	25.2231	3.64	15.6957	32.7313	0.00	72.1082
Special One Passenger	29.5431	4.04	18.3323	37.4742	0.00	78.1852

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary One Passenger	40.2386	3.68	30.5810	47.8494	10.0250	88.5235
Special One Passenger	44.5040	4.22	32.6618	52.3627	10.1793	89.9738

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Ordinary One Passenger	3904.32	106.02	3654.08	4095.07
Special One Passenger	1850.55	123.48	1604.90	2135.56

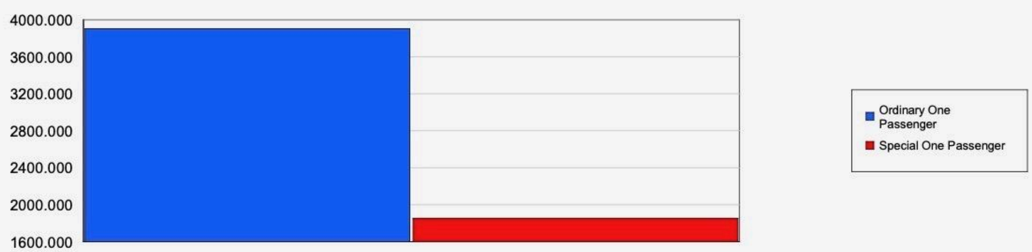


Figure 13 - Time, Even Priority Model

Melissa Holland.428
Jake Langermeier.4
Allison Spicer.135
Luyang Wang.11850

5:54:39PM **Category Overview** April 21, 2020

Values Across All Replications

Even Priority

Replications: 10 Time Units: Minutes

Station

Other

Number Entities Transferring	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Station 1	0.00	0.00	0.00	0.00	0.00	0.00
Station 2	0.6781	0.04	0.6048	0.7905	0.00	10.0000
Station 3	0.6816	0.04	0.6134	0.8067	0.00	10.0000
Station 4	0.3657	0.01	0.3437	0.3888	0.00	18.0000

User Specified

Tally

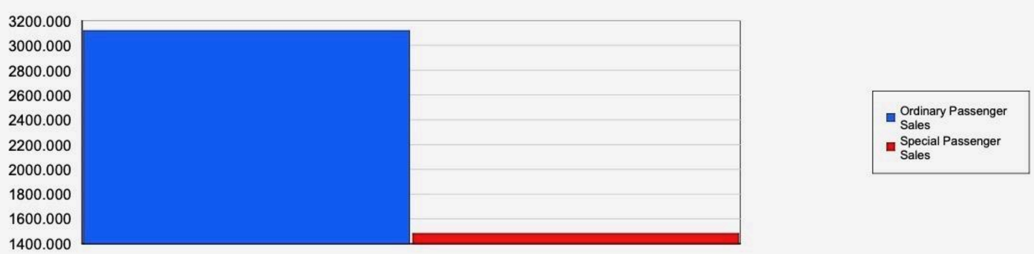
Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Special Total Time	619.06	15.90	580.84	650.36	20.6720	1257.23

Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Ordinary Sales	1604.07	50.05	1510.84	1694.10	0.00	3312.00
Special Sales	754.99	52.40	678.62	879.68	0.00	1668.00

Output

Output	Average	Half Width	Minimum Average	Maximum Average
Ordinary Passenger Sales	3120.00	77.52	2952.00	3312.00
Special Passenger Sales	1483.20	85.95	1344.00	1668.00



Model Filename: C:\Users\jacob\OneDrive\SP20\4100 - Simulations\Final Project With Animatio Page 15 of 15

Figure 14 - Sales, Even Priority Model