Faculty of Engineering, Architecture and Science

Department of Industrial Engineering

Course Number	IND600
Course Title	Systems Modelling/Simulation
Semester/Year	Winter 2023
Instructor	Dr. Hassanzadeh
Teaching Assistants	Ebrahim Sharifi

IND600 Final Project

Report Title	IND600 Final Project

Section No.	01
Submission Date	April 14th, 2023
Due Date	April 14th, 2023

Name	Student ID	Signature*
Rufat Akhmetov	xxxx42983	R.A
Sheikh Abid Rahman	xxxx42494	S.A.R
Zahra Abbasi	xxxx01622	Z.A

(Note: remove the first 4 digits from your student ID)

Abstract

The report focuses on improving the queueing system of a car wash. For the sake of this project, H2Go Car Wash located at 232 Bleams Road in Kitchener, Ontario was selected. In order to analyze and optimize the current queuing system, the model would be simulated using Arena. By replicating the system's behavior utilizing Arena, the performance metrics can be analyzed more closely and areas of improvement can be identified. The simulation of the system can help to study how various factors can impact the system's performance. Factors may include customer waiting time, queue length, service time, arrival rate, number of employees for different services, capacity, and so on. The arrival module, service module, and departure module are a few of the interrelated components that make up the simulation model. On the other hand, the service module handles customers in accordance with a set service time distribution, the arrival module creates consumers in accordance with a defined arrival rate. After the completion of the services, the departure module would remove the customers from the system. The goal of the project is to enhance the throughput of the overall process so that the system is optimized and customer satisfaction is improved. With the help of the results from the simulation, opportunities for improvement can be identified. Moreover, by analyzing the simulation model, changes can be made to the system as needed to decrease the wait times and queue length and will be able to handle high arrival rates.

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Introduction

The objective of the report is to analyze a carwash that consists of a drive through automatic and multiple manual car washes by simulating the system with Arena. A simulation would help visualize the system process better for analysis by studying internal interactions, inputs, and outputs. By collecting data regarding arrivals, service time, waiting lines, etc. design changes will be suggested to increase the effectiveness of this queuing system while reducing costs and enhancing customer satisfaction. The simulation would be generated with qualitative input such as arrival rate, number of customers in line, hours of operation, number of employees, and other data. With the simulated model, the system design changes would be tested to inspect the impact of various input scenarios, optimize system performance, and estimate capacity. Based on the results from the Arena simulation, our team plans to design an improved system that would speed up the queuing process by lowering waiting time through effective operational methods.

Analytical Model Description

Overview of the carwash system and simulation study

The system consists of 7 manual and 1 automatic car-wash station. Each station has an employee who operates the car washing process and three other employees taking payment from the customers while they are waiting in the queue lines. The car wash operates 8 hours a day for 7 days a week. Cars come into the system via the entrance and join the line to select between automatic and manual services. While selecting services, the payment is processed. Each station has a waiting line of its own and based on how busy the queuing lines are, cars drive towards the most available station for their turn. After their car washing service is completed, the cars leave the station and follow the exit lane to be removed from the system. The generated model was analyzed and evaluated based on transfer times, bottlenecks, and operational issues that may exist in the initial system.

After defining the problem and its objectives, to gain a further understanding of the model conceptualization, a visual representation of the system was drawn out (Figure 3). The model is to be verified and validated before simulating and running the model. With the help of the simulation results, suggestions can be made for an improved system and be simulated for comparison.

***Figure 1**: Seven manual Car Washes*

***Figure 2**: One Automatic Car Wash*

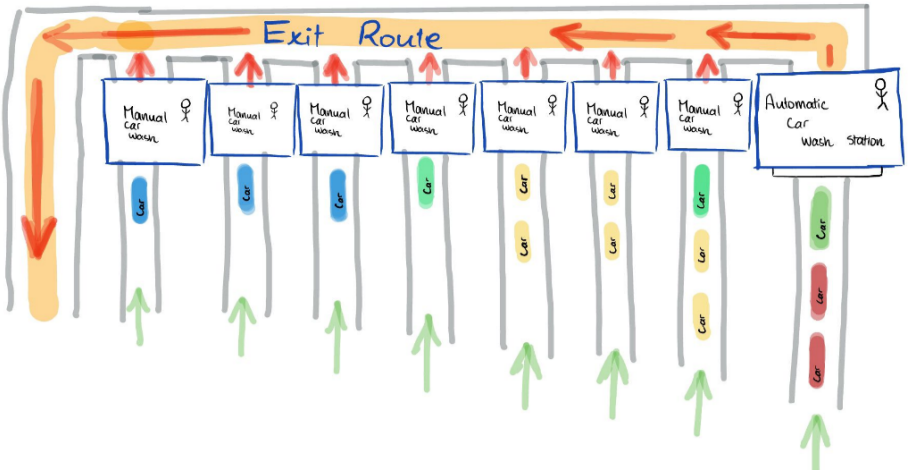


***Figure 3**: Selected Car Wash Queue System Visualization*

Data Collection

The data collection was performed on March 3rd, 2023, from 10 AM - 12:30 PM (a quarter of the shift length) to gather a sample and provide insights about the performance of the carwash. During the data collection sample period, a total of 16 customers arrived for car wash and polish services. The collected data which includes the customer's arrival time, waiting time in the queue, and service time for each step is tabulated in the appendix.

Hypothesis and Desired State

Using the collected data sample, it is possible to perform calculations for the hypothesis of final results. 16 customers arrived during the first 2 hours of opening their doors, using this it is assumed that an average of 64 customers arrive within an 8-hour period (full shift period). The sum of the waiting times in the queue for service selection and payment processing (picking a station) is 0 minutes. When a customer enters the system, they must enter one of the 8 queues. The automatic wash is fixed at 10 minutes per car, and for manual car wash stations, it takes about 15 minutes on average depending on the vehicle type.

With the current system in play, the desired state would be to maximize the flow of customers in and out of the model while providing a good quality service. To increase the efficiency of the model, we assigned a secondary worker to each manual station with aim to decrease the service times. Therefore, the desired state is to decrease the wait times and service times to increase customer satisfaction levels as there would be a quicker service while also generating more revenue by processing more customers.

Simulation Model

Using the input analyzer function in Arena, the ideal fit of the probability distribution for the collected data was obtained and the summary is shown in the table below. The type of histogram distribution along with the mean and the standard deviation of the collected data can now be used in order to simulate the car wash.

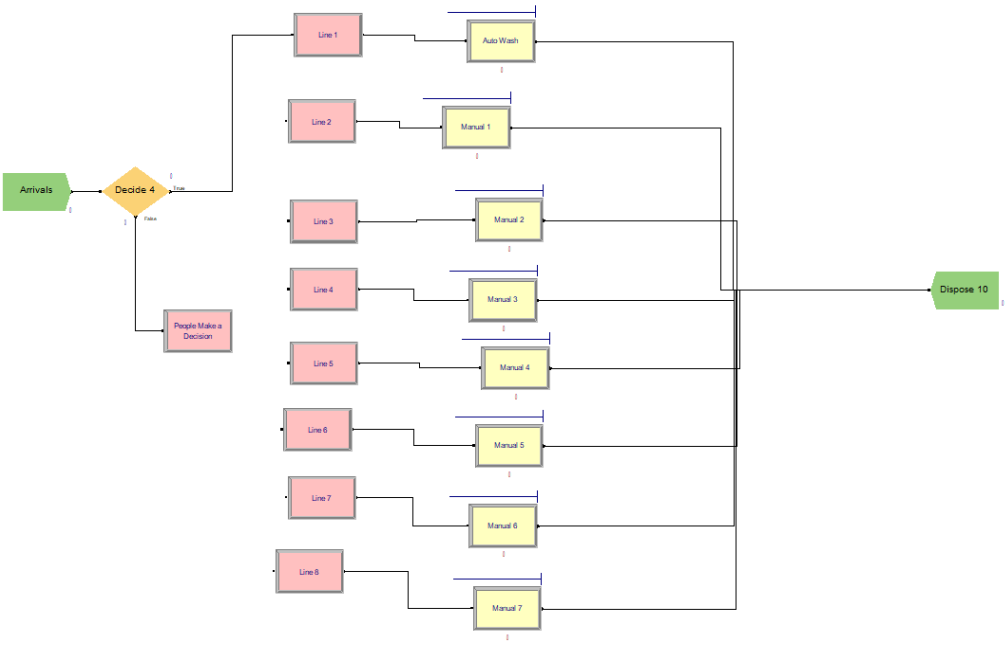
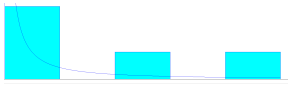
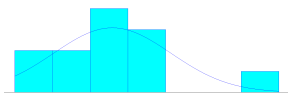


***Figure 4**: Base System Model*

***Table 1:** Input Analyzer Output*

Processes	Histogram	Data Summary	Distribution Summary
Selecting Service		Data Summary Number of Data Points = 14 Min Data Value = 1 Max Data Value = 2 Sample Mean = 1.32 Sample Std Dev = 0.421 Histogram Summary Histogram Range = 0.999 to 2 Number of Intervals = 5	Distribution Summary Distribution: Lognormal Expression: 0.999 + LOGN(3.33, 668) Square Error: 0.096704 Kolmogorov-Smirnov Test Test Statistic = 1.31 Corresponding p-value < 0.01
Auto Service	Constant distribution	10 minutes	Constant distribution
Manual Service		Data Summary Number of Data Points = 12 Min Data Value = 20 Max Data Value = 26 Sample Mean = 22.1 Sample Std Dev = 1.62 Histogram Summary Histogram Range = 19.5 to 26.5 Number of Intervals = 7	Distribution Summary Distribution: Normal Expression: NORM(22.1, 1.55) Square Error: 0.034574

Queue for Auto Service		Data Summary Number of Data Points = 9 Min Data Value = 0 Max Data Value = 15 Sample Mean = 3.33 Sample Std Dev = 6.61 Histogram Summary Histogram Range = -0.5 to 15.5 Number of Intervals = 16	Distribution Summary Distribution: Lognormal Expression: -0.5 + LOGN(2.97, 7.68) Square Error: 0.187064
Queue for Manual Service		Data Summary Number of Data Points = 17 Min Data Value = 0 Max Data Value = 14 Sample Mean = 2.24 Sample Std Dev = 4.45 Histogram Summary Histogram Range = -0.5 to 14.5 Number of Intervals = 15	Distribution Summary Distribution: Beta Expression: -0.5 + 15 * BETA(0.126, 0.567) Square Error: 0.034075

Model Translation

A model was created in Arena to simulate the carwash. The results received from Arena after running the simulation are demonstrated in Table 2. The entities defined in the model are the cars arriving in the system, while attributes such as the arrival time, service time, and waiting times and their patterns were presented from the data collected. Moreover, the queue discipline was defined using a first-in-first-out (FIFO) basis since that is how that car wash operates. The duration of the simulation was specified to be 8 hours (480 minutes) which is the daily operational hours of the car wash.

Different sets of replication were run for the simulation models to observe the results of multiple independent trials. The motive for running various replications was to produce multiple data sets for a better analysis of the model's variability and uncertainty. The model is run using the same inputs and conditions for every replication, but various random seeds are employed to get different results. It is feasible to determine the distribution of potential outcomes and evaluate the variability in the findings by executing several replications. This approach was taken to improve the reliability and accuracy of the results.

Table 2: *Simulation results for Current system*

	Single Replication	**50 Replications**	**100 Replications**
Number In	56	63.68	64.93

Number Out	37	37.68	37.3
Average Wait Time (hrs)	0.8115	1.5172	1.5567
Max Wait time (hrs)	2.2385	4.6481	4.8416
Average Total Time (hrs)	1.0166	1.7256	1.7670
Max Total Time (hrs)	2.5144	4.9301	5.0699

Simulation Results and Discussion

Next, certain changes were made in order to reach the desired state. By simulating the potential improvements, the results can be validated before implementing them in the actual system. These changes include removing two of the manual car washes and replacing them with an automatic washing station as it had a higher demand according to the results in the previous section and as the service is faster, more customers can be processed in the same time period. Additionally, hiring an additional employee to each of the manual stations to reduce waiting times and service time. The additional employee at the manual station would be modeled using TRI(10,12.5,15) since the service time decreases by 25%. Another feasible solution is to have a digital application that allows customers to pay online to once again reduce waiting periods. The application can also allow for ongoing promotions, earning user points, and rewards to attract and retain customers over the long term.

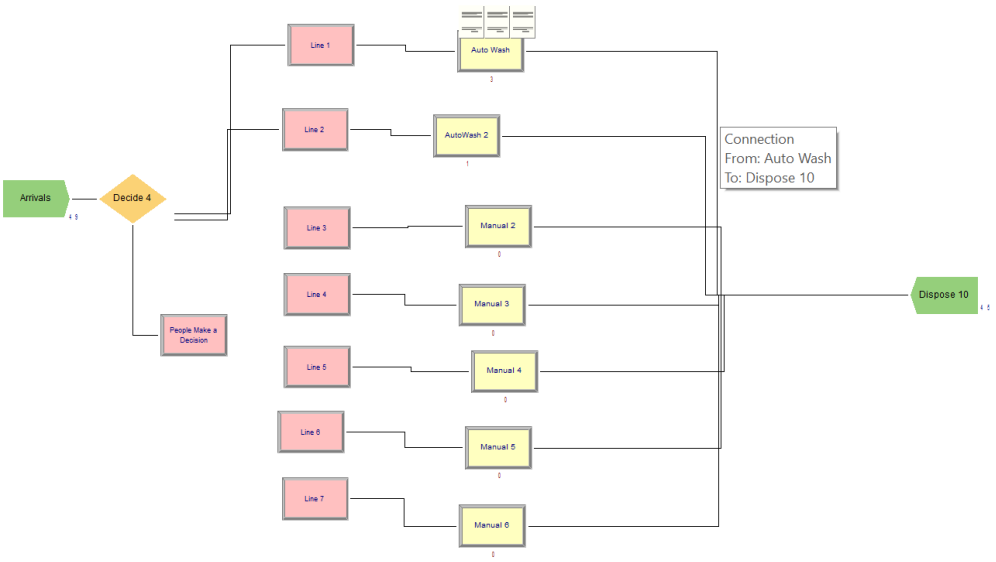


Figure 5: *Improved System Model*

Table 3: *Simulation results for Improved System*

	Single Replication	50 Replications	100 Replications
Number In	49	64.44	65.22
Number Out	45	45.02	44.85
Average Wait Time (hrs)	0.4856	1.1128	1.1258
Max Wait time (hrs)	1.1659	3.9283	3.9737
Average Total Time (hrs)	0.6599	1.2862	1.2992
Max Total Time (hrs)	1.3326	4.0950	4.1404

Validation

The data was collected in real-time from the real-world system. In order to fully validate the queuing system for the simulation, it was checked if the model was accurately representing the actual system. To analyze and validate the results, our team showed the results to the management of the car wash and welcomed their opinions and suggestions. We were informed

that the outputs were similar to their actual system. They mentioned that on a busy day, the waiting times are very accurate. Moreover, regarding the number in and out data, they suggested that many customers do not want to wait in lines and often end up leaving the system which is also comparable to the simulation output. Furthermore, as mentioned earlier in the report, the simulation was run for various replications to verify the results.

Desired State Justification

With minor changes to the current system, it was observed that more customers are processed throughout the 8-hour working day. The output of the improved system model arena file is seen in Table 3 above, it can be seen that the implementation of design improvements such as adding an additional employee to each manual station and replacing two manual stations with one automatic wash station have positive impacts on throughput data.

Using ARENA simulation software, the results of multiple replications of both models show a 21% increase in customers served. The average wait times of each queue in the original model were 1.54 hours in total and 1.12 hrs total for the improved model. Comparing the two models it can be observed that queue times substantially improved, using the data obtained from ARENA software a decrease of 27.3% in wait time was deduced.

Conclusions

The main scope of this project was to build a model utilizing ARENA simulation software in order to critically analyze the current state at the car wash and develop design changes to improve the queueing system. An observational study was conducted with the help of the site manager, and with his help, a comprehensive data set was created. Data was collected by noting down the arrival times, service times, and queue times of the customers during a 2-hour window. After closer analysis of the collected data set, redesign recommendations and suggestions were developed with the aims of decreasing service and wait times and therefore generating more revenue for the selected branch. After modeling the system and simulating results for a single replication, 50 replications, and 100 replications it could be seen that the model times were consistent in each replication. After modeling the changes and simulating the redesigned model the results obtained showed a higher number of customers processed and reduced queue times. We observed 8 additional customers were served with the improvements.

Nevertheless, since the model runs smoothly for the entire 8-hour period it does not mean there's no more area for improvement. The system could still use more improvements such as more training for employees to reduce service times and some changes to equipment and station layouts. However, these improvements are beyond the scope of ARENA simulation software and this project. In summary, it can be concluded that the desired state was achieved and the results data have shown satisfactory improvements.

References

[1] Canadian Carwash Association. (2022). Industry Overview. Retrieved March 30, 2023, from https://canadiancarwash.ca/industry-overview/

Appendix

Table 1: *Sample data set from visit to the site.*

Customer	Arrival Time	Service Type	Steps (minutes)				Service Time (minutes)
			Waiting in line for selection	Selecting service and paying	Waiting in line for service	Driving Out	
1	*10:02 AM*	***Auto***	0	2	0	*10:19 AM*	15
2	*10:20 AM*	***Manual***	0	1.5	0	*10:43 AM*	21
3	*10:25 AM*	***Manual***	0	1	0	*10:49 AM*	23
4	*10:30 AM*	***Manual***	0	1	0	*10:53 AM*	22
5	*10:35 AM*	***Auto***	0	1	0	*10:56 AM*	20
6	*10:40 AM*	***Manual***	0	2	0	*11:04 AM*	22
7	*10:50 AM*	***Auto***	0	1	5	*11:11 AM*	15
8	*10:59 AM*	***Auto***	0	1.5	10	*11:26 AM*	15
9	*11:03 AM*	***Manual***	0	1	0	*11:27 AM*	23
10	*11:09*	***Manual***	0	1	0	*11:34*	22

	AM					*AM*	
11	*11:16 AM*	***Auto***	0	1	9	*11:46 AM*	20
12	*11:21 AM*	***Manual***	0	1	0	*11:48 AM*	26
13	*11:30 AM*	***Auto***	0	1.5	14	*12:01 PM*	15
14	*11:42 AM*	***Manual***	0	1	0	*12:06 PM*	23
15	*11:50 AM*	***Manual***	0	1.5	0	*12:13 PM*	22
16	*11:59 AM*	***Manual***	0	2	0	*12:22 PM*	21

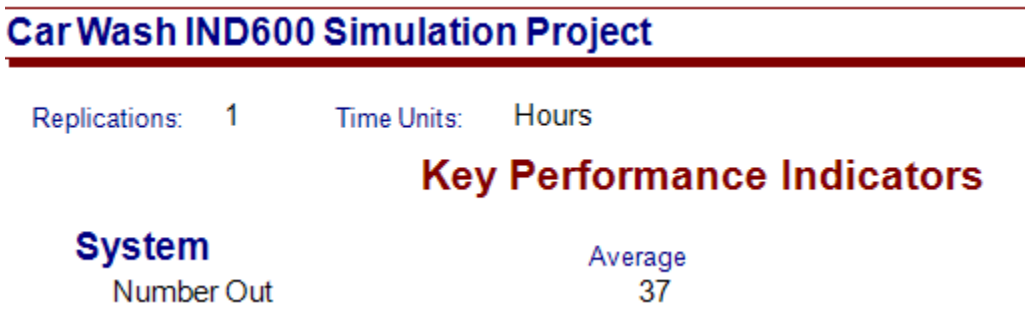


Figure 6: *System Number Out from Arena - base model*

2:34:27PM **Category Overview** April 14, 2023

Car Wash IND600 Simulation Project

Replications: 1 Time Units: Hours

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.2051	(Insufficient)	0.08333333	0.3274

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.8115	(Insufficient)	0.00	2.2385

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	1.0166	(Insufficient)	0.08333333	2.5144

Other

Number In	Value
Entity 1	56.0000

Number Out	Value
Entity 1	37.0000

WIP	Average	Half Width	Minimum Value	Maximum Value
Entity 1	7.2859	(Insufficient)	0.00	19.0000

Figure 7: *Category Overview from Arena - base model*

2:34:27PM **Category Overview** April 14, 2023

Car Wash IND600 Simulation Project

Replications: 1 Time Units: Hours

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Auto Wash	0.08333333	(Insufficient)	0.08333333	0.08333333
Manual 1	0.2990	(Insufficient)	0.2699	0.3240
Manual 2	0.3011	(Insufficient)	0.2671	0.3274
Manual 3	0.2995	(Insufficient)	0.2814	0.3176
Manual 4	0.2922	(Insufficient)	0.2852	0.2991
Manual 5	0.2963	(Insufficient)	0.2963	0.2963
Manual 6	0.2822	(Insufficient)	0.2822	0.2822

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Auto Wash	0.7603	(Insufficient)	0.00	2.2385
Manual 1	0.4703	(Insufficient)	0.00	1.9267
Manual 2	1.1086	(Insufficient)	0.4250	2.1983
Manual 3	0.9762	(Insufficient)	0.7559	1.1965
Manual 4	1.4005	(Insufficient)	1.0323	1.7688
Manual 5	1.4398	(Insufficient)	1.4398	1.4398
Manual 6	2.0594	(Insufficient)	2.0594	2.0594

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Auto Wash	0.8437	(Insufficient)	0.08333333	2.3218
Manual 1	0.7693	(Insufficient)	0.2699	2.2315
Manual 2	1.4097	(Insufficient)	0.6922	2.5144
Manual 3	1.2757	(Insufficient)	1.0734	1.4779
Manual 4	1.6927	(Insufficient)	1.3175	2.0679
Manual 5	1.7362	(Insufficient)	1.7362	1.7362
Manual 6	2.3417	(Insufficient)	2.3417	2.3417

Accumulated Time

Figure 8: *Category Overview from Arena - base model*

2:34:27PM **Category Overview** April 14, 2023

Car Wash IND600 Simulation Project

Replications: 1 Time Units: Hours

Process

Accumulated Time

Accum VA Time	Value
Auto Wash	1.3333
Manual 1	3.2894
Manual 2	1.2045
Manual 3	0.5990
Manual 4	0.5843
Manual 5	0.2963
Manual 6	0.2822
Manual 7	0.00

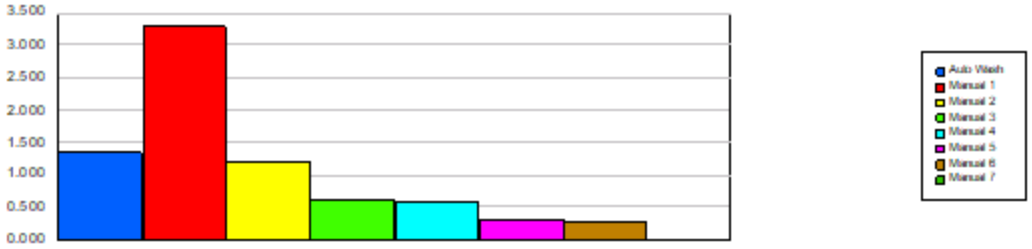


Figure 9: *Category Overview from Arena - base model*

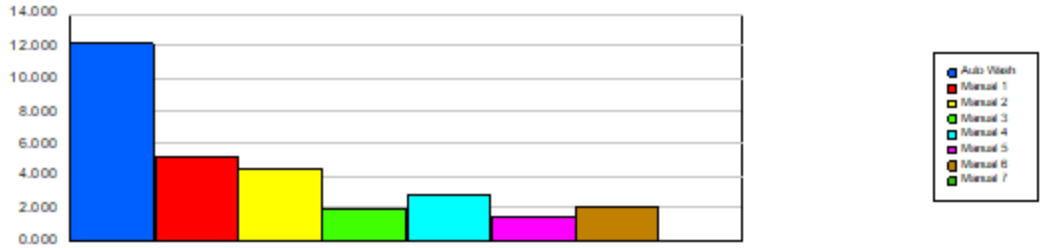
Car Wash IND600 Simulation Project

Replications: 1 Time Units: Hours

Process

Accumulated Time

Accum Wait Time	Value
Auto Wash	12.1652
Manual 1	5.1731
Manual 2	4.4343
Manual 3	1.9523
Manual 4	2.8011
Manual 5	1.4398
Manual 6	2.0594
Manual 7	0.00



Other

Figure 10: *Category Overview from Arena - base model*

2:34:27PM **Category Overview** April 14, 2023

Car Wash IND600 Simulation Project

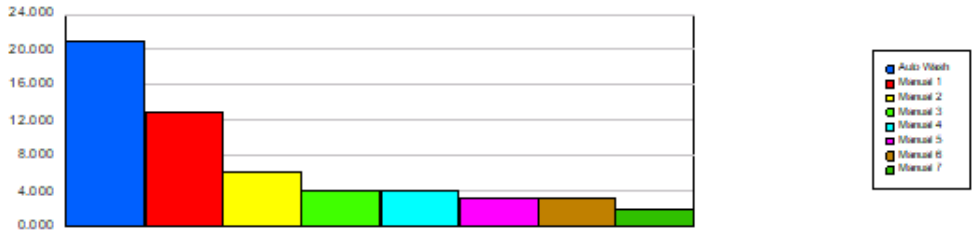
Replications: 1 Time Units: Hours

Process

Other

Number In

	Value
Auto Wash	21.0000
Manual 1	13.0000
Manual 2	6.0000
Manual 3	4.0000
Manual 4	4.0000
Manual 5	3.0000
Manual 6	3.0000
Manual 7	2.0000



Number Out

	Value
Auto Wash	16.0000
Manual 1	11.0000
Manual 2	4.0000
Manual 3	2.0000
Manual 4	2.0000
Manual 5	1.0000
Manual 6	1.0000
Manual 7	0.00

Figure 11: *Category Overview from Arena - base model*

2:34:27PM **Category Overview** April 14, 2023

Car Wash IND600 Simulation Project

Replications: 1 Time Units: Hours

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Auto Wash.Queue	0.7603	(Insufficient)	0.00	2.2385
Manual 1.Queue	0.4703	(Insufficient)	0.00	1.9267
Manual 2.Queue	1.1086	(Insufficient)	0.4250	2.1983
Manual 3.Queue	0.9762	(Insufficient)	0.7559	1.1965
Manual 4.Queue	1.4005	(Insufficient)	1.0323	1.7688
Manual 5.Queue	1.4398	(Insufficient)	1.4398	1.4398
Manual 6.Queue	2.0594	(Insufficient)	2.0594	2.0594
Manual 7.Queue	2.4519	(Insufficient)	2.4519	2.4519

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Auto Wash.Queue	2.2580	(Insufficient)	0.00	6.0000
Manual 1.Queue	0.9901	(Insufficient)	0.00	2.0000
Manual 2.Queue	0.7386	(Insufficient)	0.00	2.0000
Manual 3.Queue	0.6576	(Insufficient)	0.00	2.0000
Manual 4.Queue	0.5734	(Insufficient)	0.00	2.0000
Manual 5.Queue	0.3995	(Insufficient)	0.00	2.0000
Manual 6.Queue	0.4099	(Insufficient)	0.00	2.0000
Manual 7.Queue	0.3075	(Insufficient)	0.00	1.0000

Figure 12: *Category Overview from Arena - base model*

2:34:27PM **Category Overview** April 14, 2023

Car Wash IND600 Simulation Project

Replications: 1 Time Units: Hours

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Resource 1	0.9512	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Resource 1	0.9512	(Insufficient)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Resource 1	1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization	Value
Resource 1	0.9512

Total Number Seized	Value
Resource 1	38.0000

Figure 13: *Category Overview from Arena - base model*

2:38:51PM **Queues** April 14, 2023

Car Wash IND600 Simulation Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 8.00 Time Units: Hours

Queue Detail Summary

Time

	Waiting Time
Auto Wash.Queue	0.76
Manual 1.Queue	0.47
Manual 2.Queue	1.11
Manual 3.Queue	0.98
Manual 4.Queue	1.40
Manual 5.Queue	1.44
Manual 6.Queue	2.06
Manual 7.Queue	2.45

Other

	Number Waiting
Auto Wash.Queue	2.26
Manual 1.Queue	0.99
Manual 2.Queue	0.74
Manual 3.Queue	0.66
Manual 4.Queue	0.57
Manual 5.Queue	0.40
Manual 6.Queue	0.41
Manual 7.Queue	0.31

Figure 14: *Queue Overview from Arena - base model*