CAVITEX PARANAQUE TOLLGATE PLAZA SIMULATION

Rick Gavin A. Dela Cruz
BSCS 3-C
Technological University of the Philippines
Cavite, Philippines
rickgavin.delacruz@tup.edu.ph

Richard Andrei B. Suñga
BSCS 3-C
Technological University of the Philippines
Manila, Philippines
richardandrei.sunga@tup.edu.ph

Ella Monique T. Gonzales
BSCS 3-C
Technological University of the Philippines
Pangasinan, Philippines
ellamonique.gonzales@tup.edu.ph

Mark Aljon T. Reales
BSCS 3-C
Technological University of the Philippines
Cavite, Philippines
markaljon.reales@tup.edu.ph

Abstract

The input data used in the model was generated from the data the researchers requested from the PEATC hourly traffic online document. Further simulations will require up-to-date data which the researchers and future researchers should request again. The researchers ran a 7-day simulation and encoded the data of the number of cars, inter-arrival time and the average numbers needed in construction of a simulation sample. These numbers are to be run in the ARENA software where they would be evaluated by their accuracy. By conventional criteria, the researchers will determine whether to accept or reject the null hypothesis based on the average car per hour of the simulated model if it is related to the average car per hour of the actual data.

Keywords: Flowchart, Pseudocode, Automata, Computer Graphics

I. INTRODUCTION

The majority of roads are funded by local, state, or national governments through taxation. Tolls are similar to a tax that only the users of the toll road pay. Toll roads enable new roads to be built and maintained without raising taxes on the general public [10].

Tolls provide a long-term source of revenue for road maintenance and improvement. Tolling is a novel and cost-effective approach to addressing our nation's transportation infrastructure challenges while also providing a safe and dependable way for travelers to reach their destinations [5].

Toll roads are those that have periodic stops where people must pay a fee to use the roads. These roads are also known as turnpikes, tollways, and express toll routes. The fee charged for traveling on a toll road is what is referred to as a toll. This paper discusses the purpose of imposing toll roads despite the presence of free roads, the benefits and drawbacks to drivers, the economic implications of toll roads, and why an individual should pay a toll rather than use a free road [6].

Toll roads are necessary because they ensure a free flow of traffic by utilizing technologies that eliminate delays. Drivers can pay by having monthly bills mailed to them or by using an electronic transponder linked to a prepaid account. Toll roads also reduce pollution from greenhouse gas emissions and other emissions caused by sitting and wasting fuel in traffic. A toll road also allows vehicles to travel at faster, more fuel-efficient speeds [8]. Tolling serves as an economic instrument that is uniquely suited to the collection of efficient prices in the use of roads.

The Cavite-Paranaque is a 14-kilometer expressway connecting Roxas Boulevard and Cavite. The Manila-Cavite Toll Expressway Project (MCTEP), often known as CAVITEX, is made up of five segments. The CAVITEX C5 Link, which connects Paranaque and Taguig with an operational flyover over SLEX connecting Taguig and Merville, is currently under construction. Commuters and motorists will find this road to be convenient, safe, and fun to travel on.CAVITEX, or the Manila-Cavite Toll Expressway Project, improves travel safety and convenience. It comprises the R-1 and R1 extension, which runs along Manila's coast and connects Roxas Boulevard to Cavite, as well as two toll plazas, Paranaque Toll Plaza and Kawit Toll Plaza [1].

The focus of the paper would be to monitor the average number of cars per hour passing through the CAVITEX tollgate.

II. METHODS

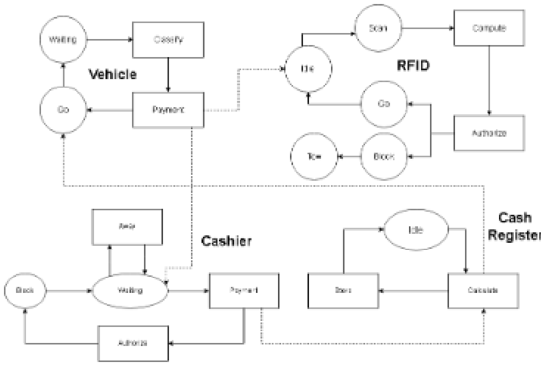

Figure 1. Tollgate Activity Cycle

Activity Cycle of the tollgate shown in Figure 1 illustrates the relationships of the entities which are relevant to the process of toll gate simulation. These entities are the vehicles, cashiers on the tollgates, automatic cash registers and RFID scanners. The cycle involves different processes in which cars can choose from.

The researchers hypothesize:

- **Null Hypothesis:**

The average car per hour of the simulated model is related to the average car per hour of the actual data.

- **Alternative Hypothesis:**

The average car per hour of the simulated model is not related to the average car per hour of the actual data.

The researchers created a simulated flow of the toll gates in Cavitex Parañaque Toll Plaza shown in Figure 1 to determine the average time it takes to travel from the start to the end of the specific toll gate. The researchers also aim to measure the estimated time how long it would take for vehicles to arrive at their destination.

Annex A – "Hourly Traffic Parañaque Toll Plaza February 2022"

Hour	01-Feb	02-Feb	03-Feb	04-Feb	05-Feb	06-Feb	07-Feb	08-Feb	09-Feb	10-Feb	11-Feb	12-Feb	13-Feb	14-Feb
5	2,489	4,216	3,669	3,862	2,895	2,450	4,968	3,683	3,788	3,917	3,815	3,126	2,403	4,696
6	3,107	6,112	5,704	5,926	3,882	2,925	6,546	6,046	6,087	6,101	5,974	4,044	3,012	6,524
7	3,456	6,771	6,608	6,402	4,685	3,179	6,808	6,892	6,727	6,680	6,485	4,773	3,388	6,808
8	3,851	6,049	5,998	5,903	4,968	3,782	6,265	6,029	6,066	6,255	6,354	5,033	3,944	6,350
9	4,291	5,944	5,204	5,416	5,212	4,178	5,690	5,560	5,583	5,522	5,596	5,492	4,459	5,588
10	4,400	5,225	5,032	5,256	5,458	4,422	5,071	5,076	5,026	5,095	5,177	5,501	4,804	5,226
11	4,490	4,950	4,648	4,783	5,376	4,489	4,860	4,647	4,808	4,872	4,953	5,540	4,876	4,932
12	4,491	4,836	4,612	4,682	5,277	4,307	4,708	4,682	4,841	4,985	5,119	5,399	4,859	4,860
13	4,581	4,905	4,592	4,945	5,595	4,746	4,796	4,841	4,799	4,862	5,230	5,592	5,227	4,851
14	4,645	5,004	4,930	5,125	5,598	4,933	4,878	4,942	5,014	4,985	5,301	5,641	5,268	5,176
15	4,732	5,116	5,196	5,316	5,633	5,123	5,359	5,164	5,316	5,154	5,762	5,727	5,344	5,324
16	4,636	6,046	6,154	5,919	5,526	5,508	6,037	5,989	5,908	5,841	6,204	5,828	5,715	6,208
17	4,613	6,448	6,289	6,366	5,607	5,231	6,463	6,338	6,494	6,266	6,304	5,418	5,560	6,053
18	4,254	5,900	5,768	5,972	5,101	5,065	6,035	5,902	6,235	6,187	6,131	5,284	5,324	6,027
19	3,795	5,586	5,194	5,715	4,822	4,875	5,491	5,408	5,466	5,361	5,960	4,818	5,027	5,741
20	3,728	4,586	4,419	5,394	4,451	4,493	4,474	4,582	4,659	4,924	5,734	4,653	4,870	5,174
21	3,459	3,655	3,450	4,660	3,994	4,306	3,450	3,534	3,779	3,771	4,753	4,449	4,629	4,375
22	2,747	2,586	2,612	3,370	3,151	3,279	2,628	2,675	2,877	2,881	3,643	3,796	4,025	3,492
23	1,899	1,981	1,885	2,453	2,502	2,365	1,941	2,000	1,990	2,094	2,697	2,709	2,838	2,649
0	1,395	1,451	1,363	1,931	1,743	1,495	1,419	1,493	1,501	1,511	1,992	2,045	1,861	1,782
1	1,036	1,151	1,123	1,395	1,384	1,112	1,124	1,133	1,170	1,252	1,598	1,479	1,240	1,363
2	929	991	1,052	1,261	1,186	928	1,056	1,011	984	1,083	1,374	1,219	1,057	1,134
3	1,288	1,214	1,230	1,448	1,238	1,322	1,140	1,175	1,216	1,323	1,443	1,237	1,356	1,267
4	2,224	1,922	2,089	2,015	1,799	2,591	2,112	2,034	2,064	2,008	2,028	1,654	2,789	2,281
TOTAL	**80,536**	**102,645**	**98,821**	**105,515**	**97,083**	**87,104**	**103,319**	**100,836**	**102,398**	**102,930**	**109,627**	**100,457**	**93,875**	**107,881**

Hour	15-Feb	16-Feb	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb
5	4,154	3,943	4,118	4,113	3,125	2,572	5,095	4,206	4,262	4,094	3,257	3,018	2,440	4,936
6	6,236	6,357	6,140	5,970	4,149	3,069	6,172	6,273	6,156	5,926	3,911	4,039	2,984	6,875
7	6,426	6,927	6,699	6,575	4,786	3,399	7,187	6,719	6,845	6,981	4,324	4,485	3,358	6,869
8	6,342	6,082	6,304	6,359	5,131	3,847	6,877	6,043	6,241	6,241	4,646	4,648	3,641	6,455
9	5,725	5,699	5,495	5,671	5,453	4,303	5,616	5,765	5,468	5,542	5,093	5,024	4,382	5,345
10	5,270	5,194	5,243	5,441	5,656	4,563	5,162	5,058	5,254	5,194	5,243	5,124	4,572	5,154
11	4,910	4,791	4,760	4,959	5,374	4,685	4,828	4,641	4,833	4,995	5,371	5,148	4,848	4,911
12	4,583	4,758	4,918	5,169	5,134	4,450	4,833	4,692	4,941	4,856	5,030	5,080	4,659	4,710
13	5,024	4,673	4,825	5,098	5,553	4,840	4,902	4,912	5,014	4,851	5,290	5,325	4,915	4,946
14	4,867	4,972	4,898	5,350	5,623	4,938	5,047	4,973	5,058	5,447	5,286	5,615	5,279	5,090
15	5,367	5,257	4,865	5,619	5,394	5,198	5,157	5,131	5,729	5,321	5,581	5,668	5,443	5,361
16	5,997	6,163	6,141	6,156	5,618	5,181	6,110	5,993	6,091	6,234	5,472	5,851	5,485	6,027
17	6,188	6,447	6,548	6,336	5,313	5,261	6,414	6,340	6,546	6,678	5,476	5,700	5,507	6,258
18	5,881	5,774	6,089	5,940	5,608	4,804	6,066	6,094	6,216	6,250	4,974	5,277	5,346	6,083
19	5,556	5,736	5,562	5,808	5,068	5,050	5,608	5,834	5,824	5,894	4,890	4,965	5,067	5,783
20	4,955	5,146	4,985	5,562	5,131	4,527	4,752	5,057	5,189	5,864	4,455	4,731	4,960	5,250
21	4,012	4,120	3,857	5,012	4,431	4,467	3,884	3,916	4,192	5,315	4,147	4,451	4,827	4,488
22	2,820	3,041	3,041	3,931	3,883	3,800	2,785	2,832	3,022	4,322	3,500	3,622	3,949	3,260
23	2,235	2,227	2,147	2,759	2,758	2,684	2,024	2,054	2,109	2,877	2,655	2,816	2,867	2,419
0	1,690	1,600	1,576	2,203	1,993	1,705	1,547	1,533	1,579	2,135	1,871	1,933	1,945	1,763
1	1,336	1,266	1,242	1,565	1,544	1,250	1,224	1,070	1,245	1,561	1,519	1,430	1,342	1,240
2	1,094	1,072	1,088	1,316	1,283	1,136	1,037	1,000	1,089	1,417	1,311	1,156	1,104	1,167
3	1,273	1,310	1,290	1,497	1,280	1,472	1,263	1,258	1,316	1,473	1,381	1,256	1,477	1,311
4	2,185	2,242	2,114	2,121	1,772	2,781	2,085	2,251	2,176	2,208	2,050	1,758	2,890	2,355
TOTAL	**104,126**	**104,797**	**103,945**	**110,530**	**101,060**	**89,982**	**105,675**	**103,645**	**106,395**	**111,676**	**96,733**	**98,120**	**93,287**	**108,056**

Figure 2. Hourly Traffic in the Cavitex Parañaque Toll Plaza

Above are the data regarding the number of vehicles hourly that have used the toll gates in Cavitex Parañaque Toll Plaza for the whole month of february 2022. The data was retrieved from FOI where the researchers emailed the PEATC (PEA Tollway Corporation.)

Input and Output data requirements

The input data used in the model was generated from the data the researchers requested from the PEATC hourly traffic online document. Further simulations will require up-to-date data which the researchers and future researchers should request again. The output will be evaluated in the next chapter and would have the results at the results chapter.

Simulation Software

The researchers will use simulation software to simulate the data they have gathered into a model they would create. Simulation software is based on the process of modeling a real phenomenon with a set of mathematical formulas. It is, essentially, a program that allows the user to observe an operation through simulation without actually performing that operation [2].

Simulation software is used widely to design equipment so that the final product will be as close to design specs as possible without expensive in process modification [9].

ARENA

The researchers would use ARENA, a simulation software recommended by their instructor. The researchers deemed that ARENA was the best in terms of UI, learning curve, and usability based on the various demonstrations the instructor demonstrated. Arena is a simulation software product that provides an integrated framework for building simulation models in a wide variety of applications [3].

Arena makes it possible to analyze the current system, which aids in developing low-cost improvements to decision-making and capital investment decisions. It enables you to pinpoint system restrictions and limitations as well as the causes of particular system situations. It gives you the ability to consider "what if" situations and offers system-specific performance metrics.

Exponential Distribution

The researchers also used the exponential distribution from the input analyzer in the ARENA application to further the simulation process of the model.

Exponential distribution is the probability distribution that describes the time between events in a Poisson process, i.e. a process in which events occur continuously and independently at a constant average rate—lambda [7].

III. MODEL

In this chapter, the researchers will discuss the design and the flow of the model and its implementation in the research.

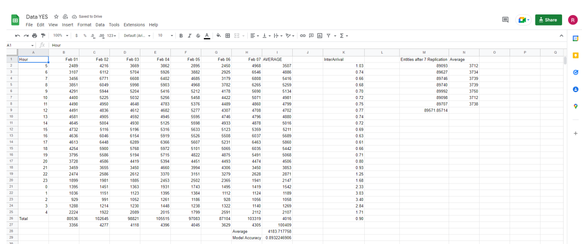

Figure 3. Sample Data for 7 Day Simulation

The researchers ran a 7-day simulation and encoded the data of the number of cars, inter-arrival time and the average numbers needed in construction of a simulation sample. These numbers are to be run in the ARENA software where they would be evaluated by their accuracy. More information will be provided in the results section.

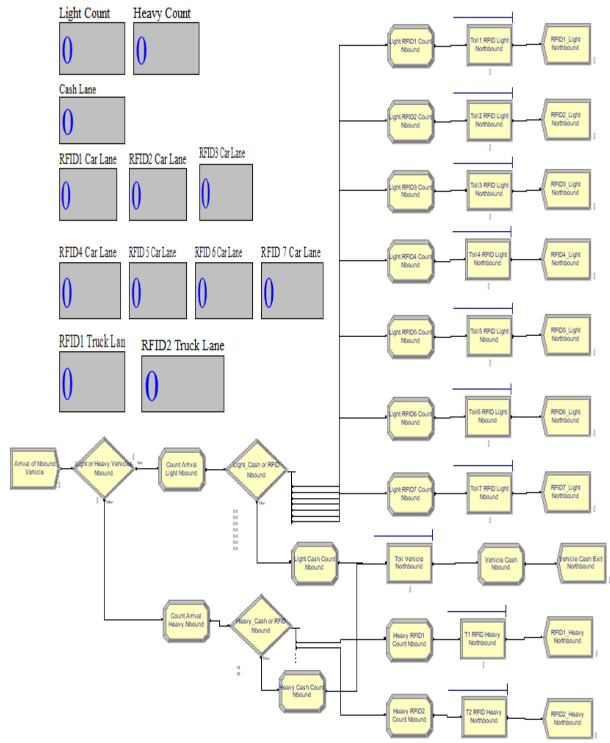

Figure 4. Simulated Model for Northbound

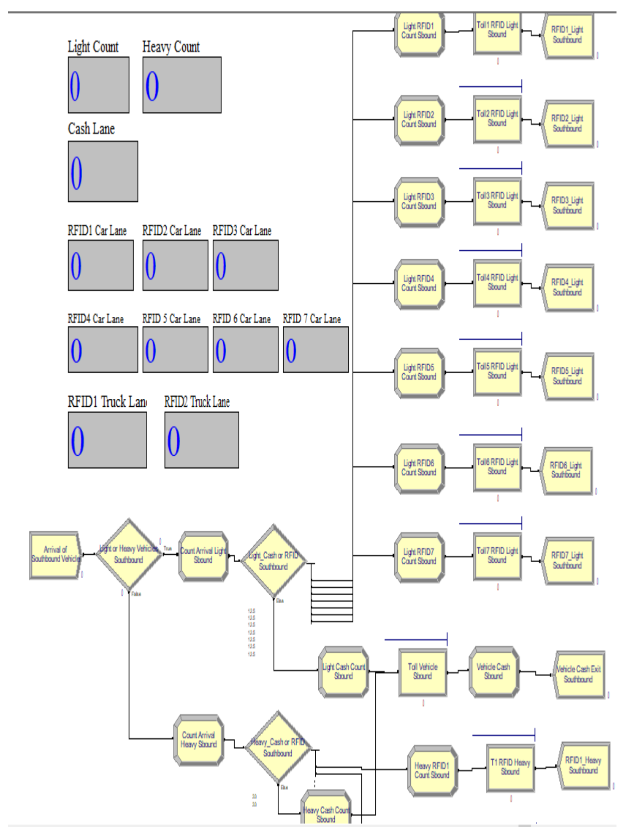

Figure 5. Simulated Model for Southbound

Figure 4 and 5 shows the model for the northbound and southbound of the tollgate that will be run simultaneously in the arena to simulate the whole to. Both models of the northbound and southbound will have the same values for their entities such as their inter arrivals, entities per arrival, and values of the queueing system for the results to be closer to the actual data.

The model will start with the arrival of the cars in which the arrival of entities will have a value of 1. The Input Analyzer tool is used to get the expression for the exponential distribution from the same input data which gives the expression 0.33 + EXPO(1.6) that will be set as the inter-arrival value.

After that, the simulation will choose what type of vehicle arrived at the tollgate with the likelihood of the vehicle to be a light vehicle is 75% and 25% to be a heavy vehicle. This percentage can be manipulated to either increase or decrease the chance of a specific type of vehicle (e.g. 60% chance that it will be a light vehicle, 30% on the other). The model will have a variable before going to the queue that will act as a counter for the number of cars. The count is shown in Figure 3 with a name of Light Count for the light vehicles and Heavy Count for the heavy vehicles.

The model will also have a n-way if else that will determine if the vehicle will pay via cash or RFID. This will be the same for both light and heavy vehicles.

The queue time will be handled by the process called 'Toll RFID Light' for light vehicles paying by RFID, 'Toll RFID Heavy' for heavy vehicles paying by RFID, and 'Toll Vehicle' for both vehicles paying by cash. The values for the queueing will be set to seconds and will be shown in table 1.

Type of Lane	Minimum	Most Likely	Maximum
Car RFID	5	10	15
Cash	5	10	20
Truck RFID	5	10	15

Table 1. Values in seconds for waiting area of lanes

The Arena Simulation will be used to run the model that will be set to 24 hours of simulation with 7 replications. The results of the model will display the average cars entered per day along with various information that will be discussed in the next chapter.

IV. RESULTS

A. Validation Results

The researchers ran the model for 7 replications with the use of ARENA. The researchers compared the data requested from FOI to the data generated by the model to validate the results. The data from the average of February 1-7, 2022 was used as a reference for the current model. This data presented the average, presumably both light and heavy weight, cars passed through the tollgate was estimated to be 100, 409. The simulation showed the average 89, 688. This would mean the model exhibited an estimation of 11% error of margin by using the equation shown below. This suggests that the model can well capture the system dynamics. This validates that the tollgate and number of toll gates conform to the real data, and these factors are directly relevant to determining the toll gates.

$$\text{Margin of error} = \frac{simulated\ data - actual\ data}{actual\ data} * 100$$

Equation 1. Equation used for accuracy

B. System Replication Report

The Figure 6 below exhibits the average queue time and number of cars occurred in the model during the 7 replications. According to the figure, the maximum time for the vehicles to pay in the cash lane on the Northbound was 2.15 minutes, the average time was around 0.12 minutes, and there were a maximum of 11 cars waiting in line. Meanwhile in all of the RFID light weight vehicles lanes, the RFID on the Southbound queue in Toll 1 had a maximum queue time of 1.43 minutes, had an average of 0.09 minutes, and had a total of 9 cars waiting in line.

The shortest time that occurred in the data was on the light vehicle Northbound lane RFID Toll 3 with an average estimation of 0.09 minutes, maximum estimation of 1.13 minutes, and maximum of 8 light vehicles in line.

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
T1 RFID Heavy Northbound.Queue	1.1389	0.10	0.9204	1.3121	0.00	6.0710
T1 RFID Heavy Sbound.Queue	1.1274	0.10	0.9140	1.3317	0.00	6.6698
T2 RFID Heavy Northbound.Queue	1.0921	0.08	0.9628	1.2496	0.00	6.1877
T2 RFID Heavy Sbound.Queue	1.0658	0.11	0.8293	1.3361	0.00	5.9492
Toll Vehicle Northbound.Queue	10.2305	1.94	7.8376	17.0299	0.00	70.3229
Toll Vehicle Sbound.Queue	13.2980	5.61	8.8344	35.2432	0.00	99.69
Toll1 RFID Light Northbound.Queue	1.2879	0.10	1.0947	1.4956	0.00	7.7811
Toll1 RFID Light Sbound.Queue	1.2019	0.10	1.0076	1.4467	0.00	6.4915
Toll2 RFID Light Northbound.Queue	1.2348	0.10	1.0162	1.4832	0.00	10.6606
Toll2 RFID Light Sbound.Queue	1.3633	0.11	1.0959	1.5682	0.00	9.4539
Toll3 RFID Light Northbound.Queue	1.2893	0.13	0.9854	1.6386	0.00	8.6847
Toll3 RFID Light Sbound.Queue	1.2586	0.13	0.9675	1.5695	0.00	9.5656
Toll4 RFID Light Northbound.Queue	1.3376	0.11	1.1121	1.6226	0.00	8.2781
Toll4 RFID Light Sbound.Queue	1.3143	0.13	1.1064	1.7088	0.00	7.7529
Toll5 RFID Light Nbound.Queue	1.3549	0.13	1.0495	1.5895	0.00	8.3769
Toll5 RFID Light Sbound.Queue	1.3124	0.06	1.1545	1.4141	0.00	8.1227
Toll6 RFID Light Nbound.Queue	1.2993	0.12	1.0842	1.5734	0.00	6.8898
Toll6 RFID Light Sbound.Queue	1.4232	0.09	1.2424	1.6078	0.00	9.1385
Toll7 RFID Light Nbound.Queue	1.2771	0.12	1.0639	1.5897	0.00	8.1022
Toll7 RFID Light Sbound.Queue	1.2334	0.20	0.9333	1.8362	0.00	9.2586

Figure 6. Average queue time after 7 replication

Figure 7 displays the average cars passed entered the lanes during the 7 replications.

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
T1 RFID Heavy Northbound.Queue	0.0975	0.01	0.06387737	0.1309	0.00	5.0000
T1 RFID Heavy Sbound.Queue	0.08898414	0.02	0.05144838	0.1308	0.00	6.0000
T2 RFID Heavy Northbound.Queue	0.0918	0.01	0.06819568	0.1163	0.00	6.0000
T2 RFID Heavy Sbound.Queue	0.08838924	0.01	0.05816906	0.1106	0.00	5.0000
Toll Vehicle Northbound.Queue	1.8007	0.43	1.1603	3.3098	0.00	24.0000
Toll Vehicle Sbound.Queue	2.5585	1.49	1.3413	8.3288	0.00	34.0000
Toll1 RFID Light Northbound.Queue	0.1242	0.01	0.0924	0.1568	0.00	7.0000
Toll1 RFID Light Sbound.Queue	0.1128	0.02	0.08680667	0.1573	0.00	7.0000
Toll2 RFID Light Northbound.Queue	0.1164	0.02	0.07762724	0.1567	0.00	9.0000
Toll2 RFID Light Sbound.Queue	0.1394	0.03	0.07762605	0.1830	0.00	7.0000
Toll3 RFID Light Northbound.Queue	0.1244	0.02	0.07117079	0.1764	0.00	9.0000
Toll3 RFID Light Sbound.Queue	0.1114	0.02	0.07095521	0.1875	0.00	9.0000
Toll4 RFID Light Northbound.Queue	0.1314	0.01	0.0979	0.1585	0.00	7.0000
Toll4 RFID Light Sbound.Queue	0.1190	0.03	0.08912968	0.2241	0.00	7.0000
Toll5 RFID Light Nbound.Queue	0.1362	0.02	0.0908	0.1899	0.00	9.0000
Toll5 RFID Light Sbound.Queue	0.1266	0.02	0.08578368	0.1683	0.00	6.0000
Toll6 RFID Light Nbound.Queue	0.1278	0.02	0.07908437	0.1732	0.00	7.0000
Toll6 RFID Light Sbound.Queue	0.1412	0.02	0.1028	0.2128	0.00	9.0000
Toll7 RFID Light Nbound.Queue	0.1198	0.02	0.0901	0.1711	0.00	7.0000
Toll7 RFID Light Sbound.Queue	0.1122	0.03	0.07134350	0.2015	0.00	9.0000

Figure 7. Average number of cars after 7 replication

C. T-test results

Replication No. / Day No.	Simulated Average per Hour	Actual Average per Hour
1	89093	80536
2	89627	102645
3	89746	98821
4	89740	105515
5	89992	97083
6	89098	87104
7	89707	103319

Table 2. Replication values from the model and Day values from the data

Difference Scores Calculations

Treatment 1

N_1: 7

$df_1 = N - 1 = 7 - 1 = 6$

M_1: 3732

SS_1: 1262

$s^2{}_1 = SS_1/(N - 1) = 1262/(7-1) = 210.33$

Treatment 2

N_2: 7

$df_2 = N - 1 = 7 - 1 = 6$

M_2: 4018

SS_2: 892628

$s^2{}_2 = SS_2/(N - 1) = 892628/(7-1) = 148771.33$

T-value Calculation

$s^2{}_p = ((df_1/(df_1 + df_2)) * s^2{}_1) + ((df_2/(df_2 + df_2)) * s^2{}_2) = ((6/12) * 210.33) + ((6/12) * 148771.33) = 74490.83$

$s^2{}_{M1} = s^2{}_p/N_1 = 74490.83/7 = 10641.55$

$s^2{}_{M2} = s^2{}_p/N_2 = 74490.83/7 = 10641.55$

$t = (M_1 - M_2)/\sqrt{(s^2_{M1} + s^2_{M2})} = -286/\sqrt{21283.1} = \underline{\mathbf{-1.96}}$

Group	Simulated Average per Hour	Actual Average per Hour
Mean	3732.16285714	4017.99404757
Standard Deviation	14.33588006	385.78568990
Standard Error of Mean	5.41845335	145.81328498
N	7	7

Table 3. Statistical values used for t-test calculation

Intermediate values used in calculations:

T-value = **1.96**

Df = 12

Standard error of difference = 145.914

Critical value = 2.18

Confidence interval:

The mean of Group One minus Group Two equals -285.83119043

95% confidence interval of this difference: From -603.75018549 to 32.08780464

V. CONCLUSION

The critical value is less than the t-value, this means that the value of the simulated model is close to the actual value from the data.

By conventional criteria, the researchers will accept the null hypothesis and reject the alternative because the average car per hour of the simulated model is related to the average car per hour of the actual data due to the fact that the result value of the P-value is higher than 0.05 or 5% more which determines whether our simulated data has close relation with the data we acquired from the actual data.

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