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Modeling Queue Length at The Toll Gate Using Promodel Before and After Ramp-Off Construction

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Abstract

In everyday life, queues often occur. Waiting at the counter to get train or movie tickets, at the toll gate, at the bank, at the supermarket, and in other situations that we often encounter Queues occur when the need for services exceeds the capacity or capacity of the service facility. As a result, users of the facility cannot get immediate service due to the busyness of the service. The Amplas Toll Gate queue is the object of this research. The Amplas Toll Gate is one of the densest toll gates that is heavily traveled by vehicles both entering and exiting. This makes it often seen a fairly long queue, especially during peak hours in the late afternoon to evening. The Medan City Government built an off ramp at the Amplas flyover in 2016. This off ramp leads directly to the Amplas toll gate. The vehicle arrival rate increases along with the queue length because vehicles can arrive faster to the toll gate. This study aims to calculate the queue length at the Amplas toll gate before and after the construction of the ramp off. Data is obtained by recording the volume of vehicles at the research location. With an average service time of 7 seconds, the queuing method produces a queue length of 11.98 meters, while the results using Pro Model software are 11.98 meters. In addition, the queue length after the construction of the ramp off decreased to 6.67 meters from before the construction of the ramp off. Promodel is a windows-based simulation software used to simulate and analyze a system.

Keywords: Toll Gate, Ramp Off, Queue

1. Introduction

These days, many vehicles pass through toll gates every day. This is especially true for congested toll gates, which are used by tourists to get into the city. This leads to quite long queues, especially in the morning and evening rush hours. Certain factors cause this phenomenon, such as road sections that have a small road capacity but are able to accommodate many vehicles. Another factor is that the services provided by the operator and the number of existing toll booths are still lacking.

The Amplas toll gate is the most used toll gate by vehicles for both entry and exit. because the number of amplas toll booths is not comparable to the number of the three regions. On the other hand, the Amplas Toll Road seems long. because this location, along with Belawan, Mabar, Tanjung Mulia, Haji Anif, and Bandar Selamat, is the main choice for motorists to exit Medan city. Toll roads should investigate issues that cause congestion as their purpose is to facilitate a smooth flow of vehicles. The queuing process at the toll gate is one of the factors that often cause congestion. People have to buy admission tickets at the entry gate and pay tolls at the exit gate. Therefore, the time taken to complete the work at the toll gate affects the smooth flow of vehicles. Some previous research Some previous research on queue length at toll booths shows that queues at toll booths occur due to the speed of arrival (flow rate) of vehicles. The government built an off ramp at the Amplas flyover in 2016. This off ramp will lead directly to the Amplas toll gate, so that people who want to go to the Amplas toll road from SM. Jalan Raja do not need to go through the intersection. The longer it takes for drivers to arrive at the toll booth, the more people will arrive, which in turn leads to longer queues. Thus, the purpose of this study is to investigate whether the construction of the ramp off has a real impact on the queue length at the Amplas toll booth.

2. Literature Review

2.1. Model and Simulation

According to Daellenbach (1994), a model is a representation or abstraction of an actual object or situation. An iconic model presents a system or object into a model object that is similar in shape to the system. Analog models are models that have the ability to describe the nature of the system to be simpler. A symbolic or mathematical model is an abstract representation of the system.

Mathematical or symbolic models have two types of purposes: descriptive (normative) and prescriptive. Descriptive models describe a system, while prescriptive models deal with optimization methods. as well as heuristic and other techniques to produce an ideal model.

According to Bankset et al. (2004), simulation is the simulation over time of the operating process of a real system or condition. Simulation is used to describe and analyze the behavior of a system, ask what if or "what if" questions about the actual system, and assist in the design process of real systems. A broad set of techniques and applications to describe the behavior of real systems is called simulation. According to Law (2007), simulation models are a good choice for describing complex systems. This is especially true when analytical mathematical models are used.

2.2. Queue

Queuing is a common symptom when the need for service exceeds the available capacity (Mufidah, 2018; Prawira, 2017). In addition, Mujahidin et al. (2014) stated that vehicle queues can affect vehicle fuel consumption.

Queuing (waiting line) is a situation where people or goods are in line waiting to be served. The queuing system is created if the customer comes to the service place, the customer waits to be served if the service is not done immediately and the customer leaves the service system if it has been served (Lesmini et al., 2017).

Queues occur due to an imbalance between those served and those served. Queuing systems use customers coming to get service, waiting to be served if the server is still busy, getting service, and then leaving the system. Queuing is a common phenomenon in society. It occurs because the need for service is greater than the capacity (capacity) of the service or service facility. As a result, new customers who come to the facility cannot get service immediately due to the busyness of the service (Mehri & Djemel, 2007).

The basic structure of queuing systems can be classified based on the number of channels and service stages. A single channel-single phase is a system with one entry point to one service facility, where individuals receive service at one service station before exiting the system. In contrast, a single channel-multi phase has one entry point, but the service process is carried out in several sequential stages, such as in mass production or motor vehicle inspection. A multi-channel-single phase system involves multiple service facilities that are served by a single queue, allowing multiple services to take place simultaneously, but with a single queue. allows multiple services to take place simultaneously, but each individual passes through only one stage of service. Finally, the multi-channel-multi-phase system includes several service lines with various stages carried out in stages, for example in the student registration process at a university or hospital services involving registration, diagnosis, treatment, and payment stages (Lesmini et al., 2017).

2.3. Toll Gate

Toll roads as freeways provide a real difference with ordinary roads. This difference is expected to provide more quality considering the increasing level of community mobility (Fahza, 2019).

Toll roads are equipped with toll gates, which are locations where the toll transaction process takes place. This toll gate consists of several toll booths which are a place for toll officers to carry out their duties. One of the systems used in the current toll collection process is the Automatic Toll Gate (GTO) system. Given that the main function of toll roads is to ensure the smooth flow of vehicles without significant obstacles, evaluation of toll road performance is important. One of the main problems that often arise on toll roads is congestion, especially in the toll gate area. This congestion usually occurs due to the imbalance between the number of toll gates and the volume of vehicle flow as well as the transaction time that is too long, causing unwanted queues of vehicles. Therefore, the number of toll gates operated must be adjusted to the volume of vehicles. If there are too few, long queues will occur, but if there are too many, operating costs will increase significantly (Handika, 2019).

Toll roads are designed to support the development of local roads, both directly and indirectly. Improving the quality of local roads around toll roads can also encourage growth and anticipate the opening of new access in the area. The effects of exit ramp blockages are well understood, and their impact has been empirically proven. However, there are still limited analytical results that can provide a deeper understanding of this phenomenon. To illustrate the specific impact of exit ramp blockage, simulations were conducted to analyze the relationship between total demand, total inflow, outflow through the exit ramp, and the number of vehicles in the toll road system (Wang et al., 2016).

3. Methodology

The flow of this research can be seen in Figure 1 below.

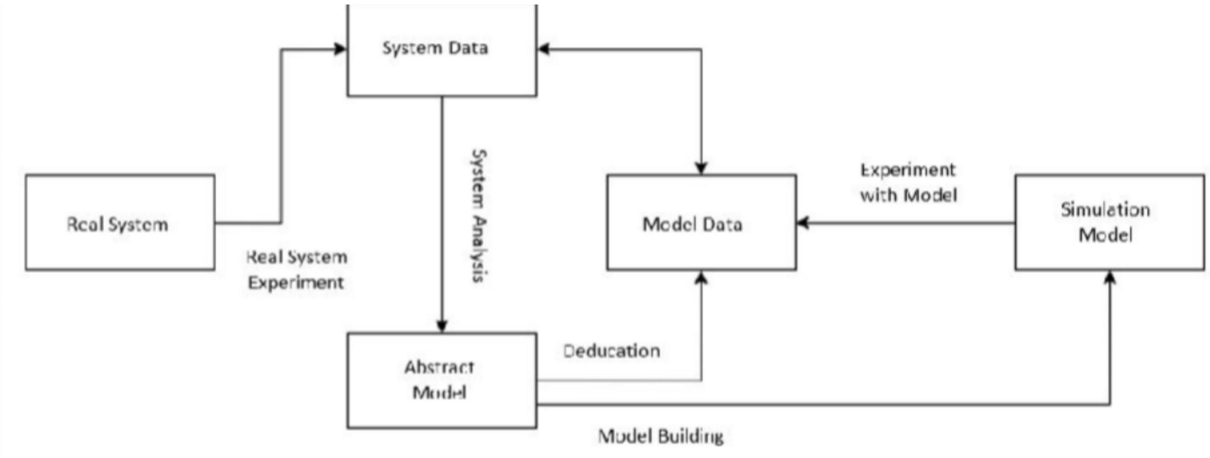

Figure 1: Research Method

3.1. Real System

An effective system is developed through an in-depth understanding of the real-time behavior of the system, as well as by analyzing how its components interact with each other. By examining and analyzing queue data at the Amplas Toll Gate.

3.2. System Data

System data collection is done by determining various parameters that will be observed during the simulation. In the queue data at the Amplas Toll Gate, the system considered includes the main aspects of inventory management, such as the vehicle arrival rate, the level of service at each toll booth, the number of toll booths available, the length of the queue formed, and the waiting time of the vehicle in the queue.

3.3. Abstract Model

An abstract model is a conceptual model developed through relationships between components to simplify and understand the dynamics of a system. In the context of the Amplas Toll Gate survey, each component analyzed helps form an abstract model that accurately predicts the queuing process, including vehicle arrival patterns, substation service capacity, and other variables.

3.4. Model Data

A data model is an abstract representation that defines how data in a system or process is analyzed, organized, and connected. The data model serves to simplify the information structure by describing the data elements, the relationships between elements, and the rules that govern the interaction of the data.

3.5. Simulation Model

This method implements an abstract model into the ProModel simulator to model and simulate manufacturing and service systems. The use of the ProModel simulator is expected to assist in providing an overview of the queuing process at the Amplas Toll Gate Queue, reduce risk, provide clarity on complex decisions. Basic elements of ProModel:

a. Location: A fixed area where raw materials, semi-finished materials, or final products wait or undergo processing. Here, entities may be processed, delayed, stored, or undergo other activities.
b. Entities: Any material to be processed in the model. Entities are objects that are observed in the system.
c. Arrival: Indicates the mechanism by which entities enter the system, both in terms of the number of arrival locations as well as the frequency and time of arrival, which is set periodically.
d. Processing: Operations that occur in the location. This process describes what the entity experiences from the time it enters until it leaves the system.
e. Resource: Resources that are used to perform certain operations in the system. In Promodel, objects that act as resources can move as needed.

f. Path Network: Determines the direction and path that a resource or entity will take when moving from one location to another. This path network is needed if you want to use a moving resource or entity.
g. Running the Simulation: Before running the model created, some settings need to be considered so that the simulation runs as expected.

4. Results and Discussion

4.1. Real System

The selected real system is an Amplas Toll Road Gate, located at Jl. Tol No.8, Timbang Deli, Kec. Medan Amplas, Medan City, North Sumatra. The queuing system at the Amplas toll gate, including the vehicle entry process, payment at the substation (counter), and vehicle movement after the transaction is completed. In this system, the construction of the ramp off at the Amplas flyover affects the vehicle arrival rate and queue length as shown in Figure 2 below.

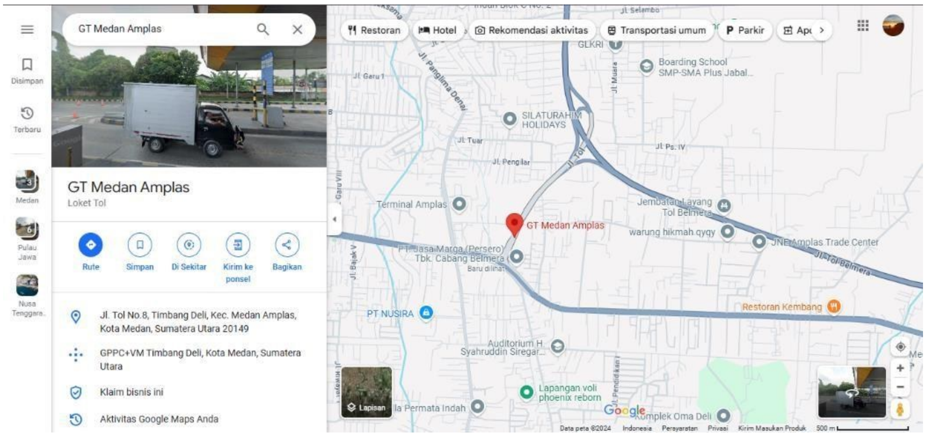

Figure 2: Amplas Toll Gate Locations

4.2. Model Evaluation

The following is secondary data from the arrival rate of the Amplas Toll Gate contained in Table 1.

Table 1: Secondary Data of Vehicle Arrivals

No	Time	Vehicles
1	07.00 – 08.00	837
2	08.00 – 09.00	919
3	09.00 – 10.00	937
4	10.00 – 11.00	973
5	11.00 – 12.00	1004
	Total	4698

Average vehicle arrival (λ)

$$\lambda = \frac{\varepsilon x}{N} = \frac{4698}{5} = 93 \approx 94 \text{ vehicle/hour}$$

There is also secondary data on the average service time of the Amplas Toll Gate found in Table 2.

Table 2: Secondary Data of Time Services

Sub-stations	Service Averages (Sec)
1	6.73
2	6.82
3	7.34
Average Times	6.96

Average service level of substations (μ)

$$\mu = 3600/7 = 517.2 \approx 517 \text{ vehicle/hour}$$

Calculation of queue length with queuing theory:

Using ST = 7 seconds/vehicle

$$n = \frac{940/3}{515 - (940/3)} = 1.553 \approx 2 \text{ vehicle}$$

$$q = \frac{(940/3)^2}{515(515 - (940/3))} = 0.945 \approx 1 \text{ vehicle}$$

$$d = 515 - (940/3) \times 3600 = 17.851 \approx 18 \text{ sec}$$

$$w = \frac{(940/3)}{515(515 - (940/3))} \times 3600 = 10.860 \approx 11 \text{ sec}$$

Calculation of queue length with a combination of service times can be seen in table 3 below

Table 3: Secondary Data Queue Length

ST	Service Level (vehicle/hour) (μ)	Number of vehicles in queue (vehicles) (n)	Queue length (m) (n)	Number of vehicles in queue (vehicles) (q)	Queue length (m) (q)	Waiting time (second) (d)	Waiting time (second) (w)
7	515	1.553	6.212	0.945	3.78	17,851	10,86
8	450	2.292	9.168	1.596	6.384	26,341	18,341
9	400	3.615	14.46	2.832	11.328	41,538	32,538
10	360	6.714	26.856	5.843	23.372	77,142	67,142
11	328	21.363	85.452	20.408	81.632	245,454	234,478
12	300	-23.5	-94	-24.54	-98.16	-270	-282

Description:
- n - q = 1
- d - w = service time
- 1 vehicle = 4 meters
- Minus sign (-): Indicates that the queue will continue to grow in length (infinite).

4.3. Abstract Model

In Figure 3 and Figure 4 below is an abstract of the Amplas Toll Gate simulation before and after the construction of the Ramp Off:

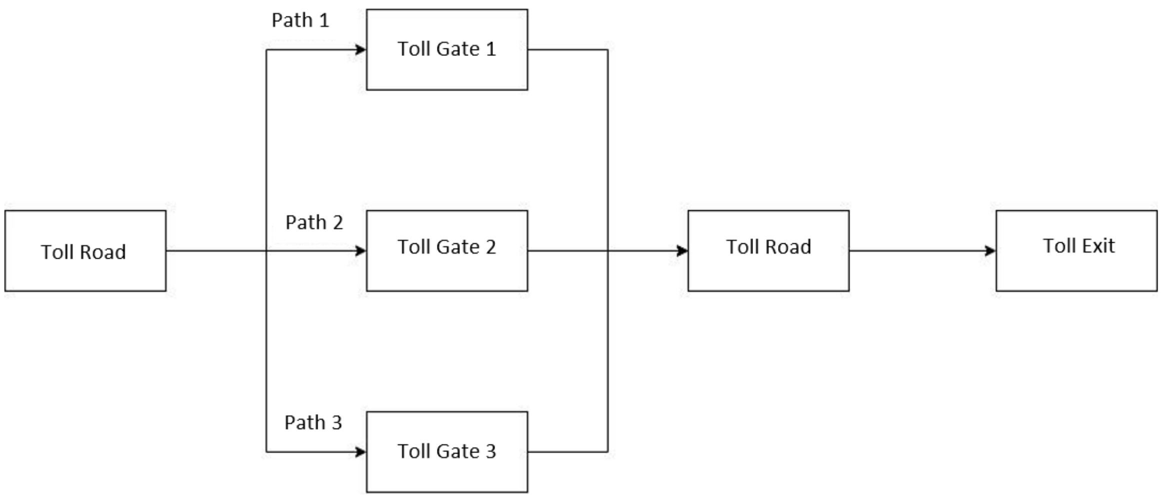

Figure 3: Abstract Model Before Ramp Off

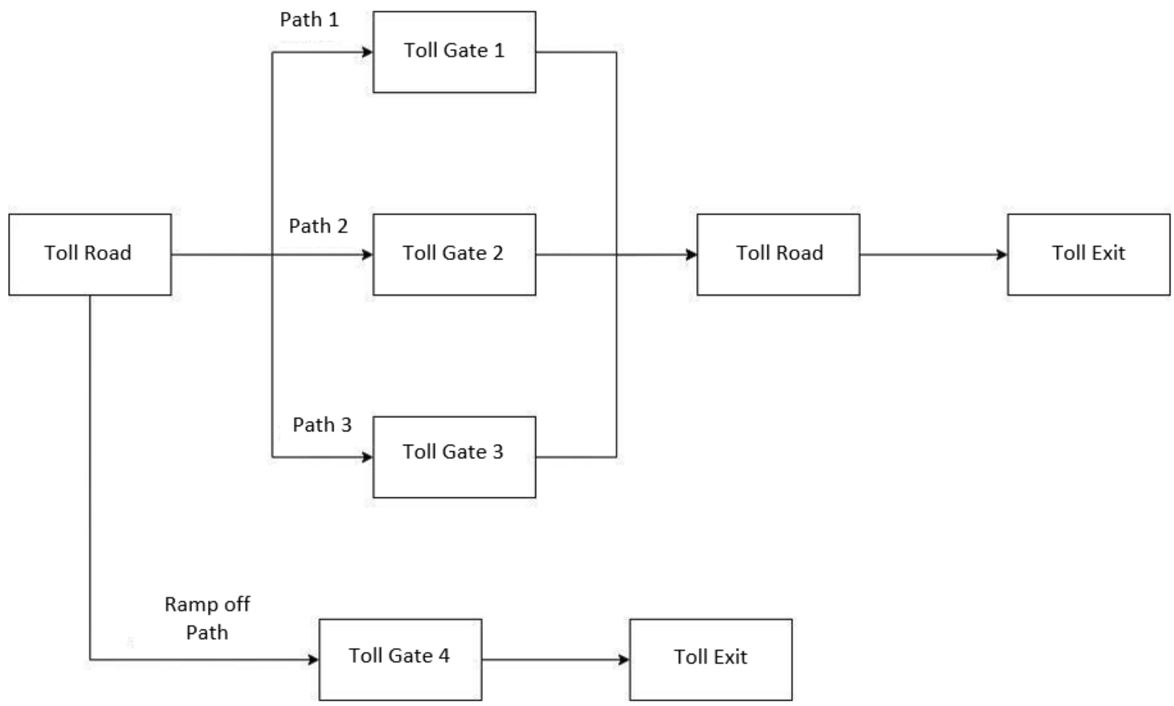

Figure 4: Abstract Model After Ramp Off

4.4. Model Data

Model data is obtained by reconstructing secondary data by multiplying it using an exponential arrival pattern so that it can be run in simulation.

Cumulative Exponential Distribution:

$$y = 1 - e - \lambda t$$

Inverse:

$$\lambda t = -\ln(1 - y)$$
$$(1 - y) \rightarrow 1 - 0$$

If y values are Uniformly distributed:

$$-\ln(y)$$
$$t = \lambda = -T_a \ln(y)$$

The Amplas Toll Gate has 3 Substations or Substations at its main gate. Model data is obtained in table 4 below:

Table 4: Overall Data

No	Time	Number of Vehicles Arriving	Average Service Time (seconds)	Queue Length (meter)
1	07.00 - 08.00	837	6.73	3348
2	08.00 - 09.00	919	6.73	3676
3	09.00 - 10.00	937	6.73	3748
4	10.00 - 11.00	973	6.73	3892
5	11.00 - 12.00	1004	6.73	4016
..	..	..	..	..
20	02.00 - 03.00	1344	6.73	5376
21	03.00 - 04.00	1351	6.73	5402

22	04.00 - 05.00	1359	6.73	5434
23	05.00 - 06.00	1379	6.73	5517
24	06.00 - 07.00	1387	6.73	5547

Then also obtained data from each Toll Substation which is displayed in Table 5, Table 6 and Table 7 below

Table 5: Toll Sub-stations 1 (Car) Data

No	Time	Number of Vehicles Arriving	Average Service Time (seconds)	Queue Length (meter)
1	07.00 - 08.00	279	6.73	1116
2	08.00 - 09.00	306	6.73	1224
3	09.00 - 10.00	322	6.73	1288
4	10.00 - 11.00	324	6.73	1296
5	11.00 - 12.00	335	6.73	1340
..	..	..	..	..
20	02.00 - 03.00	449	6.73	1796
21	03.00 - 04.00	451	6.73	1805
22	04.00 - 05.00	454	6.73	1816
23	05.00 - 06.00	461	6.73	1843
24	06.00 - 07.00	463	6.73	1854

Table 6: Toll Sub-stations 2 (Pickup) Data

No	Time	Number of Vehicles Arriving	Average Service Time (seconds)	Queue Length (meter)
1	07.00 - 08.00	279	6.82	1116
2	08.00 - 09.00	306	6.82	1224
3	09.00 - 10.00	322	6.82	1288
4	10.00 - 11.00	324	6.82	1296
5	11.00 - 12.00	335	6.82	1340
..	..	..	..	..
20	02.00 - 03.00	489	6.82	1956
21	03.00 - 04.00	506	6.82	2024

22	04.00 - 05.00	515	6.82	2059
23	05.00 - 06.00	524	6.82	2098
24	06.00 - 07.00	559	6.82	2236

Table 7: Toll Sub-stations 3 (Truck) Data

No	Time	Number of Vehicles Arriving	Average Service Time (seconds)	Queue Length (meter)
1	07.00 - 08.00	279	7.34	1116
2	08.00 - 09.00	306	7.34	1224
3	09.00 - 10.00	322	7.34	1288
4	10.00 - 11.00	324	7.34	1296
5	11.00 - 12.00	335	7.34	1340
..	..	..	..	..
20	02.00 - 03.00	422	7.34	1689
21	03.00 - 04.00	426	7.34	1705
22	04.00 - 05.00	430	7.34	1721
23	05.00 - 06.00	435	7.34	1741
24	06.00 - 07.00	452	7.34	1807

From some of the data above, it was found that there was traffic congestion which caused the queue length to reach 5 KM. So it is necessary to build a Ramp Off before the main exit gate of the Amplas Toll Road. A simulation was made before and after the construction of the Ramp Off at the Amplas Toll Road.

4.5. Simulation Model

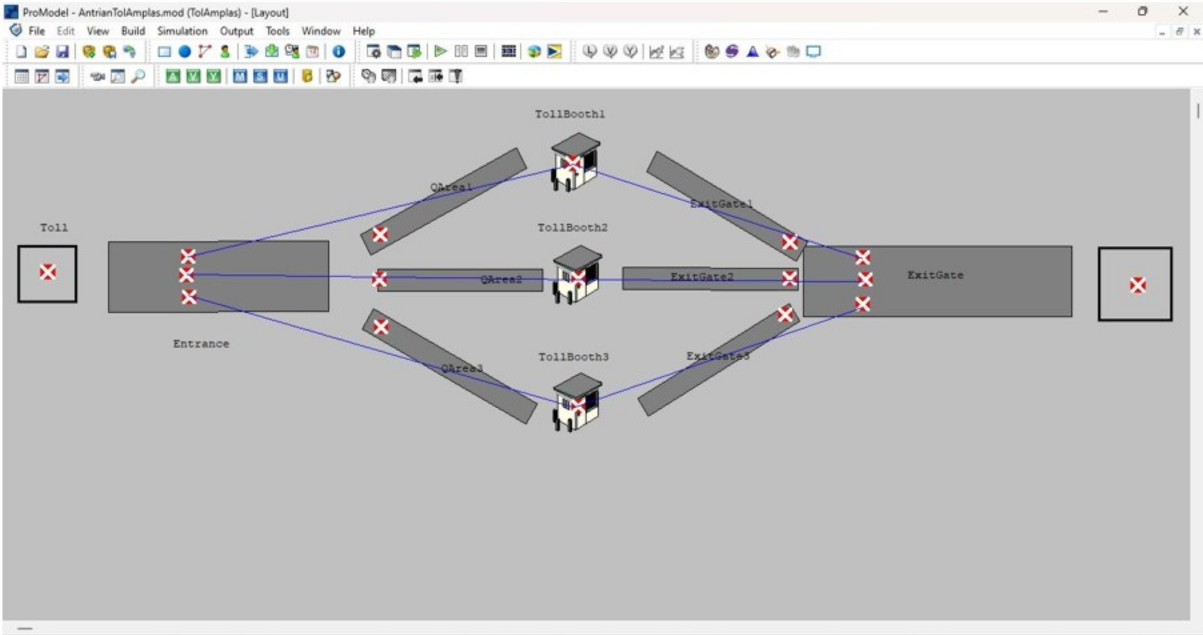

Figure 5: Simulation 1 Promodel Before Ramp Off Construction

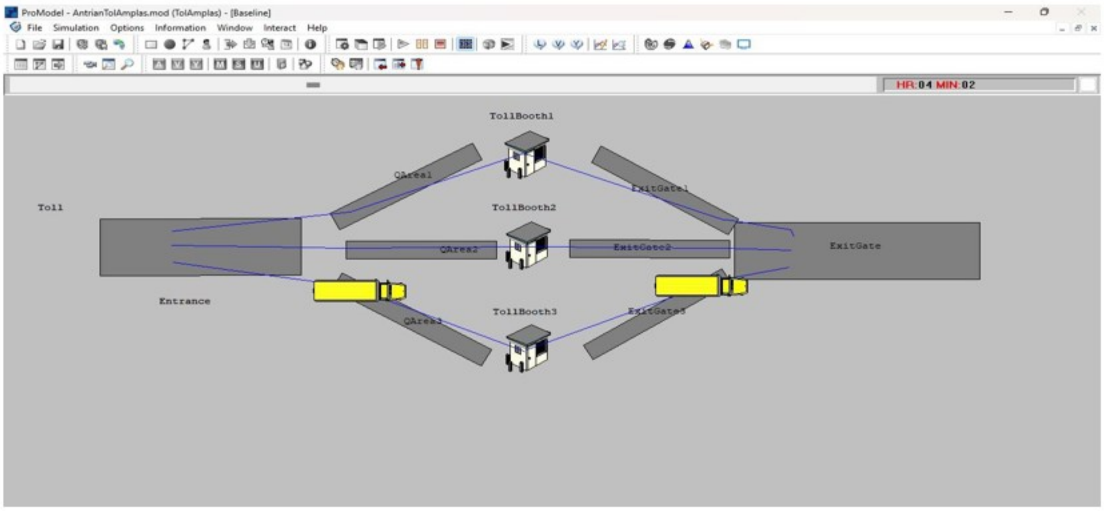

Figure 6: Simulation 1 Promodel After Ramp Off Construction

The simulation in Figure 5 and Figure 6 aims to see the flow of service at the main gate of the Amplas Toll Road at the three toll booths. So that the right Ramp Off construction position can be determined.

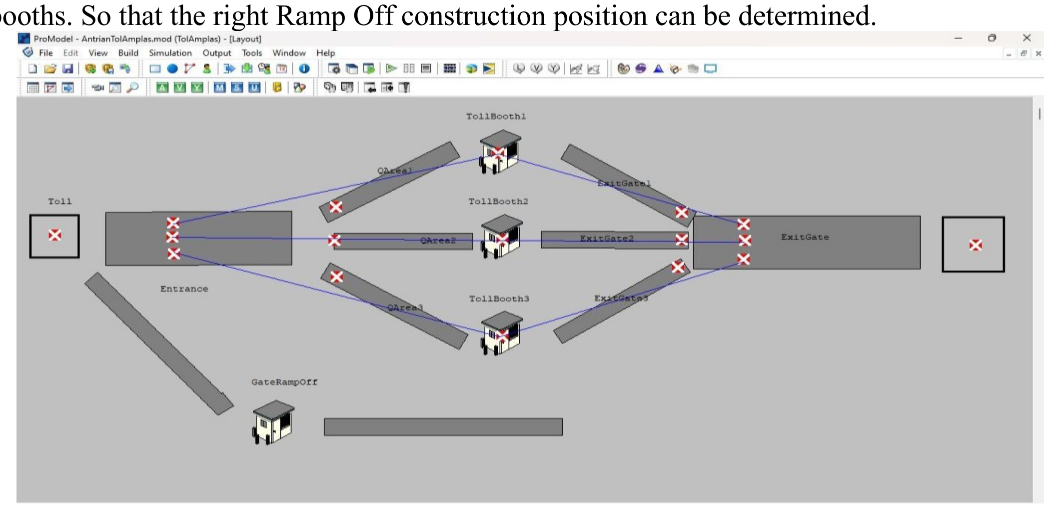

Figure 7: Simulation 1 Promodel After Ramp Off

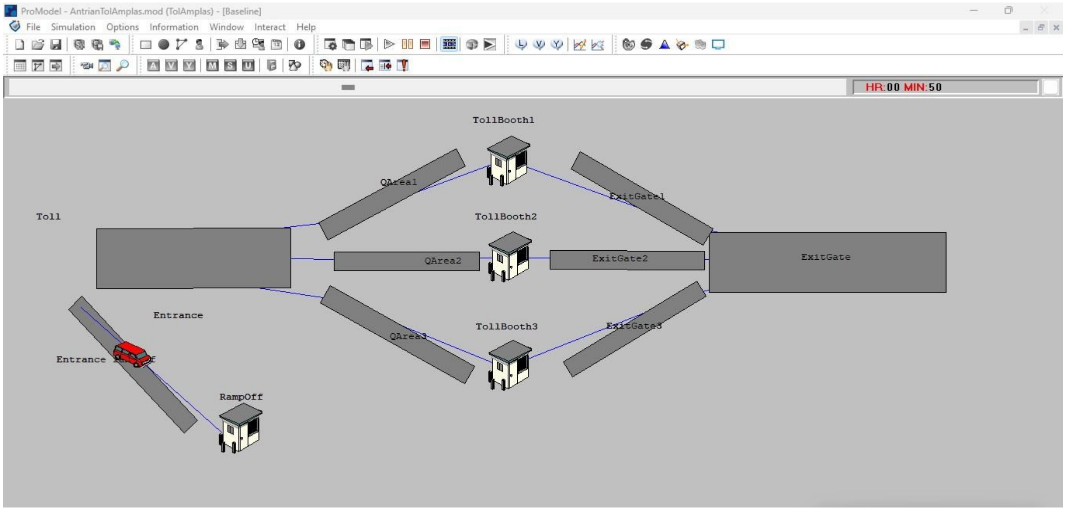

Figure 8: Simulation 2 Promodel After Ramp Off

The simulation results in Figure 7 and Figure 8 show a reduction in queue length from 11.98 meters to 6.67 meters after the construction of the ramp off.

5. Conclusion

In the above research, it can be concluded that by using ProModel simulation software, this research compares the situation before and after the implementation of the ramp-off. The simulation results show that the presence of ramp-offs is able to significantly reduce the length and duration of vehicle queues, thereby reducing congestion that previously occurred frequently. This finding underscores the importance of ramp-offs as an infrastructure solution that has the potential to optimize traffic flow at the Amplas toll gate, increase the gate's capacity to accommodate vehicles, and minimize waiting time for road users.

Furthermore, the success of ramp-offs in reducing congestion at toll gates also has a direct impact on the overall driving experience and traffic efficiency on toll roads. The reduction in queuing time not only saves motorists time, but also reduces fuel usage and vehicle emissions that typically increase when stuck in long queues. The implications of this study suggest that infrastructure strategies such as ramp-off can be adopted at other toll gates with

similar traffic patterns to support a more efficient and environmentally friendly transportation system. Thus, ramp-offs are an important step in modern traffic planning, providing a long- term solution to congestion problems and improving motorist convenience.

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