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**Modelling and Simulation of Tollbooth improvement  
Strategies: Application of VISSIM**

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## Executive Summary

The Kubease Toll Booth, located on the Accra–Kumasi highway in Ghana, is a vital infrastructure asset that facilitates efficient toll collection and plays a crucial role in traffic management. The toll revenues are used for road maintenance and expansion, supporting the nation's infrastructure resilience and economic development. However, the Kubease Toll Booth faces significant operational challenges, primarily due to heavy traffic congestion during peak hours. The current manual toll collection (MTC) system, with only one booth per direction, creates bottlenecks, leading to long queues and delays. This congestion results in increased fuel consumption, higher emissions, and lost productivity. The study aims to analyze the current traffic conditions at the Kubease toll booth and propose effective strategies to enhance toll operations, reduce congestion, and minimize delays. The objectives include analyzing current traffic metrics, evaluating the impact of the existing MTC system, assessing the benefits of expanding the MTC setup, evaluating the benefits of implementing Electronic Toll Collection (ETC), and comparing the effectiveness of different improvement strategies. The study used a mixed-methods approach, including remote sensing via Google Earth, field observations, and informal interviews with highway commuters. Secondary data from the Ghana Highway Authority provided traffic demand and composition details. Travel time and queue length measurements were recorded to assess the current conditions. The study modeled various improvement strategies. Adding one lane and one MTC booth showed significant improvements in travel times and queue lengths. Further improvements were observed with three MTC booths, but congestion and delays persisted. Introducing an ETC lane alongside two MTC booths reduced delays and improved traffic flow. Converting all three booths to ETC resulted in the most efficient traffic management, with minimal delays and stable queue lengths. The analysis highlights the superiority of ETC systems in reducing congestion, queue lengths, and travel times. The recommended strategy for the Kubease toll booth is to implement an ETC system, converting all three MTC booths to ETC. This approach offers significant benefits in terms of efficiency, reduced delays, and improved overall toll operations, providing a smoother experience for drivers and enhancing the transportation system.

## Table of Contents

Executive Summary.....	i
Chapter 1: Introduction.....	1
1.1 Background.....	1
1.2 Problem Statement.....	1
1.3 Aim and Objectives .....	2
Chapter 2: Methodology .....	3
2.1 Introduction .....	3
2.2 Secondary Data.....	3
2.3 Data Collection Methods .....	3
Chapter 3: Calibration Of Baseline Model .....	5
3.1 Introduction .....	5
3.2 Validating the Model.....	5
Chapter 4: Improvement Strategies .....	9
Introduction .....	9
4.1 Two-MTC model system.....	9
4.2 Three- MTC model system.....	11
4.3 Two-MTC And One-ETC model system .....	13
4.4 Three ETC model system .....	16
Chapter 5: Summary Of Results .....	19
Introduction .....	19
5.1 Queue Length Comparison .....	19
5.2 Delay Comparison .....	19
5.3 Travel Time Comparison.....	19
5.4 Conclusion .....	20
Chapter 6: Conclusion .....	22
References .....	24

## List of Tables

Table 3.1	Baseline travel time results.....	7
Table 3.2	Baseline queue results .....	7
Table 3.3	Baseline delay results .....	8
Table 4.1	Queue results for two MTC.....	10
Table 4.2	Travel time results for five simulation runs .....	11
Table 4.3	Delay results for three MTC.....	12
Table 4.4	Queue results for three MTC.....	12
Table 4.5	Travel time results for three MTC.....	13
Table 4.6	Delay results for two MTC and one ETC model.....	14
Table 4.7	Travel time results for two MTC and one ETC model.....	15
Table 4.8	Queue results for two MTC and one ETC model.....	15
Table 4.9	Travel time results for three ETC model.....	17
Table 4.10	Queue results for three ETC model.....	17
Table 4.11	Delay results for three ETC model.....	18

## List of Figures

Figure 2.1	Flowchart of the modelling methodology .....	4
Figure 3.1	Paired T-test results.....	6
Figure 3.2	Modelling the baseline in VISSIM .....	6
Figure 4.1	Addition of lane and additional MTC .....	10
Figure 5.1	Travel time graph of the four different models.....	20
Figure 5.2	Graph of delay for the four different models .....	21
Figure 5.3	Queue length graph of the four different models .....	21

## List of Abbreviations

MTC	Manual Toll Collection System
ETC	Electronic Toll Collection

# Chapter 1: Introduction

## 1.1 Background

The Kubease Toll Booth is a critical infrastructure asset located on the heavily traveled Accra–Kumasi highway, a key economic corridor in Ghana. Its strategic positioning at a major intersection not only facilitates efficient toll collection from a wide range of vehicles but also plays an essential role in the overall management of traffic flow along the highway (Andoh, 2022). The toll booth is integral to the nation’s strategy for maintaining and upgrading its roadway systems, as the revenues collected are earmarked for road repairs, expansion projects, and the general upkeep of the highway network. This systematic collection and allocation of funds help ensure that the infrastructure remains resilient against wear and tear, accommodating the continuous increase in vehicular traffic over time (Dapaah, J. D., & Provencal, S., 2023).

In addition to its contribution to infrastructure funding, the toll booth system supports broader economic and social objectives. The fee structure, which varies according to vehicle type, is designed to reflect the different impacts of various vehicles on road deterioration and congestion. This tailored approach not only aids in recovering a fair share of maintenance costs but also incentivizes the use of alternative transportation methods where feasible. Furthermore, the operational model of the toll booth creates substantial employment opportunities for local communities, ranging from toll collectors and administrators to maintenance personnel, thereby reinforcing its role in local economic development (Armah, F. A., Yawson, D. O., & Pappoe, A. A. N. M., 2010)

## 1.2 Problem Statement

Despite its pivotal role in supporting Ghana’s transport infrastructure, the Kubease Toll Booth section on the N6 faces significant operational challenges that undermine its efficiency. One of the most pressing issues is the persistent heavy traffic congestion, particularly during peak hours, which results in long queues and delays for commuters. This congestion is largely attributed to the current manual toll collection (MTC) system, where each direction is served by only one booth, creating a bottleneck effect that hampers the smooth flow of vehicles

The congestion not only leads to extended waiting times and driver frustration but also poses broader economic implications, such as increased fuel consumption, higher emissions, and lost productivity due to travel delays (Agyemang, 2022). Public concern has grown as commuters, local businesses, and other stakeholders call for a reevaluation of the toll collection process. In response to these challenges, an in-depth analysis of the current traffic conditions and the

operational framework of the toll booth needs to be conducted to identify the root causes of the congestion and to propose effective mitigation strategies that could include technological upgrades, process re-engineering, or infrastructural modifications to enhance toll operations and reduce traffic delays.

### 1.3 Aim and Objectives

The primary aim of this study is to analyze the current traffic conditions at the Kubease toll booth section and to propose effective mitigation strategies to enhance toll operations, reduce congestion, and minimize delays.

#### 1. **Analyze Current Traffic Conditions**

Examine key traffic metrics at the Kubease toll booth section, including traffic demand, travel time, and queue length data.

#### 2. **Evaluate the Impact of the Existing Manual Toll Collection (MTC) System**

Assess how the current MTC system influences traffic congestion and causes delays.

#### 3. **Assess the Benefits of Expanding the Manual Toll Booth Setup (Scenario 1)**

Model and evaluate two sub-scenarios:

- **Scenario 1a:** Implementation of a two-booth MTC system.
- **Scenario 1b:** Implementation of a three-booth MTC system.

#### 4. **Evaluate the Benefits of Implementing Electronic Toll Collection (ETC) (Scenario 2)**

Model and assess two sub-scenarios:

- **Scenario 2a:** Conversion of the right exterior lane of the three-booth MTC system to an ETC-only lane.
- **Scenario 2b:** Conversion of all three MTC booths into ETC booths.

#### 5. **Compare Improvement Strategies**

Compare the effectiveness of the different proposed strategies in terms of reducing traffic congestion, minimizing delays, and improving overall toll operations.

## Chapter 2: Methodology

### 2.1 Introduction

The study area was initially examined using the Google Earth application to gain a spatial understanding of the site. A toll booth is currently in place at the location, and discussions with highway commuters revealed that there have been two toll booths, one serving the east approach and the other serving the west approach. This qualitative information, corroborated by news reports, provided a comprehensive insight into the area and reinforced the reliability of the data collected for the study.

### 2.2 Secondary Data

Secondary data was requested from the Ghana Highway Authority which indicate that the traffic demand on the east approach is estimated at 900 vehicles per hour. The traffic composition is approximately 70% cars, 27% buses, and 3% heavy goods vehicles (HGVs). The desired speeds for these vehicles are 60 km/h for cars, 50 km/h for buses, and 30 km/h for HGVs. However, a speed limit of 30 km/h is enforced starting 40 meters upstream of the toll booth, after which vehicles are expected to return to their desired speeds.

Travel time measurements were recorded for a 600-meter section upstream from the toll booth, with recorded times of 265, 278, 298, 300, 267, 280, and 278 seconds. During peak periods, the maximum observed queue length on the east approach was 812 meters. In terms of service efficiency, the manual toll collection (MTC) system exhibits service times ranging from a minimum of 3 seconds to a maximum of 35 seconds, while the electronic toll collection (ETC) system is expected to offer reduced service times, ranging from 1.8 seconds to 12 seconds.

### 2.3 Data Collection Methods

Data for this study were gathered using a mixed methods approach to ensure accuracy and reliability. Remote sensing via Google Earth provided an initial spatial overview of the study area, including the toll booth's location and its surrounding infrastructure. Complementing this, field observations were conducted during both peak and off-peak hours. Research assistants manually measured traffic parameters such as queue lengths, travel times along a defined 600-meter section, and service times at the toll booth using digital stopwatches and distance measuring tools.

Additionally, informal interviews with highway commuters were carried out to gather firsthand accounts of the toll booth operations and historical data regarding the previous configuration with

two toll booths serving different approaches. These discussions, combined with information extracted from local news reports, helped to validate and contextualize the secondary data, providing a robust basis for the study's analysis.

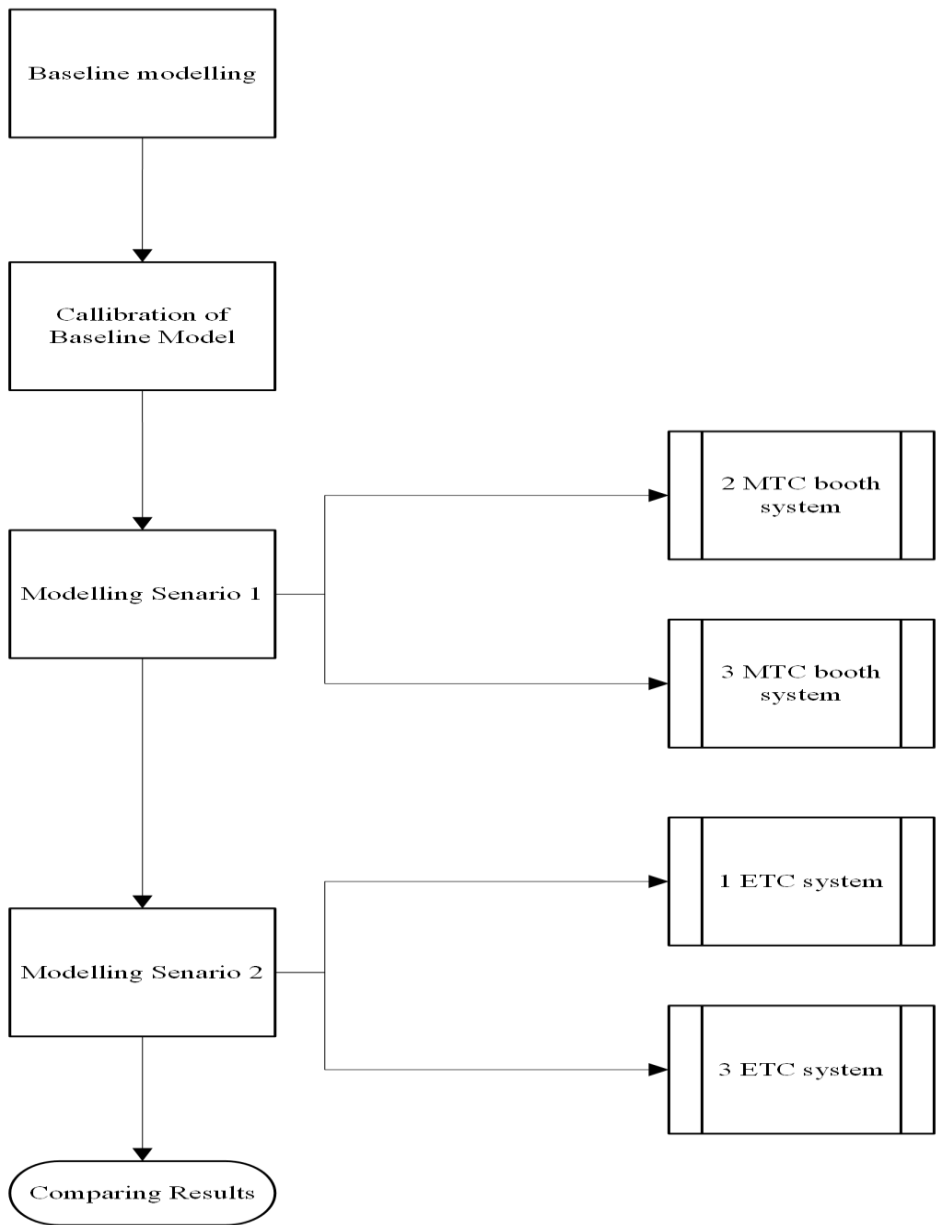


Figure 2.1 Flowchart of the modelling methodology

## Chapter 3: Calibration Of Baseline Model

### 3.1 Introduction

The baseline model of the study area was developed and calibrated to accurately reflect real-world traffic conditions at the site. The toll booth was modeled using a stop sign with a service time distribution ranging from 3 to 35 seconds. Travel time measurements were collected along a 450-meter section of the road, starting from a defined reference point.

### 3.2 Validating the Model

A paired t-test was conducted to compare the travel time data collected from the field (var2) with the modeled travel time data (var1) to determine whether there was a significant difference between them. The sample size consisted of seven observations. The mean travel time for the modeled data was 300.35 seconds with a standard error of 8.48, while the field data had a mean travel time of 280.86 seconds with a standard error of 5.17. The standard deviations were 22.44 and 13.67 for the modeled and field data, respectively.

The difference between the two datasets had a mean value of 19.50 seconds, with a standard error of 9.20 and a standard deviation of 24.35. The 95% confidence interval for the difference ranged from -3.02 to 42.01 seconds. The hypothesis test was performed with the null hypothesis ( $H_0$ ) stating that there was no significant difference between the two travel time datasets (mean difference = 0), while the alternative hypothesis ( $H_a$ ) suggested that a difference existed. The t-statistic was calculated as 2.1184 with 6 degrees of freedom.

The p-value for the two-tailed test was 0.0785. Since this value is greater than the conventional significance level of 0.05, the null hypothesis cannot be rejected at the 5% significance level, indicating that there is no statistically significant difference between the modeled and field travel times.

### Paired t test

Variable	Obs	Mean	Std. err.	Std. dev.	[95% conf. interval]	
var1	7	300.3543	8.48013	22.43632	279.6042	321.1044
var2	7	280.8571	5.165953	13.66783	268.2165	293.4978
diff	7	19.49715	9.203904	24.35124	-3.023994	42.01829

$\text{mean}(\text{diff}) = \text{mean}(\text{var1} - \text{var2})$   $t = 2.1184$   
 $H_0: \text{mean}(\text{diff}) = 0$  Degrees of freedom = 6

$H_a: \text{mean}(\text{diff}) < 0$   $H_a: \text{mean}(\text{diff}) \neq 0$   $H_a: \text{mean}(\text{diff}) > 0$   
 $\text{Pr}(T < t) = 0.9608$   $\text{Pr}(|T| > |t|) = 0.0785$   $\text{Pr}(T > t) = 0.0392$

Figure 3.1 Paired T-test results

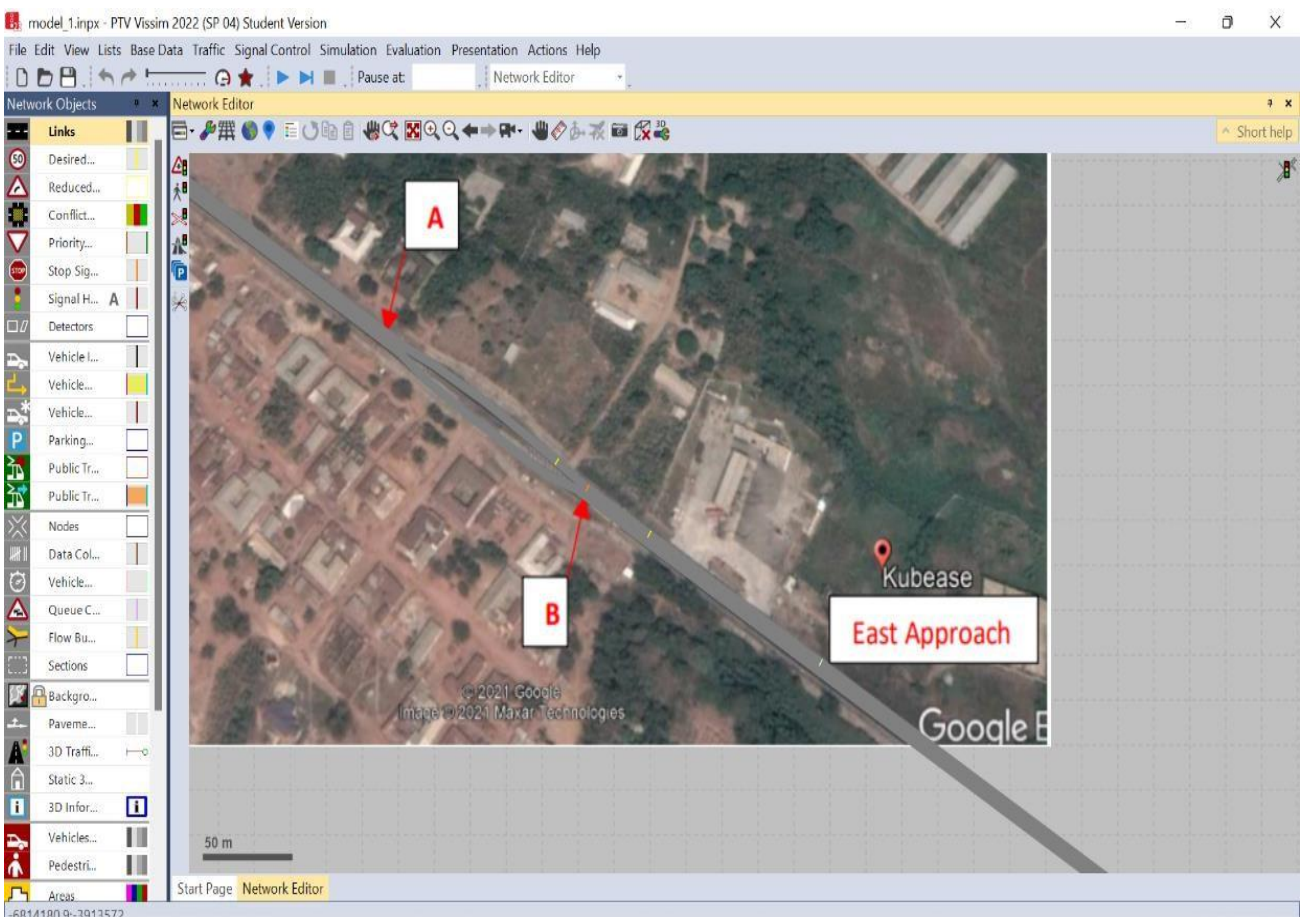


Figure 3.2 Modelling the baseline in VISSIM

Table 3.1 Baseline travel time results

	<b>Time Interval</b>	<b>Vehicles</b>	<b>Travel Time</b>	<b>Distance Travelled</b>
<b>1</b>	300-600	12	293.13	450.05
<b>2</b>	300-600	14	277.48	450.05
<b>3</b>	300-600	10	271.23	450.05
<b>4</b>	300-600	16	338.25	450.05
<b>5</b>	300-600	17	306.28	450.05
<b>6</b>	300-600	9	306.2	450.05
<b>7</b>	300-600	13	309.91	450.05
<b>AVG</b>	300-600	13	300.35	450.05
<b>STDDEV</b>	300-600	3	22.44	0
<b>MIN</b>	300-600	9	271.23	450.05
<b>MAX</b>	300-600	17	338.25	450.05

Table 3.2 Baseline queue results

	<b>Time Interval</b>	<b>Vehicles</b>	<b>Travel Time</b>	<b>Distance Travelled</b>
<b>1</b>	300-600	500.32	512.39	54
<b>2</b>	300-600	491.38	512.35	114
<b>3</b>	300-600	504.28	512.39	85
<b>4</b>	300-600	503.78	512.38	113
<b>5</b>	300-600	502.5	512.38	116
<b>6</b>	300-600	501.72	512.37	67
<b>7</b>	300-600	501.45	512.4	66
<b>AVG</b>	300-600	410.98	476.72	81
<b>STDDEV</b>	300-600	104.51	70.99	40
<b>MIN</b>	300-600	239.48	262.25	0
<b>MAX</b>	300-600	504.28	512.4	145

Table 3.3 Baseline delay results

	<b>Time Interval</b>	<b>Stop Delay(All)</b>	<b>Stops (All)</b>	<b>Vehicle delay (All)</b>	<b>Vehicles (All)</b>	<b>Persons (All)</b>
<b>1</b>	300-600	125.53	22.25	265.9	12	12
<b>2</b>	300-600	107.65	22.5	249.12	14	14
<b>3</b>	300-600	92.19	21.9	244.22	10	10
<b>4</b>	300-600	118.46	33.44	311.84	16	16
<b>5</b>	300-600	112.19	26.47	280.78	17	17
<b>6</b>	300-600	115.44	23.78	275.88	9	9
<b>7</b>	300-600	114.28	23.77	280.76	13	13
<b>AVG</b>	300-600	112.25	24.87	272.64	13	13
<b>STDDEV</b>	300-600	10.43	4.08	22.68	3	3
<b>MIN</b>	300-600	92.19	21.9	244.22	9	9
<b>MAX</b>	300-600	125.53	33.44	311.84	17	17

## Chapter 4: Improvement Strategies

### Introduction

This chapter presents the results for the modelling of the various improvement strategies. First, the addition of one lane and one MTC brought about a major improvement in the travel times. The average travel time was found to be 109.78 which is 75% less than the average travel time of the base line model. Also, the average travel times for the subsequent improvements showed a significant reduction in the travel times. The queue results also showed a major improvement in them.

### 4.1 Two-MTC model system

The queue analysis and travel time data were collected within the 300-600 second time interval to assess traffic conditions at the study location. The queue analysis results show variations in queue length, maximum queue length, and the number of vehicles stops. The average queue length recorded was 109.78 meters, with a maximum queue length of 157.02 meters. The highest queue length observed was 168.15 meters, while the minimum was 61.31 meters. The standard deviation for queue length was 42.22 meters, indicating moderate variability in queuing conditions. The number of stops varied between 57 and 104, with an average of 79 stops across the observation periods.

In terms of travel time and vehicle throughput, the number of vehicles passing through the toll booth ranged from 33 to 42 per interval, with an average of 38 vehicles. The corresponding travel time fluctuated between a minimum of 27.3 seconds and a maximum of 54.71 seconds, averaging 34.65 seconds. The standard deviation of travel time was 11.55 seconds, highlighting variability in vehicular flow. The distance traveled remained constant at 450.73 meters for all observations, reinforcing the consistency of the measurement section.

The findings suggest that queue formation and travel time experience noticeable fluctuations, likely due to variations in vehicle arrival rates, toll processing times, and peak-hour demand. The high travel time recorded in some intervals indicates possible congestion or operational inefficiencies that could be addressed through improved toll management strategies.

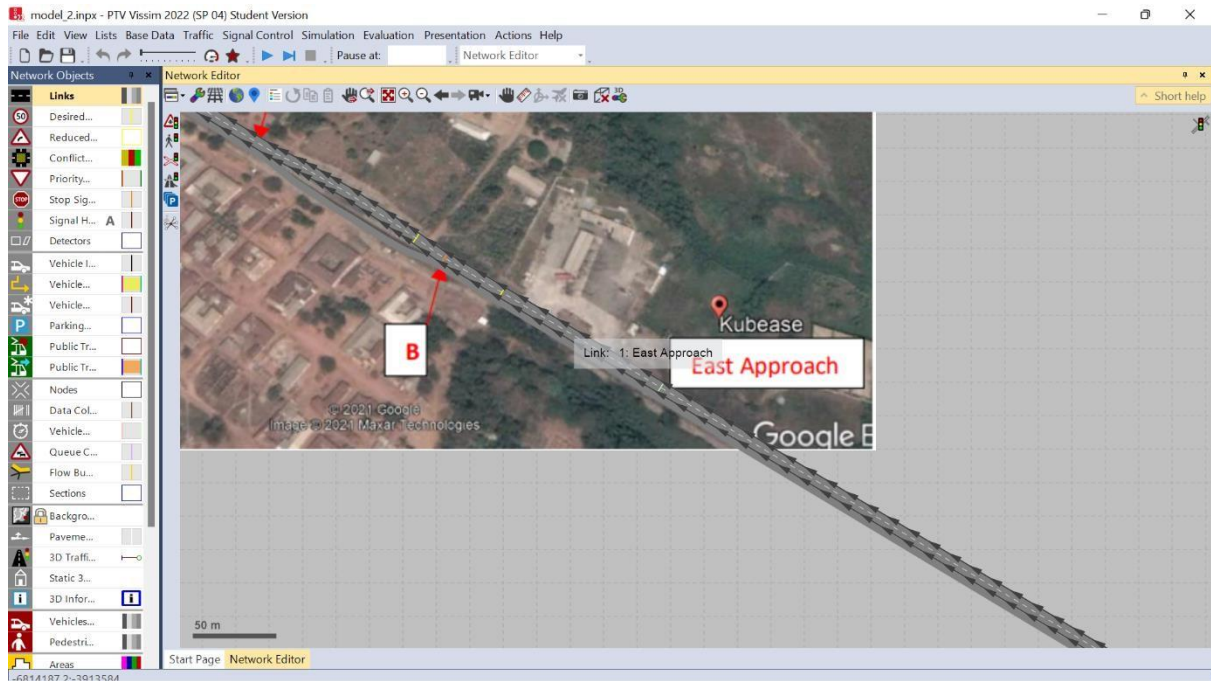


Figure 4.1 Addition of lane and additional MTC

Table 4.1 Queue results for two MTC

	<b>Timeint</b>	<b>Queue Counter</b>	<b>Queue Length</b>	<b>Maximum Queue Length</b>	<b>STOPS</b>
<b>1</b>	300-600	1	93.93	133.84	72
<b>2</b>	300-600	1	61.31	99.61	57
<b>3</b>	300-600	1	89.24	148.87	78
<b>4</b>	300-600	1	168.15	221.92	104
<b>5</b>	300-600	1	136.26	180.86	86
<b>AVG</b>	300-600	1	109.78	157.02	79
<b>STDDEV</b>	300-600	1	42.22	46.58	17
<b>MIN</b>	300-600	1	61.31	99.61	57
<b>MAX</b>	300-600	1	168.15	221.92	104

Table 4.2 Travel time results for five simulation runs

	<b>TIME</b>	<b>Vehicles(ALL)</b>	<b>Travel</b>	<b>Distance</b>
	<b>Interval</b>		<b>Time(ALL)</b>	<b>Travelled(ALL)</b>
<b>1</b>	300-600	39	29.18	450.73
<b>2</b>	300-600	40	27.3	450.73
<b>3</b>	300-600	42	27.75	450.73
<b>4</b>	300-600	33	54.71	450.73
<b>5</b>	300-600	38	34.34	450.73
<b>AVG</b>	300-600	38	34.65	450.73
<b>STDDEV</b>	300-600	3	11.55	0
<b>MIN</b>	300-600	33	27.3	450.73
<b>MAX</b>	300-600	42	54.71	450.73

#### 4.2 Three- MTC model system

The analysis of delay and stops shows that the average vehicle delay is 18.65 seconds, with a maximum of 42.06 seconds and a minimum of 5.66 seconds. The standard deviation is 16.03 seconds, indicating variations in traffic conditions. For persons, the average delay is 38.81 seconds, reaching a maximum of 82.84 seconds and a minimum of 13.18 seconds, with a standard deviation of 29.95 seconds. The high delay variability suggests fluctuating congestion levels or signal timing inefficiencies.

The queue length and stop data indicate an average queue length of 185.36 meters, with a maximum of 223.27 meters and a minimum of 148.59 meters. The standard deviation is 31.82 meters. The average queue stops are recorded at 170, reaching a maximum of 175 and a minimum of 162. These values suggest considerable congestion, which may require improvements in traffic control measures.

Traffic flow and travel time data reveal that the average number of vehicles passing through the system is 47, with a maximum of 63 and a minimum of 31. The standard deviation of 12 shows variations in vehicle flow. The average travel time is 66.33 seconds, with a maximum of 111.01 seconds and a minimum of 39.86 seconds, with a standard deviation of 30.56 seconds. The

significant range in travel times indicates inconsistencies in vehicle movement, which may be caused by varying levels of congestion or intersection inefficiencies.

Table 4.3 Delay results for three MTC

	<b>Timeint</b>	<b>Delay</b>	<b>Stop</b>	<b>Stops(</b>	<b>Vehicle</b>	<b>Vehicles(</b>	<b>Persons</b>	<b>Persons(</b>
		<b>Mea</b>	<b>Dela</b>	<b>All)</b>	<b>Dela</b>	<b>All)</b>	<b>Dela</b>	<b>All)</b>
		<b>Surement</b>	<b>Y(All)</b>		<b>Y(All)</b>		<b>Y(All)</b>	
<b>1</b>	300-600	3	5.99	1.13	15.31	54	15.31	54
<b>2</b>	300-600	3	5.66	0.9	13.18	63	13.18	63
<b>3</b>	300-600	3	11.16	1.96	26.77	46	26.77	46
<b>4</b>	300-600	3	42.06	5.68	82.84	31	82.84	31
<b>5</b>	300-600	3	28.36	3.88	55.98	43	55.98	43
<b>AVG</b>	300-600	3	18.65	2.71	38.81	47	38.81	47
<b>STD</b>	300-600	3	16.03	2.03	29.95	12	29.95	12
<b>DEV</b>								
<b>MIN</b>	300-600	3	5.66	0.9	13.18	31	13.18	31
<b>MAX</b>	300-600	3	42.06	5.68	82.84	63	82.84	63

Table 4.4 Queue results for three MTC

	<b>TIME</b>	<b>QUEUE</b>	<b>Queue</b>	<b>Max</b>	<b>STOPS</b>
	<b>INTerval</b>	<b>COUNTER</b>	<b>LENGth</b>	<b>queue</b>	
				<b>length</b>	
<b>1</b>	300-600	1	159.82	222.02	172
<b>2</b>	300-600	1	148.59	240.27	162
<b>3</b>	300-600	1	185.09	256.75	173
<b>4</b>	300-600	1	223.27	287.5	168
<b>5</b>	300-600	1	210.03	280.76	175
<b>AVG</b>	300-600	1	185.36	257.46	170
<b>STDDEV</b>	300-600	1	31.82	27.37	5
<b>MIN</b>	300-600	1	148.59	222.02	162
<b>MAX</b>	300-600	1	223.27	287.5	175

Table 4.5 Travel time results for three MTC

	<b>TIME Interval</b>	<b>Vehicles(ALL)</b>	<b>Travel Time(ALL)</b>	<b>Distance Travelled(ALL)</b>
<b>1</b>	300-600	54	41.81	450
<b>2</b>	300-600	63	39.86	450
<b>3</b>	300-600	46	55.03	450
<b>4</b>	300-600	31	111.01	450
<b>5</b>	300-600	43	83.95	450
<b>AVG</b>	300-600	47	66.33	450
<b>STDDEV</b>	300-600	12	30.56	0
<b>MIN</b>	300-600	31	39.86	450
<b>MAX</b>	300-600	63	111.01	450

### 4.3 Two-MTC And One-ETC model system

The stop delay analysis shows that the average stop delay is 7.13 seconds, with a maximum of 16.89 seconds and a minimum of 0.28 seconds. The standard deviation of 7.35 seconds indicates significant variability in stop delays across different intervals. The number of stops per vehicle averages at 1.49, with a maximum of 3.15 and a minimum of 0.14, further suggesting fluctuating traffic conditions. Vehicle delay values show an average of 18.96 seconds, with a maximum of 42.72 seconds and a minimum of 2.15 seconds. The standard deviation of 17.03 seconds highlights inconsistencies in traffic flow, likely due to varying congestion levels and traffic signal efficiency. The number of vehicles per interval averages at 61, with a maximum of 77 and a minimum of 46. A similar pattern is observed in person delays, where the average delay is 18.96 seconds, with the same maximum, minimum, and standard deviation values as vehicle delay.

Vehicle travel time measurements show that the average travel time is 46.56 seconds, with a maximum of 70.41 seconds and a minimum of 28.7 seconds. The standard deviation of 17.44 seconds indicates a notable range in travel times, which may be influenced by traffic congestion or varying intersection performance. The number of vehicles processed within each interval averages at 61, with a maximum of 77 and a minimum of 46. Despite the variation in travel time, the total distance traveled remains constant at 450 meters.

Queue length and stops data reveal an average queue length of 155.28 meters, with a maximum of 194.3 meters and a minimum of 120.49 meters. The standard deviation of 32.57 meters suggests substantial fluctuation in queue lengths. The maximum queue length reaches 245.29 meters, while the minimum is recorded at 180.38 meters. The number of queue stops averages at 177, with a maximum of 189 and a minimum of 168. These values indicate significant congestion at certain points, which may require improved traffic management strategies.

*Table 4.6 Delay results for two MTC and one ETC model*

	<b>TIMEI NT</b>	<b>STOPDEL AY( ALL)</b>	<b>STOPS (A LL)</b>	<b>VEHDELA Y(A LL)</b>	<b>VEHS( AL L)</b>	<b>PERSDELA Y(A LL)</b>	<b>PERS( AL L)</b>
<b>1</b>	300-600	1.13	0.28	4.12	69	4.12	69
<b>2</b>	300-600	0.28	0.14	2.15	77	2.15	77
<b>3</b>	300-600	4.61	1.77	17.35	60	17.35	60
<b>4</b>	300-600	16.89	3.15	42.72	46	42.72	46
<b>5</b>	300-600	12.75	2.11	28.46	54	28.46	54
<b>AVG</b>	300-600	7.13	1.49	18.96	61	18.96	61
<b>STD</b>	300-600	7.35	1.28	17.03	12	17.03	12
<b>DE V</b>							
<b>MIN</b>	300-600	0.28	0.14	2.15	46	2.15	46
<b>MAX</b>	300-600	16.89	3.15	42.72	77	42.72	77

Table 4.7 Travel time results for two MTC and one ETC model

	<b>TIMEINT</b>	<b>VEHICLE</b>	<b>VEHS(</b>	<b>TRAVTM(ALL)</b>	<b>DISTTRAV</b>
		<b>TRAVELTI</b>	<b>ME</b>	<b>ALL)</b>	<b>(ALL)</b>
		<b>MEASUREMENT</b>			
<b>1</b>	300-600	1	69	31.24	450
<b>2</b>	300-600	1	77	28.7	450
<b>3</b>	300-600	1	60	46.19	450
<b>4</b>	300-600	1	46	70.41	450
<b>5</b>	300-600	1	54	56.27	450
<b>AVG</b>	300-600	1	61	46.56	450
<b>STDD</b>	300-600	1	12	17.44	0
<b>EV</b>					
<b>MIN</b>	300-600	1	46	28.7	450
<b>MAX</b>	300-600	1	77	70.41	450

Table 4.8 Queue results for two MTC and one ETC model

	<b>TIMEINT</b>	<b>QUEUECOUNTER</b>	<b>QLEN</b>	<b>QLENMAX</b>	<b>QSTOPS</b>
<b>1</b>	300-600	1	125.81	180.38	170
<b>2</b>	300-600	1	120.49	202.89	182
<b>3</b>	300-600	1	155.22	205.18	176
<b>4</b>	300-600	1	194.3	239.88	189
<b>5</b>	300-600	1	180.59	245.29	168
<b>AVG</b>	300-600	1	155.28	214.72	177
<b>STDDEV</b>	300-600	1	32.57	27.29	9
<b>MIN</b>	300-600	1	120.49	180.38	168
<b>MAX</b>	300-600	1	194.3	245.29	189

#### 4.4 Three ETC model system

The stop delay data indicates that no vehicles experienced stop delays throughout the interval, as all values are recorded as zero. Similarly, the number of stops per vehicle is also zero, suggesting smooth traffic flow without unnecessary interruptions. Vehicle delay values remain low, with an average of 0.39 seconds, a maximum of 0.7 seconds, and a minimum of 0.08 seconds. The standard deviation of 0.23 seconds indicates minimal fluctuations in delay times. The number of vehicles per interval averages at 79, with a maximum of 92 and a minimum of 71. The person delay values mirror the vehicle delay, confirming that individual passengers experienced negligible waiting times.

Vehicle travel time measurements reveal an average travel time of 27.83 seconds, with a maximum of 28.6 seconds and a minimum of 26.92 seconds. The standard deviation is 0.73 seconds, indicating very little variation in travel time across different intervals. The number of vehicles per interval remains consistent with the previous data, averaging at 79, while the total distance traveled is constant at 450 meters.

Queue length and stops data show that the average queue length is 87.79 meters, with a maximum of 114.69 meters and a minimum of 59.51 meters. The standard deviation of 23.86 meters suggests moderate fluctuations in queue lengths. The maximum queue length reaches 154.51 meters, while the minimum is 99.72 meters. The number of queue stops averages at 165, with a maximum of 190 and a minimum of 139. These values indicate that while vehicles are queuing at certain points, the absence of significant delays suggests efficient signal operations and smooth traffic flow.

Table 4.9 Travel time results for three ETC model

	<b>TIMEIN T</b>	<b>VEHICLETRAVELTIMEM EASUREMENT</b>	<b>VEHS( ALL)</b>	<b>TRAVTM( ALL)</b>	<b>DISTTRAV (ALL)</b>
<b>1</b>	300-600	1	74	27.24	450
<b>2</b>	300-600	1	92	26.92	450
<b>3</b>	300-600	1	77	28.6	450
<b>4</b>	300-600	1	71	27.96	450
<b>5</b>	300-600	1	83	28.42	450
<b>AVG</b>	300-600	1	79	27.83	450
<b>STDDEV</b>	300-600	1	8	0.73	0
<b>MIN</b>	300-600	1	71	26.92	450
<b>MAX</b>	300-600	1	92	28.6	450

Table 4.10 Queue results for three ETC model

	<b>TIMEINT</b>	<b>QUEUECOUNTER</b>	<b>QLEN</b>	<b>QLENMAX</b>	<b>QSTOPS</b>
<b>1</b>	300-600	1	59.51	99.72	139
<b>2</b>	300-600	1	71.58	128.63	146
<b>3</b>	300-600	1	83.64	124.95	170
<b>4</b>	300-600	1	109.55	130.75	190
<b>5</b>	300-600	1	114.69	154.51	180
<b>AVG</b>	300-600	1	87.79	127.71	165
<b>STDDEV</b>	300-600	1	23.86	19.49	22
<b>MIN</b>	300-600	1	59.51	99.72	139
<b>MAX</b>	300-600	1	114.69	154.51	190

Table 4.11 Delay results for three ETC model

	<b>TIMEINT</b>	<b>STOP DELA Y</b>	<b>STOPS</b>	<b>VEH DELAY</b>	<b>VEHS</b>	<b>PERSDE LAY</b>	<b>PERS</b>
<b>1</b>	300-600	0	0	0.08	74	0.08	74
<b>2</b>	300-600	0	0	0.3	92	0.3	92
<b>3</b>	300-600	0	0	0.38	77	0.38	77
<b>4</b>	300-600	0	0	0.47	71	0.47	71
<b>5</b>	300-600	0	0	0.7	83	0.7	83
<b>AVG</b>	300-600	0	0	0.39	79	0.39	79
<b>STDDE</b>	300-600	0	0	0.23	8	0.23	8
<b>V</b>							
<b>MIN</b>	300-600	0	0	0.08	71	0.08	71
<b>MAX</b>	300-600	0	0	0.7	92	0.7	92

## Chapter 5: Summary Of Results

### Introduction

The models analyzed include Model 2, which represents a system with two manual toll collection booths; Model 3, which has three manual toll collection booths; Model 4, which features one electronic toll collection (ETC) system; and Model 5, which incorporates three electronic toll collection systems.

### 5.1 Queue Length Comparison

The first graph shows the queue length variations for different models. Model 5, which uses three ETC systems, has the shortest and most stable queue length, indicating efficient vehicle processing. Model 4, with one ETC system, exhibits lower queue lengths compared to manual toll booths but still experiences some congestion at peak periods. The manual toll models, particularly Model 3 with three booths, display significantly higher queue lengths, although it performs slightly better than Model 2, which has only two booths. The longest queue lengths occur at peak demand for manual toll booths, with Model 3 showing a slight advantage over Model 2.

### 5.2 Delay Comparison

The second graph illustrates vehicle delays across the models. Model 5 exhibits negligible delays, confirming that multiple ETC systems significantly reduce waiting times. Model 4 shows lower delays than manual toll systems but still experiences some congestion. The manual toll collection models experience increasing delays, with Model 3 showing the highest peak delay at one point. The delay trends suggest that ETC systems considerably reduce overall waiting time for vehicles, whereas manual toll collection results in substantial delays.

### 5.3 Travel Time Comparison

The third graph represents vehicle travel times under different toll collection models. Model 5 maintains the lowest and most stable travel time, reinforcing its efficiency in traffic management. Model 4 also performs well but shows slight fluctuations in travel time. Manual toll collection models have significantly longer travel times, particularly Model 3, which reaches the highest peak travel time. The trend suggests that increasing the number of manual toll booths improves capacity slightly but does not eliminate congestion and delays as effectively as ETC systems.

## 5.4 Conclusion

The results highlight the superiority of electronic toll collection systems in reducing congestion, queue lengths, and travel times. Among the models, Model 5 with three ETC systems proves to be the most efficient, ensuring smooth traffic flow with minimal delays. Model 4 with one ETC system performs well but could benefit from additional lanes. Model 3 with three manual toll booths reduces congestion slightly compared to Model 2 but still suffers from long queues and delays. Model 2, with only two manual toll booths, is the least efficient, showing the highest delays and travel times. Implementing more ETC lanes significantly enhances traffic performance, reducing congestion and improving overall efficiency.

- Model 2 represents the two manual toll collection system
- Model 3 represents the three manual toll collection system
- Model 4 represent the one electronic toll collection system
- Model 5 represents three electronic toll collection system.

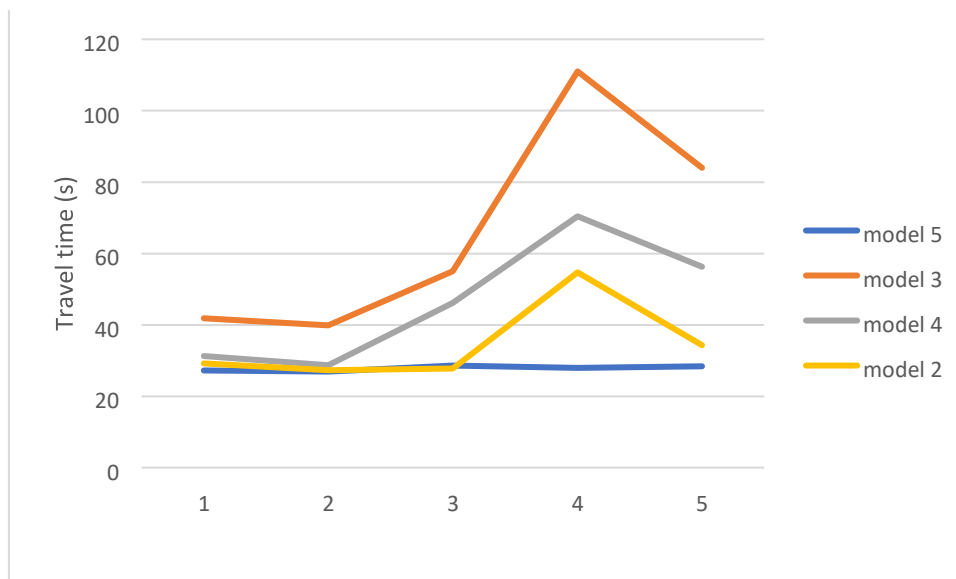


Figure 5.1 Travel time graph of the four different models

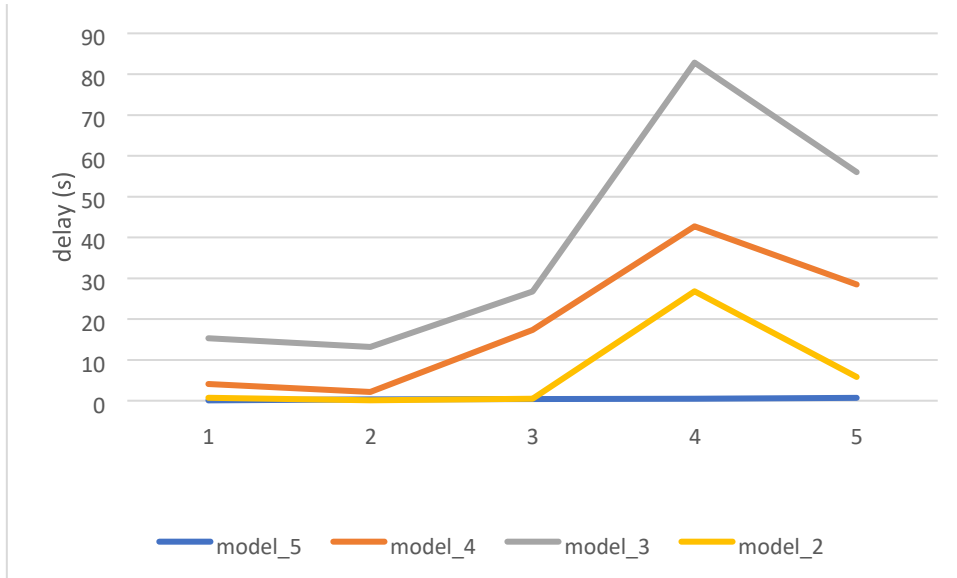


Figure 5.2 Graph of delay for the four different models

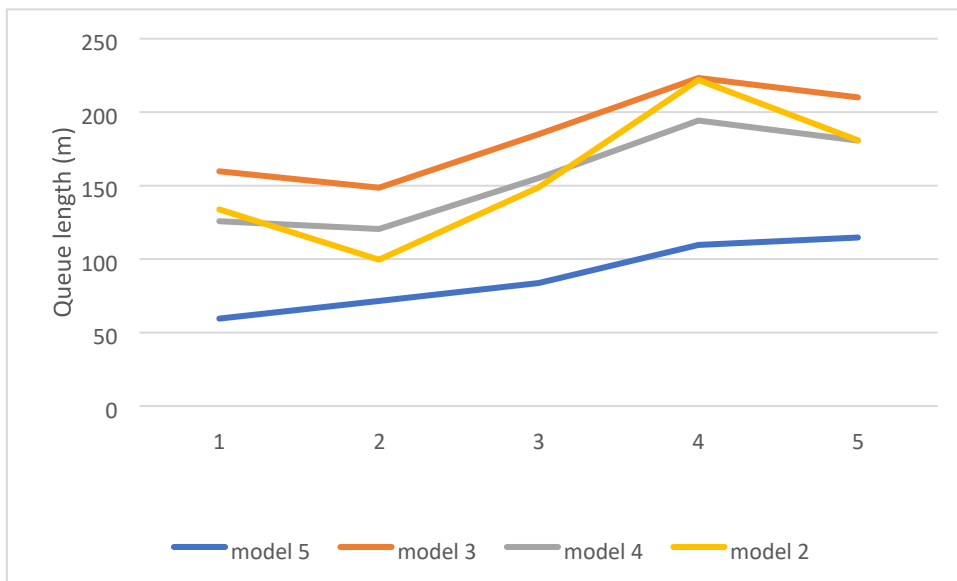


Figure 5.3 Queue length graph of the four different models

## Chapter 6: Conclusion

In conclusion, the objectives of the analysis and modelling for the Kubease toll booth section have provided valuable insights into the existing traffic conditions and toll collection systems. The study aimed to address the issues of traffic congestion, delays, and overall toll operation improvement. By analysing the existing traffic conditions at the Kubease toll booth section, including traffic demand, travel time, and queue length data, a clear understanding of the current situation was obtained. This information served as a baseline for evaluating the impact of the manual toll collection (MTC) system on traffic congestion and delays. It was found that the MTC system contributed to significant congestion and delays, indicating the need for improvement. The benefits of adding manual toll booths and lanes were assessed through two sub-scenarios: a two-booth MTC system and a three-booth MTC system. These modeling exercises revealed potential improvements in traffic flow and reduced delays compared to the current system, suggesting that increasing the number of toll booths could be a viable solution.

Additionally, the benefits of implementing electronic toll collection (ETC) were evaluated through two sub-scenarios: converting the right exterior lane of the three-booth MTC system to an ETC-only lane and converting all three MTC booths into ETC booths. The analysis showed that ETC implementation offered substantial advantages in terms of reducing congestion and improving overall toll operations, indicating its potential as an effective solution. Comparing the effectiveness of the different improvement strategies, it was observed that both increasing the number of manual toll booths and implementing ETC systems led to improved traffic flow, reduced delays, and enhanced toll operations. However, the ETC systems demonstrated greater efficiency and effectiveness compared to the manual toll collection, suggesting that an ETC-based solution might be the most suitable improvement strategy for the Kubease toll booth section.

Furthermore, the analysis considered the service time distribution for both MTC and ETC systems, enabling a comprehensive evaluation of the efficiency and effectiveness of each system. These findings provided crucial insights into the operational aspects of toll collection and reinforced the advantages of ETC systems. Based on the analysis and modeling results, the recommended improvement strategy for the Kubease toll booth section is the implementation of an electronic toll collection system. This approach offers significant benefits in terms of reducing traffic congestion, minimizing delays, and improving overall toll operations. Converting all three MTC

booths into ETC booths proved to be the most effective sub-scenario within the ETC implementation strategy. Implementing these recommendations will not only enhance the efficiency and effectiveness of toll collection but also provide a smoother and more convenient experience for drivers, leading to improved traffic conditions and a better overall transportation system at the Kubease toll booth section.

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