Optimization Toll Plaza Operation using micro simulation | Case Study : Sanand Toll plaza

Background

- L&T IDPL, intends to Optimize toll plaza operations using Micro-Simulation for increasing the efficiency of their existing toll plaza and upcoming toll plaza
- Case study for a toll plaza near the Ahmedabad city is taken, Sanand Toll plaza.

Need for the Study

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Following points are identified in understanding the need for the study:

Some Toll sections experience huge delays and queues during the first few years of the operations itself. An example being the Delhi-Gurgaon expressway toll plaza

Higher queue length and delays increase road user cost, drivers might avoid the road use in future to save time and cost

To get rid of long lines, common sense suggests that providing as many tollbooths as possible wi minimize the toll payment delay, but more tollbooths mean more costs, improper utilization anc more merging/weaving and hence more congestion after the tolls are paid.

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Objective of the study

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Preparation of a Calibrated and Validated Simulation base model for toll plaza traffic flow conditions

Develop scenarios to improve the level of service, optimize operation costs and increase throughput volume

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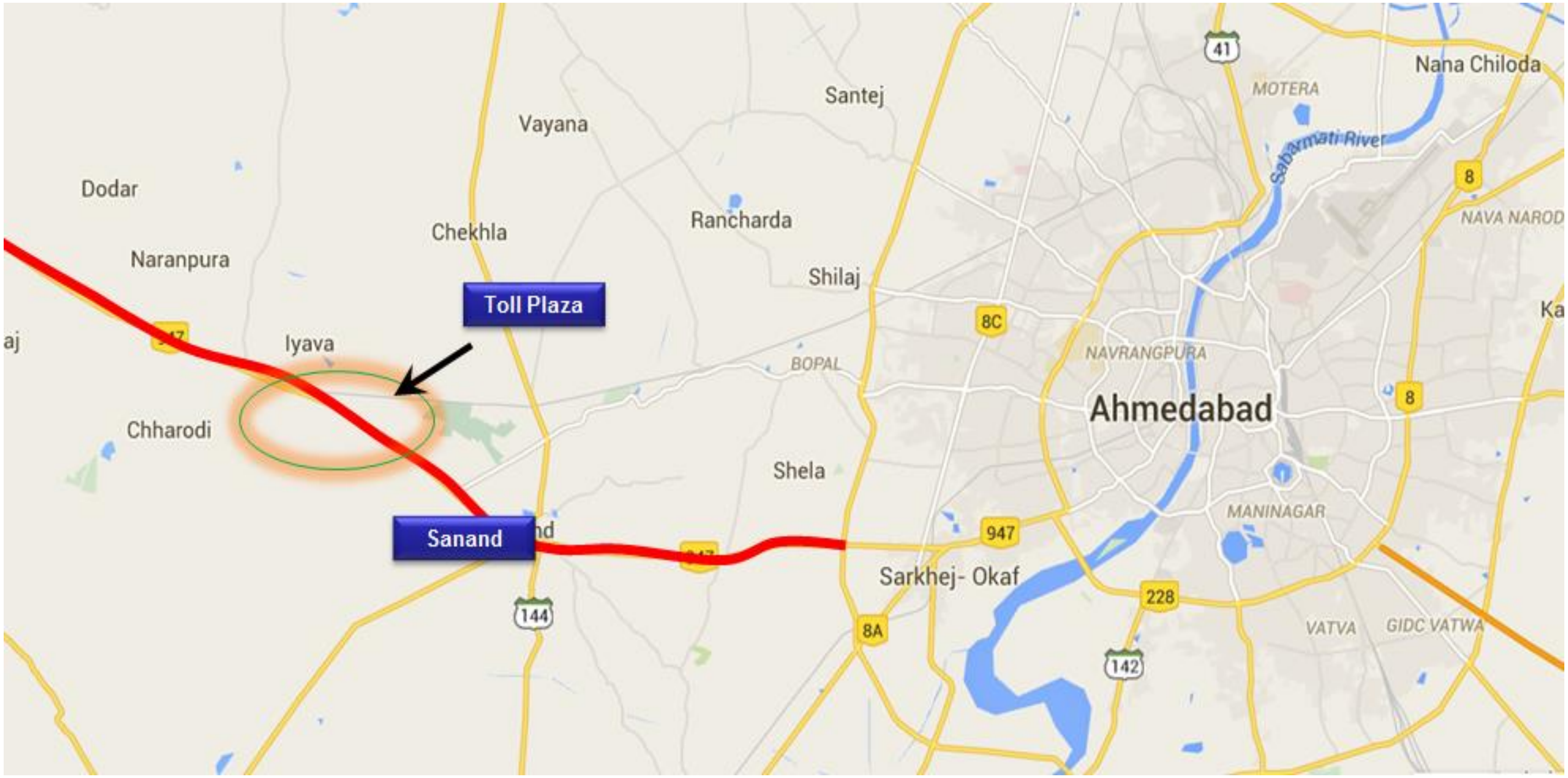
Study Stretch

The site sanand toll plaza which is located on the outskirts of the city of Ahmedabad in Gujrat, India (Western part of India). The road network is a **four-land divided** carriage with paved shoulder on either sides.



Toll Plaza layout

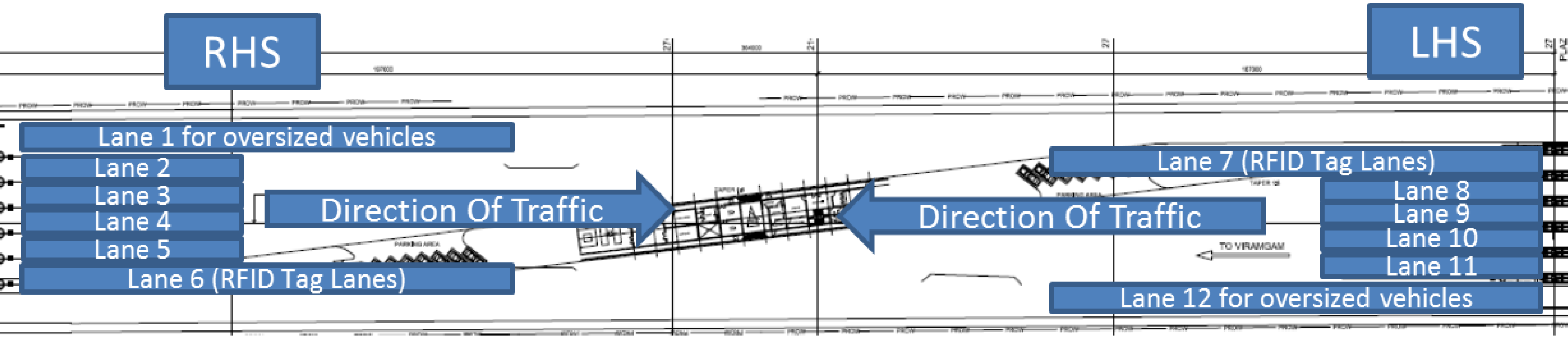


Figure above shows the layout for the toll plaza, RHS is right hand side with 6 toll booths and LHS is left hand side with 6 toll booths

Data Collection and Analysis

Classified 5-minute arrival volume data with payment category at the toll plaza October 6, 2015 to October 13, 2015 for 24 hour period

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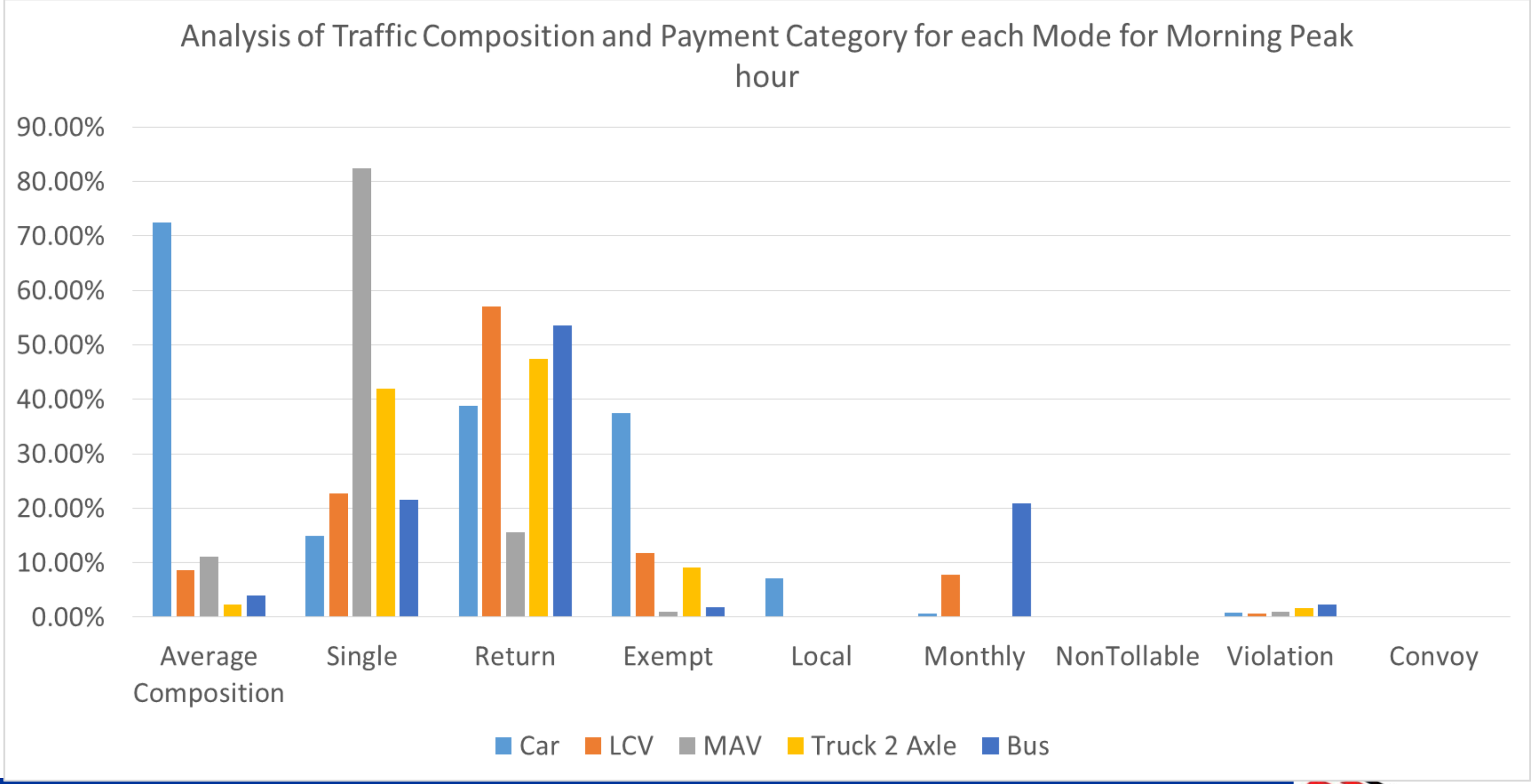
It is observed that during the morning peak hour composition of the cars (73%) is highest, followed by MAV (12%) (Multi-Axle Vehicles) and LCV (8%) (Light Commercial Vehicles) with an average volume of 960 vehicles/hour for both directions of flow. Among cars, return ticket type trips (38%) are maximum followed by tagged vehicle trips (36%). Since in peak-hour return trip transactions are maximum, it leads to longer queue lengths and delays due to highest service time. Similar observations are made for the evening peak hour also.



Hourly arrival volume data at the toll plaza December 01,2014 - Nov 30,2015 for 24 hour period

This data is analysed to understand the seasonal and hourly variation of volume over a period of one year. It is observed that during morning and evening peak hour total volume in one direction of flow ranges from 650-730 vehicles/hour.

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Travel Time Survey

The tr… …hile crossing the toll pl… …cle number plate along … …ng the identified morni… …after crossing the toll pl…

Queu…

To est… …re placed on the upstre… …ning peak period from 8…

Video…

Video … …ced at the top of the canopy of the toll plaza station, providing complete field view to understand the different behavioural characteristics such as lane changing behaviour, queue preference, variation in speed of vehicles and visibility of the different toll booths while approaching the toll booth stations. The video survey is also used to validate the queue lengths.

Service Time Distribution and arrival rate

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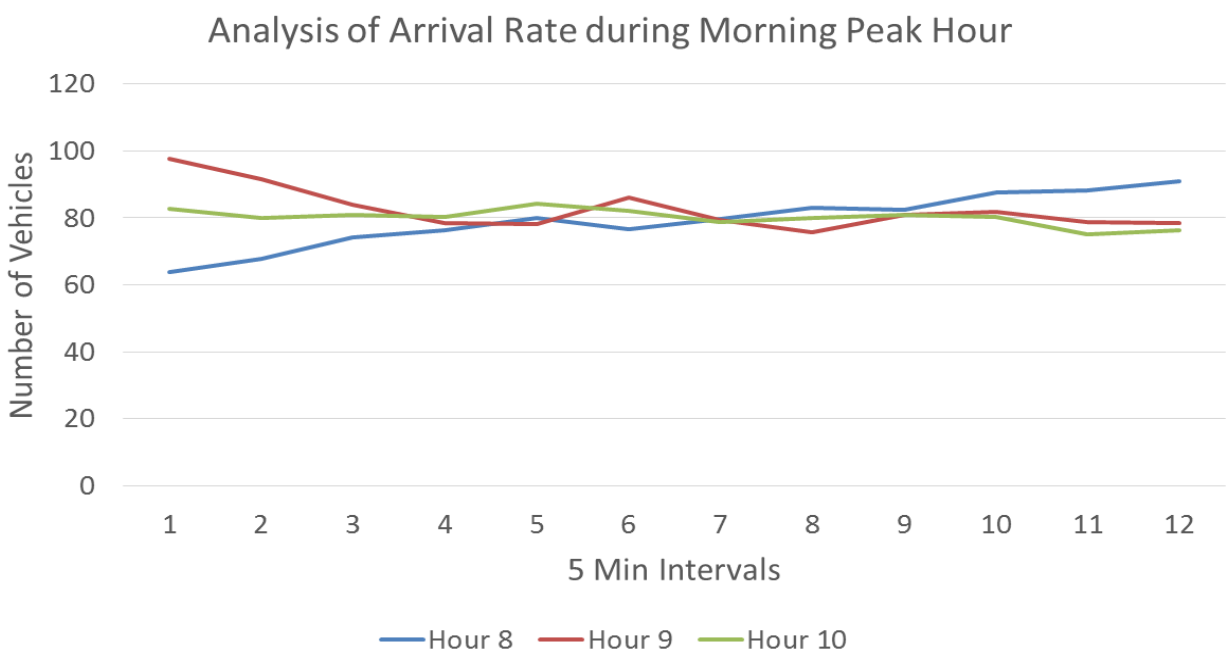
From a sample set of 256 vehicles, collected on January 18, 2016 from 08:00 to 10:00, following data is extracted for the service time:

- Return Ticket (Mean : 39 Seconds, Standard Deviation : 16 seconds)
- Single Ticket (Mean : 30 Seconds, Standard Deviation : 18 seconds)
- RFID Tag vehicle have stop and go motion

Arrival rate of vehicles on the toll plaza is consistent and doesn't have sharp peak. Similar graph of arrival rate is observed for all the 24 hours of the day.



Simulation Model Development

Set up the Network

Using links and connectors we code the network with the scaled background image as a reference.

Vehicle Types and Vehicle Classes

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: 43	No	Name	VehTypes	UseVehTypeColor	Color
7	70	Car_Single	610	☑	(255, 0, 0,
8	80	Car_Return	620	☑	(255, 0, 0,
9	90	Car_Exempt_R	630	☑	(255, 0, 0,
10	100	Car_Others	640	☑	(255, 0, 0,
11	110	Bus_Single	650	☑	(255, 0, 0,
12	120	Bus_Return	660	☑	(255, 0, 0,
13	130	Bus_Exempt_R	670	☑	(255, 0, 0,
14	140	Bus_Others	680	☑	(255, 0, 0,
15	150	LCV_Single	690	☑	(255, 0, 0,
16	160	LCV_Return	700	☑	(255, 0, 0,
17	170	LCV_Exempt_R	710	☑	(255, 0, 0,
18	180	LCV_Others	720	☑	(255, 0, 0,
19	190	MAV_Single	730	☑	(255, 0, 0,
20	200	MAV_Return	740	☑	(255, 0, 0,
21	210	MAV_Exempt_R	750	☑	(255, 0, 0,
22	220	MAV_Others	760	☑	(255, 0, 0,
23	230	Truck2Axle_Single	770	☑	(255, 0, 0,
24	240	Truck2Axle_Return	780	☑	(255, 0, 0,
25	250	Truck2Axle_Exempt_R	790	☑	(255, 0, 0,
26	260	Truck2Axle_Others	800	☑	(255, 0, 0,
27	270	Two Wheelers_Model	810	☑	(255, 0, 0,
28	280	Three Wheeler_Model	820	☑	(255, 0, 0,
29	290	Tractor_Model	830	☑	(255, 0, 0,
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Next Step is to define the different vehicle types and vehicle classes, which define composition of the traffic. This data is available from the count volumes

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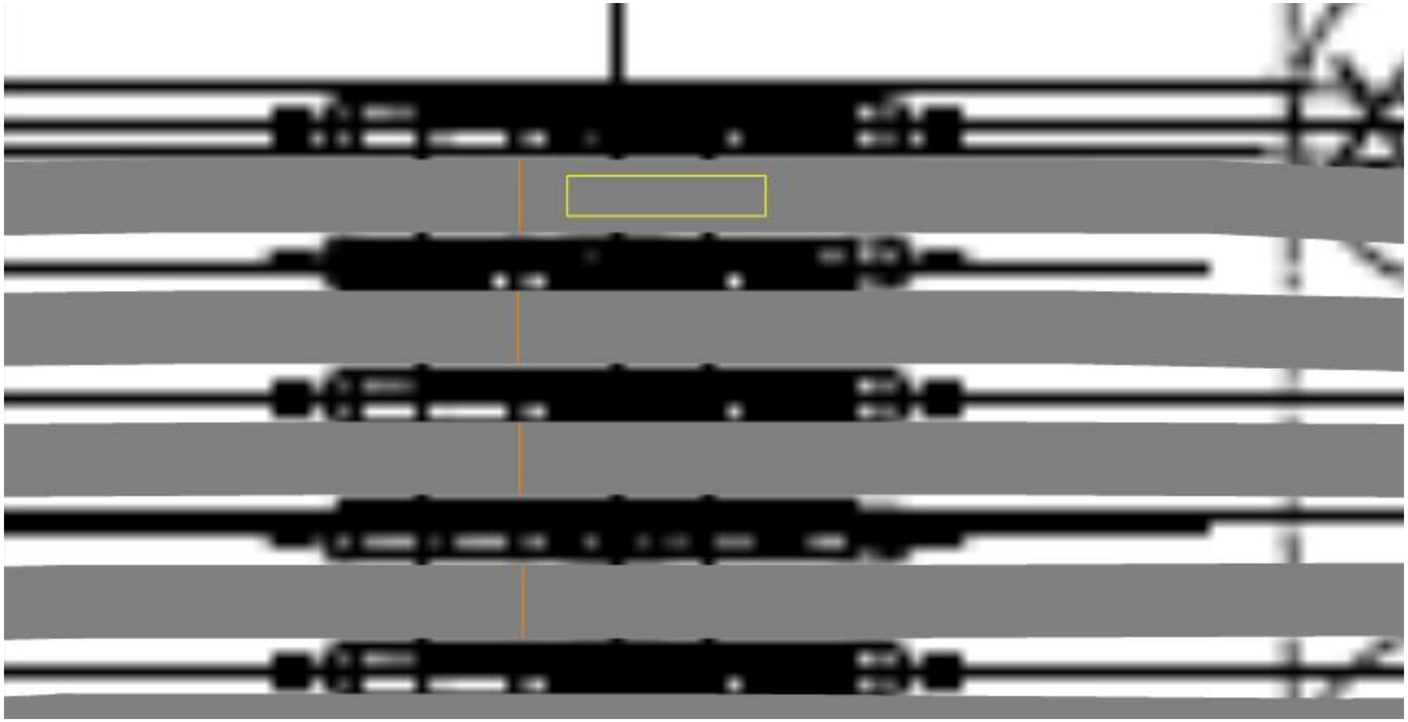
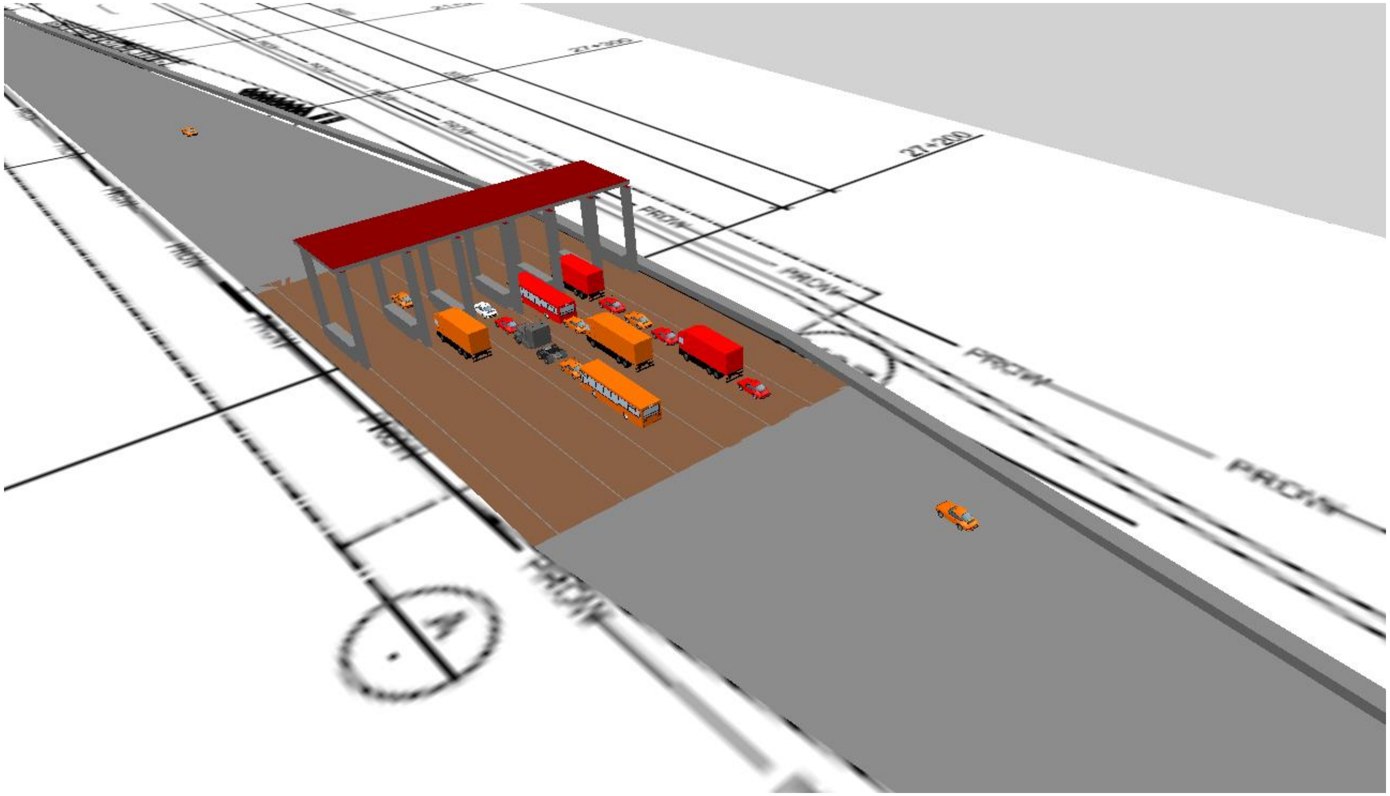
Model reduced speed areas and Stops



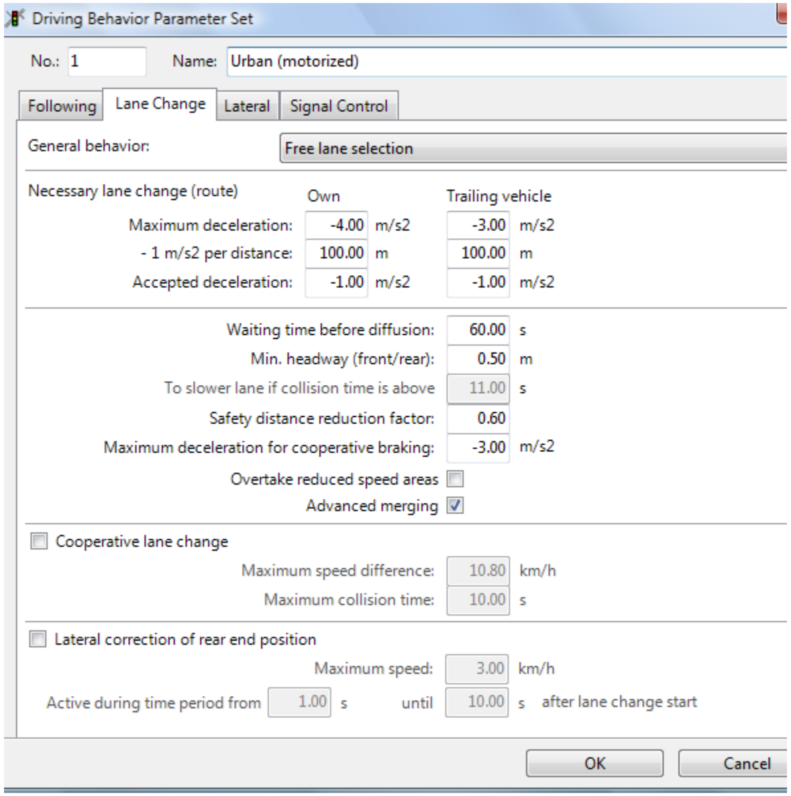
Modelling reduced speed areas and stop signs for vehicle to slow down and stop at toll booths for getting the ticket

Set vehicle input and Routes for the peak hour



The input volume for the observed time period is coded, and routes are decided as per the COM algorithm

Set driving behavior parameters



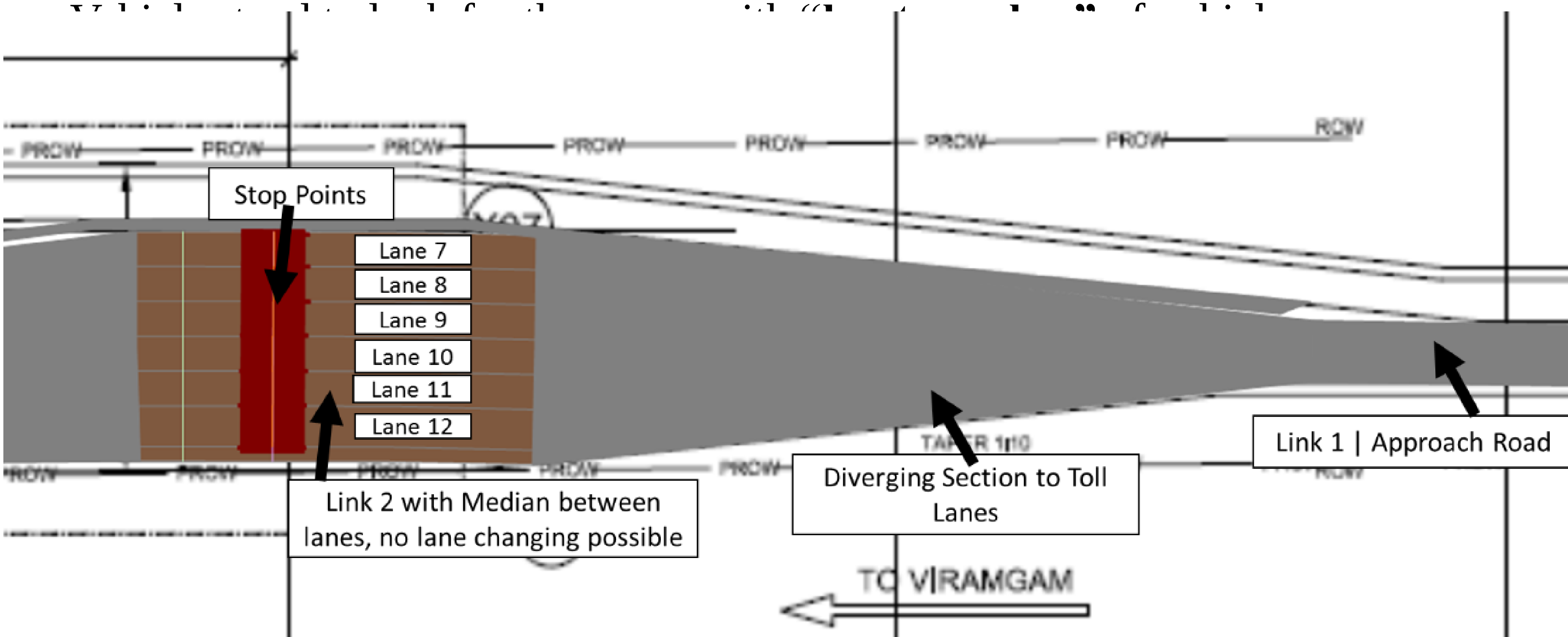
The drivers were coded with Indian urban traffic driver behavior typology according to the parameters shown in figure below. The lane changing behavior, lateral gap etc. was calibrated according to site and video survey observations. These parameters are calibrated to validate the model

Lane Selection Methodology

Observations from the Site

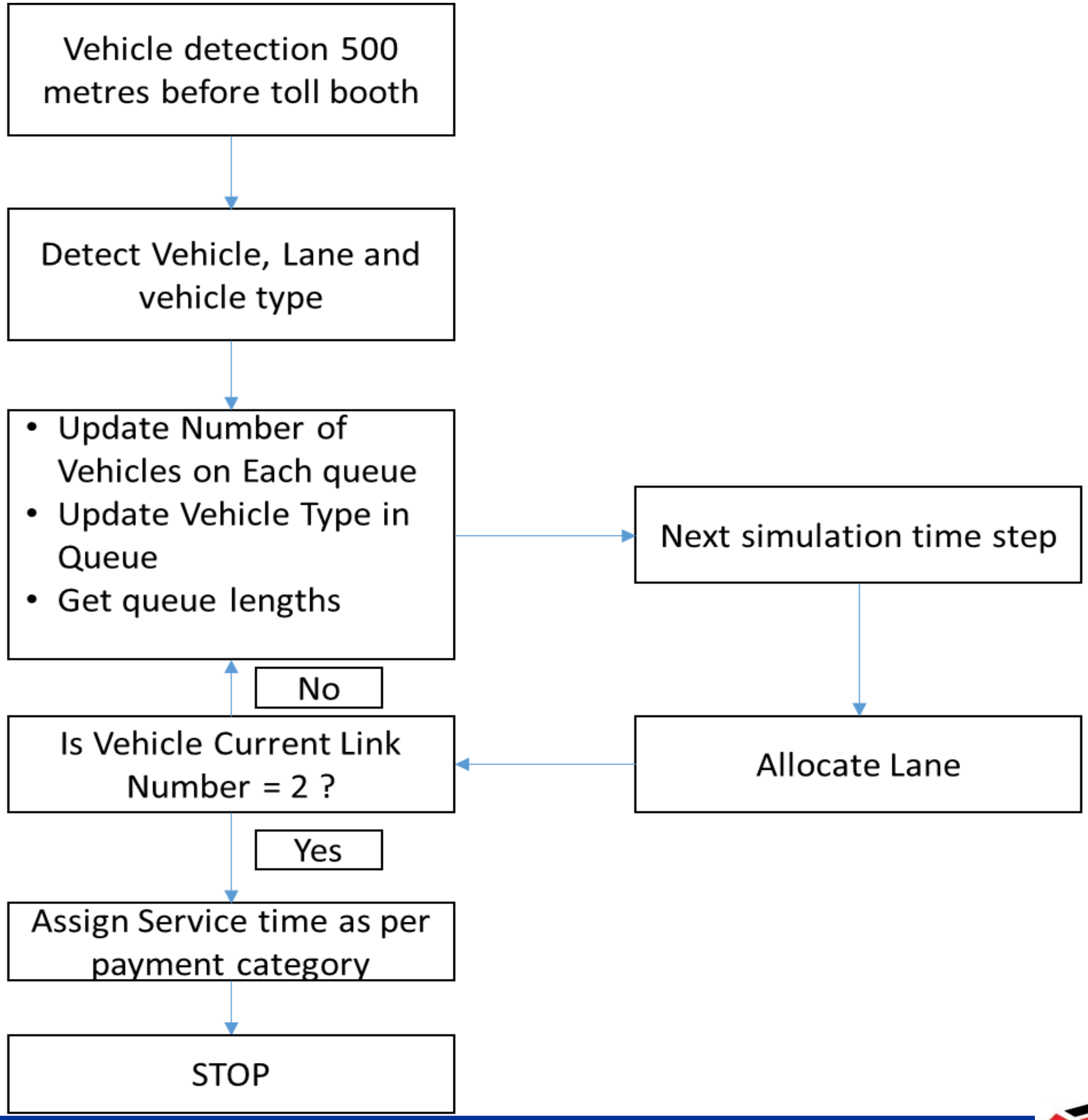
Lane selection behaviour

Following observations are made with reference to LHS side:

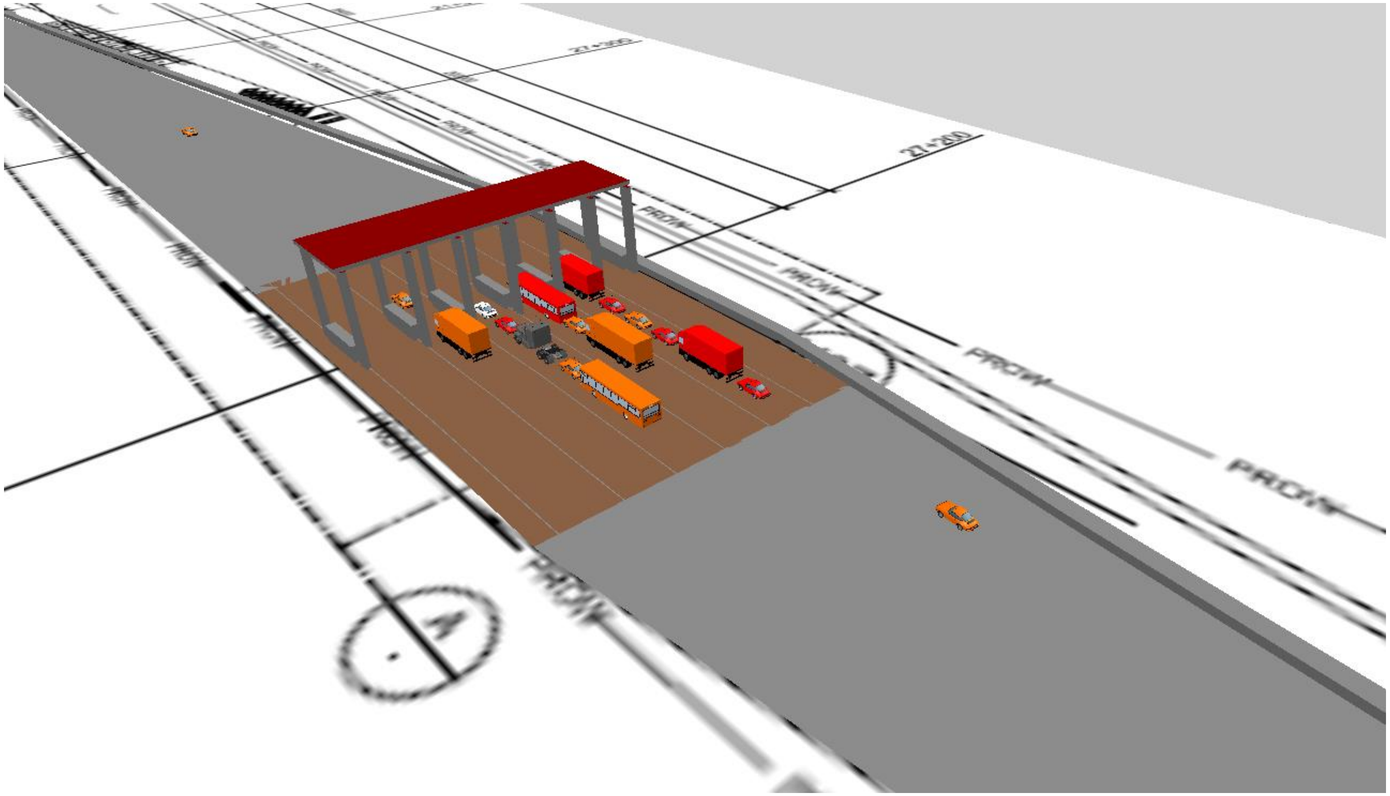


section with a median between two toll lanes

Lane Selection Methodology



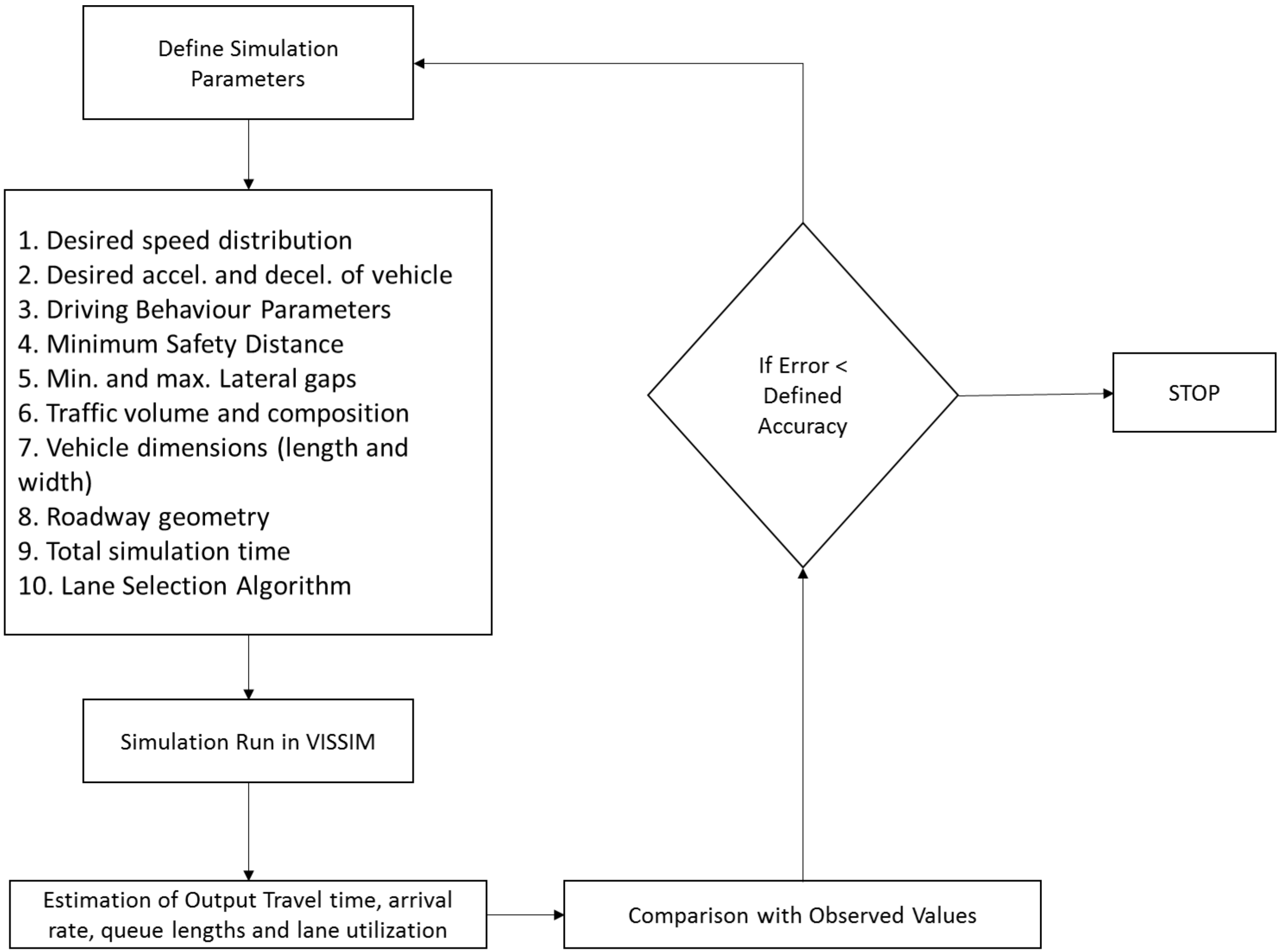
Calibration and Validation



Once the network is setup the model is run iteratively and outputs of queue lengths and delays are taken. Outputs are compared with observed values and model parameters are calibrated to reduce error, and increase credibility of the simulation model

Calibration of the Simulation Model

Calibration Methodology



Calibration Parameters

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VehicleType/Calibration Parameter	On the Approach Road to the Toll Booths								
	Following Behaviour			Lateral Behaviour					
VehicleType/Calibration Parameter	Average Standstill Safety Distance (m)	Additive Part of Safety Distance	Multiplicative Part of Safety Distance	Keep Lateral Distance from Vehicle(s) on Next Lane	Desired lateral position on Lane	Minimum Longitudinol Speed	Time Between Direction Changes (Seconds)	Minimum Lateral (m) Distance at 0km/hr	Minimum Lateral(m)Distance at 50km/hr
Default Values	2	2	3	Not Active	Middle	3.6Km/Hr	0	1	1
Car/LCV	0.8	1.2	1.15	Active	Any	1Km/Hr	3	0.3	0.7
Trucks/MAV/Bus	1	1.25	1.3	Active	Any	1Km/Hr	5	0.3	1
	While in Queue at the Toll Booths with no possibility of lane changing								
Car/LCV	1	1.26	1.15	Active	Middle	3.6Km/Hr	3	1	1
Trucks/MAV/Bus	1	1.25	1.3	Active	Middle	3.6Km/Hr	5	1	1

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Validation Results

Comparison of Observed and Simulation Volumes Arrival rates

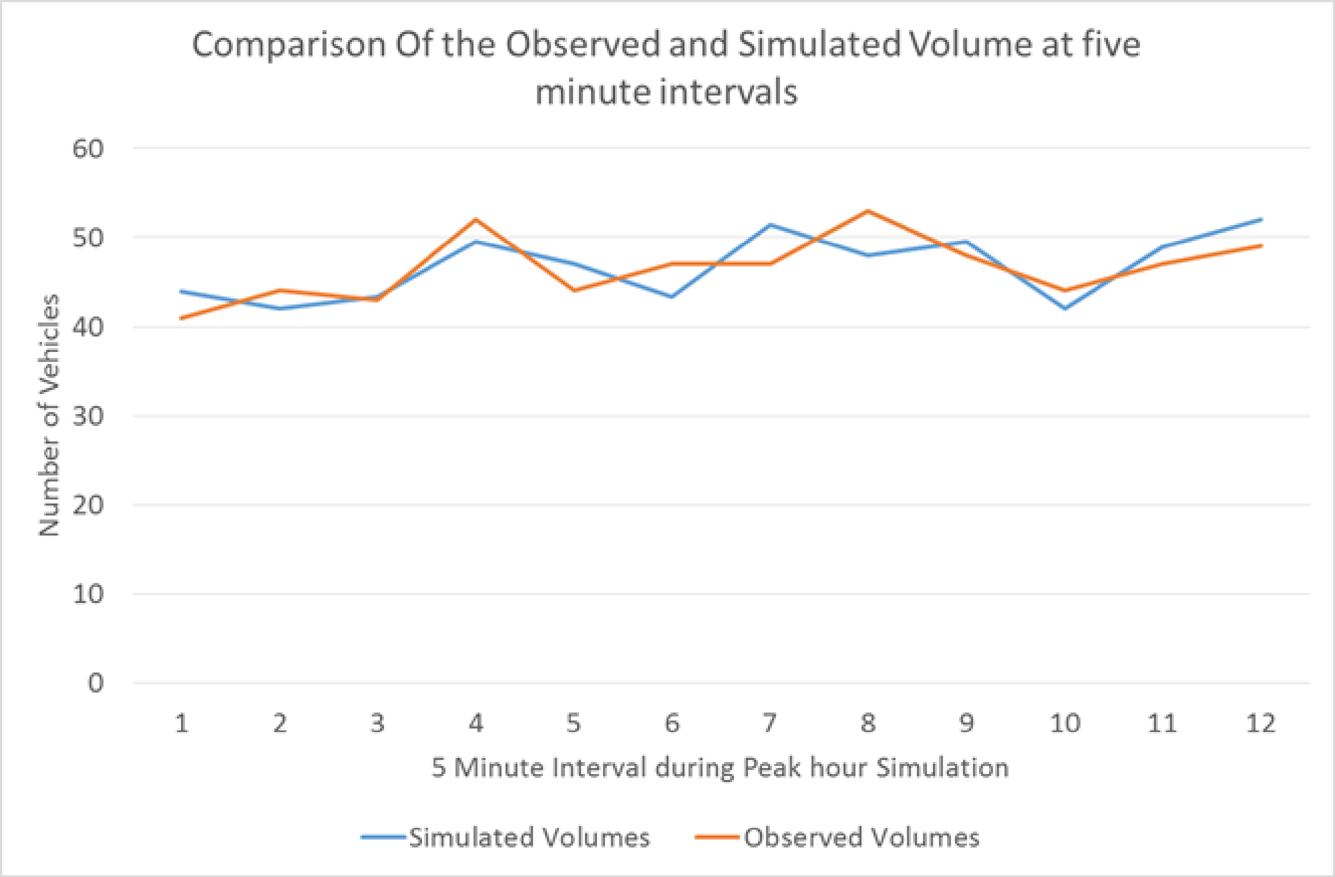
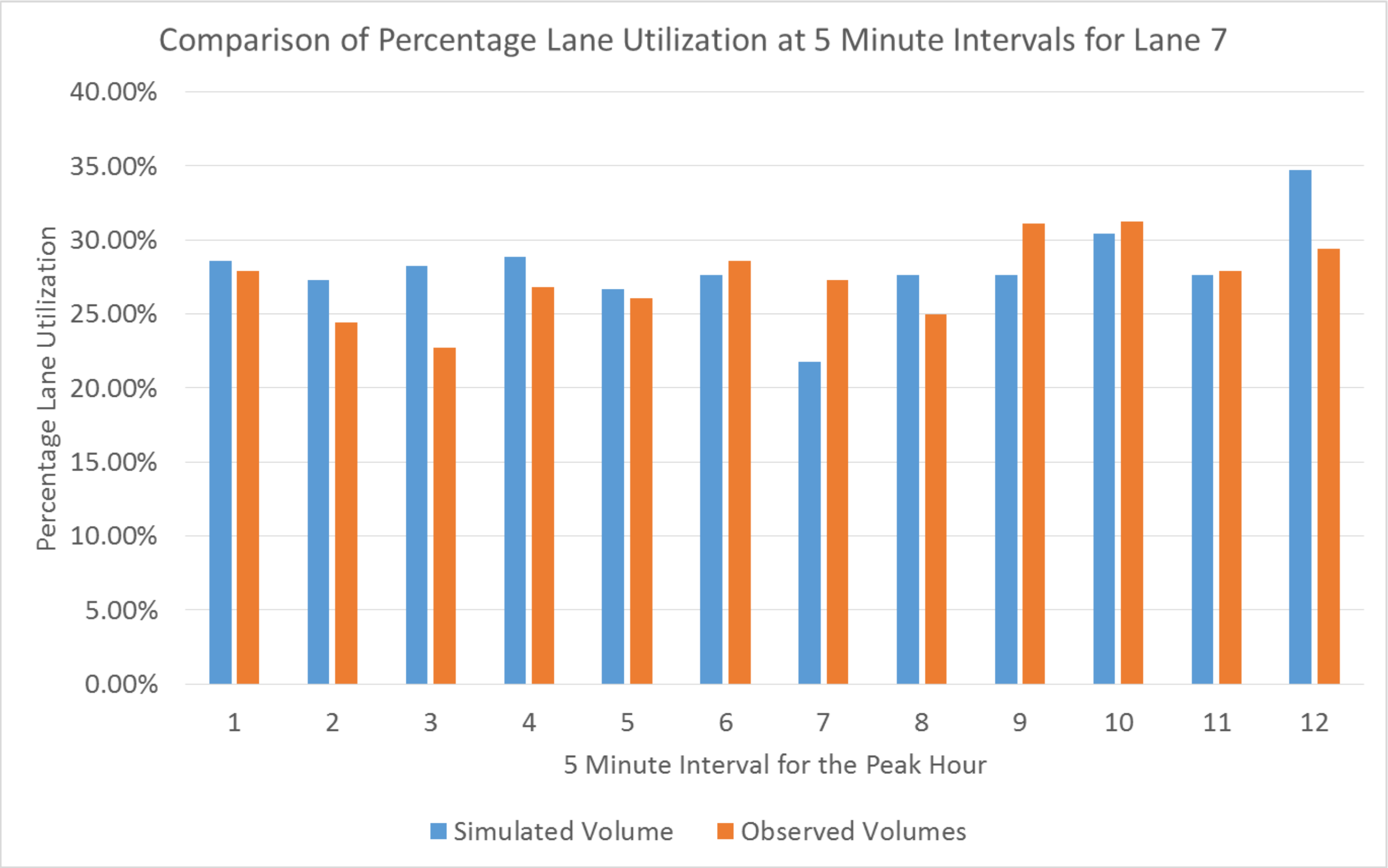


Figure above compares the observed and the simulated volumes for 12 five minute intervals for the analysed peak period between 9:15 am to 10:15 am. **The Mean Absolute Percentage Error (MAPE) is found to be 6.18%**

Comparison of Observed and Simulation Volumes Percentage Lane Utilization



From the results, it is observed that, in all the cases, the value of estimated t-statistic (0.00108 to 0.00348) is lesser than the critical value of t-statistic (2.57) obtained from standard t-distribution table at 5% level of significance.

Comparison of Observed and Simulation Volumes | Average Delay

From a sample set of 81 vehicles selected randomly, one more derived parameter, that is, **observed average travel time for passing the toll plaza is found to be 250 seconds** during morning peak period from 08:00 to 10:00, whereas the average **simulated value for the same time interval is obtained as 241 seconds**, indicating model credibility to replicate observed conditions over space as well.

Scenario 1: Using Number plate Recognition Technology to Improve Service Rate

Inputs/Outputs from the Simulation Model Collected

Following inputs are given to the calibrated Simulation Model :

Inputs

- Peak hour Traffic Composition
- Mean Observed Volumes
- Transaction Time As per Toll Type

  With NPRT transaction time for Return Ticket Category is Same as Single Ticket Category

Outputs

- Average and Maximum Throughput Volumes
- Average and Maximum Queue Lengths

Analysis of Performance Measures with NPRT

Increasing queue lengths and blocking lanes for heavy vehicles due to geometry of the section

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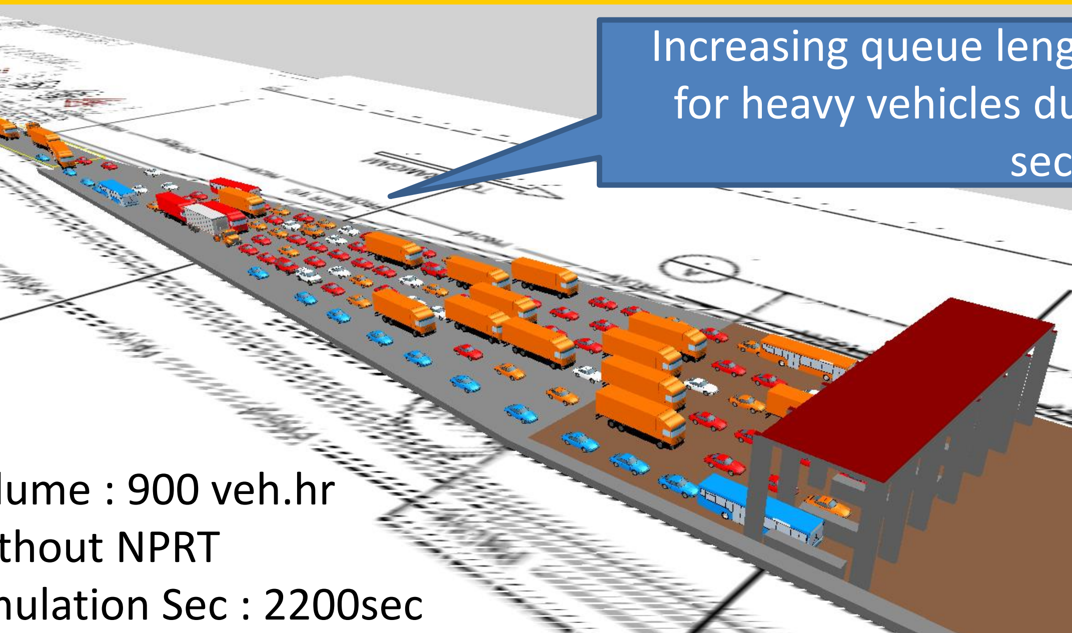
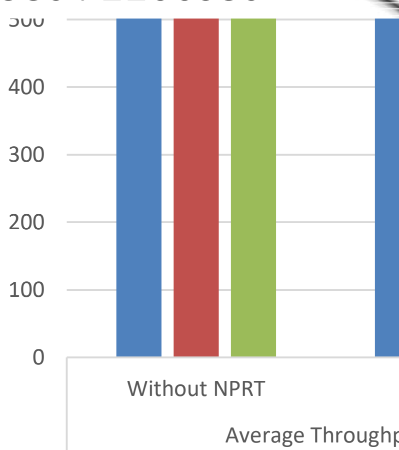
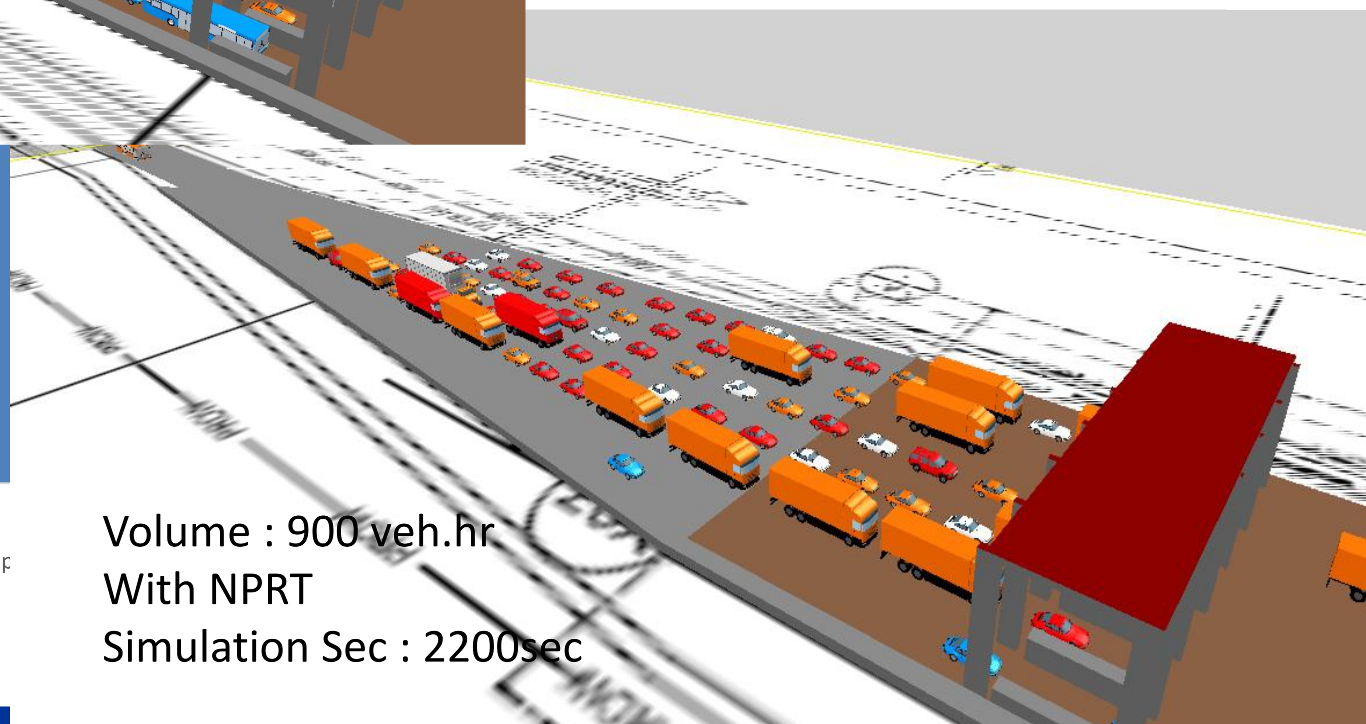


lume : 900 veh.hr
thout NPRT
nulation Sec : 2200sec





Volume : 900 veh.hr
With NPRT
Simulation Sec : 2200sec

Summary of Observations

With the introduction of the NPRT the transaction time for the return ticket category reduces which improves the throughput volume by 10-12% and also the Level of service

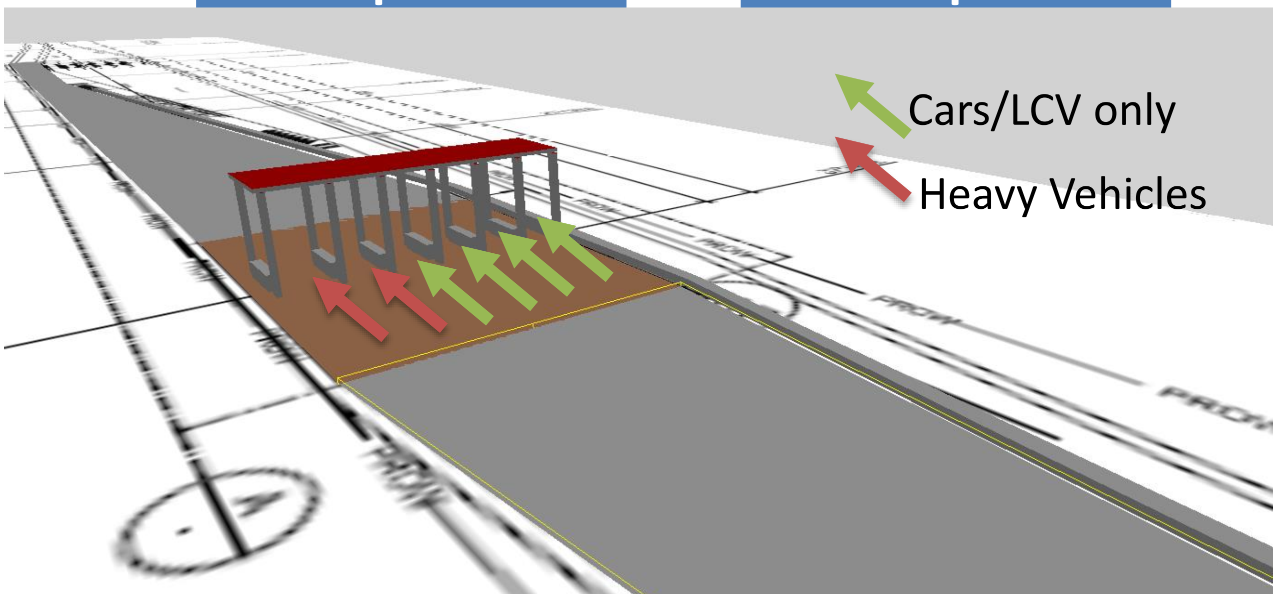
Scenario 2 : Using Segregated Lanes for Cars/LCV and Heavy Vehicles

Inputs/Outputs from the Simulation Model Collected

Following inputs are given to the calibrated Simulation Model :

Inputs

Outputs



Transaction Time As per Toll Type

4 Lanes are reserved for Car/LCV use Only

And 2 Lanes for Other vehicles

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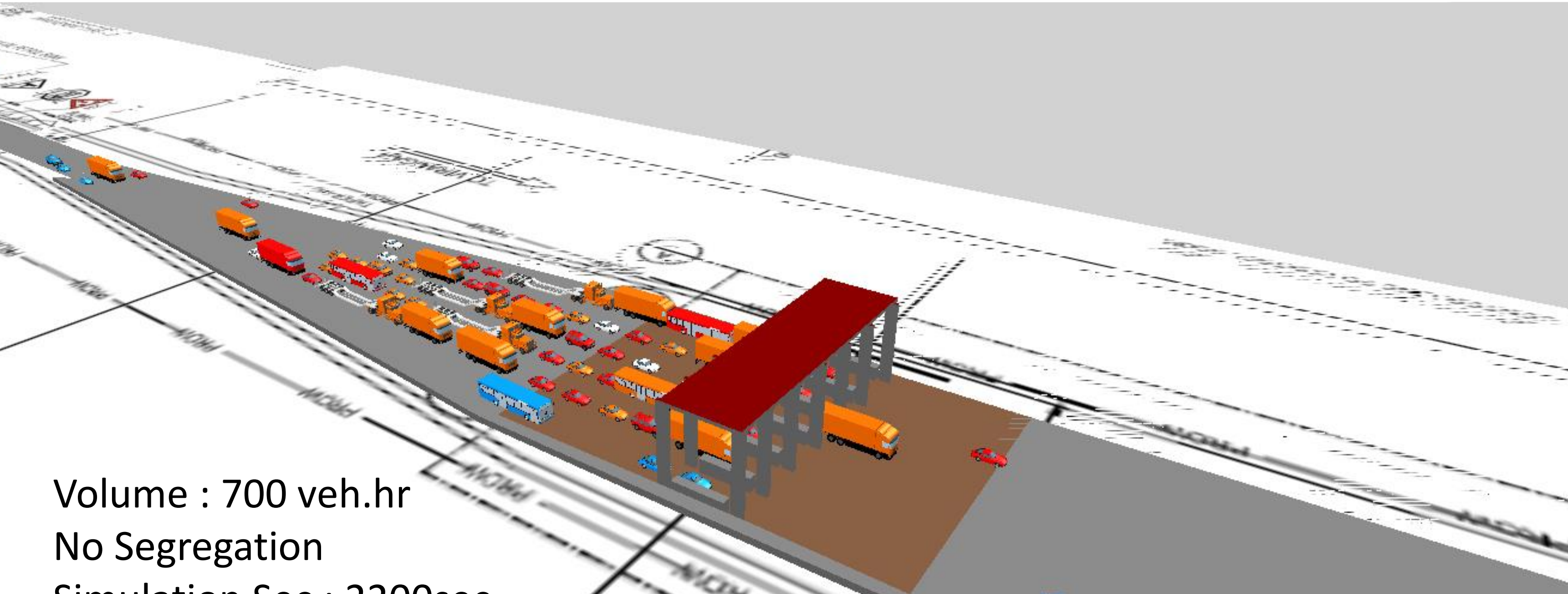
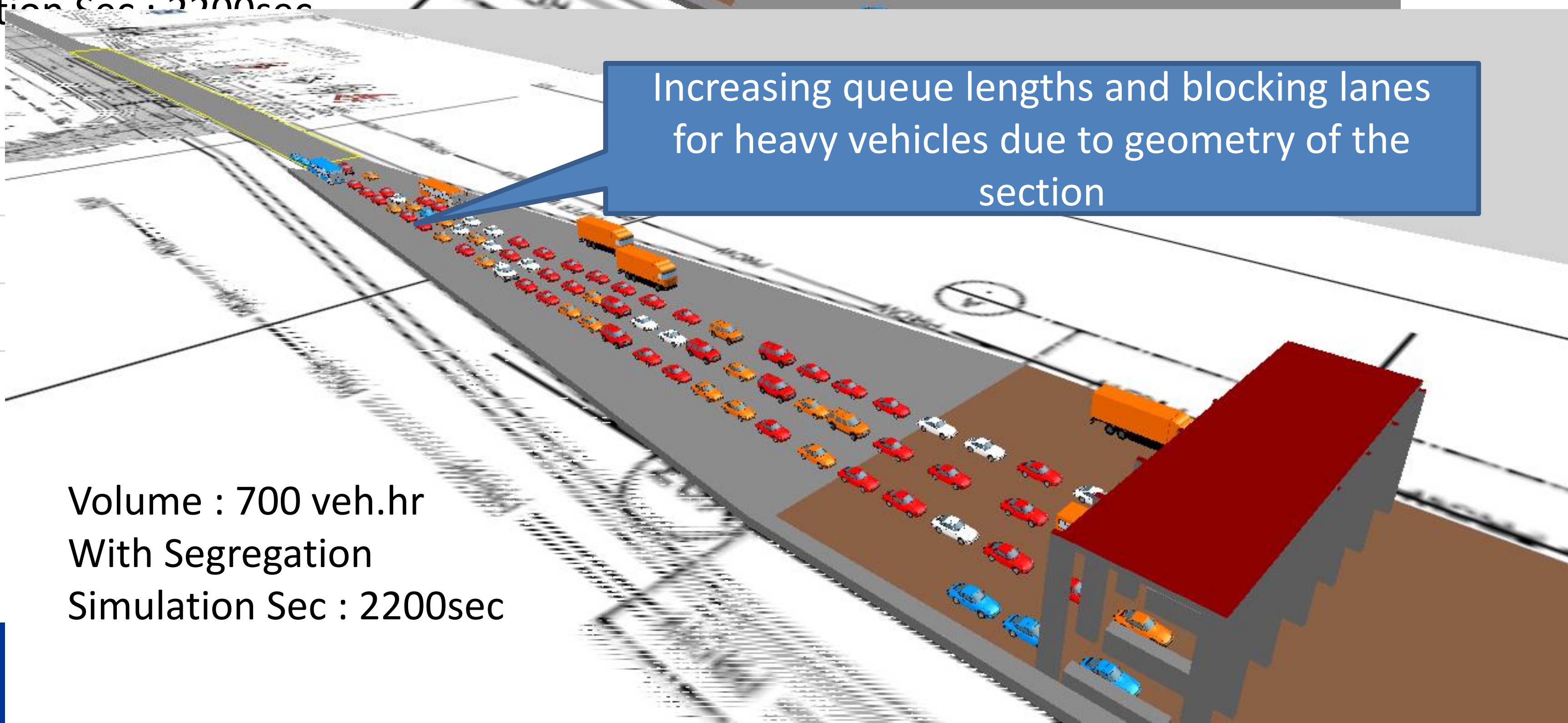
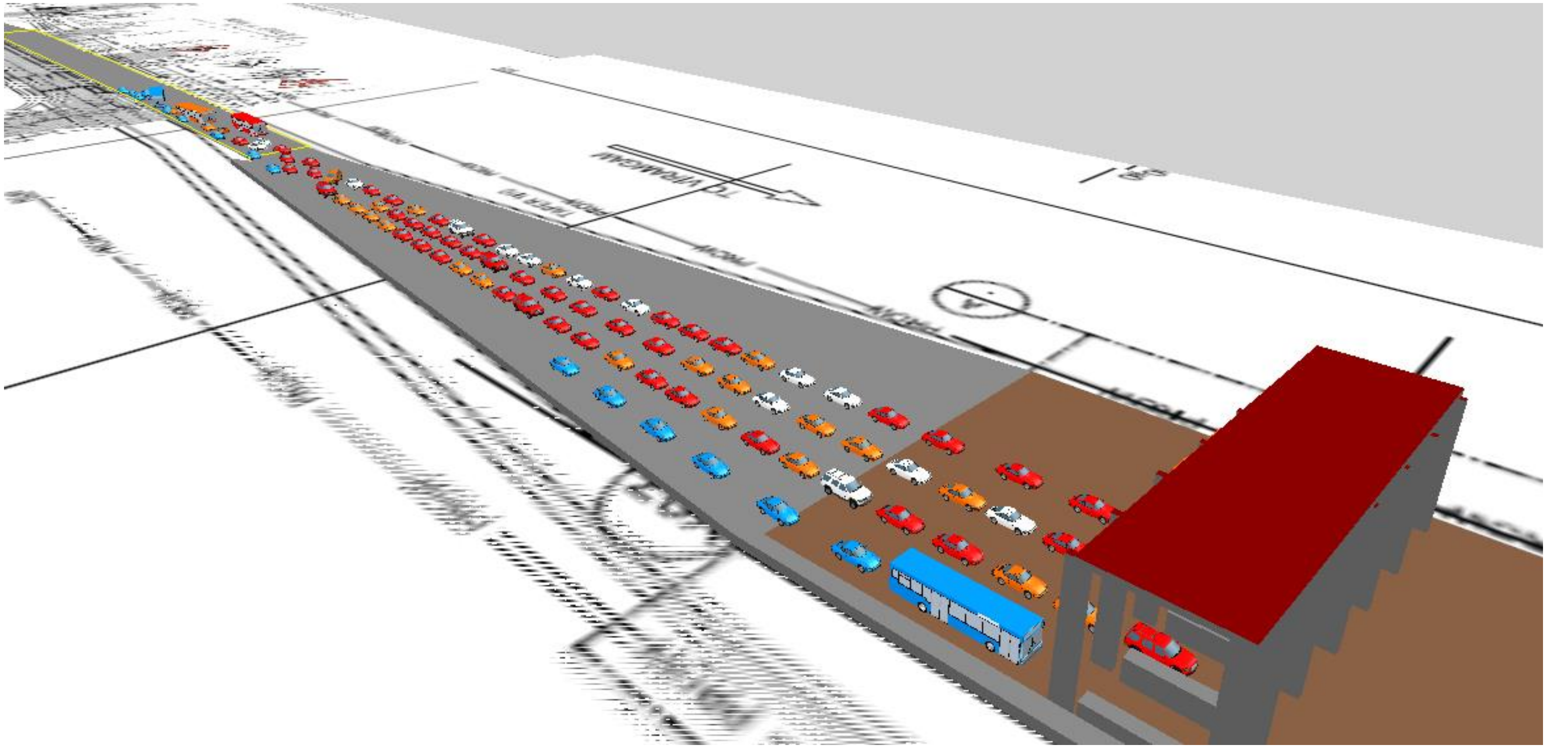


300
200
100
0



Summary of Observations

Due to the high volume of cars in the peak hour and the geometry of the section the segregation of lanes reduces the throughput volume by 15% and the queue length are also increased



Scenario 3 : Optimization toll plaza gates Configuration

Defining Classes and Class Intervals

S no	Category
1	Very Low Volume (0-300)
2	Low Volume (300-600)
3	Medium Volume (600-900)
4	High Volume (900-1200)
5	Very High Volume (1200-1500)

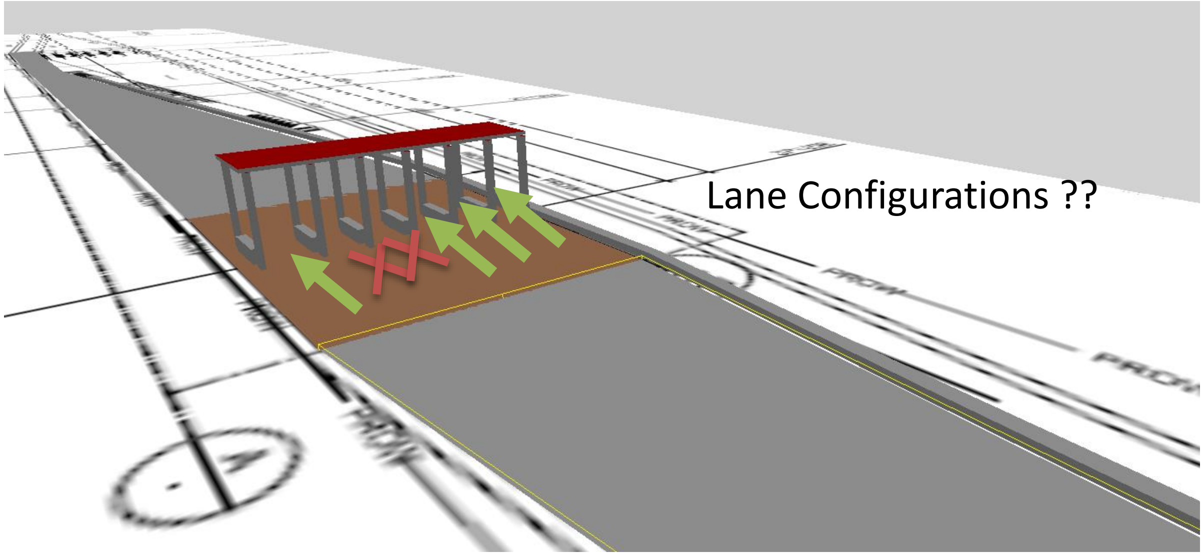
Based on the statistical principle of defining classes, 5 different time periods are identified based on hourly volumes. The data analysis is divided in these 5 categories

Classification of Time periods into different categories

Very Low Volume (0-300)	Hour 1
	Hour 2
	Hour 3
	Hour 4
Low Volume (300-600)	Hour 0
	Hour 5
	Hour 6
	Hour 21
	Hour 22
	Hour 23
Medium Volume (600-900)	Hour 7
	Hour 13
	Hour 20
High Volume (900-1200)	Hour 8
	Hour 9
	Hour 10
	Hour 11
	Hour 12
	Hour 14
	Hour 15
	Hour 16
	Hour 17
	Hour 18
	Hour 19

Based on the hourly volume … e day are divided into the following categories

Observation from on Site Survey and Data Collected



- It is observed from the on site survey and data provided by the client, during normal operations, currently there is no fixed timetable for closing/opening lanes.
- The vehicles arrival rate is random (poison distributed) this provides an opportunity to optimize the lane operations.

Need for Optimizing lane configuration

Following benefits can be attained from optimizing lane configuration for different time periods of the day :

- Reduces toll operation costs
- Clarity in the toll operation configurations
- Easier handling of maintenance or other similar situation where a lane needs to be closed
- Improving the level of service for the customers

Inputs/Outputs from the Simulation Model Collected

Following inputs are given to the calibrated Simulation Model :

Inputs

- Traffic Composition as per Time period
- Mean Observed Volumes
- Transaction Time As per Toll Type

Outputs

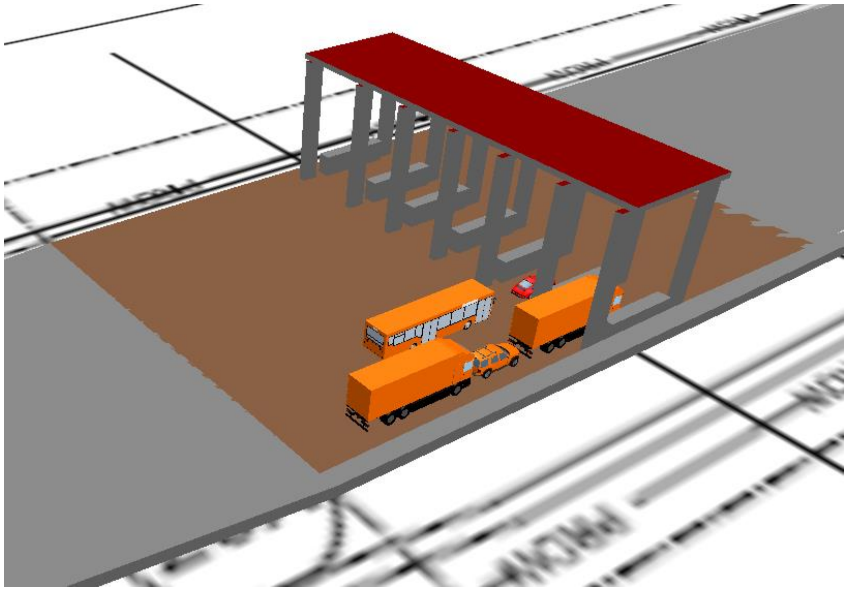
- Average and Maximum Throughput Volumes
- Average and Maximum Queue Lengths

Illustration for Optimization toll plaza gates Configuration For Very Low Volume Hours

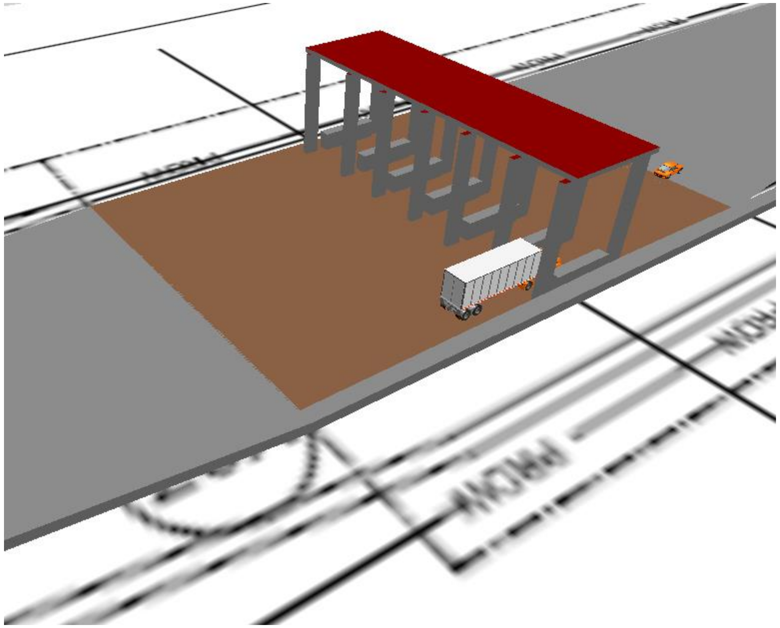
Very Low Volume Hours | Hour 1, Hour 2, Hour 3, Hour 4

Throughput Volume and Queue Analysis | Active Lanes 2

Below snapshots compare active lanes 2 and lanes 3, with volume 150 veh.hr at Simulation second 2800 secs



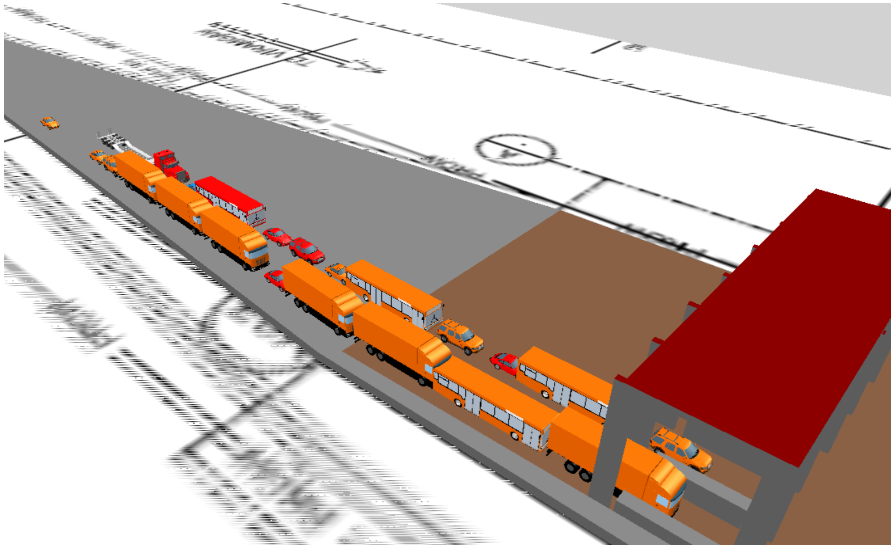
Active Lanes 2



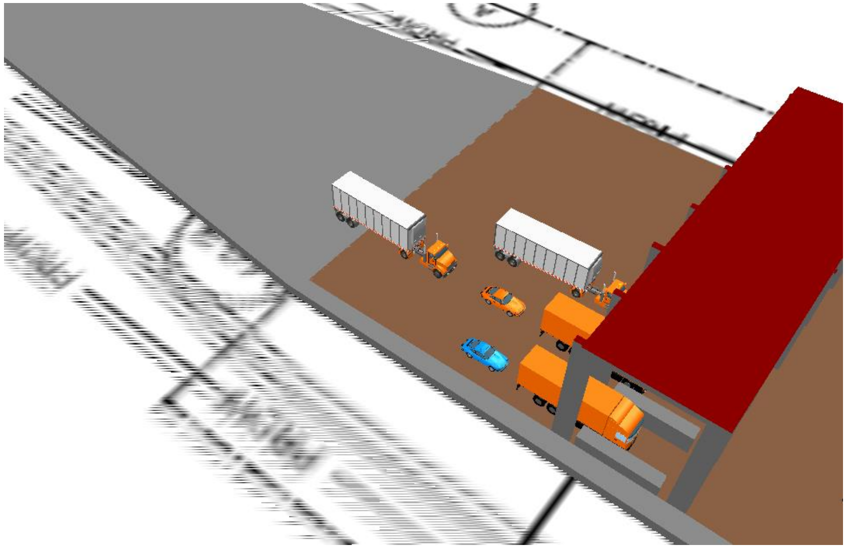
Active Lanes 3

Throughput Volume and Queue Analysis |

Below snapshots compare active lanes 2 and lanes 3, with volume 250 veh.hr at Simulation second 2800 secs



Active Lanes 2

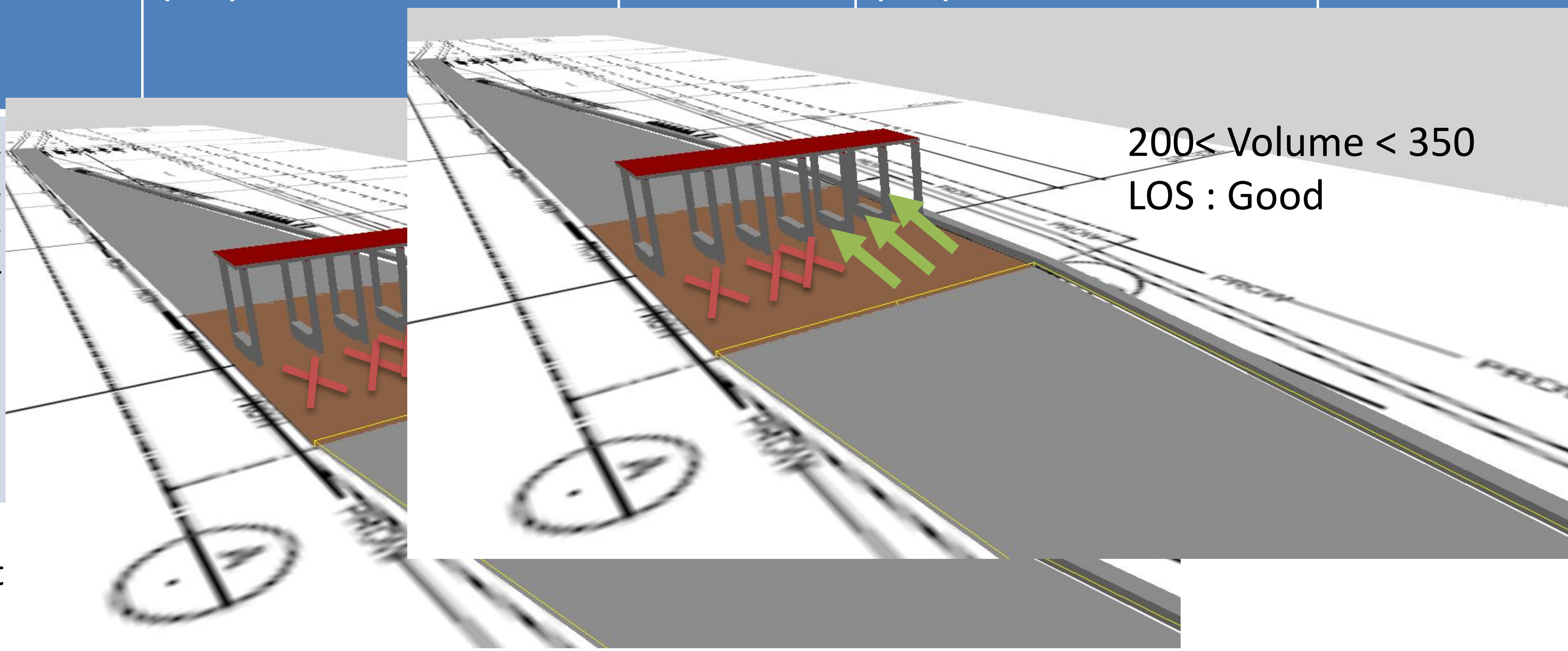


Active Lanes 3

Recommendations | Very low Volume Hours | RHS

The Table below gives the recommended lane configuration at different time periods of the day. **As per data RHS observe maximum volume during these hours. All Volume in Veh/Hr**

Time of the Day	Lane Configuration (RHS)	Estimated Level of	Lane Configuration (RHS)	Estimated Level of Service
Hour 1 Hour 2 Hour 3 Hour 4				



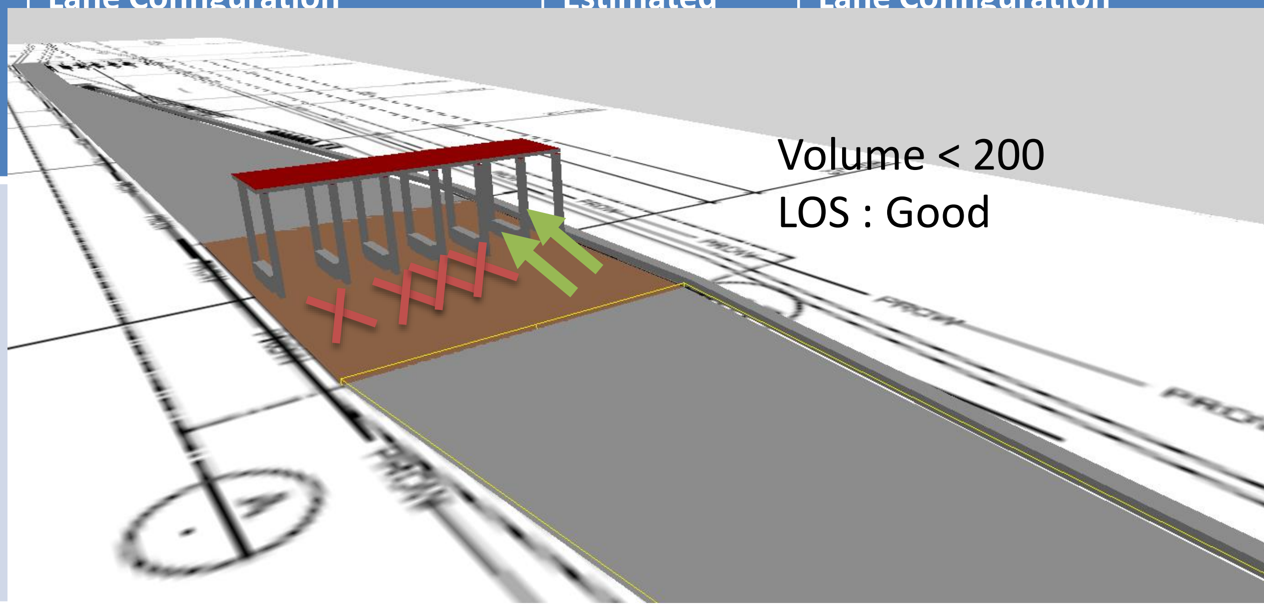
- Eit

Only lane 12 allows access for oversized vehicles, due to geometry of the toll plaza, the visibility of lane 12 is limited and requires lane changing to access the lane. Visibility of lane 8 and lane 9 is better and requires less weaving effort.

Recommendations | Very low Volume Hours | LHS

The Table below gives the recommended lane configuration at different time periods of the day. Detail analysis of each scenario are given in annexure 1.

Time of the Day	Lane Configuration	Estimated	Lane Configuration	Estimated Level of Service
Hour 1 Hour 2 Hour 3 Hour 4				Good



- Either one can be open

Only lane 1 allows access for oversized vehicles, due to geometry of the toll plaza, the visibility of lane 1 is limited and requires lane changing to access the lane. Visibility of lane 2 and lane 3 is better and requires less weaving effort.

Final Recommended Table

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Time of Day	Recommended Active Lane (RHS)	Recommended Active Lane (LHS)
Hour 0	3	2
Hour 1	2	2
Hour 2	2	2
Hour 3	2	2
Hour 4	2	2
Hour 5	3	3
Hour 6	3	4
Hour 7	3	5
Hour 8	3	6
Hour 9	5	6
Hour 10	5	6
Hour 11	4	5
Hour 12	4	4
Hour 13	4	4
Hour 14	4	6
Hour 15	5	4
Hour 16	6	4
Hour 17	6	4
Hour 18	6	4
Hour 19	5	4
Hour 20	4	3
Hour 21	3	3
Hour 22	3	3
Hour 23	3	3

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Conclusions and Way forward

- It is observed that a simulation model with an accurate representation of the toll plaza configuration including the ability to consider lane-use imbalance, service time distributions, traffic arrival pattern and other particular user behaviours can be calibrated and validated to study toll operation for Indian highways using PTV Vissim.

- The array of outputs like average queue lengths, travel times, volumes that can be extracted from the model allows for in-depth analyses of the plaza operation.

- This opens up countless possibilities of evaluating strategies both long term and short term on Indian highways before implementing on the site for optimizing operations.

Questions ??