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CALIBRATION AND APPLICATION OF MICROSCOPIC TRAFFIC SIMULATION MODEL

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ABSTRACT

In recent times more and more countries are successfully adopting intelligent transport system (ITS) as a means of managing the transport system including some developing countries. Microscopic traffic simulation plays a vital role when it comes to intelligent transport system especially for dynamic traffic assignment and route guidance. In this study a microscopic traffic simulation model for Shibbari in Khulna of Bangladesh has been calibrated to simulate the demand and supply parameters as well as to experiment practical applications of the model to increase the performance of the roundabout. Shibbari roundabout is a roundabout at the confluence of Majid Sharani, KDA Avenue and Upper Jessore Road. Traffic congestion occurs during peak hour at this roundabout which increases the queue length and travel time. Root mean squares of queue length, travel time and combination of both have been used to calibrate the simulated model. Simulation of Urban mobility (SUMO) software version 0.21.0 has been used to calibrate the model based on *car following theory* to replicate the reality reflected in traffic measurement. From the calibrated model it can be seen that the parameter driver imperfection and driver's reaction time have significantly greater influence on the model comparing to other parameters. To illustrate the practical application of the calibrated model two alternative scenarios have been developed and comparison between them has been done to find the optimal measure to be taken to manage the traffic and improve the performance of Shibbari roundabout of Khulna city.

KEYWORDS: Car following model, SUMO, Roundabout, Root mean square error, Queue length, Travel time

1. INTRODUCTION

Khulna, the third largest city of Bangladesh after the capital city Dhaka and the metropolitan city of Chittagong, is the Divisional headquarter of the administrative division Khulna, an important inland river port and provides link to Mongla port by road and waterway. Following Dhaka and Chittagong in recent years Khulna is frequently plagued by a continuing increase of traffic congestion which leads to motorists' frustration, increased accidents, longer travel times, increased freight transportation cost and reduced air quality. In a situation like this simulated traffic model can play an important role by simulating alternative scenarios in the laboratory environment to find solutions- both the solutions related to infrastructural development and solutions related to better traffic management. Since finding solutions in the transportation sector is very expensive and time consuming simulation can provide very efficient solution package in respect to both time and money; decisions can be taken by evaluating them in simulated environment prior to physical realization. Microscopic traffic simulation enables us

to simulate the individual vehicles instead of all the vehicles on a network as a continuum, like the macroscopic models do.

Since the behaviour of drivers play an important role in daily traffic situation it becomes crucial to simulate the drivers' behaviour and investigate it. Thus the behaviour of drivers in specific situation can be observed in a simulated environment and decisions considering that behaviour can be taken. Simulation can help to evaluate the change in road infrastructure also. Large scale events, like international cricket tournaments, religious and cultural festivals, demand changes in road infrastructure, many roads are temporarily closed for the regular urban trip to facilitate the event. When many roads are closed traffic on the other roads may get out of control. Situations like this can be investigated in a simulated environment and optimal decision, regarding which roads need to be closed or kept open during the event and what arrangement can be made to avoid the traffic chaos, can be taken. Application of simulated microscopic traffic model is not limited in these situations only; there exists a huge set of application areas. Simulated traffic model can be used to measure travel time or traffic flows on specific road segments at specific instants in time. This model can prove to be vital if changes in the infrastructure have to be made. Evaluating these changes in a simulated model and if it is found that these changes are reasonable, decision to implement in the physical world can be taken and thereby risks of unconsidered factors can be minimized. Microscopic traffic simulation that simulates drivers' behaviour can be useful to study impact of accident, specific weather situation etc. on them. It is possible to observe how an aggressive young driver acts on the road in contrast to an experienced cool headed driver as well as interactions between them.

Microscopic traffic simulation models become more vital when it is used with intelligent transport system. Keeping these in mind this research attempts to calibrate, validate and experiment the application of a simulated model of traffic at Shibbari roundabout. This study will use three types of field data- traffic flow, travel time and the queue length. This data is used in calibration and validation of the model to represent field measurements. After that, two alternative scenarios have been developed to reduce travel time and evaluate which one is the best scenario for improving performance of the roundabout.

2. MICROSCOPIC TRAFFIC SIMULATION

Barceló et al. (1998) explain simulation as a process developed using computer program to represent real world system by developing simulated model and this can be used to find solution by proposing several alternative scenarios along with the existing system.

Microscopic traffic simulation model gives high level of details by modeling movement of individual vehicle travelling on a road and the interaction between them (Olstam, 2005). The movement of vehicle is determined by using simple car following, lane changing and gap acceptance rules (Fox, n.d.), acceleration, speed adaptation etc. (Olstam, 2005). According to Krauss, dynamics of individual vehicle is a function of the location (position) and speed of neighboring vehicles, so one has to consider dynamic processes of car-following and lane-changing for microscopic traffic simulation (Krauss, 1998).

Simulation of Urban Mobility (SUMO) is a highly portable, open source, microscopic road traffic simulation package capable of managing large road networks. It includes the safe distance based Krauss' car following model, an extension of Gipps model, and Krajzewicz's model of lane change. In contrast to the space-discrete time-discrete CA based simulation, SUMO uses space-continuous time-discrete approach. The system capable to simulate various vehicle types, various intersections with or without traffic signals, for networks with a number of links exceeding 10,000. Besides, SUMO includes processes for dynamic traffic assignment proposed by Gawron. SUMO has its own format to develop traffic simulation, and it requires traffic demand and road network to simulate (Behrisch et al. 2011).

3. METHODOLOGY

3.1. Study area

Shibbari roundabout is a roundabout at the confluence of Majid Sharani, KDA Avenue and Upper Jessore Road. The roundabout location can be seen in Figure 1.

These three roads are busy arterial roads with shopping, residential and educational area along them. The diversified land uses around this roundabout makes the demand for those roads higher in peak hours of the day. High demand for use of these roads leads to queuing.



Source: Google maps, 2015

Figure 1: Shibbari Roundabout

3.2. Car following model

Car following model, developed by Krauss in 1998, is a microscopic, space-continuous model based on the safe speed paradigm: a driver tries to maintain a distance and a safe speed to stay away from the driver in front of him which enable him to adapt to this leader's deceleration. Speed, acceleration, and deceleration of a car depend upon the previous car (Olstam, 2005). This model assumes that the drivers have a reaction time 'tau' of about one second. The model has following parameters:

a : the maximum acceleration of the vehicle (in ms^{-2})
b : the maximum deceleration of the vehicle (in (in ms^{-2})
V_{max} : the maximum velocity of the vehicle (in m/s)
l : the length of the vehicle (in m)
Sigma : the driver's imperfection in holding the desired speed (between 0 and 1)
Tau : driver's reaction time
By assuming that a vehicle has desired speed similar to the previous vehicle, the car following model can be expressed by equation 1 (Krauss, 1998).

$$\frac{dv_i(t)}{dt} = \frac{v_{i+1}(t) - v_i(t)}{\tau} \quad \text{..... (1)}$$

Where:
v_i = speed of vehicle i
v_{1+i} = speed of preceding vehicle i
τ = driver's reaction time (s)
By default, SUMO uses Krauss' car-following model to simulate. This model is based on safety condition derived from braking distances of individual vehicle. In Krauss's model, distance between two cars is determined by the maximum safe velocity (v_{safe}). This relationship is expressed by equation 2.

$$v_{safe} = v_{n+1}(t) + \frac{g_n(t) - v_{n-1}(t)\tau}{\frac{v_n(t) + v_{n-1}(t)}{2b} + \tau} \quad \text{..... (2)}$$

Where:
$g_n(t) = x_{n-1}(t) - x_n(t) - s$
$v_{des} \leftarrow \min\{v_n(t) + a.\Delta t, v_{safe}, v_{max}\}$
$v_n(t+\Delta t) \leftarrow \max[0, \text{rand}\{v_{des} - \epsilon a, v_{des}\}]$
n =The position of the vehicle, predecessor vehicle has higher index
$g_n(t)$ = distance between two vehicle
v_{des} = vehicle desired speed ,
Δt = the time step (assumed to be equal to the driver reaction time)
According to this equation, in the traffic, leading vehicle has the highest index. The maximum acceleration (a), deceleration (b), and jammed spacing (s) are assumed constant.

3.3. Calibration and validation

Calibration of a model is the adjustment of constants and other parameters in estimated model so that the model can replicate observed real world data for a base year and produce more reasonable results. (Dowling et al. 2004). RMSE (Root Mean Square Error) (Holmes, 2000) has been used for calibration of the simulated model in this research. (equation 3)

$$RMSE = \sqrt{\frac{1}{N}\sum_n (M - F)^2} \quad \text{..... (3)}$$

Where:
F = field measurement
M= model output
N= number of data points
Algorithm for nonlinear least-squares parameter estimation has been used to find the optimal values of parameters that can minimize RMSE between model and the field measurements.

Validation of a model requires application of the calibrated models and evaluating the results against observed data whether they still represent the reality or not; ideally, for validation the observed data are a new set of data from the set used for model estimation or calibration to ensure the results are reasonable (TSS, 2010).

$H_0 : \mu_x = \mu_y$
$H_A : \mu_x \neq \mu_y$
Where:
μ_x = field measurement
μ_y = model output
In testing hypothesis, the H_0 will be rejected if:

- $T_{statistic} < -T_{table}$, the average travel time of the proposed scenarios decreased or
- $T_{statistic} > T_{table}$, the average travel time of the proposed scenarios increased

, H_0 will be rejected which means the model is not valid.
Where:

$$T = \frac{\bar{x}_x - \bar{x}_y}{s_p} \sqrt{\frac{n_x n_y}{n_x + n_y}} \quad \text{..... (4)}$$

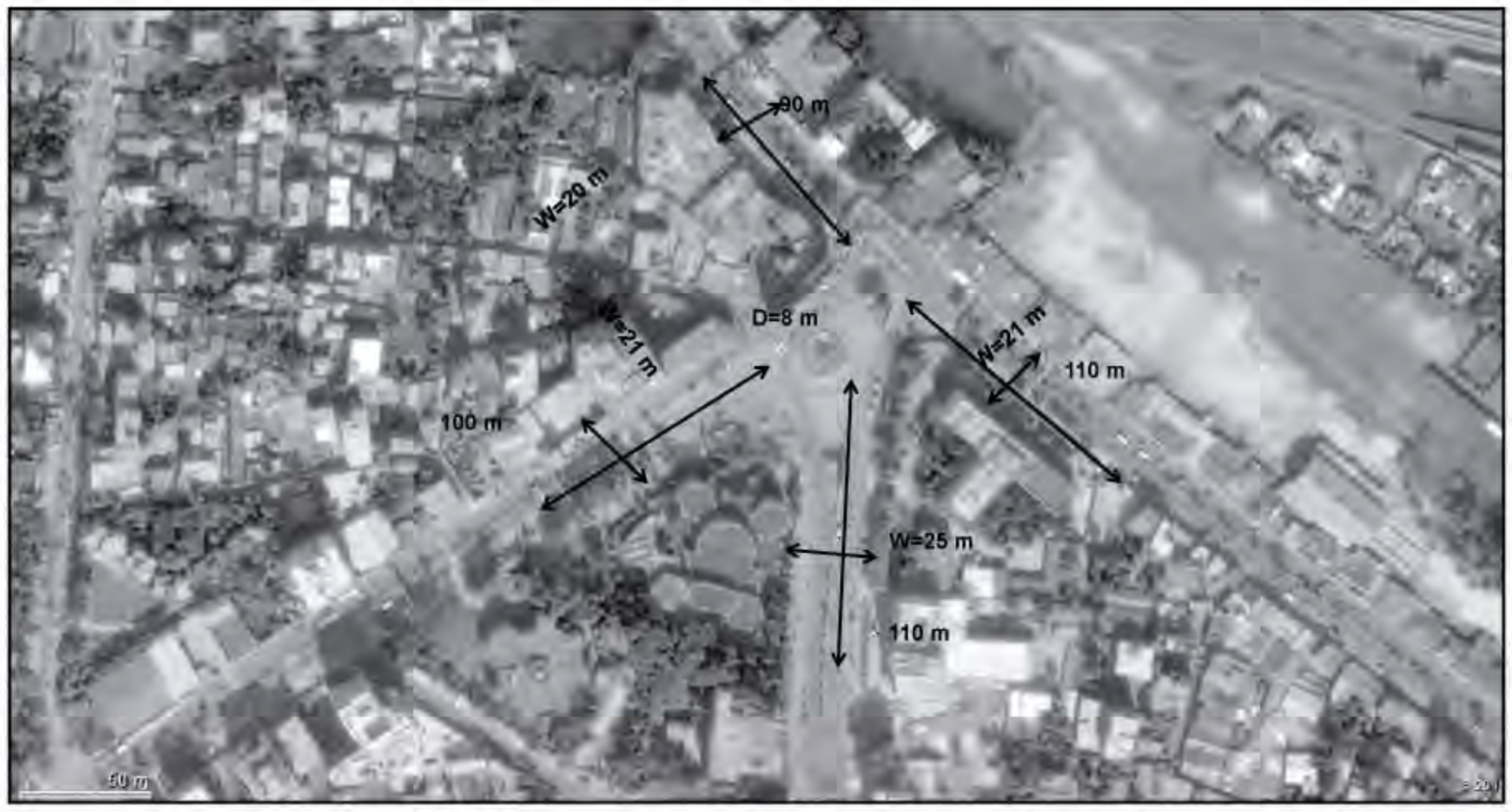
$$s_p^2 = \frac{(n_x - 1)s_x^2 + (n_y - 1)s_y^2}{n_x + n_y - 2} \quad \text{..... (5)}$$

This validation process uses the confidence level of 95% ($\alpha = 0.05$). The T value is obtained from T-table, while n_x is observed data sizes and n_y is data sizes of the estimated model's output. X and Y are mean of observed data and estimated model, respectively.
In equation 5, s_x^2 is variance of observed data and s_x^2 is variance of estimated model.

3.4. Data collection

The data collection for this research has been conducted in three days in a week- Tuesday, Wednesday and Thursday and the time for survey was during morning peak hour (08.30-09.30), and evening peak hour (16.30-17.30). Data regarding traffic flow, turning movement, queue length and travel time have been collected in five minutes intervals during one hour observation for each leg in three days. Collected data types are-
a. Road geometry of Shibbari roundabout (Figure 2).
b. Traffic flow and turning movement of the vehicle passing the roundabout.

c. Queue length of each section in certain time period.
d. Travel time data that will be used for calibration.

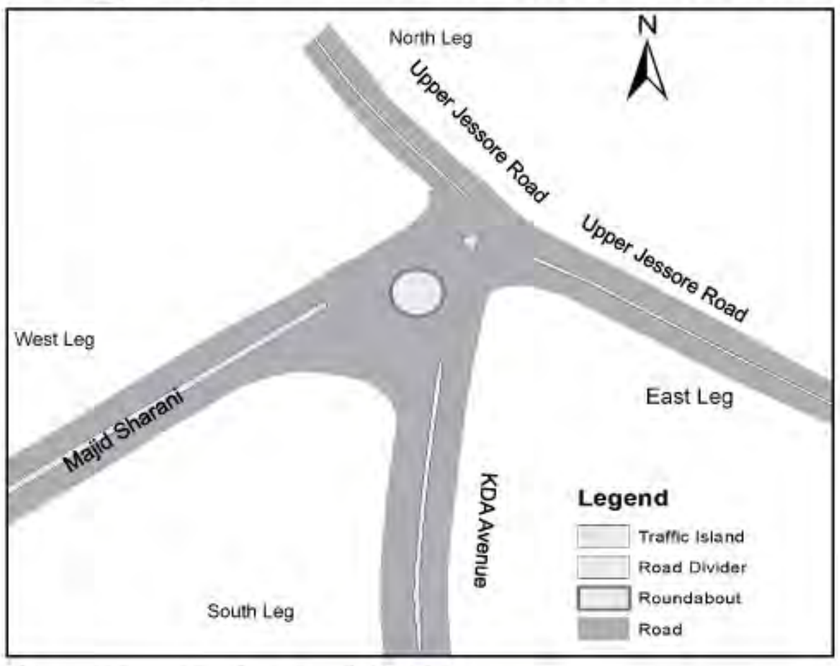


Source: Google maps, 2015
Figure 2: Road Geometry of Shibbari Roundabout

4. DATA PROCESSING AND ANALYSIS

4.1. Base model development

Base model is built so that it can represent real world existing situation in a laboratory environment by using observed data. The first step in building base model is to build the network. For this research road network has been built by importing map from open street map (OSM) and making necessary adjustments and corrections, and ignoring pedestrian paths.



Source: Authors, 2015
Figure 3: Road Network for Base Model (Shibbari Intersection of Khulna City)

To model demand, in second step of building the base model, vehicle properties, route possibilities and flow proportions of vehicles have been stated. For this research motorcycle and other two wheeler vehicles have been excluded because they have less frequency in traffic and this exclusion will increase the accuracy of the model. The vehicle properties have been defined by the following attributes.

Table 1: Vehicle Properties

Attribute Name	Value Type	Desription
id	Id (string)	The name of the vehicle type
length	float	The vehicle's netto-length (length) (in m); default: 5m
miniGap	float	Empty space after leader [m]; default: 2.5m
maxSpeed	float	The vehicle's maximum velocity (in m/s); default: 70.0m/s
guiShape	shape (enum)	How this vehicle is rendered; default: "unknown"
guiWidth	float	The vehicle's width [m]; default: 2m

Source: Systems, 2015

By default SUMO uses modified Krauss' car following model. The parameters used for this car following model are stated in Table 2.

Table 2: Car-Following Model Parameters Based on Krauss' Model

Attribute	Description
accel	The acceleration ability of vehicles of this type (in m/s2)
decel	The deceleration ability of vehicles of this type (in m/s2)
sigma	The driver imperfection (between 0 and 1)
tau	The driver's reaction time (in second)

Source: Systems, 2015

The next step to build the base model is to state route possibilities and flow proportions of the vehicles. Origin and destination of the vehicles are defined considering their nodal connectivity. The vehicles flow has been aggregated in 5 minutes period for the model. The parameters for route possibilities and flow proportion are stated in Table 3. After this step demand model has been combined with road network.

Table 3: Route Possibilities and Flow Proportion Parameters

Attribute Name	Description
id	The name of route in certain interval
from	The name of the edge from which the route starts
to	The name of the edge where the route stops
Number	The number of vehicles generated
Type	The name of vehicle types

Source: Systems, 2015

The third step is to create additional files to generate output data. In this study creating additional file contains two parts. First to add detector to give maximum queue length and second to add edge dump that calculate average travel time in output. These two outputs will be used for calibration and validation of the model. Parameters of additional file are stated in Table 4.

Table 4: Additional File Parameters
Detector

Attribute Name	Description
id	id of the detector
type	The type of detector
lane	The id of the lane where detector shall be laid on
pos	The position on the lane where detector shall be laid on (m)
length	The length of detector (m)
freq	The aggregation of time period (second)
file	The name of output file that will be generated (xml-file)
measures	Contain the list of measures that will be computed (ALL to compute all measures)
timeTreshold	Time that describe how much time that assumed as vehicle has stopped (default: 1s)
speedTreshold	Speed that describe how speed that assumed as vehicle has stopped (default: 1.39 m/s)
jamTreshold	Minimum distance to the next vehicle that assumed this vehicle count has suffered from jam (default: 10 m)
keep_for	Information how long the memory of the detector has to be (default: 1800 s)

Source: Systems, 2015

Table 5: Additional File Parameters
Edge Dump

Attribute Name	Description
id	The name of output in certain aggregated time
freq	Aggregated time
file	The name of output file

Source: Systems, 2015

In the final step configuration file has been created to call all the files i.e. network file, demand file, and additional file which are used in simulation. It also contains begin and end time of simulation.

4.2. Calibration of the model

After error checking of the files for the initial model, calibration has been done using RMSE to find the optimal values of parameters that give more accurate representation of real world situation. The calibration is done separately for the data collected in the morning and data collected in the afternoon. So, after the calibration process there will be two calibrated model- one for morning and one for afternoon. Average travel time and average maximum queue length have been used to calibrate both the model.

To calibrate the initial model there are several parameters at hand that can be adjusted to in order to find the optimal value through trial and error process. Initially, parameters under consideration are- the minimum distance allowed between two vehicles (minGap), the maximum acceleration/deceleration as the maximum acceleration/deceleration that can be achieved by the driver, the driver imperfection (sigma) and the driver's reaction time (tau).

Adjustments of minGap, maximum acceleration and maximum deceleration in calibration process resulted small impact on the changes in the simulation, i.e. travel time and queue length. On the other hand, adjustments of driver imperfection (sigma) and driver's reaction time (tau) resulted significant changes in the simulation in terms of queue length and travel time. From this trial and error process (Table 6-8) it can be concluded that sigma and tau are parameters that have major influence in micro-simulation of a roundabout. Based on this, sigma and tau have been chosen as final parameters for calibration.

The driver imperfection (sigma) is a parameter whose value ranges from 0 to 1, the lower the value the better the driver is in driving their vehicle (Krajzewicz & Behrisch, n.d.). The tau parameter is the driver's reaction time to changes of speed in the preceding vehicle. The value of tau in initial model is 1 second based on parameters of vehicles after calibration in research (Maciejewski, 2010). The initial model before calibration and trial and error process of adjusting parameters is shown in the Tables 6-8.

Table 6: The Initial Model before Adjusting Parameters Based on Krauss' Car Following Model

vType	length, m	maxSpeed, (m/s)	minGap, (m)	guiWidth, m	max Accel (m/s2)	max Decel (m/s2)	sigma	tau (s)*
Car	5.00	27.78	2.50	2.00	3.00*	5.50*	0.50	1.00
Bus	15.00	27.78	2.50	3.00	3.00*	5.50*	0.50	1.00
Truck	10.00	27.78	2.50	3.00	3.00*	5.50*	0.50	1.00
Pickup, Leguna	6.00	25.00	2.50	2.3	3.00	5.50	0.50	1.00
Easy Bike	2.85	8.33	1.50	1.05	1.00	3.00	0.50	1.00
Tempu, Mahindra	2.85	13.5	2.00	2.2	2.00	3.50	0.50	1.00
Rickshaw	2.36	3.33	0.80	2.60	0.20	1.00	0.50	1.00

*max accel, max decel and tau value based on research (Maciejewski, M., 2010)

Table 7: Trial and Error of Adjusting Parameters in the Morning Based on Krauss' Car Following Model

vType	length, m	maxSpeed, (m/s)	minGap, (m)	guiWidth, m	max Accel (m/s2)	max Decel (m/s2)	sigma	tau (s)*
Car	5.00	27.78	1.70	2.00	4.00	6.00	0.20	1.30
Bus	15.00	27.78	1.80	3.00	3.00	5.50	0.20	1.30
Truck	10.00	27.78	1.80	3.00	3.00	5.50	0.20	1.30
Pickup, Leguna	6.00	25.00	1.70	2.3	3.00	5.50	0.20	1.30
Easy Bike	2.85	8.33	1.00	1.05	1.20	3.50	0.20	1.30
Tempu, Mahindra	2.85	13.5	1.20	2.2	2.10	4.00	0.20	1.30
Rickshaw	2.36	3.33	0.50	2.60	0.18	1.20	0.20	1.30

Source: Authors, 2015

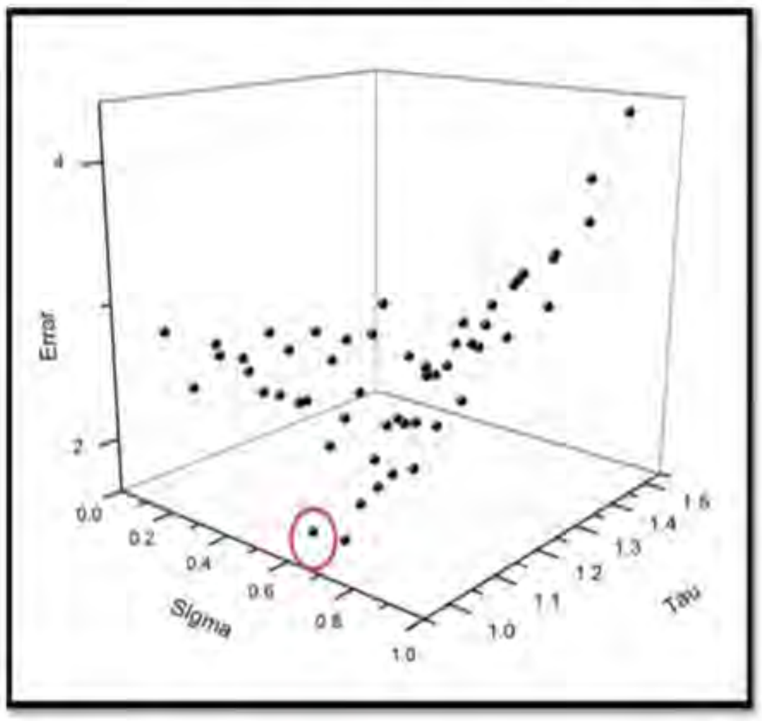
Table 8: Trial and Error of Adjusting Parameters in the Afternoon Based on Krauss' Car Following Model

vType	length, m	maxSpeed, (m/s)	minGap, (m)	guiWidth, m	max Accel (m/s2)	max Decel (m/s2)	sigma	tau (s)*
Car	5.00	27.78	1.60	2.00	4.50	7.00	0.20	1.10
Bus	15.00	27.78	1.90	3.00	3.00	5.50	0.20	1.10
Truck	10.00	27.78	1.90	3.00	3.00	5.50	0.20	1.10
Pickup, Leguna	6.00	25.00	1.70	2.3	3.00	5.50	0.20	1.10
Easy Bike	2.85	8.33	0.90	1.05	1.20	3.40	0.20	1.10
Tempu, Mahindra	2.85	13.5	1.10	2.2	2.05	4.10	0.20	1.10
Rickshaw	2.36	3.33	0.40	2.60	0.17	1.25	0.20	1.10

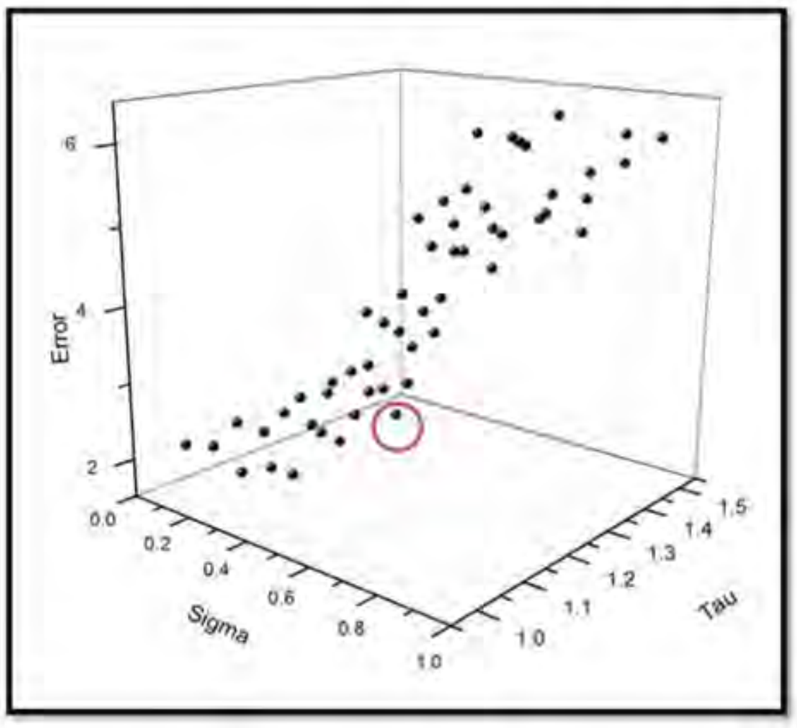
Source: Authors, 2015

In Table 7 and Table 8, the italic numbers are the values for the parameters for which there is no major impact on the simulation output. Bold numbers are the values of parameters sigma and tau which have major influence in the result of calibration and also optimum values for the model. According to Table 7 and 8, driver imperfection (sigma) and driver reaction time (tau) have been selected as parameters to estimate in the calibration process. RMSE have been used to estimate the optimal values for the parameters based on queue length, travel time and combination of queue length and travel time on the principle that optimal values of the parameters will lead to minimum RMSE. By using equation 3 this research calculated RMSE for four legs of the roundabout.

First, queue length data have been used to calculate RMSE value based on the sigma and tau parameters for both morning and afternoon. The minimum RMSE is shown in figure 4 and figure 5.



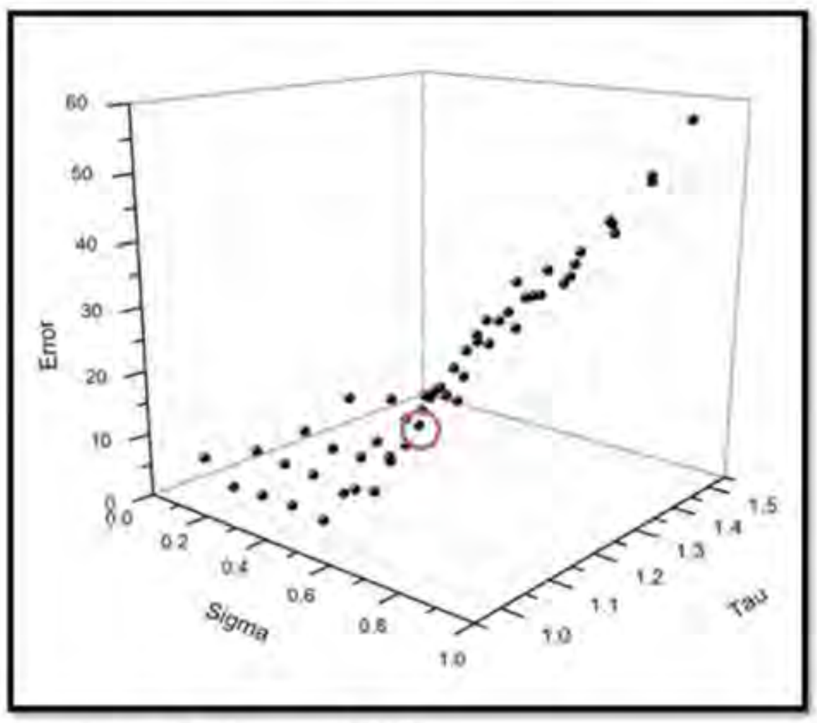
Source: Authors, 2015
Figure 4: RMSE of Queue in Morning



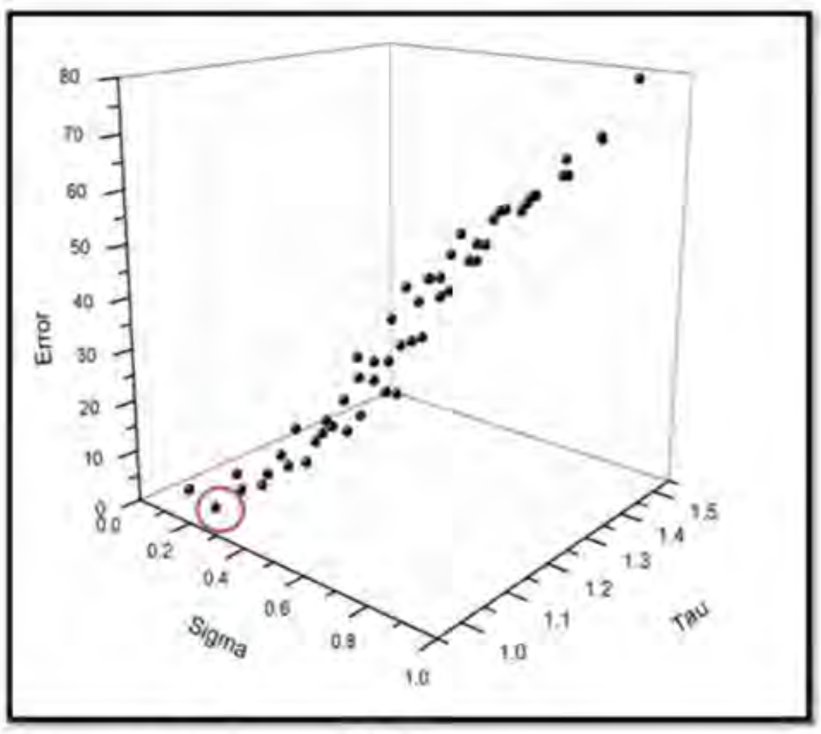
Source: Authors, 2015
Figure 5: RMSE of Queue in Afternoon

From figure 4 and figure 5, using queue length data minimum RMSE 1.72 in the morning is calculated when driver imperfection (sigma) value is 0.6 and driver's reaction time (tau) value is 1.0s. In the afternoon, the minimum RMSE 1.77 using queue length data is calculated for sigma value 0.2 and the tau value 1.4s.

Next, RMSE has been calculated using travel time data. Minimum RMSE of travel time 1.16 second has been calculated for sigma 0.2 and tau 1.4s for morning. In the afternoon, minimum RMSE is 0.77 second for sigma 0.2 and tau 1.0s. Minimum RMSE values of travel time are shown in figure 6 and figure 7.

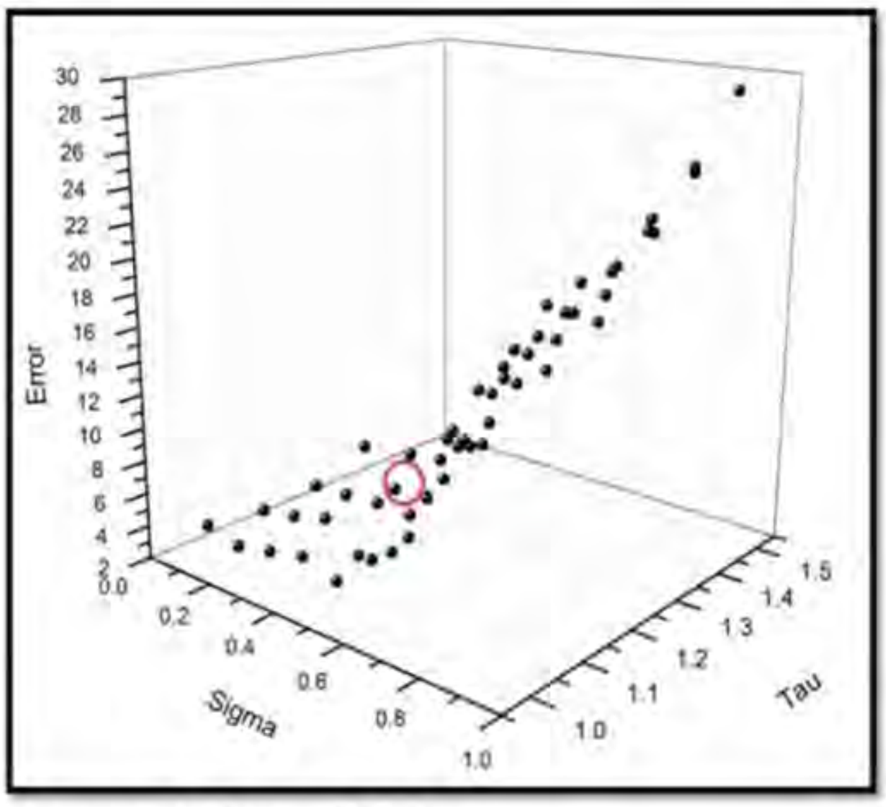


Source: Authors, 2015
Figure 6: RMSE of Travel Time in Morning



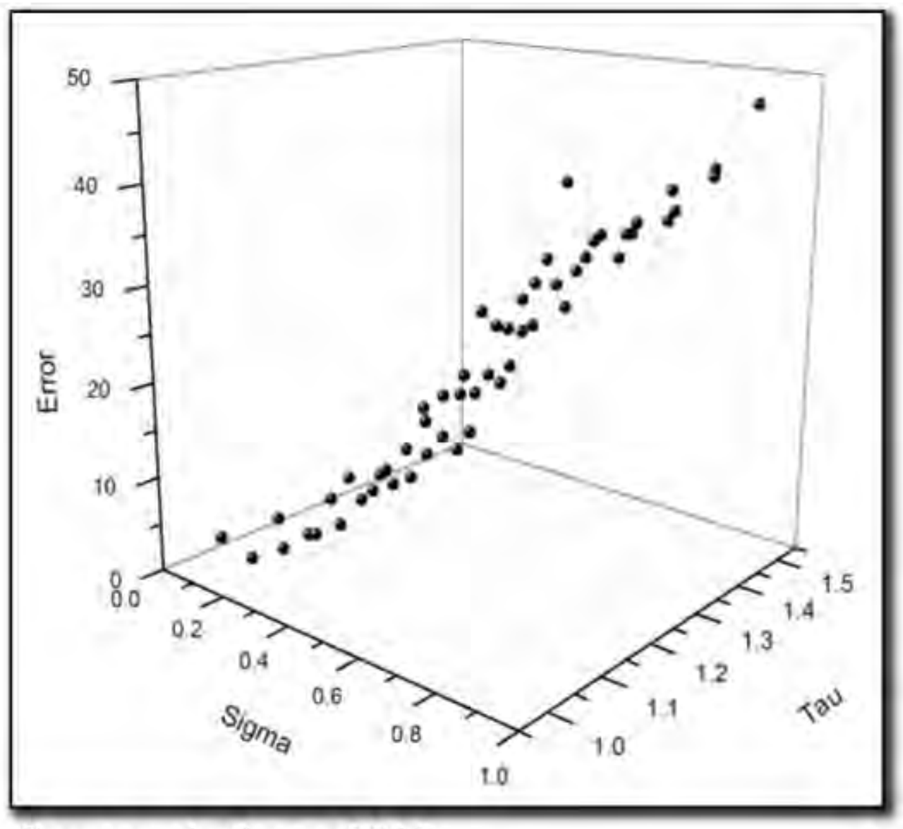
Source: Authors, 2015
Figure 7: RMSE of Travel Time in Afternoon

In the third method RMSE has been calculated combining RMSE of queue length and travel time. As two RMSE values have different units the unit for RMSE of travel time, which is second, has been converted to vehicle number using a conversion factor calculated from flow data.



Source: Authors, 2015

Figure 8: Combined RMSE of Queue length and Travel Time in the Morning



Source: Authors, 2015

Figure 9: Combined RMSE of Queue length and Travel Time in the Afternoon

From figure 8 and 9, the minimum combined RMSE in the morning is 2.80 for sigma 0.2 and tau 1.3s and the minimum combined RMSE in the afternoon is 2.56 for sigma 0.2 and tau 1.1s. A summary for all the minimum RMSE values is shown in Table 9 and Table 10.

Table 9: Minimum RMSE values in the Morning

No	Parameters		RMSE			Note
	sigma	tau	Queue (veh)	Travel Time (s)	Combination	
1	0.6	1.0	1.78	9.28	5.86	minimum RMSE of queue
2	0.2	1.3	2.31	1.12	2.80	minimum RMSE of travel time
3	0.2	1.3	2.31	1.12	2.80	minimum RMSE of combination

Source: Authors, 2015

Table 10: Minimum RMSE values in the Afternoon

No	Parameters		RMSE			Note
	sigma	tau	Queue (veh)	Travel Time (s)	Combination	
1	0.2	1.4	1.81	8.15	5.97	minimum RMSE of queue
2	0.2	1.0	2.29	0.71	2.68	minimum RMSE of travel time
3	0.2	1.1	2.02	1.05	2.56	minimum RMSE of combination

Source: Authors, 2015

To get the best values for the parameters to be used in the model to represent the real world measurement all minimum RMSE from the above tables have been validated.

4.3. Validation

To conclude that the calibrated model represents the real world the model needs to be validated. Validation has been done by T-test using travel time data.

Table 11: Validation of Parameters in the Morning

Leg	Measurement		Calibrated Model		Tstatistic	Validation	
	Average	Standard Deviation	Average	Standard Deviation		ttable	Conclusion
For parameters that resulted minimum RMSE of queue							
North	18.10	3.01	22.43	4.07	2.70	2.10	*Reject H0*
East	31.13	14.11	47.88	32.93	1.48	2.10	Not reject H0
South	22.97	7.02	28.12	3.03	2.13	2.10	*Reject H0*
West	17.17	2.97	18.14	2.31	0.82	2.10	Not reject H0
For parameters that resulted minimum RMSE of travel time							
North	18.10	3.01	19.07	2.23	0.82	2.10	Not reject H0
East	31.13	14.11	30.23	15.04	0.14	2.10	Not reject H0
South	22.97	7.02	25.21	2.17	0.96	2.10	Not reject H0
West	17.17	2.97	16.02	1.81	1.05	2.10	Not reject H0
For parameters that resulted minimum combined RMSE of queue and travel time							
North	18.10	3.01	19.52	2.21	1.20	2.10	Not reject H0
East	31.13	14.11	30.63	13.32	0.08	2.10	Not reject H0
South	22.97	7.02	25.31	3.05	0.97	2.10	Not reject H0
West	17.17	2.97	18.31	2.48	0.93	2.10	Not reject H0

Source: Authors, 2015

According to table 11, for morning minimum RMSE 1.12 of travel time and minimum combined RMSE 2.80 both are validated for all the four legs of the roundabout. An interesting finding is that both RMSE values are actually the same for sigma 0.2 and tau 1.3s. Generally combined RMSE gives more accuracy in calibrating simulation model based on car following model because both the queue length and travel time is very important in car following model. Considering all these, it can be concluded that the values of parameters that resulted in minimum combined RMSE 2.80 are optimal values for parameters driver imperfection (sigma) and driver reaction time (tau).

Table 12: Validation of parameters in the Afternoon

Leg	Measurement		Calibrated Model		Tstatistic	Validation	
	Average	Standard Deviation	Average	Standard Deviation		ttable	Conclusion
For parameters that resulted minimum RMSE of queue							
North	21.13	2.01	29.11	9.87	2.51	2.10	*Reject H0*
East	22.07	3.14	20.21	2.07	1.56	2.10	Not reject H0
South	20.33	4.95	22.78	0.91	1.54	2.10	Not reject H0
West	24.82	5.02	39.95	13.56	3.31	2.10	*Reject H0*

Table 12: Validation of parameters in the Afternoon (Continued)

For parameters that resulted minimum RMSE of travel time

North	21.13	2.01	22.71	6.39	0.75	2.10	Not reject H0
East	22.07	3.14	20.11	2.08	1.65	2.10	Not reject H0
South	20.33	4.95	18.79	1.35	0.99	2.10	Not reject H0
West	24.82	5.02	25.50	3.12	0.36	2.10	Not reject H0

For parameters that resulted minimum combined RMSE of queue and travel time

North	21.13	2.01	22.33	6.29	0.57	2.10	Not reject H0
East	22.07	3.14	19.83	2.17	1.86	2.10	Not reject H0
South	20.33	4.95	19.86	1.91	0.28	2.10	Not reject H0
West	24.82	5.02	26.55	5.21	0.76	2.10	Not reject H0

Source: Authors, 2015

According to table 12, for afternoon minimum RMSE 0.71 of travel time and minimum combined RMSE 2.56 both are validated for all the four legs of the roundabout. As stated earlier generally combined RMSE gives more accuracy in calibrating simulation model based on car following model because both the queue length and travel time is very important in car following model. For this reason though two RMSE values are validated, combined minimum RMSE 2.56 has been chosen to get the optimal value of parameters. Moreover, combined minimum RMSE 2.56 maintains a good balance between other two RMSE values keeping the value of parameter tau as median value of the three values of tau for all the RMSE values. Considering all these, it can be concluded that sigma 0.2 and tau 1.1s that resulted in combined minimum RMSE 2.56 are optimal values for parameters driver imperfection (sigma) and driver reaction time (tau) for the calibrated model.

5. DEVELOPING ALTERNATIVE SCENARIOS

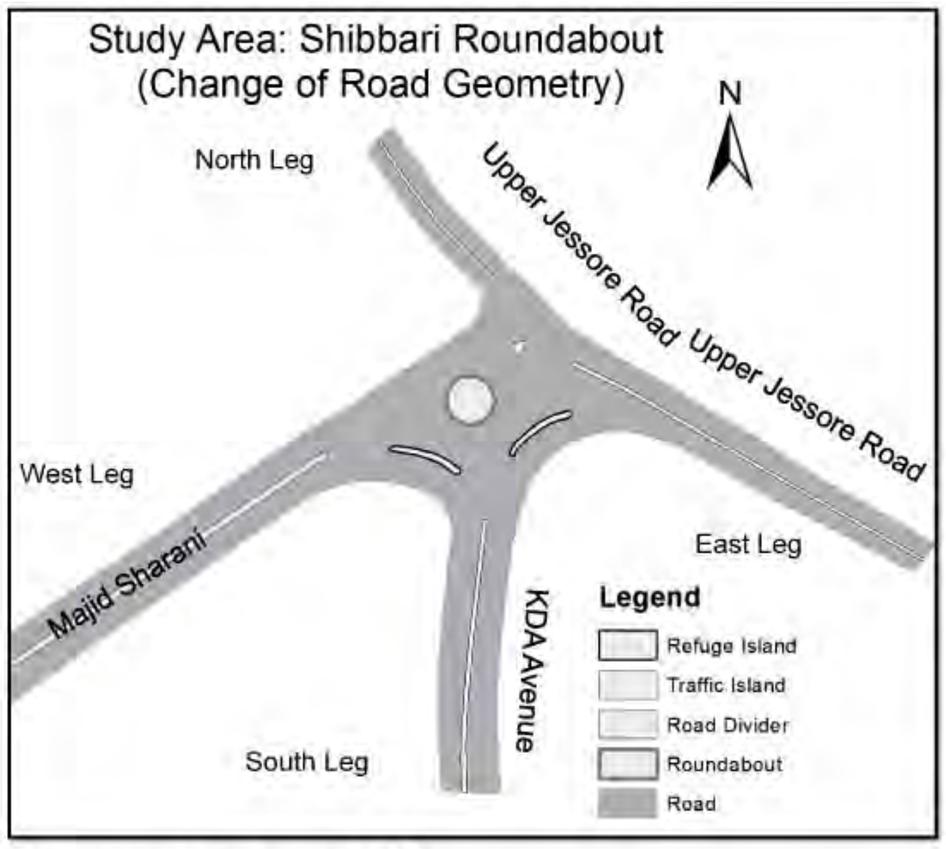
Using the final model which has been calibrated and validated two alternative scenarios have been developed to reduce the travel time and thereby improve the performance of the roundabout- one by changing geometric design and another by imposing traffic management measure at Shibbari roundabout.

5.1. Scenario 1: Change of Geometric Design

In the first scenario to change geometric design two additional lanes in the South (KDA Avenue) and West (Majid Sharani) sections for the entire roundabout has been built with expectation that the vehicles could turn right directly through additional lane from South to East and from West to South and this will reduce the travel time.

This situation is incorporated in the model by widening (with the width of an additional lane of 3.5 meters) the approach road from South to East and building additional lane with Refuge Island. The West to South will not require road widening; creating an additional lane with Refuge Island will create a direct pass.

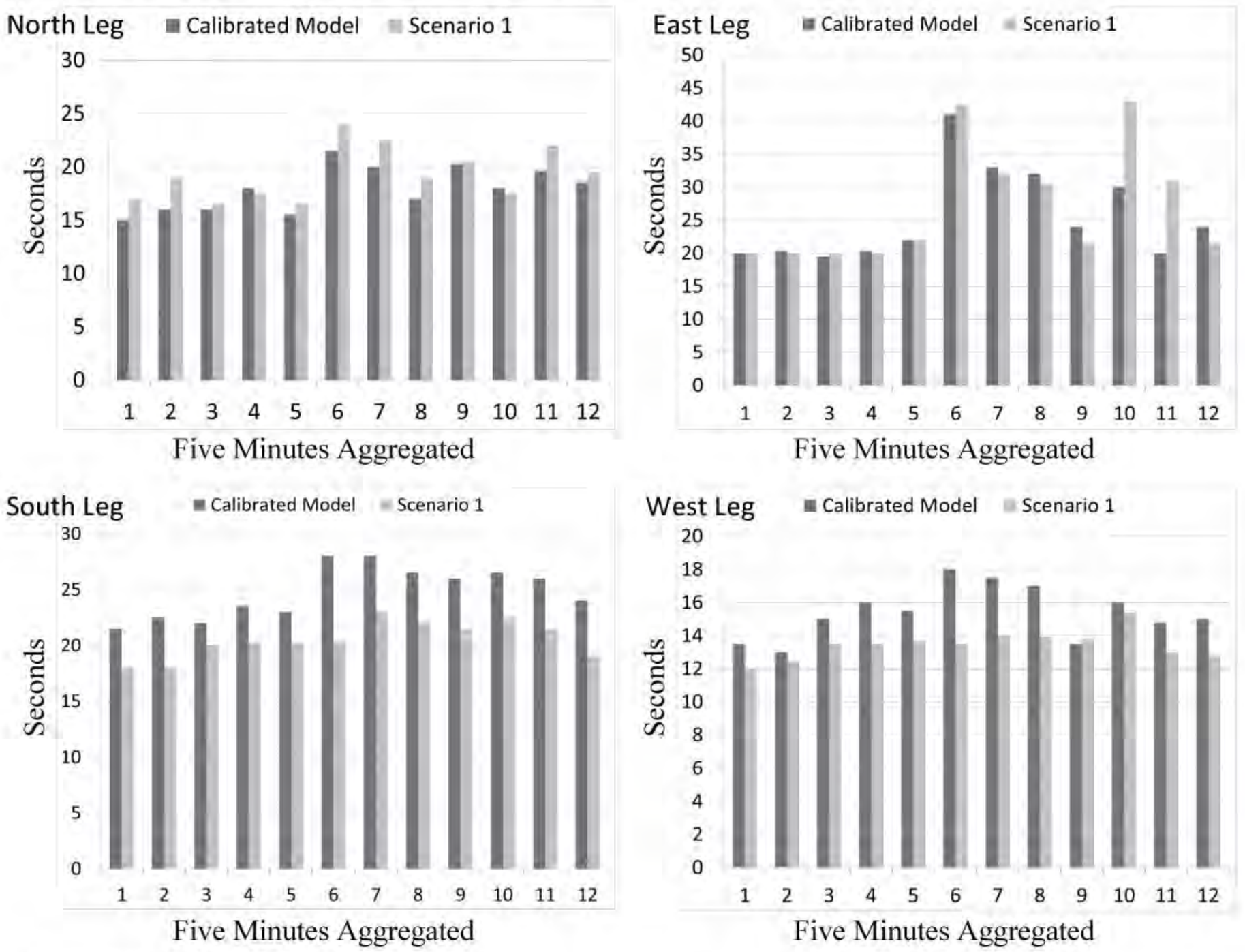
Refuge Island will separate the additional lane from original lane and it will be easier and faster for drivers either from West or South leg to turn right and pass the roundabout.



Source: Authors, 2015

Figure 10: Road Network for Scenario 1

After the modifications of the road geometry applied in the model, the results for each leg have been shown in Figure 11 for morning and Figure 12 for afternoon.

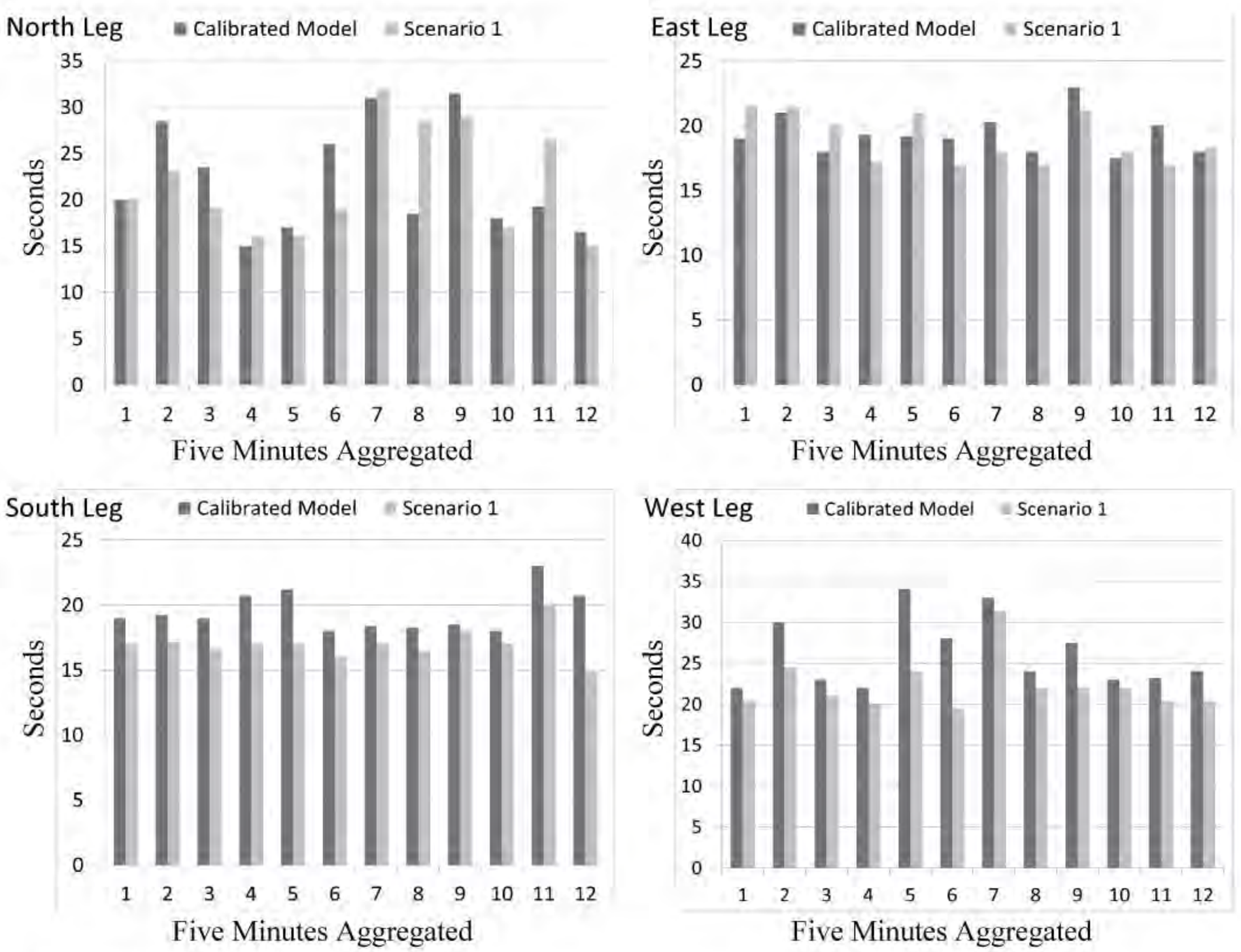


Source: Authors, 2015

Figure 11: Comparison of Travel Time between Calibrated Model and Scenario 1 in the Morning

From figure 11,

- Average travel time in one hour in the morning in scenario 1 has decreased for south leg and west leg.
- Decreasse of travel time is highest for South leg with 17.0035%, followed by West leg with 11.98%.
- The travel time at North leg and East leg is increased by 7.55% and 4.85% respectively.



Source: Authors, 2015

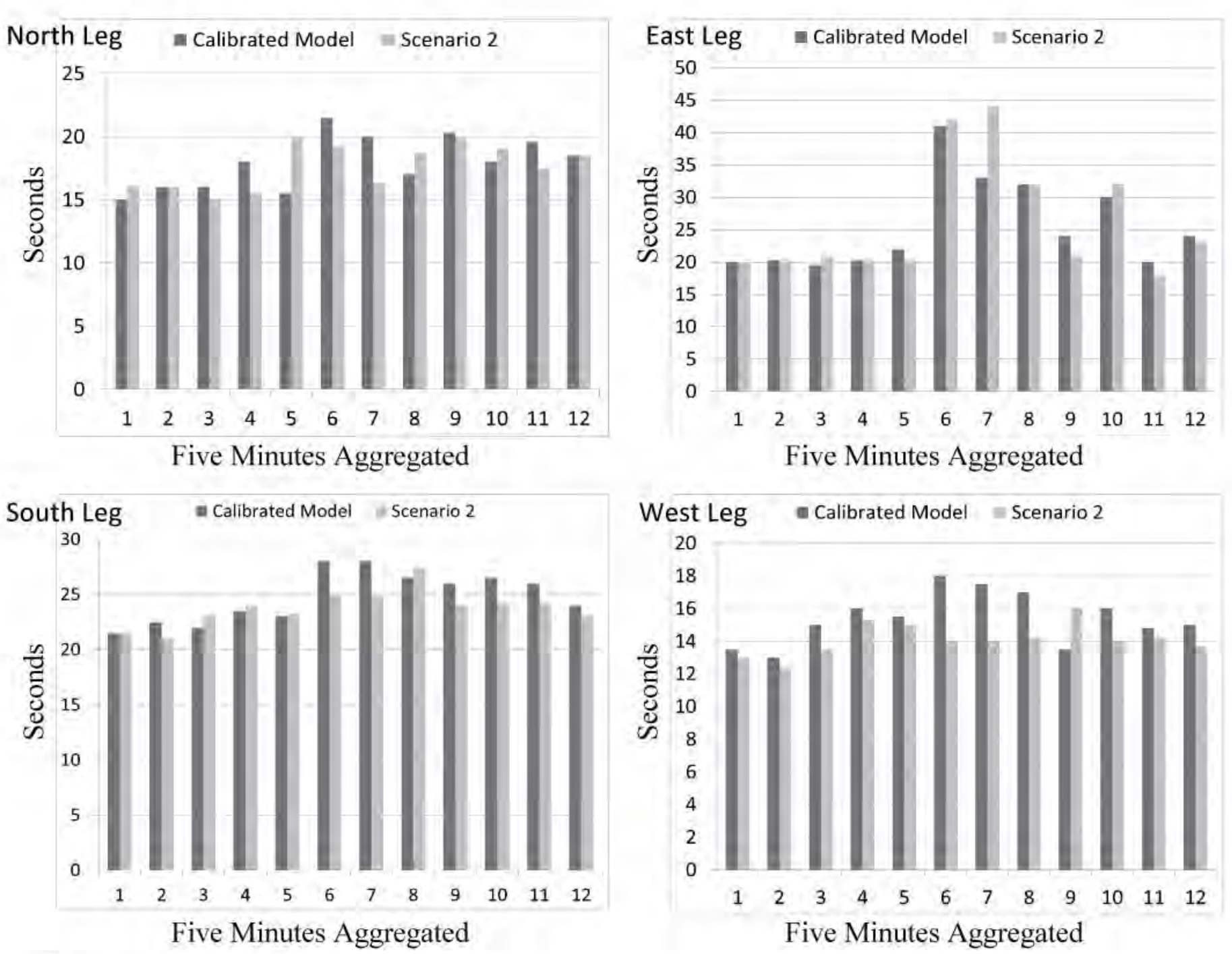
Figure 12: Comparison of Travel Time between Calibrated Model and Scenario 1 in Afternoon

From figure 12,

- In the afternoon travel time for three legs has been decreased comparing to morning model but the reduction is very small in the East section
- The percentages of travel time reduced are 1.62% for East,12.42% for South and 14.015% for the West leg
- Travel time at North leg is increased by 0.79%

5.2. Scenario 2: Traffic management

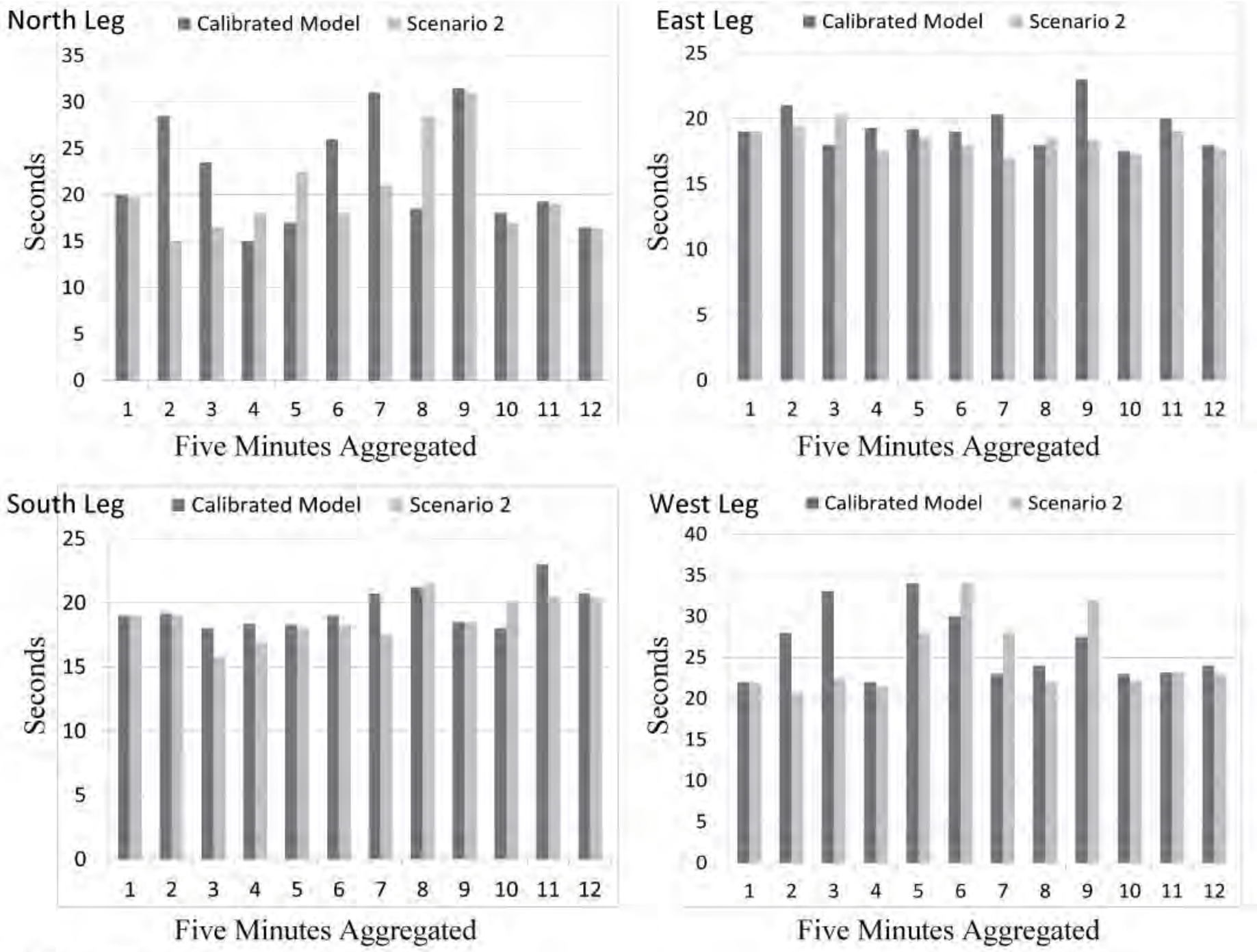
As an traffic management measure to increase the performance of Shibbari roundabout restriction on rickshaw and other non-motorized vehicles have been proposed. Restriction is applied to rickshaw and other non-motorized vehicles that passing Shibbari roundabout in peak hour with expectation that the travel time will be reduced.



Source: Authors, 2015

Figure 13: Comparison of Travel Time between Calibrated Model and Scenario 2 in the Morning

The results of simulation for the second scenario are shown in Figure 13 and Figure 14 in terms of changes in travel time. According to figure 13, for scenario 2 in the morning, travel time will be reduced in all four legs with 3.1% reduction in the North 3.1%, 4.5% in the East, 3.78% in the South and 7.95% in the East Leg.



Source: Authors, 2015

Figure 14: Comparison of Travel Time between Calibrated Model and Scenario 2 in the Afternoon

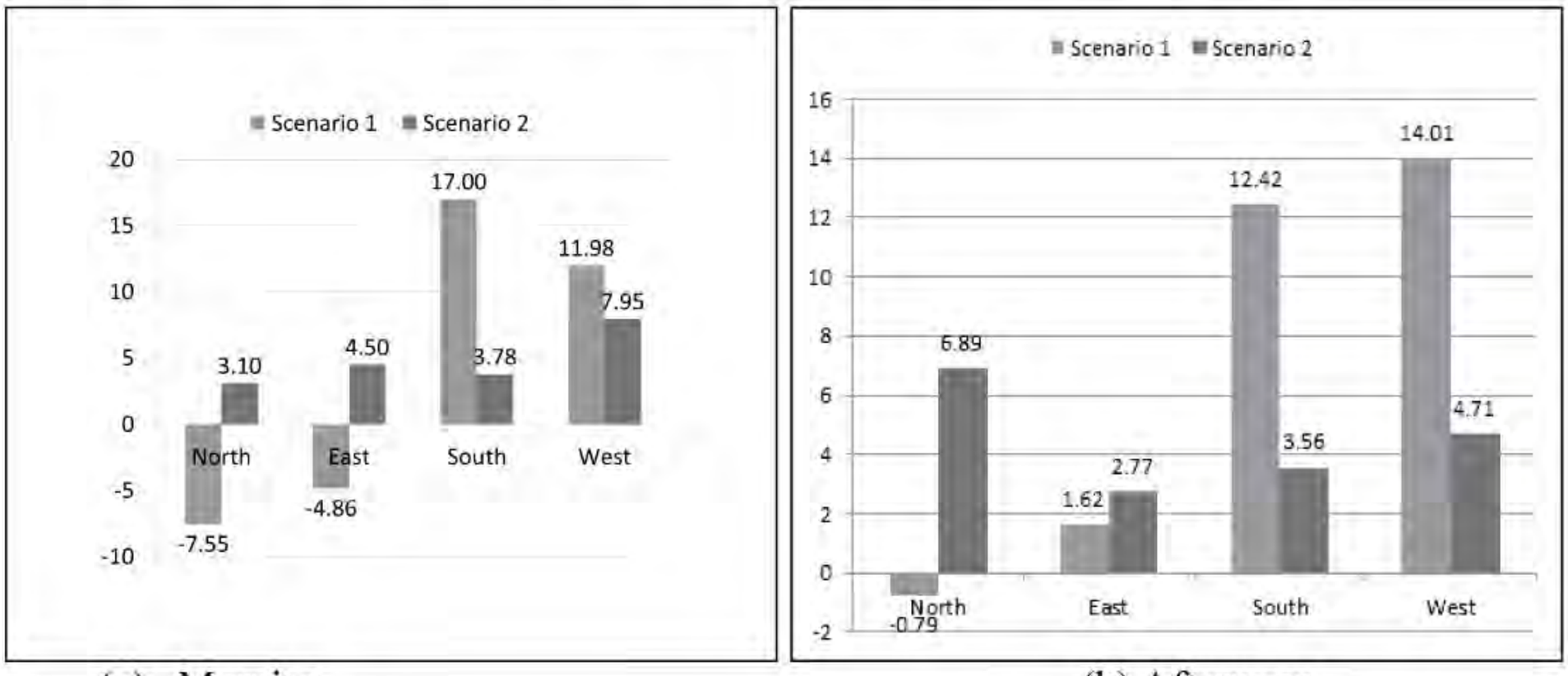
According to fogure 14, for scenario 2 in the afternoon, the travel time will be reduced in all Four legs with 6.89% reduction for the North, 2.77% for the East, 3.56% for the South and 4.71% for the West Leg.

6. FINDINGS

The results of the simulation shows that travel time has been decreased in both the two scenarios for increasing the performance of the roundabout.

In Scenario 1 due to changes of geomatric design the vehicles could turn right directly through additional lane from South to East and from West to South which reduces travel time. But the implementation of this scenario requires significant investment for construction activities to change the geometric design. Besides, decrease of travel time in two particular legs is accompanied by increase of travel time in other two legs because width of lane to pass the roundabout is decreasing and smooth running of vehicles on the two privileged legs hampered the running of vehicles on the other legs.

In scenario 2 the travel time is decreasing in all four legs. Though this scenario has disadvantage in term of less reduction of travel time in the South and West legs compared to scenario 1, but it is cheaper than the first scenario which requires significant investment to implement. Figure 15 shows the comparison of reduced travel time between Scenario 1 and Scenario 2.



(a) Morning (b) Afternoon

Source: Authors, 2015

Figure 15: The Comparison of Travel Time Reduced between Scenario 1 and Scenario 2

Now it can be concluded that travel time is reduced in both scenarios but the reduction in scenario 2 happens for all the four legs. Moreover, the scenario 2 is also the optimal scenario to be implemented because big investment is not required comparing to scenario 1.

7. CONCLUSION

While microscopic traffic simulation is quite a mature technology in the developed world, developing countries are still tyros in this world. Complex and inadequate road infrastructure, heterogenous mixture of traffic on the roads including both the motorized and non-motorized vehicles, lots of two wheelers on the roads make it dificult to simulate using theories like car following model. Still this research have shown great promise to use microscopic traffic simulation even in developing countries, even in cities like Khulna.

The claibrated model developed in this study gives acceptable accuracy and can be used to improve the performance of the roundabout. Both new strategies of managing traffic and change of road infrastructure can be evaluated before physical realization using this model to take the right decision. In settings like Shibbari rounadabout the parameters- driver imperfection (sigma) and driver's reaction time (tau) are the most significant parameters for calibrating the initial model. Of the two alternative scenarios simulated in this research scenario 2 shows better traffic performance at the roundabout while at lower cost. This way computer simulation models allow for testing alternative system designs under a controlled environment, before conducting operational tests and refining original designs. In this study, microscopic traffic simulation shows significant potentiality to be used as an essential tool in transportation planning and management.

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