Estimating Maximum Failure Rate For A Bus Rapid Transit Station

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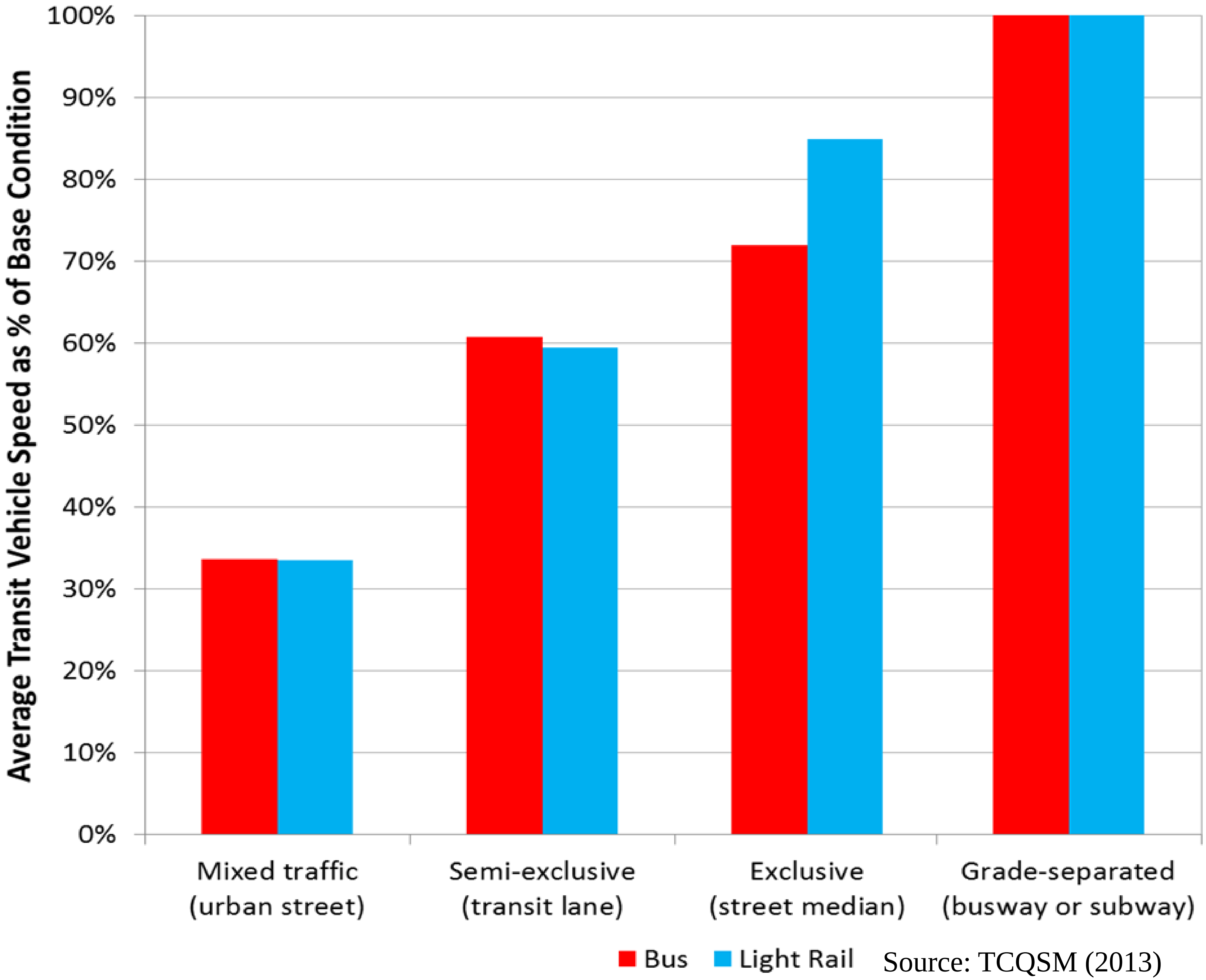
Contents

Introduction

- **Facility Type**



Source: TCQSM (2013)

Introduction

Transit Operation

Capacity

Why transit agencies should be concerned with capacity?

- Managing Passenger loads
- Planning for the future
- Analyzing the operations of the major corridors
- Transportation System Management

Speed

Why transit agencies should be concerned with Speed?

- More competitive the speed more attractive the transit service more is the ridership
- If speed can be increased on a corridor then the travel time could be saved and there is chance of unit increase in frequency

Reliability

Why transit agencies should be concerned with reliability?

- Unreliable operations on frequent service transit lines can result in vehicle bunching and more passenger experiencing crowd on-board

Need of the Study

1. There is a need to identify various scenarios of boarding and alighting in which BLT should be included as a component of dwell time.
2. A BLT value for two loading area BRT station is needed to estimate dwell time.
3. A maximum failure rate value for a BRT Station is needed to estimate the operating margin. The literature reported the maximum FR for only conventional bus transit stops.

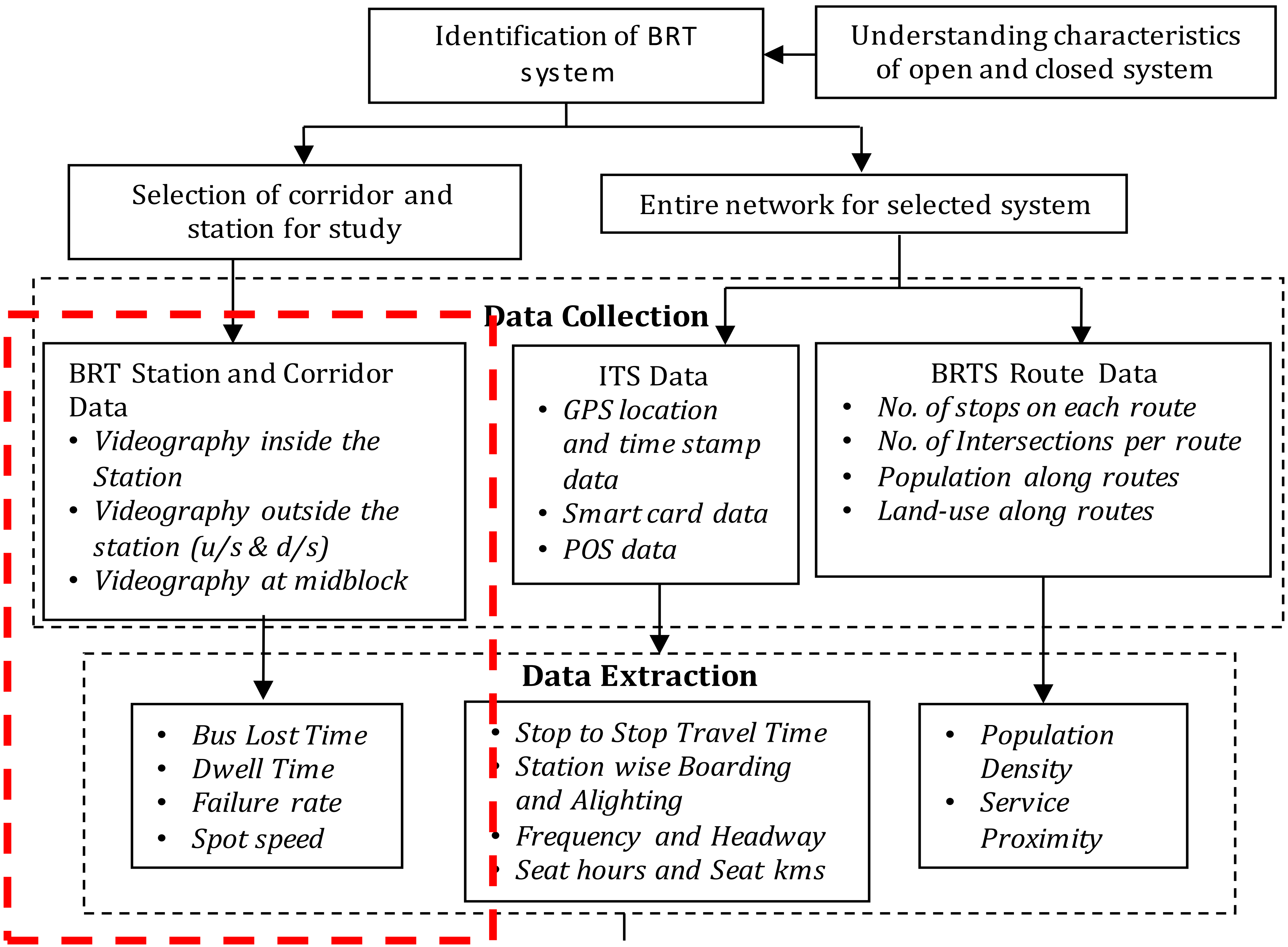
Research Scope

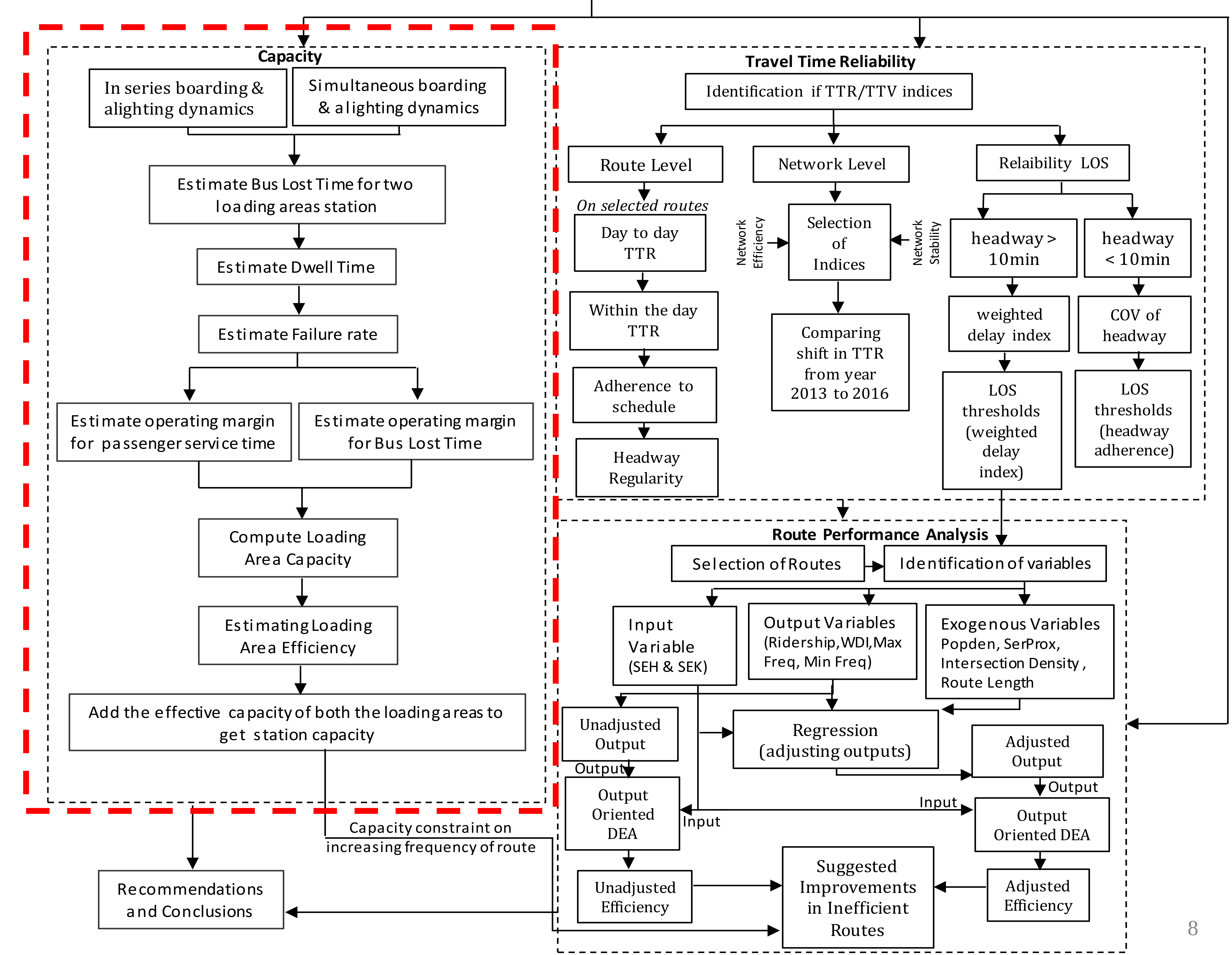
1. Research will provide guidance and is relevant to transit agencies for accurate assessment of corridor capacity and travel time reliability
2. Agencies will be able to understand in detail the considerations to be made for both future planning and improving the present operation of the BRTS.

Research Objectives

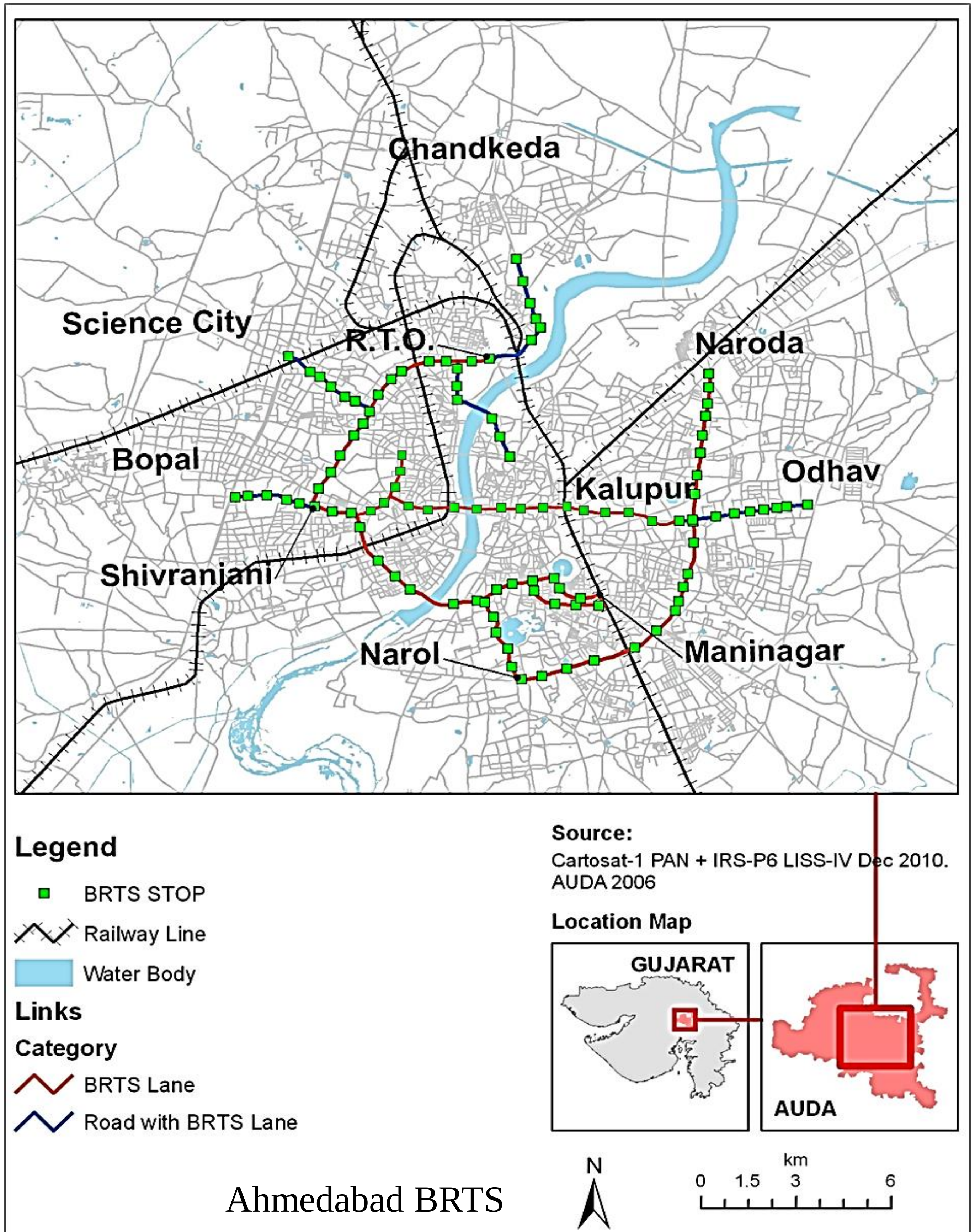
1. To estimate bus lost time and maximum failure rate for a two loading area Bus Rapid Transit station.
2. To develop a Bus Rapid Transit station capacity model.

Methodology




Capacity
In series boarding & alighting dynamics
Simultaneous boarding & alighting dynamics
Estimate Bus Lost Time for two loading areas station
Estimate Dwell Time
Estimate Failure rate
Estimate operating margin for passenger service time
Estimate operating margin for Bus Lost Time
Compute Loading Area Capacity
Estimating Loading Area Efficiency
Add the effective capacity of both the loading areas to get station capacity
Travel Time Reliability
Identification if TTR/TTV indices
Route Level
Network Level
Reliability LOS
On selected routes
Day to day TTR
Within the day TTR
Adherence to schedule
Headway Regularity
Network Efficiency
Selection of Indices
Network Stability
Comparing shift in TTR from year 2013 to 2016
headway > 10min
headway < 10min
weighted delay index
COV of headway
LOS thresholds (weighted delay index)
LOS thresholds (headway adherence)
Route Performance Analysis
Selection of Routes
Identification of variables
Input Variable (SEH & SEK)
Output Variables (Ridership, WDI, Max Freq, Min Freq)
Exogenous Variables Popden, SerProx, Intersection Density, Route Length
Unadjusted Output
Regression (adjusting outputs)
Adjusted Output
Output
Output Oriented DEA
Input
Output
Input
Output Oriented DEA
Unadjusted Efficiency
Suggested Improvements in Inefficient Routes
Adjusted Efficiency
Capacity constraint on increasing frequency of route
Recommendations and Conclusions

Ahmedabad BRTS



Ahmedabad BRTS

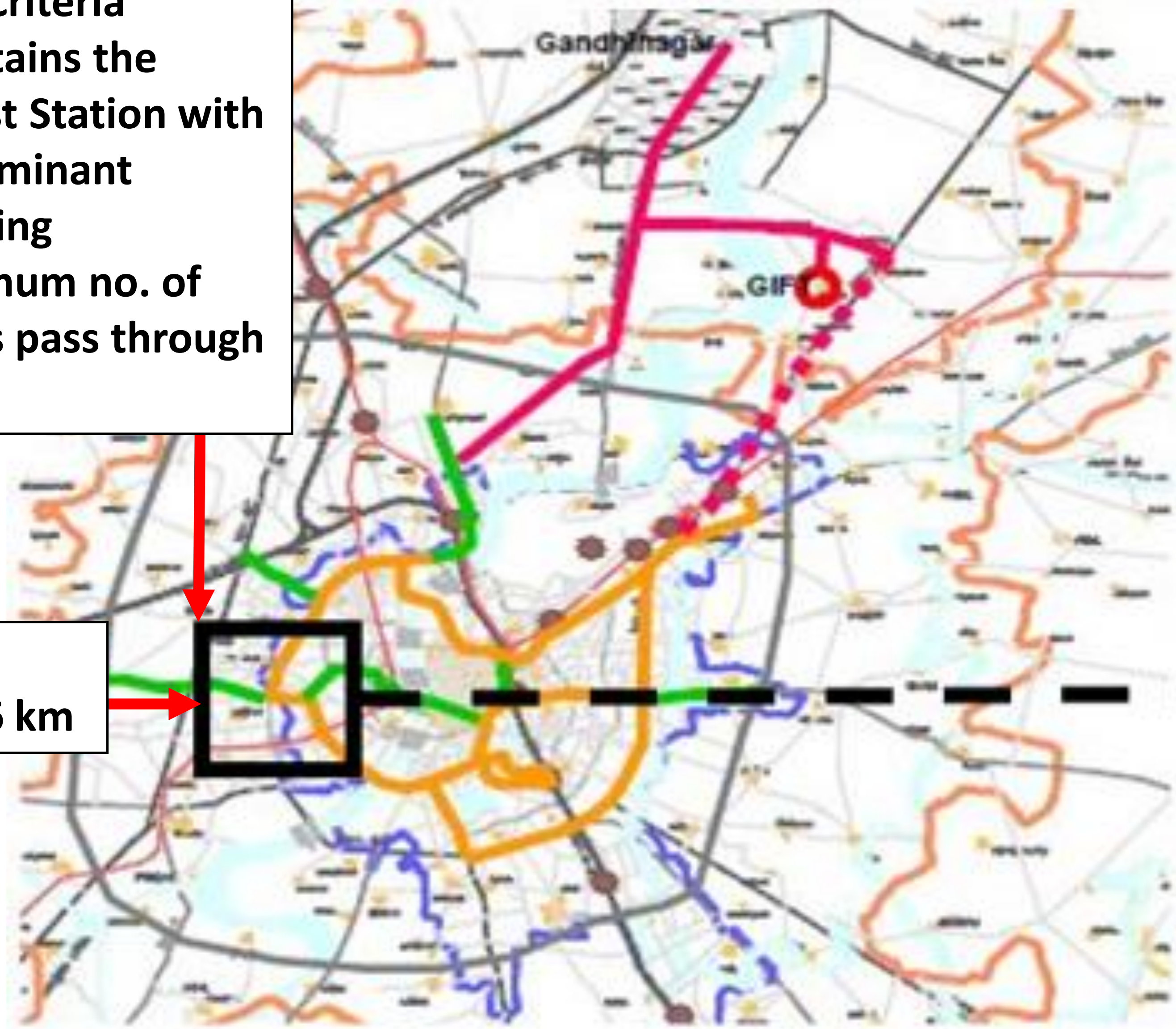
Ahmedabad BRTS	
Network Length	88 kms
No. of Stations	136
No. of Routes	12
Year Started	2009
Total Ridership	0.13 Millions per day

Selection of BRT Corridor and Station

Selection Criteria

1. It contains the busiest Station with predominant boarding
2. Maximum no. of routes pass through it.

Corridor Length 4.6 km



Shivranjani BRTS Stop

Shivranjani BRTS Station

BRTS Capacity

TRANSIT CAPACITY

3 MAJOR ELEMENTS OF BUS RAPID TRANSIT SYSTEM

MID BLOCK / ROADWAY

ROAD INTERSECTIONS

BUS STOPS

CAPACITY OF ROAD CORRIDOR > CAPACITY OF ROAD INTERSECTIONS > CAPACITY OF BUS STOPS

Sources of Bus Delay Associated with Bus Stops

1. Boarding lost time
   - Waiting for passengers to reach the bus

2. Passenger service time (dwell time)
   - Opening the doors, boarding and alighting passengers, and closing the doors

3. Bus stop failure
   - Waiting for other buses to clear the stop

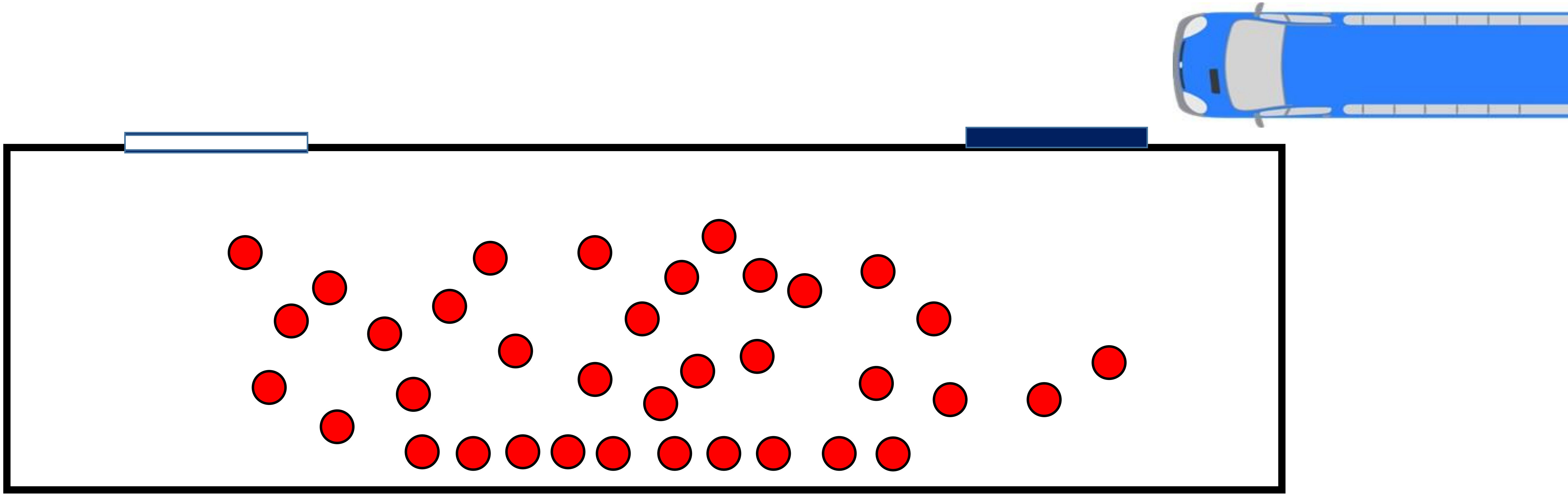
4. Traffic signal (traffic control) delay
   - Waiting for the signal to turn green, or other traffic control delay

Modelling BRTS Station Operation Parameters

Dwell Time Evolution

Authors/ Manual	Equation
Levinson 1983	$\mathbf{DT} = \mathbf{tN} + \boldsymbol{t_{oc}}$
Guenthner and Sinha (1983)	$\frac{\boldsymbol{DT}}{\boldsymbol{Total}} = 5.0 - \mathbf{1.2ln(Total)}$
TCQSM (2003)	$\mathbf{DT} = \boldsymbol{P_a t_a} + \boldsymbol{P_b t_b} + \boldsymbol{t_{oc}}$
Sun et al. 2014	$\mathbf{DT} = \boldsymbol{max}\{\boldsymbol{P_a t_a}, \boldsymbol{P_b t_b}\} + \boldsymbol{t_{oc}}$
TCQSM (2013)	$\mathbf{DT} = \mathbf{P_a t_a} + \mathbf{P_b t_b} + \mathbf{t_{oc}} + \mathbf{BLT}$

WHAT IS BUS LOST TIME (BLT) ?

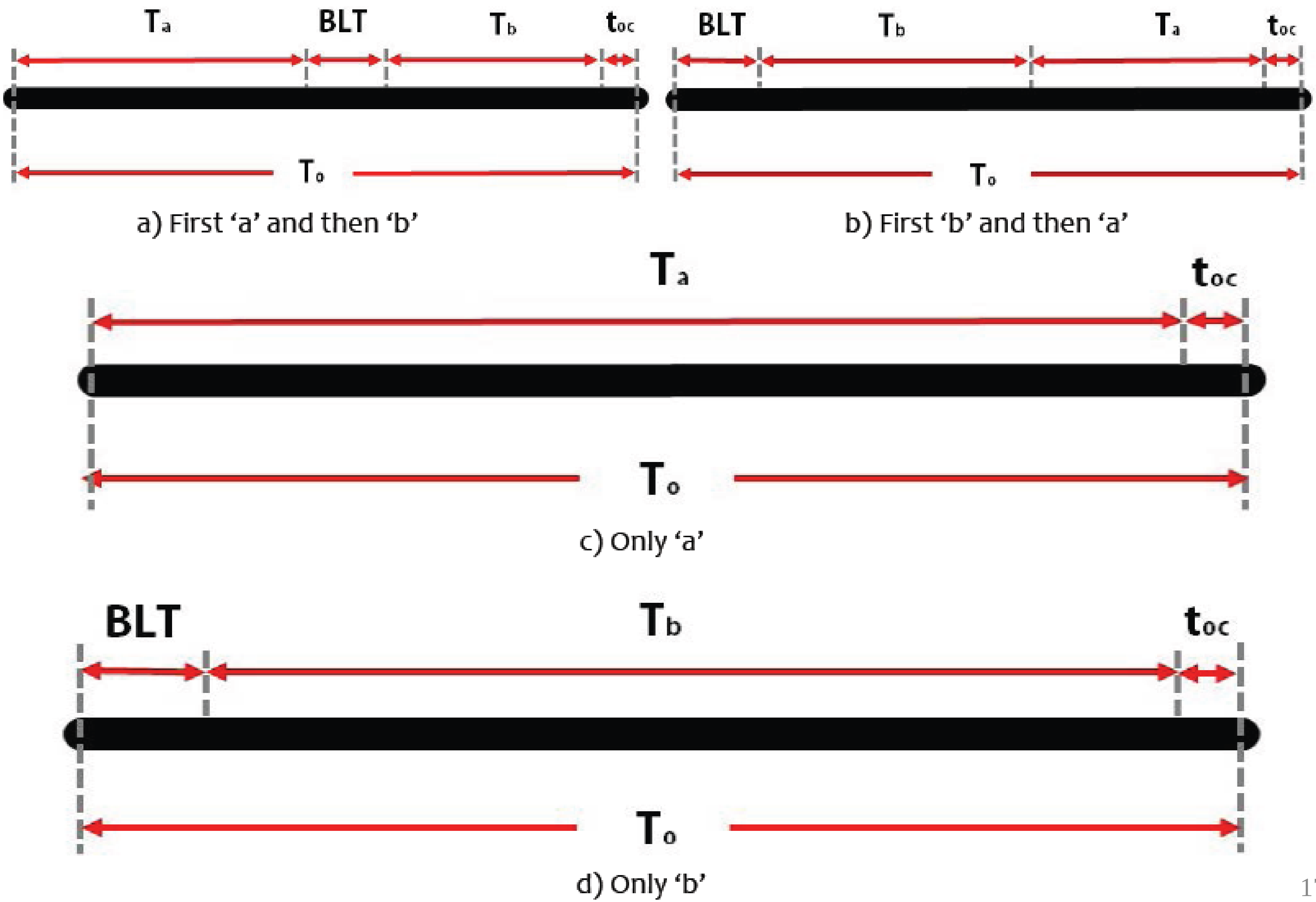


Bus lost time is the time lost by a bus between when it stops and the first passenger boards"

- TCQSM (2013)

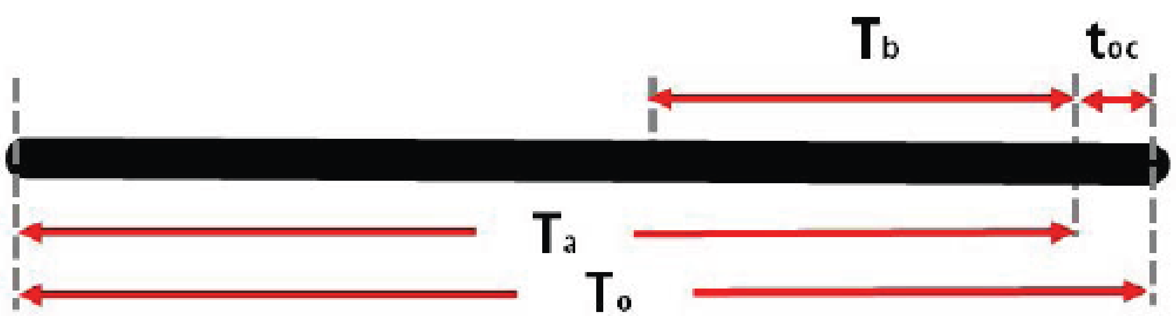
BLT Dynamics

Boarding (B) and Alighting (A) occurring in series

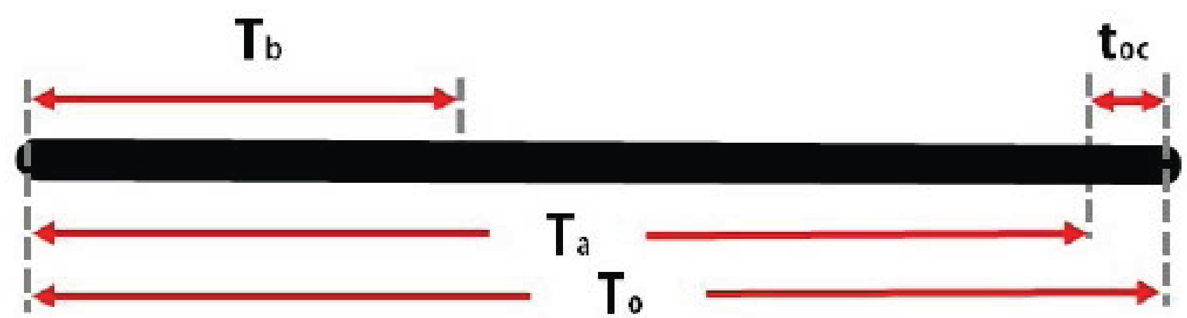


BLT Dynamics

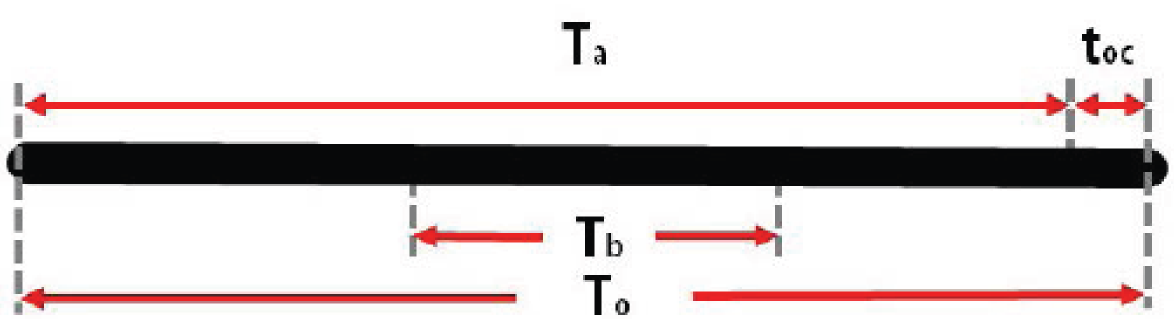
Boarding (B) and Alighting (A) occurring Simultaneously



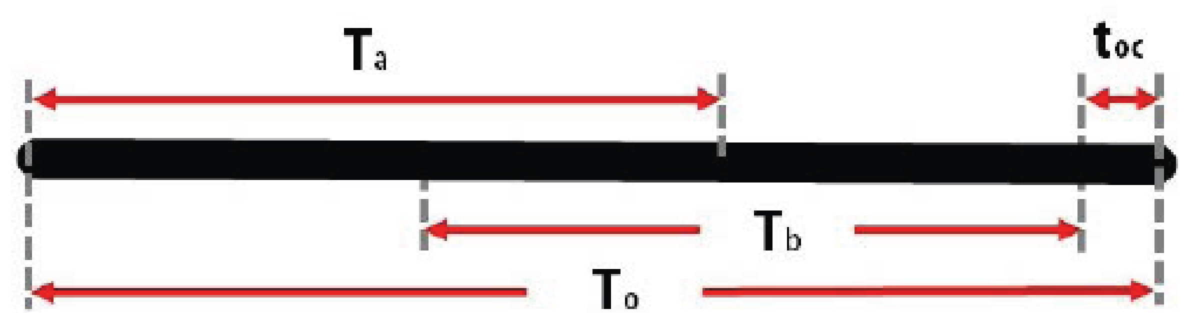
a) First A starts and then B starts in between and ends with A



b) A starts with B and ends after B



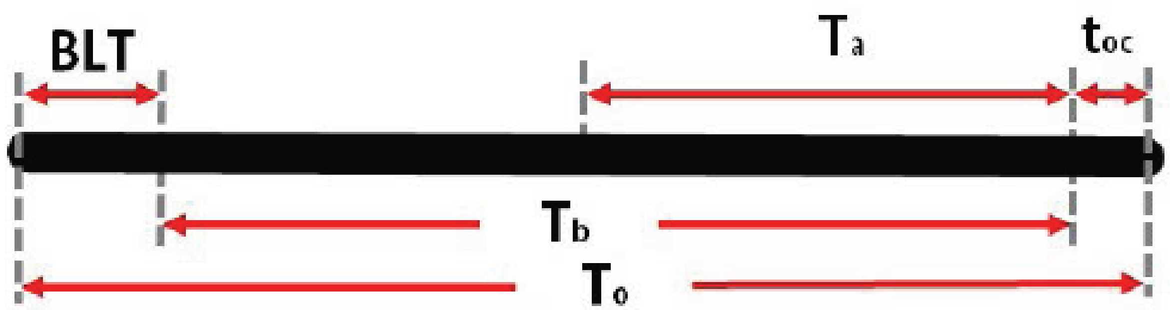
c) A starts before and ends after B



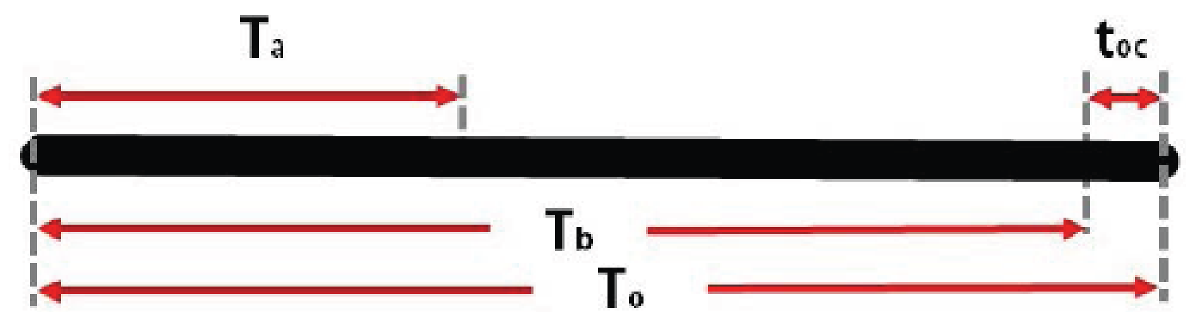
d) A starts before B and ends before B

BLT Dynamics

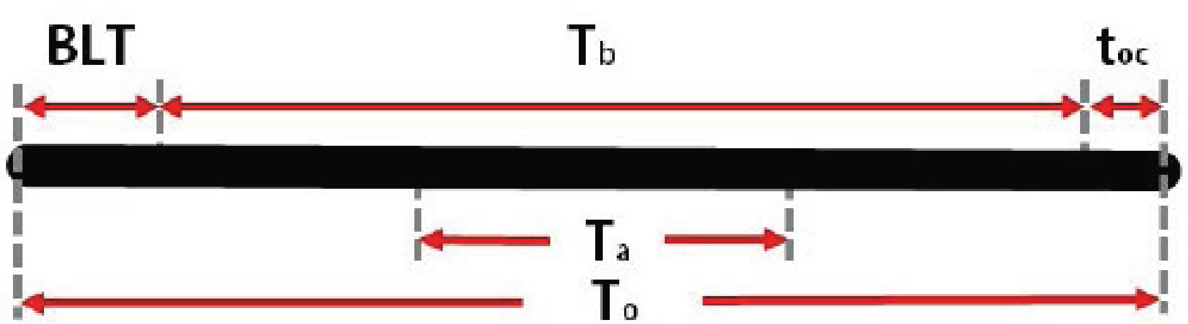
Boarding (B) and Alighting (A) occurring Simultaneously



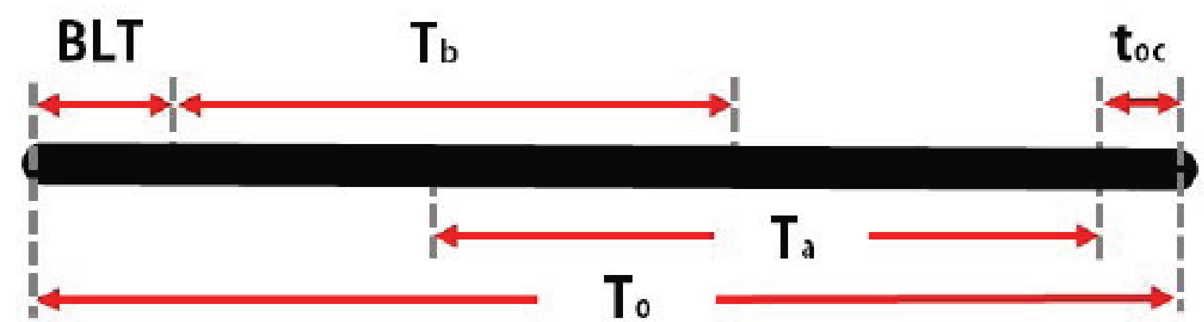
e) First B starts and then A starts in between and ends with B



f) B starts with A and ends after A



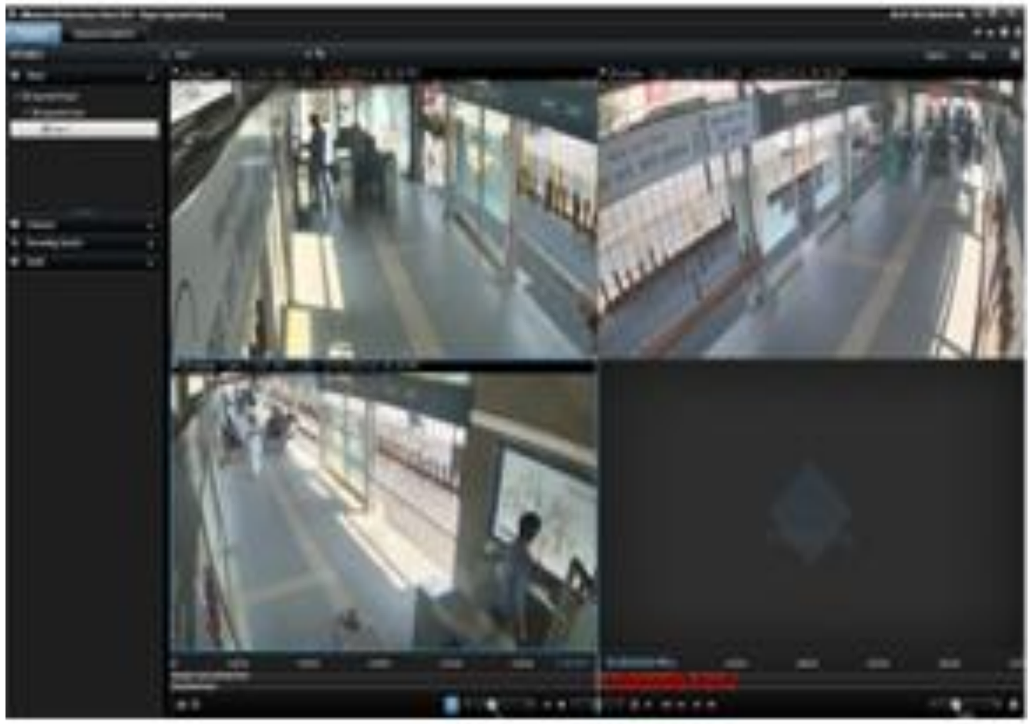
g) B starts before A and ends after A



h) B starts before A and ends before B

Data extracted from the video:

- Time when the bus comes to a complete stop
- Bus door opening time stamp
- Time when the first and the last passenger boards and alights the bus
- Number of passengers boarding and alighting
- Time taken by the first passenger to board the bus
- Bus door closing time stamp



Rule of Thumb for Considering BLT

It was comprehended from the observed data that in all the scenarios in which BLT was occurring, 94 % of then had predominant boarding passenger, as explained below:

1. **Only boarding passenger (no passenger alighting)**
2. **Number of passenger boarding ≥ ½ of Number of passenger alighting**

For all other scenarios in which BLT was not occurring, 91 % of it had either critical alighting or number of boarding was equal to number of alighting.

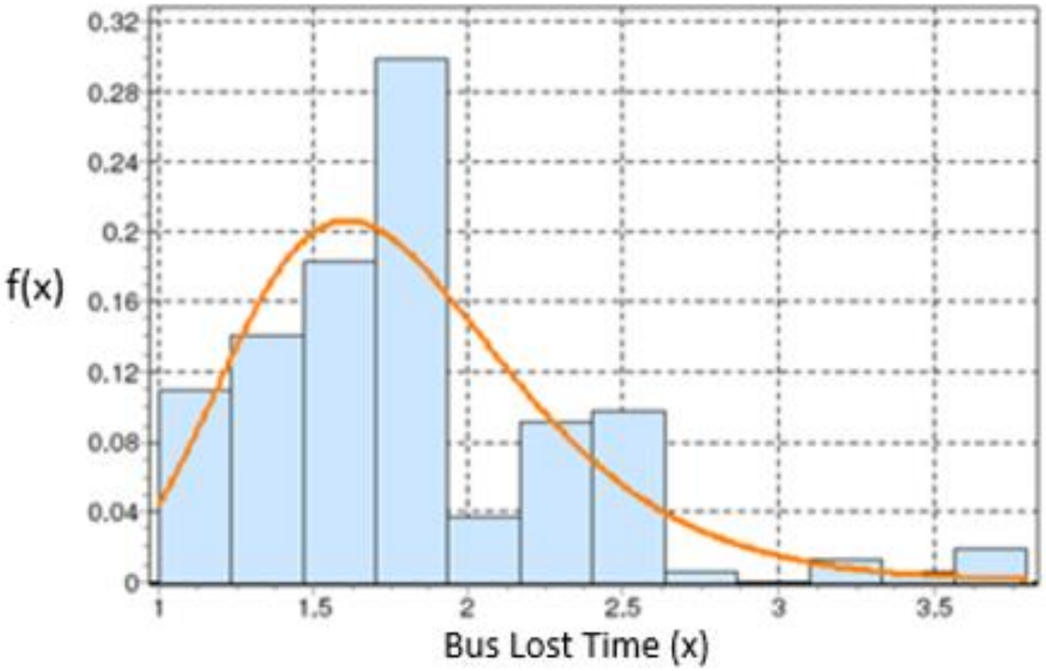
Therefore, we can add BLT to the dwell time data of stations where boarding is predominant.

Modified Definition of Bus Lost Time

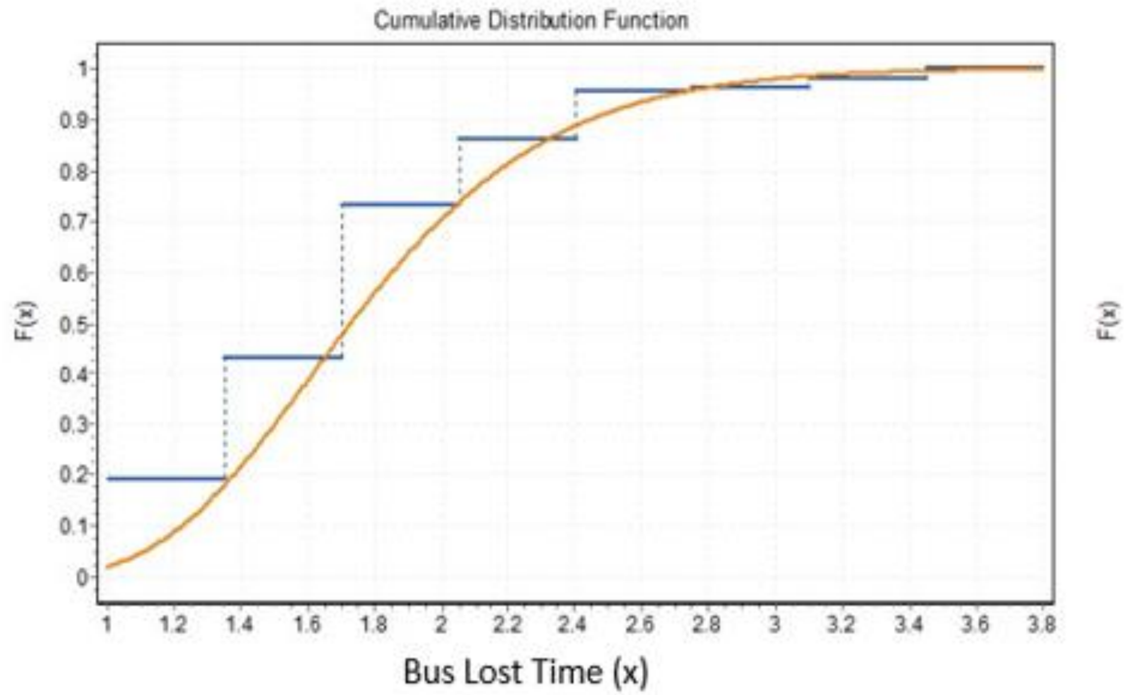
Bus Lost Time is the time lost by a bus between when it stops and the first passenger boards, given that, this time does not overlap with the alighting time and bus door opening time.

Estimating Bus Lost Time for 2 Loading Area For Ahmedabad BRT Station

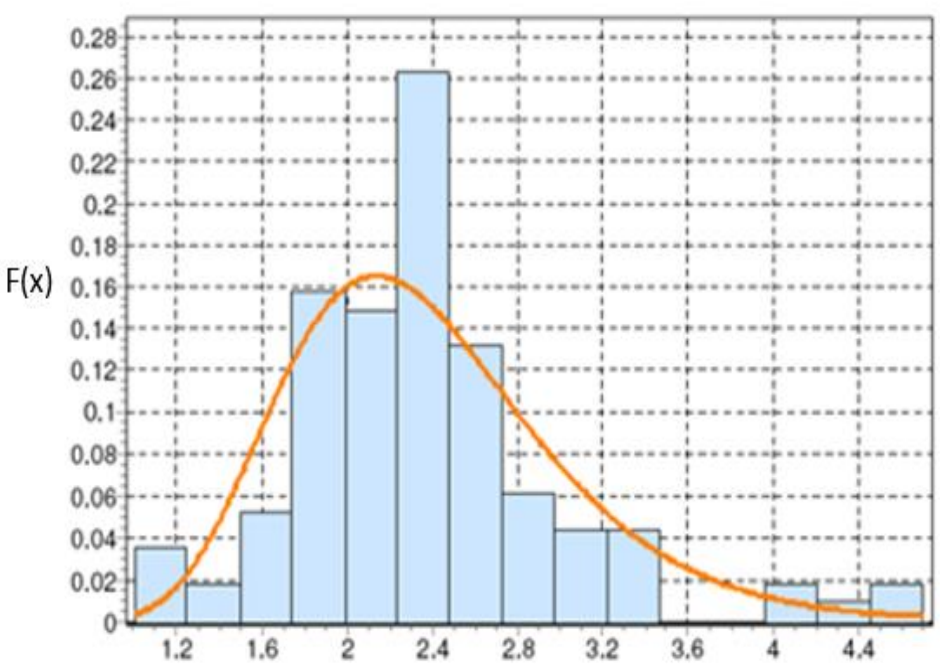
Fitted distribution and cumulative probability distribution of BLT for LA1 and LA2



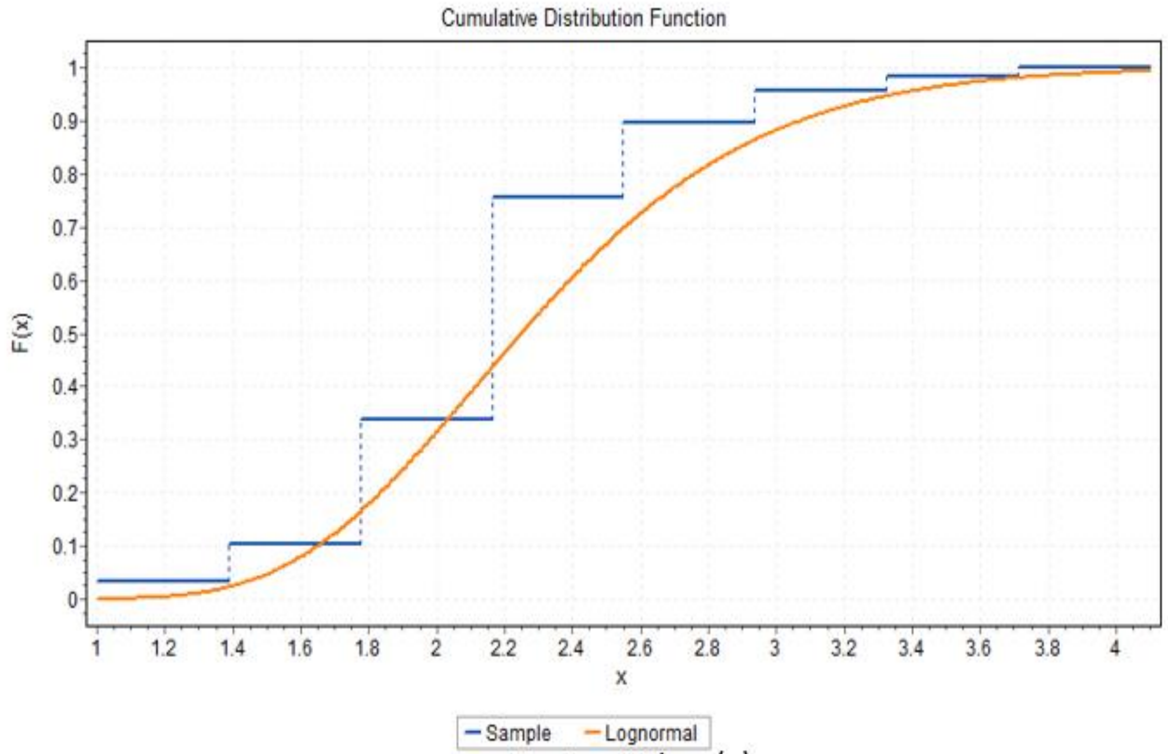
a) BLT Distribution Loading Area 1



b) Cumulative Distribution Curve for Loading Area 1



a) BLT Distribution of Loading Area 2



b) Cumulative Distribution Curve for Loading Area 2

Descriptive Statistics of Bus Lost Time (BLT)

Loading Area		BLT (6:00 -23:00)		BLT Morning peak (10:00-11:00)		BLT Off peak (14:00-15:00)		BLT Evening Peak (18:00-19:00)	
		Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated
LA1	Sample Size	212	212	35	35	23	23	33	33
	Mean(sec)	1.8	1.8	1.2	1.1	2.0	2.0	1.7	1.7
	85thpercentile (sec)	2.1	2.3	1.3	1.5	2.3	2.4	2.0	2.0
	Std dev (sec)	0.6	0.5	0.5	0.5	0.5	0.4	0.2	0.2
LA 2	Sample Size	189	189	26	26	22	22	28	28
	Mean (sec)	2.4	2.3	1.5	1.5	2.6	2.6	2.2	2.2
	85thpercentile(sec)	2.7	3.0	1.7	1.9	3.2	3.1	2.6	2.8
	Std dev(sec)	0.6	0.6	0.2	0.1	0.4	0.4	0.5	0.5

Importance of BLT

Lost Time	Average Bus Dwell Time(s)	
	LA-1	LA-2
Without BLT	14.8	16.7
Including BLT	17.1	19.7
% Change	15.5%	15.2%

Comparing BLT values for different geometric designs

1. Mater Hill Busway Station, Brisbane, Australia			
	LA -1 (sec)	LA-2 (sec)	LA-3 (sec)
BLT(3 loading area)	7.2	4.5	8.7
2. Shivranjini BRT station, Ahmedabad, India			
BLT(2 loading area)	2.3	3.0	

Loading Area Capacity

(3,600 s/h) × (% of time traffic control allows bus to enter/leave stop)

↓

$$Loading\ Area\ Capacity = \frac{Seconds\ in\ one\ hour\ available\ for\ bus\ movements}{Seconds\ that\ the\ bus\ occupies\ the\ stop}$$

↑

(Portion of dwell on green) +
(Clearance time while a bus travels its own length when leaving) +
(Allowance for particularly long dwells)

Model for Estimating Capacity of Loading Area (HCM, TCQSM)

$$B_n = \frac{3600\,(g/c)}{t_c + DT_n\,(g/c) + zC_v(DT_n)}$$

B_n = capacity of n[th] loading area (bus/hr)

3600 = number of seconds in one hour

g/C = green time ratio

Z = standard normal variable corresponding to a desired failure rate

C_v = Coefficient of variation of dwell time

Operating Margin

$$t_{om} = Z c_v t_d$$

Maximum amount of time that an individual bus dwell time can exceed the average dwell time without creating the likelihood of a bus stop failure

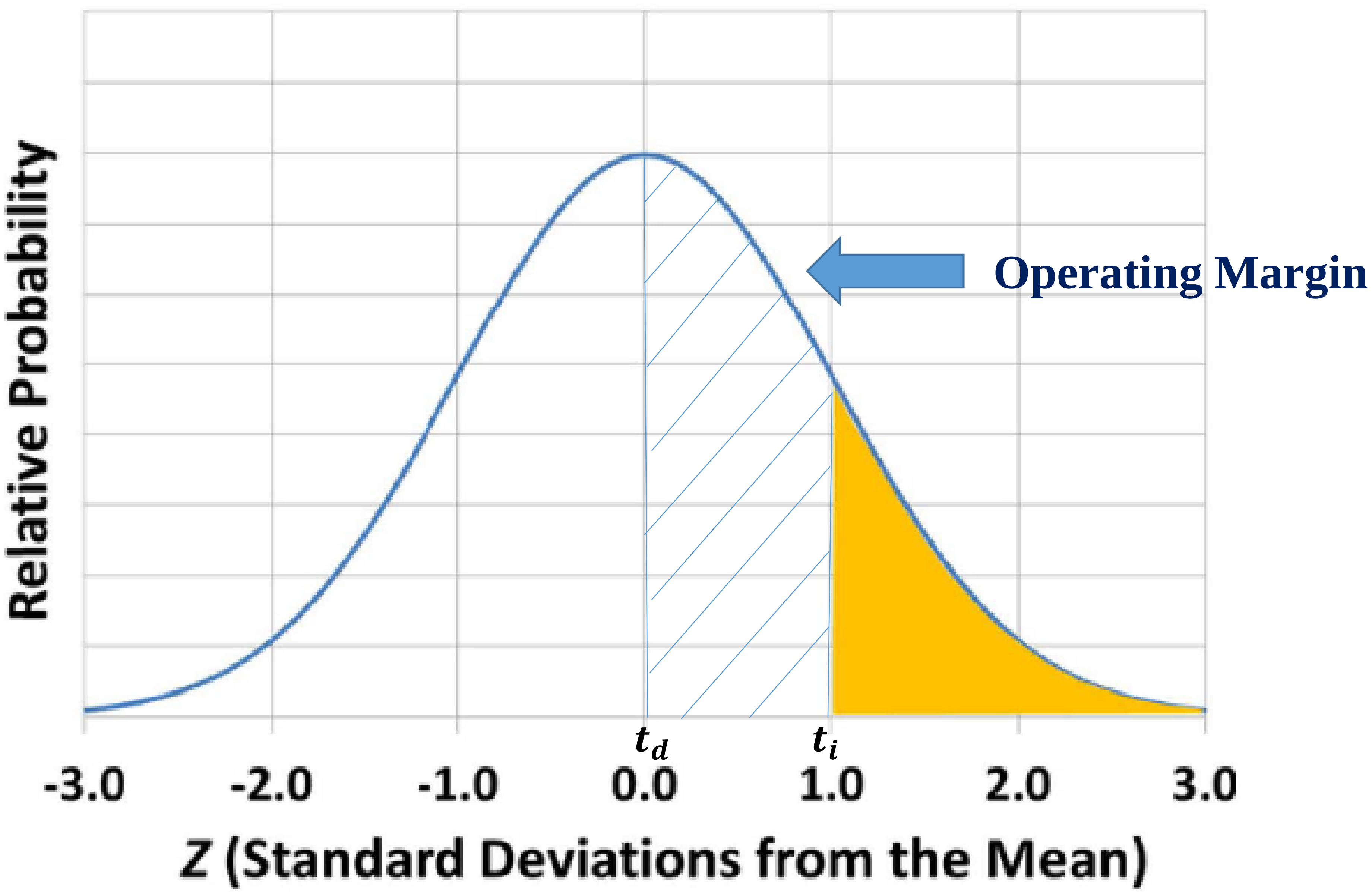
What is Failure Rate ?

"It is defined as the percentage of buses that arrive at the bus stop to find all available loading areas already occupied"

- TCQSM(2013)

- **The bus must wait in the busway until space becomes available**
- **Slows down the bus and creates schedule reliability issues**
- **Delay can range up to the other bus' dwell and traffic control delay times**

Operating Margin



$$Z = \frac{t_i - t_d}{s}$$

$$Z = \frac{t_{om}}{s}$$

$$t_{om} = sZ$$

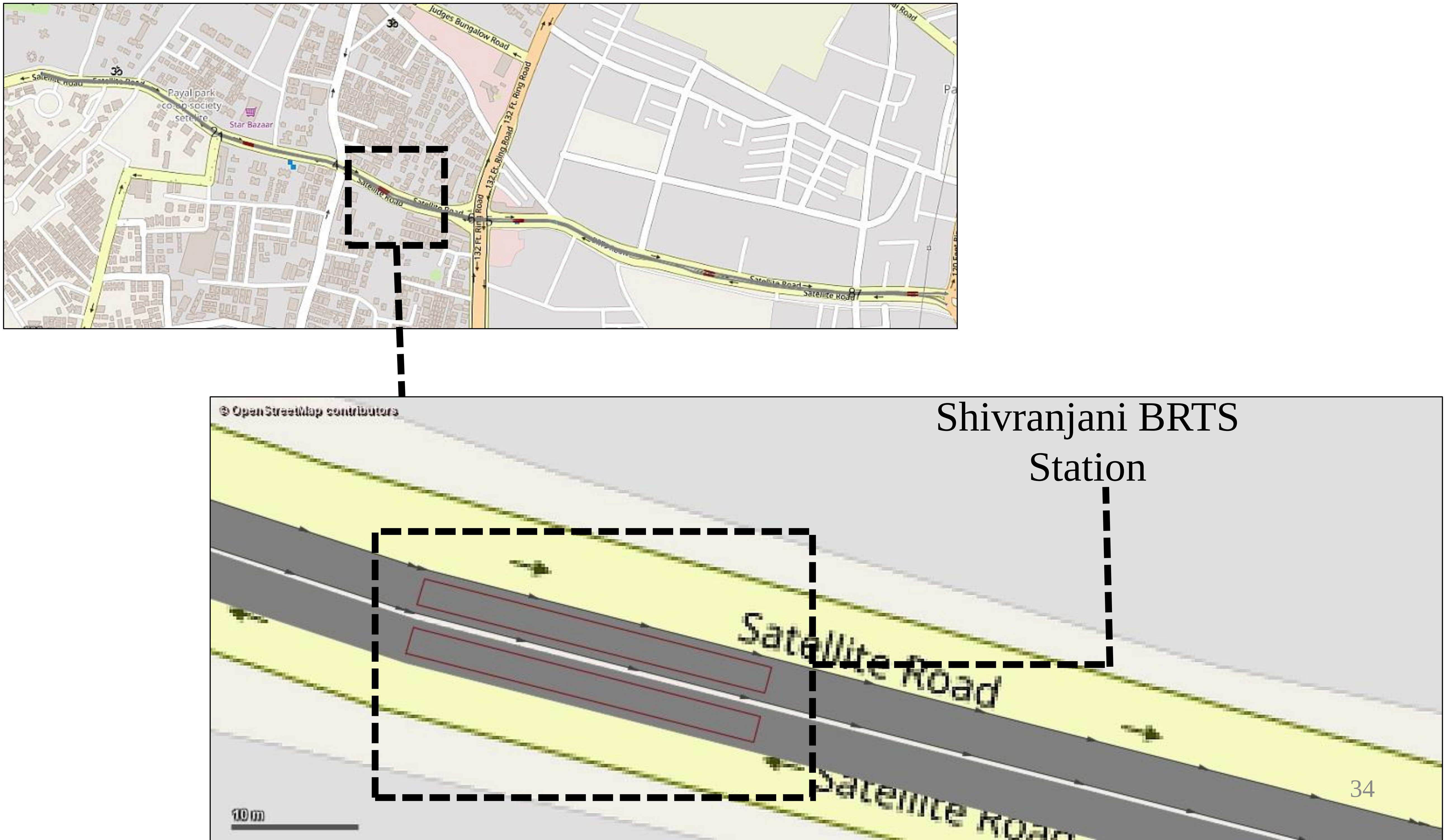
$$t_{om} = C_v t_d Z$$

For example, if the failure rate is 10% (i.e., a 90% probability that any given dwell time will not cause interference with the following bus)

Mathematically, to achieve maximum capacity, a failure of 100% should be considered but it will result in low BRT speed and the operations would be considered unacceptable.

Estimating Failure Rate for Maximum Capacity

Base Model - VISSIM



Estimating Failure Rate for Maximum Capacity

Calibration

CC0 (Standstill Distance) and CC1 (Headway Time) parameter were calibrated

Parameter	Calibrated value for BRT Buses	Default Value
CC0 (Standstill distance): (Desired distance between lead and following vehicle at v = 0 km/h)	2.4 m	1.5 m
CC1 (Headway Time):(Desired time in seconds between lead and following vehicle)	1.7 s	0.90 s
Look Ahead Distance (Min)	20 m	0 m
Look Ahead Distance (Max)	300 m	250 m
Look Back Distance (Max)	25 m	0 m
Look Back Distance (Min)	150 m	150 m
Waiting time before diffusion	90 s	60 sec
Minimum Headway (front/rear)	0.50 m	0.50 m
Safety distance reduction factor	0.60	0.60
Minimum lateral distance @0 km/h	0.50 m	1 m
Minimum lateral distance @50 km/h	0.90 m	1 m

Model Validation

Chi-Square test	
Chi-square statistic value evaluated	0.48
Chi-square critical value	3.8 (5% level of significance)
Error in average speed	
observed average speed	20.12 km/h
simulated average speed	20.24 km/h

Null hypothesis accepted; No difference between observed and simulated data

Error is 0.63 % (<1); simulation model can be accepted

GEH Statistic

Compares modeled and observed traffic volume

$$GEH = \sqrt{2(M - C)^2/(M + C)}$$

Where M is the traffic volume obtained from simulation model and C is the observed traffic volume

Average GEH statistic calculated was 1.45 (<5) ;
Hence simulation model can be accepted

Ref: ***WisDOT. (2015). Model Calibration-Wisconsin Department of Transportation (WisDOT).http://www.wisdot.info/microsimulation/index.phptitle=Model_Calibration#The _GEH _Formula. Accessed 10 November.***

Estimating Maximum Failure Rate a Trade off with Operational Speed

SCENARIO A: Constant field values of coefficient of variation (Cv), block spacing, dwell time (DT) and g/C (green is to signal cycle time) for selected corridor.

SCENARIO B: In this scenario various combinations of Cv, DT and g/C were simulated for varying bus flows.

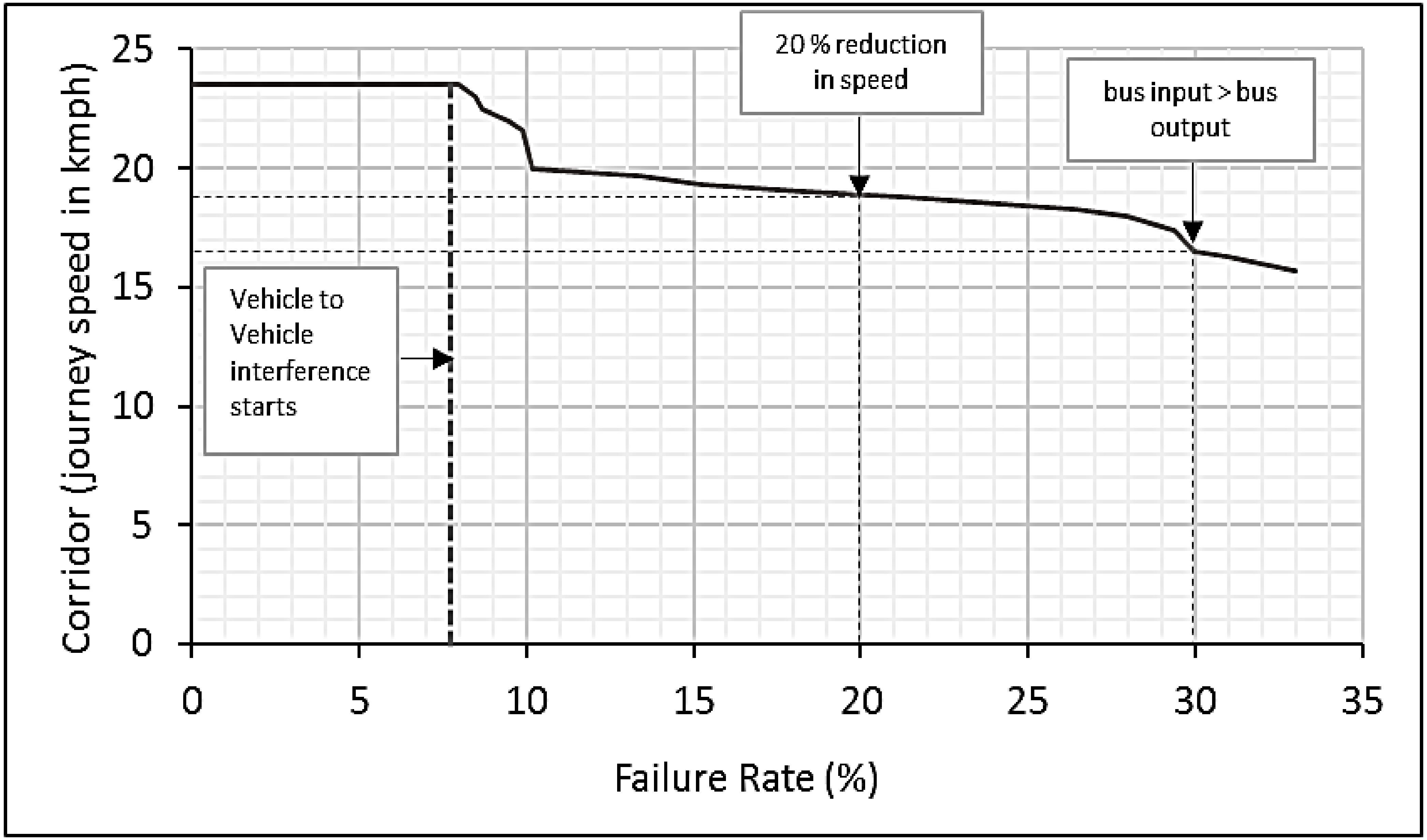
SCENARIO C: In this scenario the FR and average corridor journey speeds were estimated at different bus flows, Cv , DT and g/C.

Estimating Maximum Failure Rate a Trade off with Operational Speed

The inter departure time was started considering 10 seconds as the first value and then for every consecutive 10 second interval the failure rate and the average speeds of the corridor was estimated till the failure rate reached zero percent.

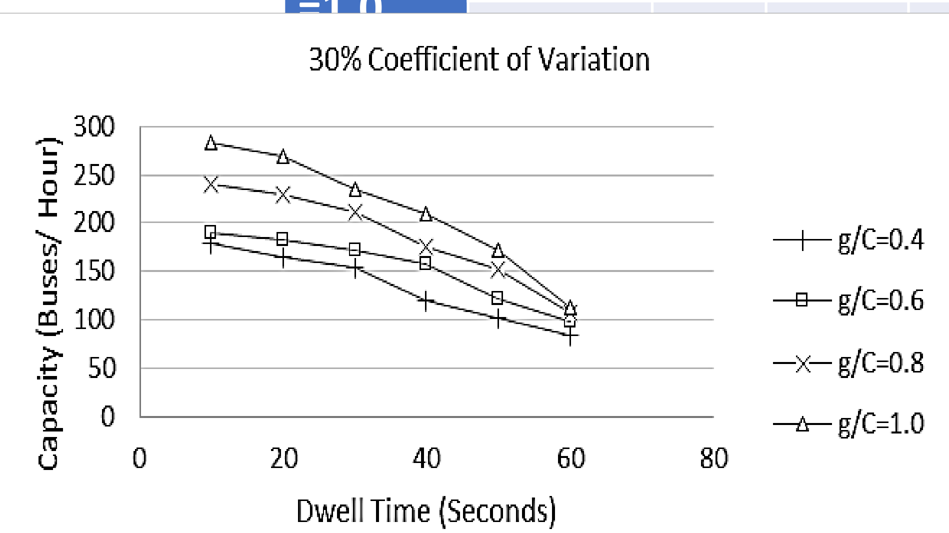
Scenario A

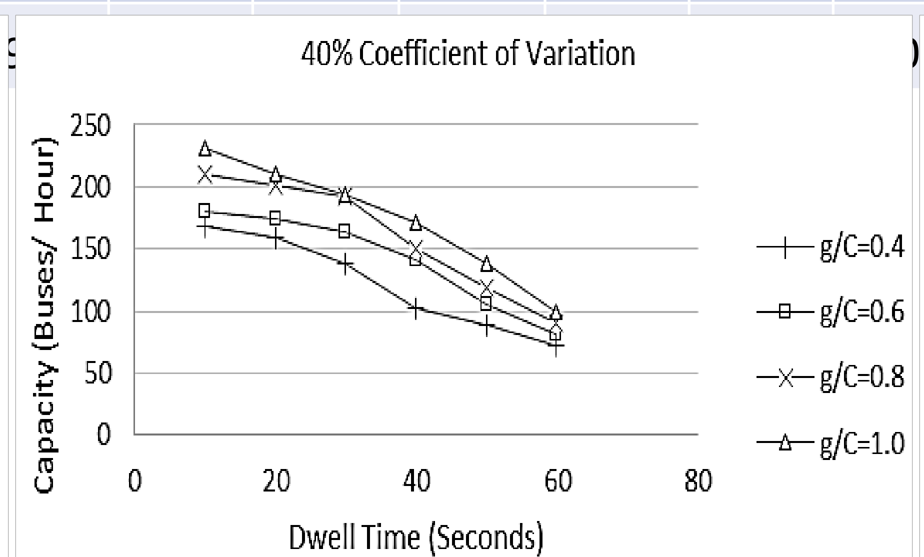
SELECTED FAILURE RATE 30 %

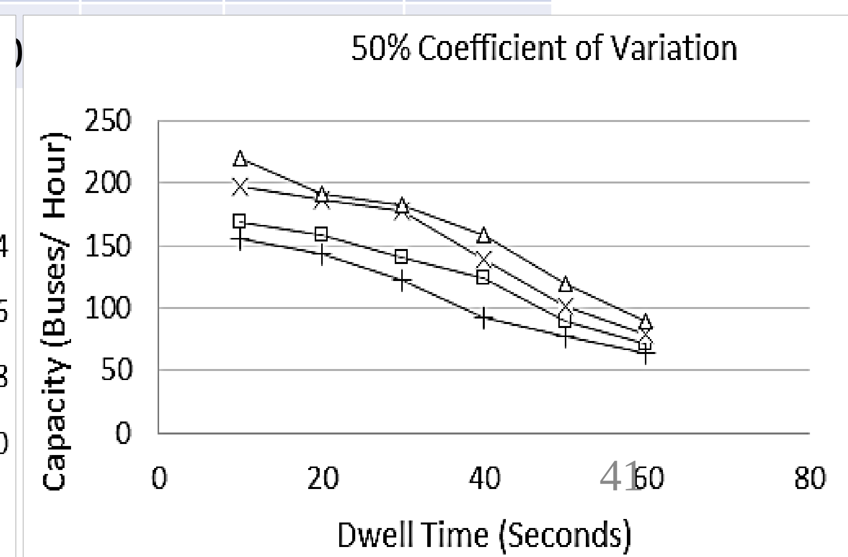


Scenario B

Condition		Dwell Time											
		10 sec		20 sec		30 sec		40 sec		50 sec		60 sec	
		MC	FR(%)	MC	FR (%)	MC	FR (%)	MC	FR (%)	MC	FR (%)	MC	FR (%)
g/C =0.4	C_v=0.3	179	34	165	36	154	32	120	26	101	35	84	31
	C_v=0.4	168	31	159	39	139	38	102	34	89	30	72	34
	C_v=0.5	155	28	143	31	123	35	93	31	78	28	64	36
g/C =0.6	C_v=0.3	189	29	182	35	172	33	157	36	121	29	98	33
	C_v=0.4	180	33	175	29	164	31	142	30	105	26	81	30
	C_v=0.5	169	31	158	26	141	29	124	37	90	28	72	39
g/C=0.8	C_v=0.3	240	36	229	33	211	29	176	37	153	30	108	35
	C_v=0.4	210	32	202	25	192	32	151	30	119	31	90	27
	C_v=0.5	198	28	187	37	178	28	139	24	101	29	79	33
g/C =1.0	C_v=0.3	283	38	269	35	234	37	210	30	171	34	112	29
	C_v=0.4	231	27	210	28	194	34	172	28	139	29	99	28







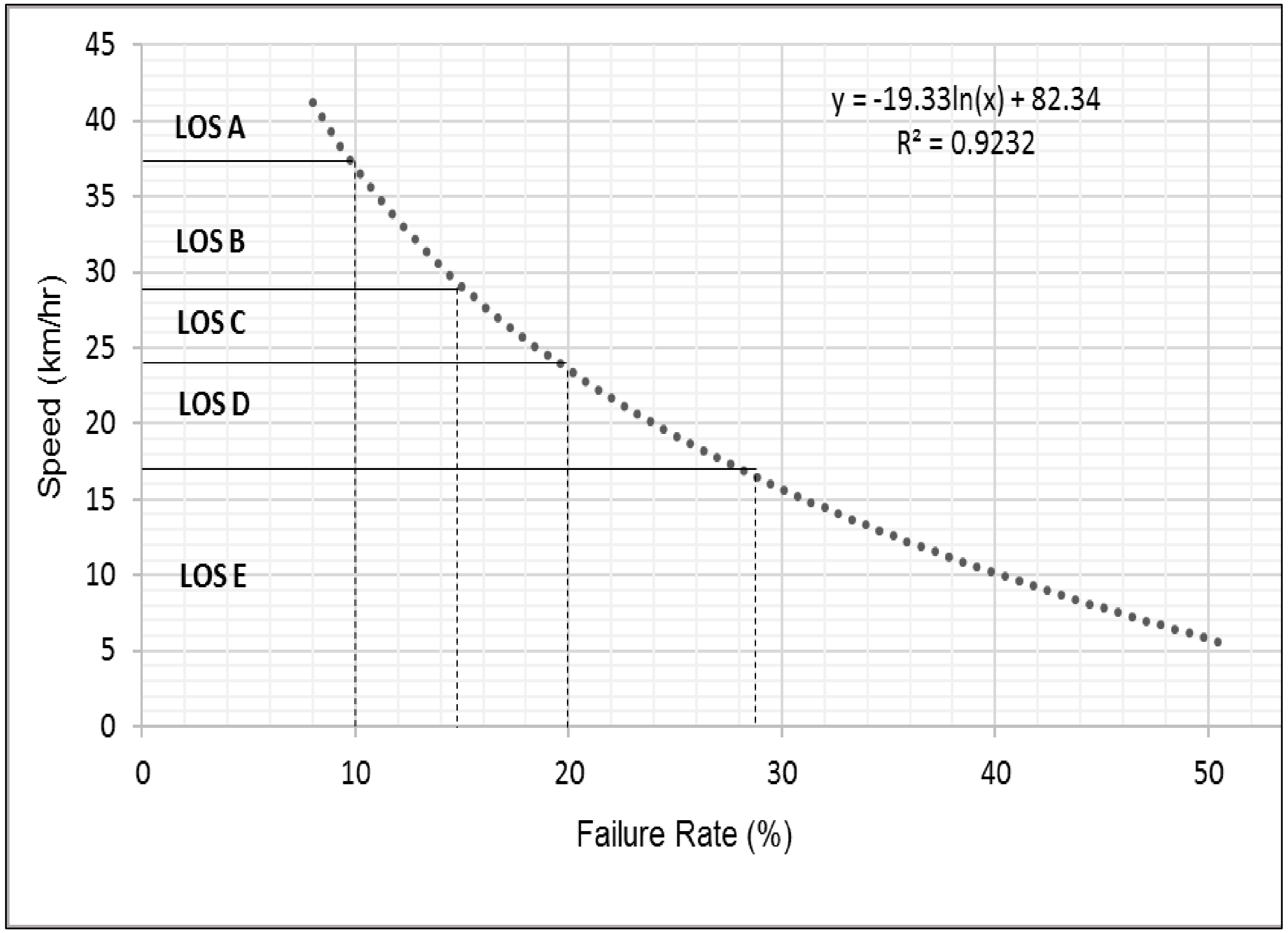
Scenario C

K- Mean Clustering – 30 days of GPS data

The mean of the silhouette coefficient for all the cluster was coming out to be 0.59 (5 Cluster)

$$y = -199.33\ln(x) + 82.34$$

Maximum FR 29%



LOS	HCM (Bus Transit)	BRTS (Present Study)
	Km/hr	Km/hr
A	>34.49	>37.1
B	26.1 - 34.4	29-37.1
C	12.7-17.6	24 -29
D	9.65-12.7	17-24
E	<9.65	<17

LOS	Failure Rate (%)
A	0-9
B	9-14
C	14-19
D	19-29
E	>29

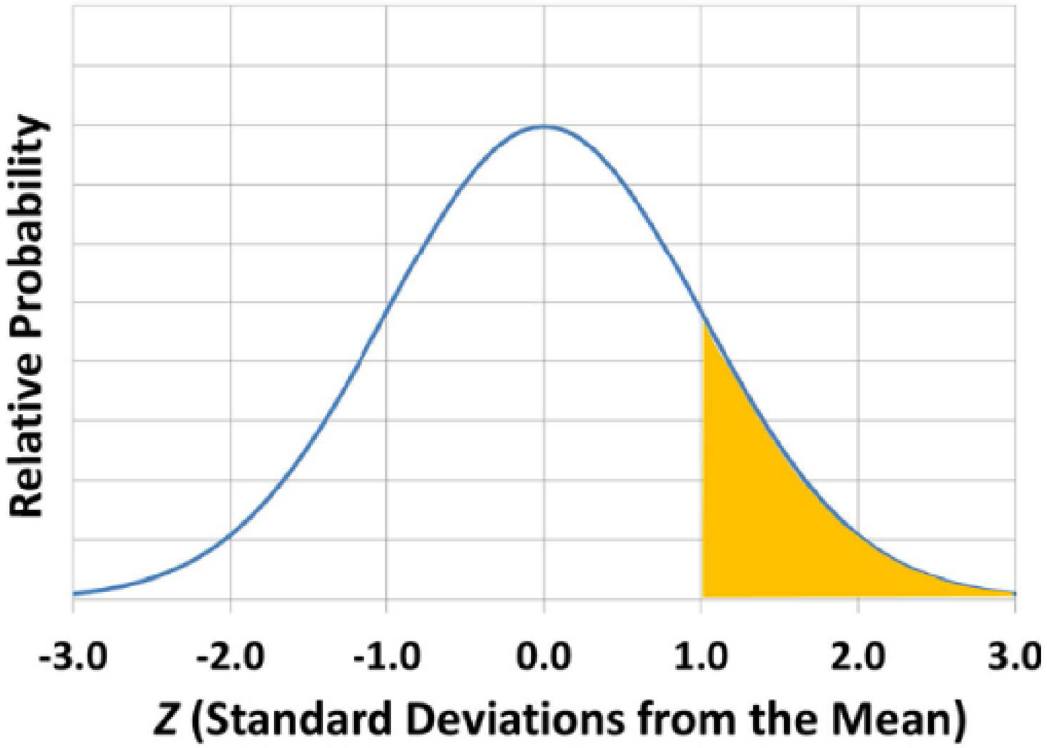
Loading Area Capacity

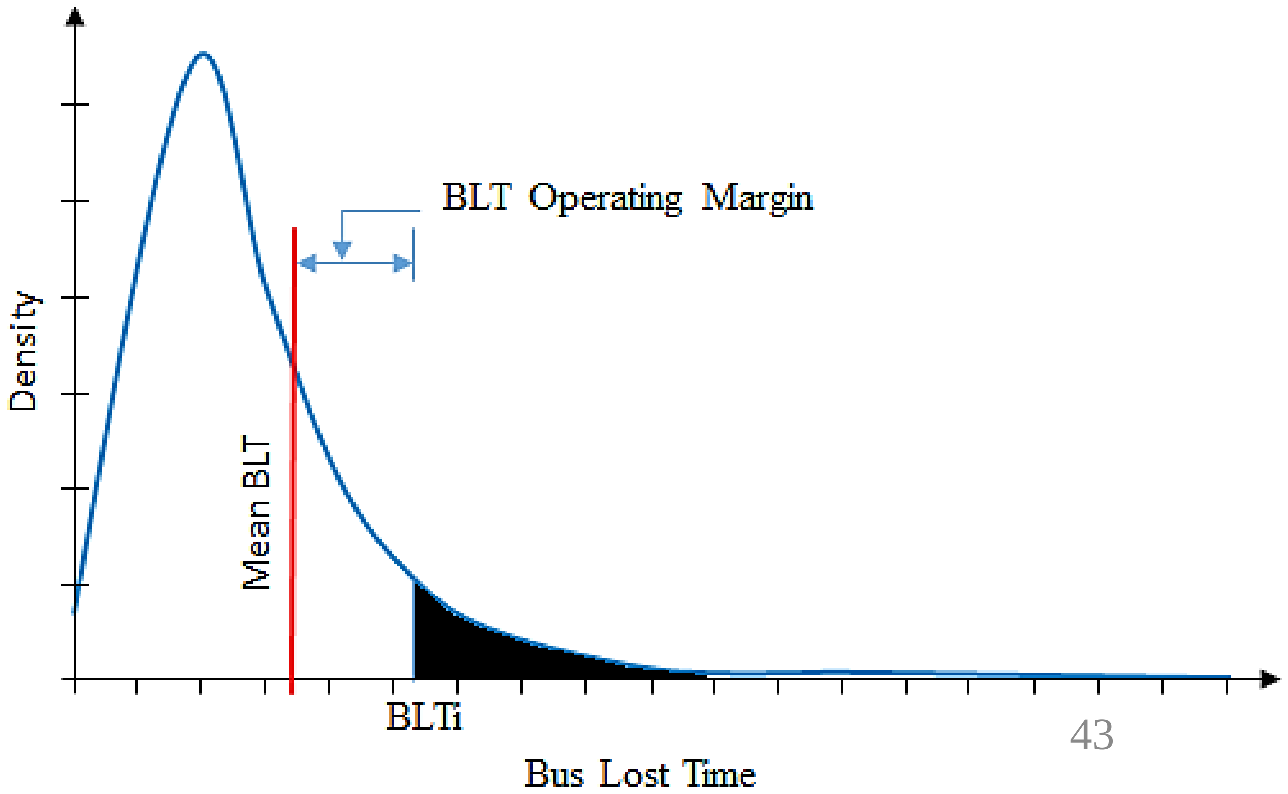
$$B_l = \frac{3600(g/C)N_b}{t_c + t_d\left({}^{g}/_{C}\right) + Z_\alpha C_v t_d}$$

$$t_{om} = t_{omp} + t_{omlt}$$

$$t_{omp} = ZC_v(t_{ps})$$

$$t_{omb} = ZC_v(BLT)$$





$$z = \frac{ln(BLT_i) - \mu}{\sigma}$$

Equation rearranged to:

$$BLT_i = e^{(Z\sigma + \mu)}$$

Subsequently, the BLT based operating margin can be shown as in equation below:

$$t_{omb} = e^{(z\sigma + \mu)} - BLT$$

Where BLT is the mean bus lost time and therefore substituting the mean of the log-normal curve in above equation to get equation

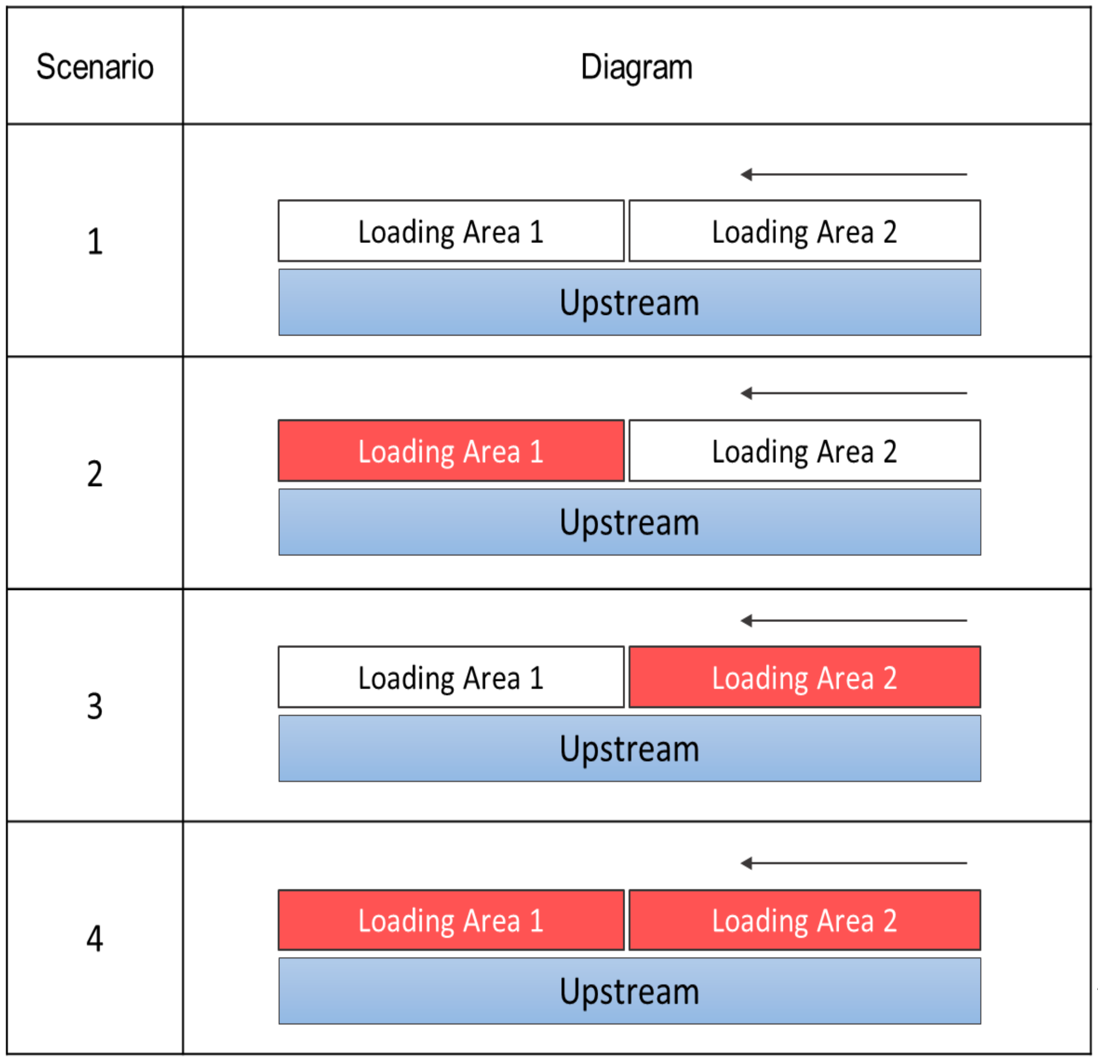
$$t_{omb} = e^{(z\sigma + \mu)} - e^{(\mu - \frac{\sigma^2}{2})}$$

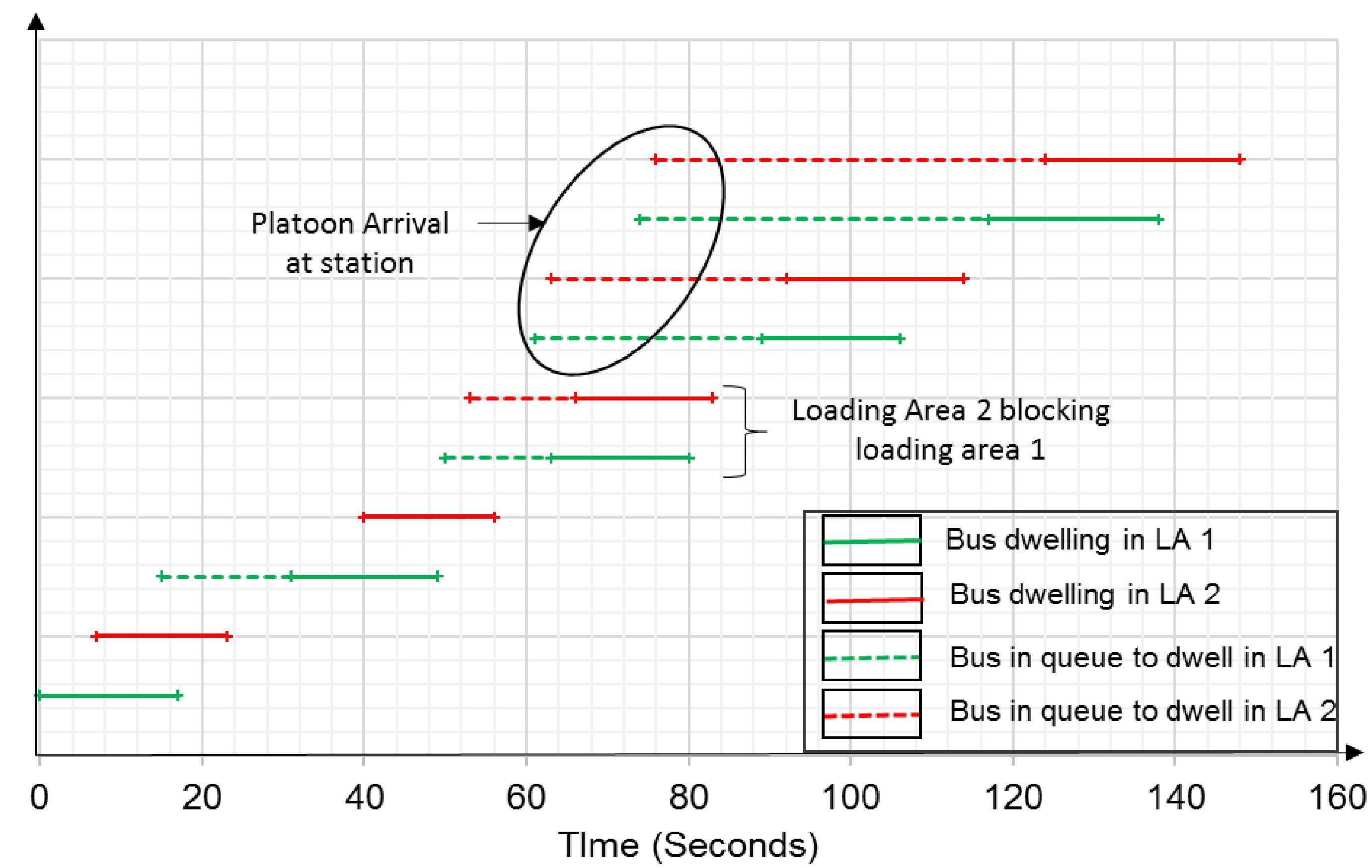
Where, $0 \leq t_{omb} \leq t_d$

The loading area capacity equation can be written as shown below:

$$B_l = \frac{3600\ (\frac{g}{c})}{t_c + t_d(^g/_C) + t_{omp} + t_{omb}}$$

BRTS Station Efficiency





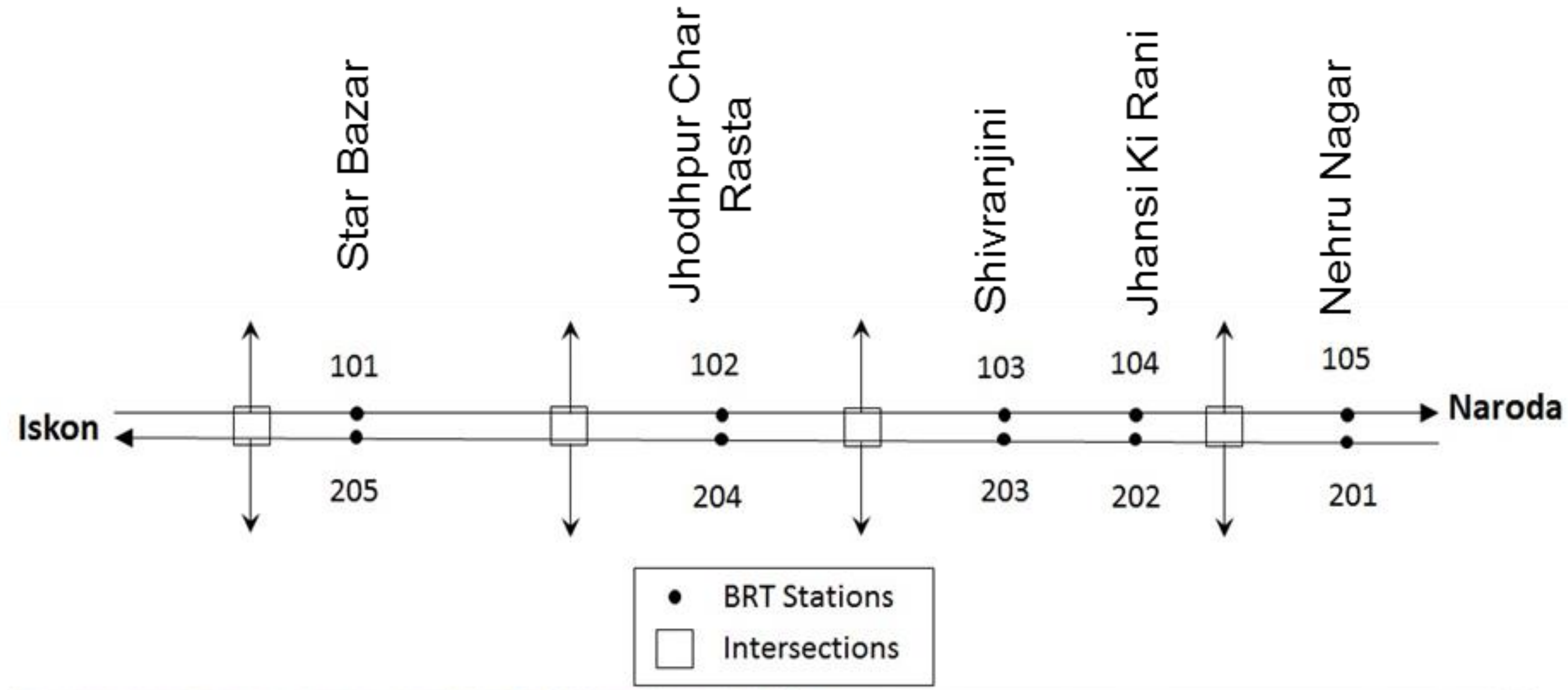
$$E_1 = \frac{T_2 - T_{1,b}}{T_2}$$

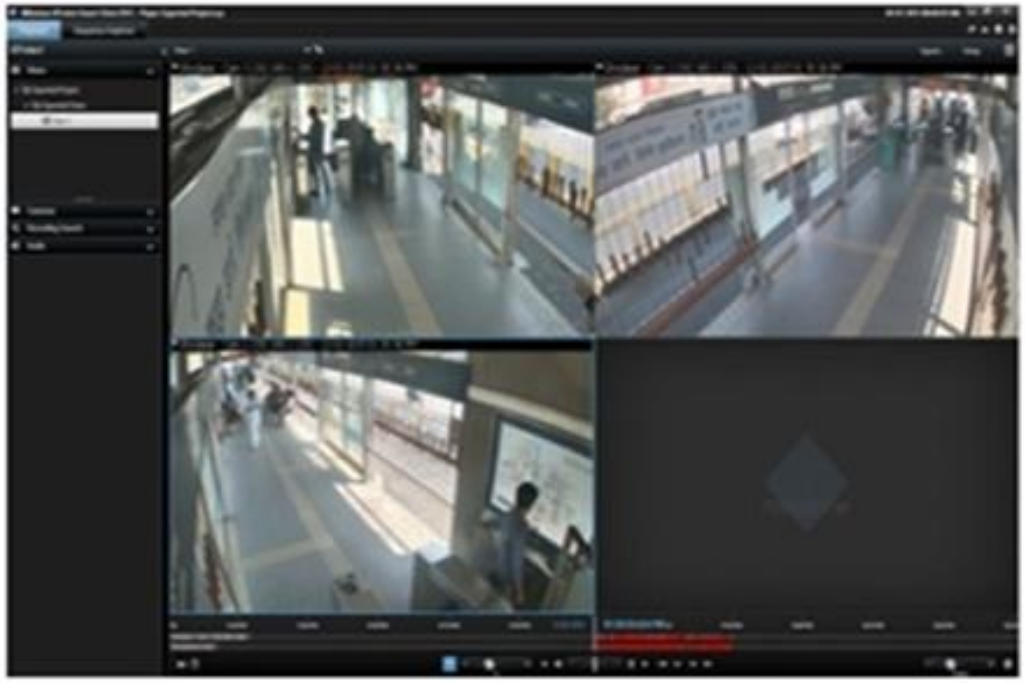
Loading Area	Occupied Time (Seconds)	Blocked Time (Seconds)
1	1948	292
2	1760	0

Loading Area	Time Preceding Loading Area Occupied (Seconds)	Time Loading Area Empty While Preceding Occupied (Seconds)	Loading Area Efficiency
1	T_2= 1760	T_b= 292	0.83
2	N/A	N/A	1.00

Loading Area	Present Study	TCQSM (2013)	Jaiswal (2010)
1	1	1	1
2	0.83	0.85	0.90

BRTS Station Capacity





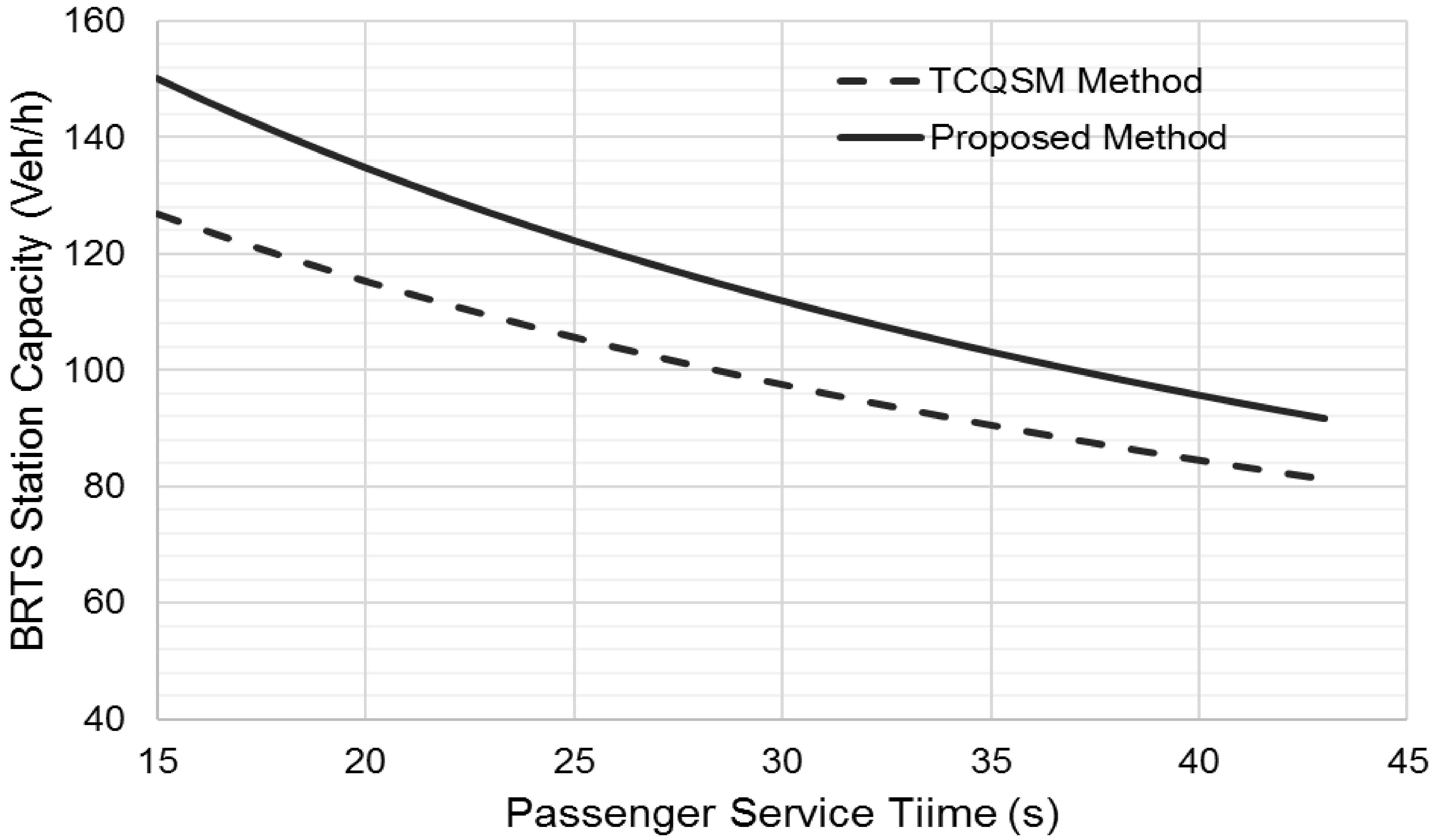
Critical Station Capacity	136 buses/hour

BRTS Station Capacity

BRTS Stations	101		102		103		104		105	
Loading Areas	LA-1	LA-2	LA-1	LA-2	LA-1	LA-2	LA-1	LA-2	LA-1	LA-2
Coefficient of Variation	0.56	0.43	0.34	0.3	0.43	0.35	0.35	0.45	0.4	0.43
Average dwell time(seconds)	9.3	7.7	8.6	9.4	13.7	13.9	9.4	8.4	12.6	11.4
Green time ration	0.43	0.43	0.47	0.47	1	1	0.38	0.38	0.42	0.42
Failure Rate (%)	15%	15%	4%	4%	30%	30%	9%	9%	15%	15%
Clearance Time(seconds)	10	10	10	10	10	10	10	10	10	10
Effective loading Area	0.83	1	0.83	1	0.83	1	0.83	1	0.83	1
Loading Area Capacity (buses/hr)	80.0	92.6	88.3	87.4	134.1	135.9	76.1	74.9	73.7	76.1
Effective Loading Area Capacity	66.4	92.6	73.2	87.4	111.3	135.9	63.1	74.9	61.2	76.1
Bus Stop Capacity (buses/hr)	159.0		160.7		247.2		138.1		137.3	
Critical Bus Stop Capacity	137 buses/hour									

The maximum capacity for the same critical bus stop was estimated considering 29% max FR, this value turned out to be 162 buses/hr.

Comparing Results of Proposed and TCQSM Method



Capacity of two loading area BRTS station for the proposed and the competing method with varying passenger service time, COV of 40% and g/C of 0.5

Model Validation

$$MAPE = \left| \frac{Estimated\ capacity - Actual\ capacity}{Actual\ capacity} \right| X\ 100$$

S.No.	BRTS Station	Stream	Field Data (bus/h)	Proposed Method		TCQSM	
				Max Capacity (bus/h)	MAPE (%)	Max Capacity (bus/h)	MAPE(%)
1	Nehru Nagar	u/s	165	154	6.7	136	17.6
		d/s	169	156	7.7	135	20.1
2	Jhansi ki Rani	u/s	260	276	6.2	234	10.0
		d/s	181	163	9.9	141	22.1
3	Shivranjani	u/s	172	162	5.8	140	18.6
		d/s	266	246	6.5	211	8.7
4	Jhodhpur Char Rasta	u/s	195	180	7.7	154	21.0
		d/s	202	196	3.0	169	16.3
5	Star Bazar	u/s	174	165	5.2	142	18.4
		d/s	191	178	6.8	152	20.4

Is 25% FR Significantly Different to the Proposed 29% FR ?

t-test was carried out on the estimated capacity values for the TCQSM and the proposed model.

$$H_o: \mu_1 - \mu_2 = 0$$

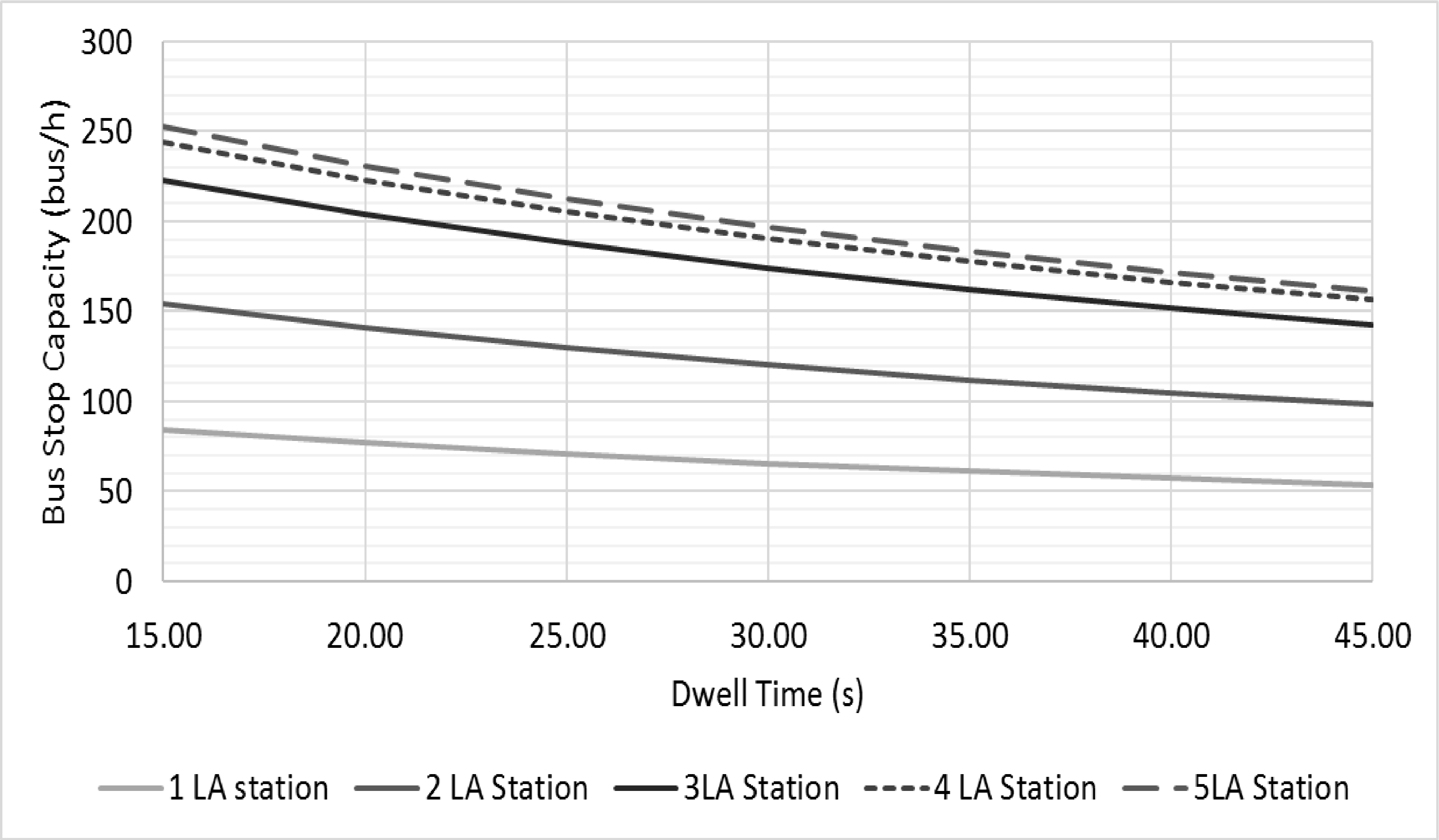
$$H_a: \mu_1 - \mu_2 \neq 0$$

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} - \frac{s_2^2}{n_2}}}$$

TCQSM Method	Proposed Method
$\bar{x}_1$ = 97.4	$\bar{x}_2$= 112.14
s_1^2 = 228.77	s_2^2 = 368.22
n_1 = 34	n_2 = 34

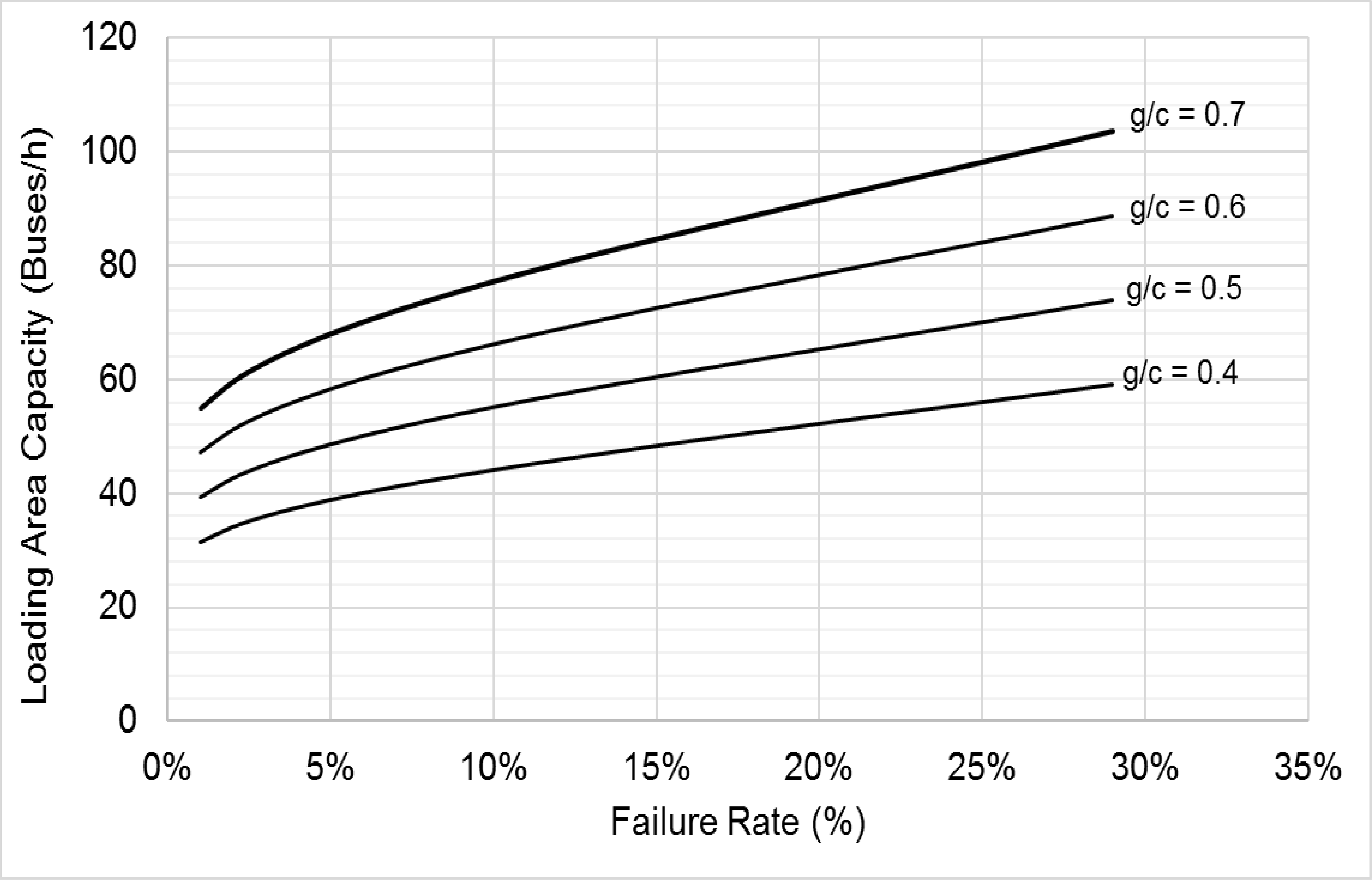
The observed value of t computed from the sample statistics is -3.51, because the observed t value is less than the lower critical table value of -1.99, observed value of t is in the rejection region. The null hypothesis is rejected. There is a significant difference in the mean scores of the two methods.

Change in Capacity with Increasing LA



Capacity Vs varying dwell time, COV of 40% and g/C of 0.5

Change in Capacity with Varying g/C



Conclusions

- **Adding BLT as a DT component to all scenarios of boarding and alighting will result in overestimation of DT.**
- **BLT data followed lognormal distribution for both loading areas 1 and 2, a BLT value of 2.3 sec for loading area 1 and 3.0 sec for loading area 2 were proposed.**
- **The present study proposed a maximum FR value of 29%, which is 4% more than the maximum FR value of conventional bus stop.**
- **A revised approach to estimate the capacity of the BRTS station is suggested in the study which includes a modification in the operating margin and dwell time estimation**

Thank you for your attention

Thank You