Case Study Report

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Contents

Overview

Public transportation plays an essential role in urban areas, particularly in India, where the majority of the population resides in rural areas, and the share of the urban population is growing. Buses are the most efficient and easiest mode of transport in urban areas. However, due to the increasing ownership of private vehicles, there is an urgent need to improve public transportation systems to reduce city congestion and pollution. The Atal Indore City Transport Service Limited (AICTSL) in India sought to optimize the bus system by improving reliability, frequency, capacity utilization, safety, and cost-effectiveness. The purpose of this report is to present strategies to optimize the bus system based on these five performance characteristics and answer specific questions on public transportation options, the advantages and disadvantages of bus rapid transit systems (BRTS) over other options such as metropolitan rail, challenges in developing and operating a BRTS, determining bus frequency, scheduling and deployment plans, and improving reliability, safety, and cost-effectiveness. The report also determines the bus frequency on each route of the BRTS, given passenger demand across each service location, and proposes bus scheduling and deployment plans on both routes given the desired frequency.

Public transportation options Available in an Urban Setting

Over 1.4 billion people call India home, and more than 31% of them reside in cities. Given the size of the population, public transportation is now an essential part of urban life. In India, there are several forms of public transportation used in various regions and in different cities. In this article, the public transportation alternatives in metropolitan India are briefly discussed, with an emphasis on the most often used types of transportation.

Modes of Public Transportation in Urban India:

The most commonly used modes of public transportation in urban India are:

1. Buses: In metropolitan India, buses are the most widely used form of public transit. They are run by either privately owned or state-owned transportation corporations. The majority of Indian cities have an extensive bus network, which is frequently the least expensive means of local transportation.
2. Trains: Another significant kind of public transportation in India is the train. One of the biggest railroad networks in the world, Indian Railways, operates them. Long-distance and suburban trains are both run by the Indian Railways, making them a crucial component of urban transportation.
3. Metro Rail: In India, metro rail is a relatively new kind of public transportation. The country's first metro rail system opened in Delhi in 2002. Since then, a number of other Indian cities, including Mumbai, Bangalore, Kolkata, Hyderabad, and Chennai, have unveiled their own metro rail systems. Particularly in places with significant traffic congestion, metro rail is a quick, effective, and comfortable means of transportation.
4. Auto-rickshaws: In Indian cities, auto-rickshaws are a common form of transportation. They are diminutive, three-wheeled automobiles that are used for quick city trips. For many people,

auto-rickshaws are a practical form of transportation because they are readily available and reasonably priced.

5. Taxis: In urban areas of India, particularly in the bigger cities, taxis are very often used. While generally more expensive than other forms of transportation, they also provide greater comfort and privacy.

Advantages and Disadvantages of a BRTS over other options such as Metropolitan Rail

Cities cannot function effectively or sustainably without public transit. The Bus Rapid Transit System (BRTS) and Metropolitan Rail are the two most widely used forms of public transportation. Although BRTS has a smaller capacity and safety concerns, it is more flexible, affordable, and has better last-mile connectivity. Metropolitan Rail is more expensive but has a higher capacity, is unaffected by traffic congestion, and requires less maintenance. Other choices include buses and trams, which have cheaper beginning expenses but are similarly hampered by traffic jams and capacity restrictions. Innovative transportation methods that can work well for specialized terrain and short distances include cable cars, water taxis, and bike-sharing schemes. To meet the demands of its citizens, communities must ultimately select a kind of public transportation that strikes a balance between price, capacity, flexibility, and safety.

Challenges Encountered in Developing and Operating a BRTS

While BRTS may seem like a good option, creating and running a BRTS can present a number of difficulties, including the need for dedicated bus lanes, which may necessitate sizable infrastructure investments, as well as the administration of bus scheduling and dispatch. In order to get finance, win over the public, and resolve any problems with other transport modes, the implementation of a BRTS may also require tremendous political will and stakeholder participation. Other difficulties could be managing the ongoing maintenance and infrastructure replacement of buses, making sure that passengers are safe and secure, and integrating the system with other modes of transportation. These issues can be addressed and a BRTS system's success can be ensured with the help of effective planning, stakeholder participation, and continuing management.

Improving Reliability and Safety of a BRTS

While public transportation helps to ease the need for transportation, safety and dependability are crucial factors that cannot be overlooked. Intersections can use modern signaling systems to reduce accidents, such as signal priority systems and real-time data optimization. Drivers can benefit from frequent training sessions and seminars that can help lessen the chance of accidents by receiving the proper information and training. Regular upkeep of buses and bus stops is necessary to guarantee the security and dependability of the system. Advanced technologies, like automated fare collecting and GPS tracking, can enhance scheduling accuracy and decrease delays. By collaborating with technology providers or utilizing open-source technologies, these safeguards can be put into place at a relatively cheap cost. By adopting these strategies, the reliability and safety of the BRTS can be improved while minimizing costs.

Analysis of Indore BRTS

Excel Calculations For Computing Demand at every Station

The number of passengers transiting from Rajiv Gandhi to every other stop on the route to Niranjanpur Square, which is 21 stops, has been provided. Similarly, we also have data about the number of passengers who traveled from one stop to another on the return trip from Niranjanpur

Square to Rajiv Gandhi. The information has been provided in the form of an Origin-Destination Demand Matrix for peak hours (7:30 am-11:30 am) and non-peak hours (11:30 am-14:30 pm).

These data can now be used to calculate demand at each stop from Rajiv Gandhi to Niranjanpur Square and the return trip. As a first step, we calculate the number of passengers before entering the bus at each stop. The next step involves calculating how many passengers boarded at each stop. We then calculate the number of passengers who got off at the previous stop, which we must subtract from the total number of passengers on the bus when it arrived at a particular station and who entered it from that station *(See Appendix-C)*.

By doing so, we can determine the peak demand at each station for four hours (7:30 am-11:30 am). For non-peak hours (11:30 am-14:30 pm), the same calculation applies. There is only one difference in this case, since the non-peak time is for three hours, while the peak time is for four hours, so we get a four-hour demand for the peak time and a three-hour demand for the non-peak time. Schedulers used data from the previous few days to determine peak and non-peak demand hours. In order to determine the hourly demand, we must divide the peak time demand by four, and the non-peak time demand by three.

In this way, we have demand at each stop along the route from Rajiv Gandhi to Niranjanpur Square, and on the return trip as well. According to the case study, transit demand for each hour follows a normal distribution with a standard deviation of approximately 20%.

A few visualizations of average hourly demand over the 21 stops on the on-journey and return routes have been plotted *(See Appendix-A)*.

R Simulations and Results

Peak Time Analysis

Rajiv Gandhi to Niranjanpur

Bottleneck Stop:

We have located the bottleneck stop (highest hourly demand) after importing data into RStudio.

```
#Find stop with highest demand
highest_demand_stop <- demand_data %>%
  slice_max(Hourly_Demand)

# print the stop with highest demand
highest_demand_stop

# visualizing demand for each stop using bar plot
ggplot(Peak_data_hourly_demand, aes(x = Stop, y = Hourly_Demand)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  labs(title = "Hourly Demand for Bus Stops", x = "Stop", y = "Hourly Demand")
```

```
> # print the stop with the highest demand
> highest_demand_stop
# A tibble: 1 × 3
  Stop   Hourly_Demand stdev
  <chr>          <dbl> <dbl>
1 GPO            1208.  242.
```

Monte Carlo Simulation at GPO

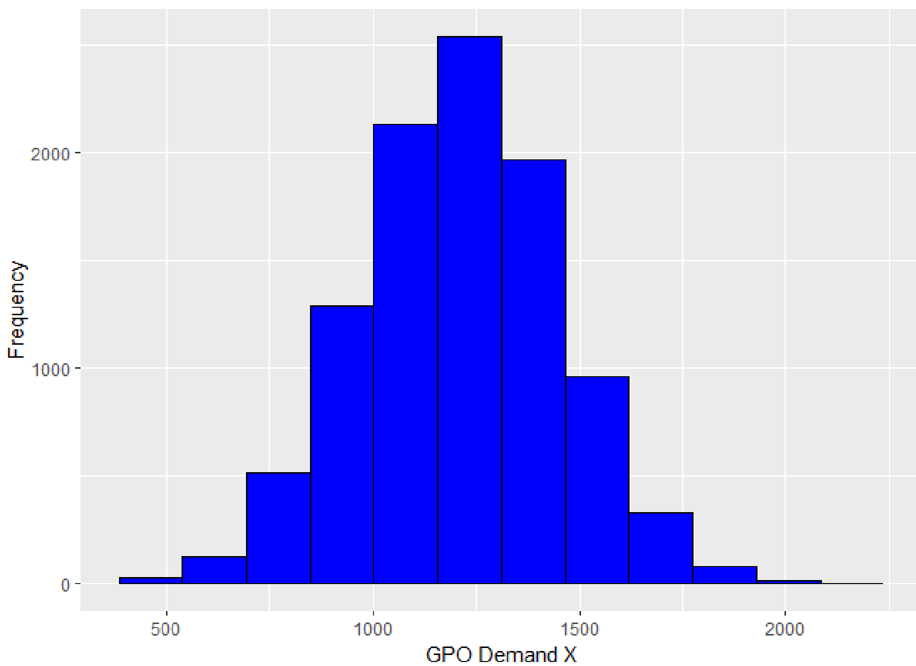
GPO has the highest demand in the 21 stops between Rajiv Gandhi and Niranjanpur *(See Appendix A)*. We should be able to meet the demand at all stops if we can satisfy demand at GPO to a reasonable extent. Our focus is on modeling GPU bus frequencies since this is the bottleneck. With the mean demand at GPO and standard deviation at the GPU stop, a Monte

Carlo simulation was run for the hourly demand at GPO for 10,000 trials.

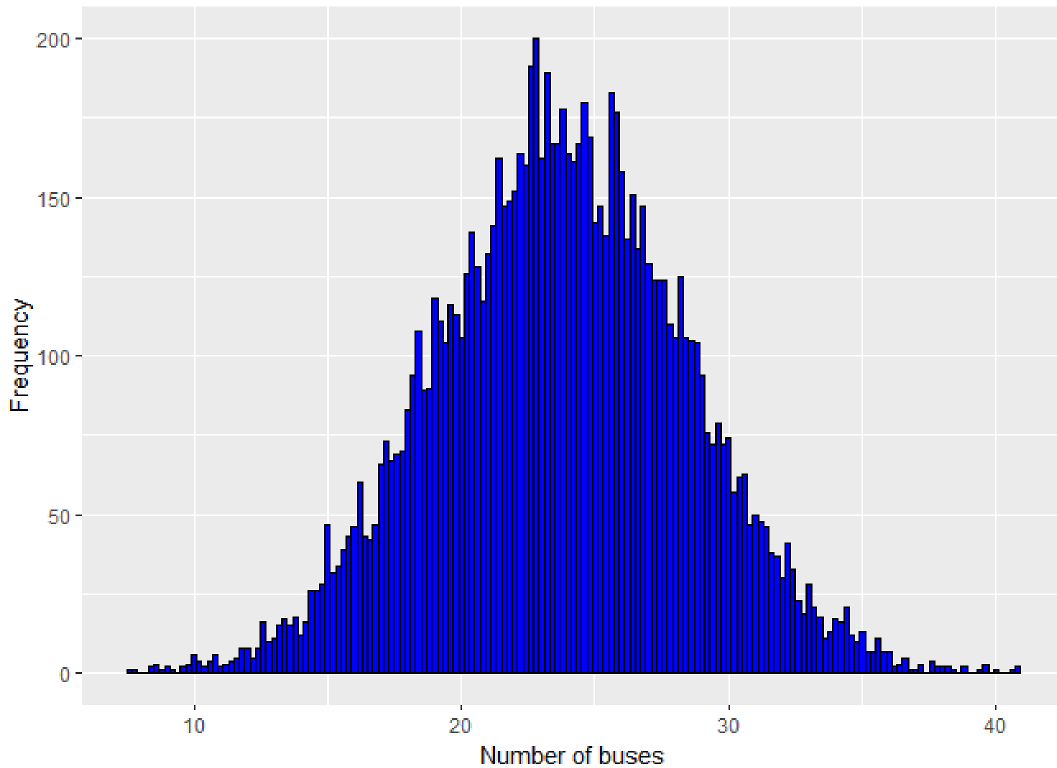
```
#simulate demand at GPO
simulate_passenger_demand <- function(mean, sd) {
  demand <-  rnorm(10000, mean, sd)
  return(demand)
}

GPO_demand <- simulate_passenger_demand (1208,242)
number_of_buses <- GPO_demand/51
```

Histogram of Simulated GPO Demand



Histogram of Number of Buses Required to satisfy Demand fully at GPO




```
> mean(number_of_buses$GPO_demand)
[1] 23.7153

> time_bw_buses_average <-
60/mean(number_of_buses$GPO_demand)
> time_bw_buses_average
[1] 2.530013

> buses_90_percent <-
floor(quantile(number_of_buses$GPO_demand, 0.90))

> time_bw_buses_bottleneck <- 60/buses_90_percent
> buses_90_percent
90%
 29
> time_bw_buses_bottleneck
     90%
2.068966
```

Inference:

To meet the demand at GPO during the on-journey from Rajiv Gandhi to Niranjanpur, consecutive buses need to be 2.06 apart in 90% of the cases.

Niranjanpur to Rajiv Gandhi

Bottleneck Stop:

We have located the bottleneck stop (highest hourly demand) after importing data into RStudio.

```
#Find stop with highest demand
highest_demand_stop <- demand_data %>%
  slice_max(Hourly_Demand)

# print the stop with highest demand
highest_demand_stop

# visualizing demand for each stop using bar plot
ggplot(Peak_data_hourly_demand, aes(x = Stop, y = Hourly_Demand)) +
  geom_bar(stat = "identity") +
  coord_flip() +
  labs(title = "Hourly Demand for Bus Stops", x = "Stop", y = "Hourly Demand")
```

```
# A tibble: 2 × 3
  Stop           Hourly_Demand stdev
  <chr>                  <dbl> <dbl>
1 LIG                     1336  267.
2 Industry House          1336  267.
```

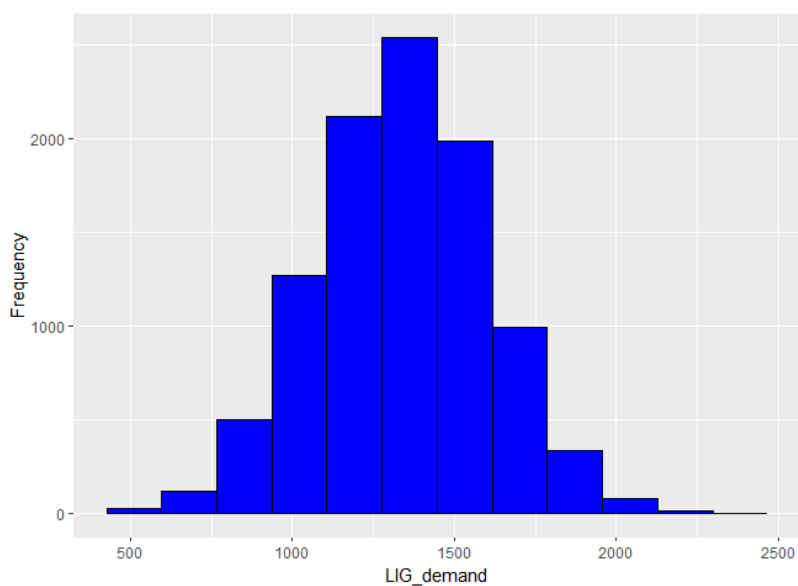
Monte Carlo Simulation -Niranjanpur to Rajiv Gandhi

LIG and Industry House have the highest demand between Niranjanpur Square and Rajiv Gandhi *(See Appendix A)*. Therefore, we can perform Monte Carlo Simulation at LIG or Industry House in R. Then we calculate the number of buses corresponding to the demand over 10000 trials.

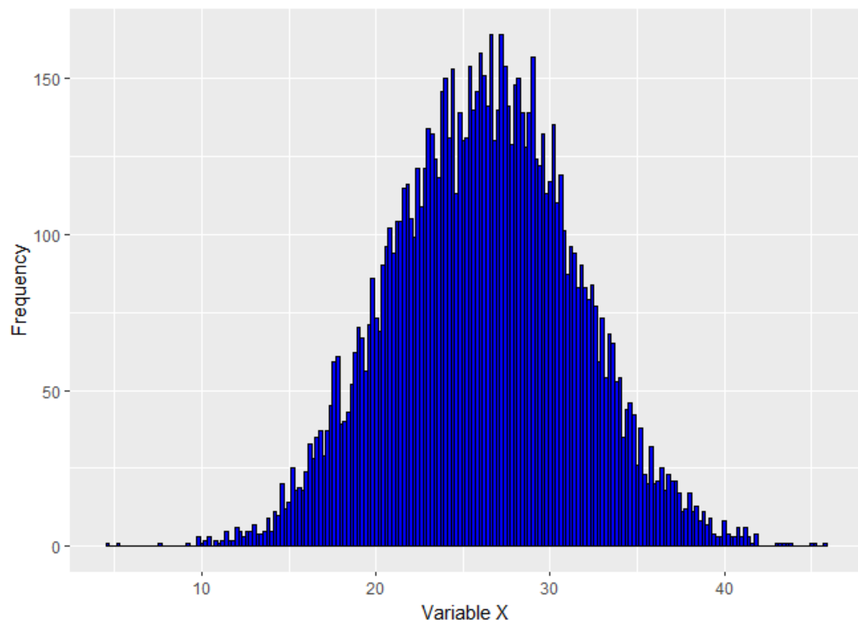
```
#simulate demand at LIG
simulate_passenger_demand <- function(mean, sd) {
  demand <-  rnorm(10000, mean, sd)
  return(demand)
}

LIG_demand <- simulate_passenger_demand (1336,267)
number_of_buses <- LIG_demand/51
```

Histogram of Simulated LIG Demand



Histogram of Number of Buses Required to satisfy Demand fully at LIG




```
> mean(number_of_buses$LIG_demand,na.rm=TRUE)
[1] 26.15552

> time_bw_buses_average <-
60/mean(number_of_buses$LIG_demand)
> time_bw_buses_average
[1] 2.293971


> buses_90_percent <-
floor(quantile(number_of_buses$LIG_demand, 0.90))

> time_bw_buses_bottleneck <- 60/buses_90_percent

> buses_90_percent
90%
 32
> time_bw_buses_bottleneck
  90%
1.875
```

Inference:

To meet the demand at LIG during the return journey from Niranjanpur Square to Rajiv Gandhi, consecutive buses need to be 1.875 apart in 90% of the cases.

PEAK TIME- BUS FREQUENCY RECOMMENDATIONS

Stop	Buses required max (99th percentile)
Rajiv Gandhi	5
Mata Gujri	8
Vishnupuri	10
Bhanwarkuan Square	19
Holkar Subway	20
Navlakha Square	32
Indra Pratima	36
GPO	38
Shivaji Vatika	38
AICTSL	37
Geeta Bhawan	34
Palasiya	28
Industry House	26
LIG	19
Press Complex	19
MR-9	13
Vijay Nagar	8
Satya Sai	7
Shalimar Township	6
Scheme No. 78	3
Niranjanpur Square	

Stop	Buses required max (99th percentile)	Time to next stop
Rajiv Gandhi	5	
Mata Gujri	10	
Vishnupuri	13	
Bhanwarkuan Square	15	
Holkar Subway	28	
Navlakha Square	38	4
Indra Pratima	41	1.2
GPO	42	1.6
Shivaji Vatika	42	2.8
AICTSL	42	2
Geeta Bhawan	37	2
Palasiya	35	2.8
Industry House	34	2
LIG	28	2.4
Press Complex	27	1.2
MR-9	22	2.8
Vijay Nagar	19	2.8
Satya Sai	5	
Shalimar Township	4	
Scheme No. 78	3	
Niranjanpur Square	0	

24 buses (2.2 min)

12 buses every 7.5 minutes (7-8 min)

It is the busiest stations that are marked in red. Thirteen stops are very busy on the return trip. There are 9 busy stations that overlap both on journey and return journey. We identified the busiest stops by looking at the number of buses needed at the (average hourly demand + 3*sigma) scenario. Stops with buses in an hour greater than 19 are considered busy stops.

From Holkar Subway to Vijay Nagar (to and fro), we recommend an **express bus route.**

Using R, the time taken by a bus to reach every stop between Holkar Subway and Vijay Nagar has been calculated based on the distance between each stop and the average speed at peak time (15 km/hr). It takes a bus 45 minutes to travel from Rajiv Gandhi to Niranjanpur Square. A bus takes 27.6 minutes to travel from Holkar Subway to Vijay Nagar. Based on the inferences made above regarding the time between buses required to meet demand at bottleneck stops (approximately 2 minutes for buses at GPO and LIC), the buses required to travel one way between the 13 busy stops (express route) would be approximately 12 buses around 2.5 minutes apart. Therefore, the number of buses required between busy stops (express route Holkar Subway to Vijay Nagar to and fro) equals about 24 buses that are approximately 2.5 minutes apart. During peak hours, 36 buses are in active operation at any given time. Therefore, the remaining buses equal 36 - 24 = 12 buses travelling on the normal route (Rajiv Gandhi to Niranjanpur Square to and fro) approximately 7.5 minutes apart (90 minutes / 12 buses).

Non-Peak Time Analysis

For computing non-peak time bus frequencies, we follow a similar calculation *(See Appendix-B for more results).* During non-peak hours, there are no bottlenecks.

Onward Journey Results

```
> buses_90_percent <- floor(quantile(number_of_buses$Geeta_demand, 0.90))
> time_bw_buses_90_percentile <- 60/buses_90_percent
> buses_99_percent <- floor(quantile(number_of_buses$Geeta_demand, 0.99))
> time_bw_buses_99_percentile <- 60/buses_99_percent
> buses_90_per> buses_90_percent <-
floor(quantile(number_of_buses$Geeta_demand, 0.90))
> time_bw_buses_90_percentile <- 60/buses_90_percent
> buses_99_percent <- floor(quantile(number_of_buses$Geeta_demand, 0.99))
> time_bw_buses_99_percentile <- 60/buses_99_percent
> time_bw_buses_average <- 60/mean(number_of_buses$Geeta_demand,na.rm=TRUE)
```

```
> buses_90_percent
90%
  7
> time_bw_buses_90_percentile
     90%
8.571429
> buses_99_percent
99%
  8
> time_bw_buses_99_percentile
99%
7.5
> time_bw_buses_average
[1] 9.86563
```

Return Journey Results

```
> buses_90_percent <- floor(quantile(number_of_buses$Geeta_demand, 0.90))
> time_bw_buses_90_percentile <- 60/buses_90_percent
> buses_99_percent <- floor(quantile(number_of_buses$Geeta_demand, 0.99))
> time_bw_buses_99_percentile <- 60/buses_99_percent
> time_bw_buses_average <- 60/mean(number_of_buses$Geeta_demand,na.rm=TRUE)
> number_of_buses <- as.data.frame(number_of_buses)
> buses_90_percent
90%
  8
> time_bw_buses_90_percentile
90%
7.5
> buses_99_percent
99%
  9
> time_bw_buses_99_percentile
     99%
6.666667
> time_bw_buses_average
[1] 9.287916
```

Non-Peak-Time Bus Frequency Recommendation

Due to lower demand during non-peak hours, we have sufficient buses available. Therefore, we perform Monte Carlo simulations for Geeta Bhavan, the busiest stop, and plot its histogram. The 99th percentile of demand at Geeta Bhavan is calculated assuming that in 99% of the scenarios, our recommended number of buses and suggested time between buses are sufficient to completely satisfy the demand at the busiest stop.

On the basis of the 99th percentile results for the required difference in time between the buses for the onward (7.5 minutes) and return journey (6.66 minutes) , it is recommended that the buses be deployed seven minutes apart from each other from both sides.

Therefore, 14 buses are in operation at any time from Rajiv Gandhi to Niranjanpur Square and the return journey during non-peak time.

Final Recommendations

Immediate Action

- This can be implemented within 2-3 weeks
- Focus is on Reliability and Frequency
- Express way

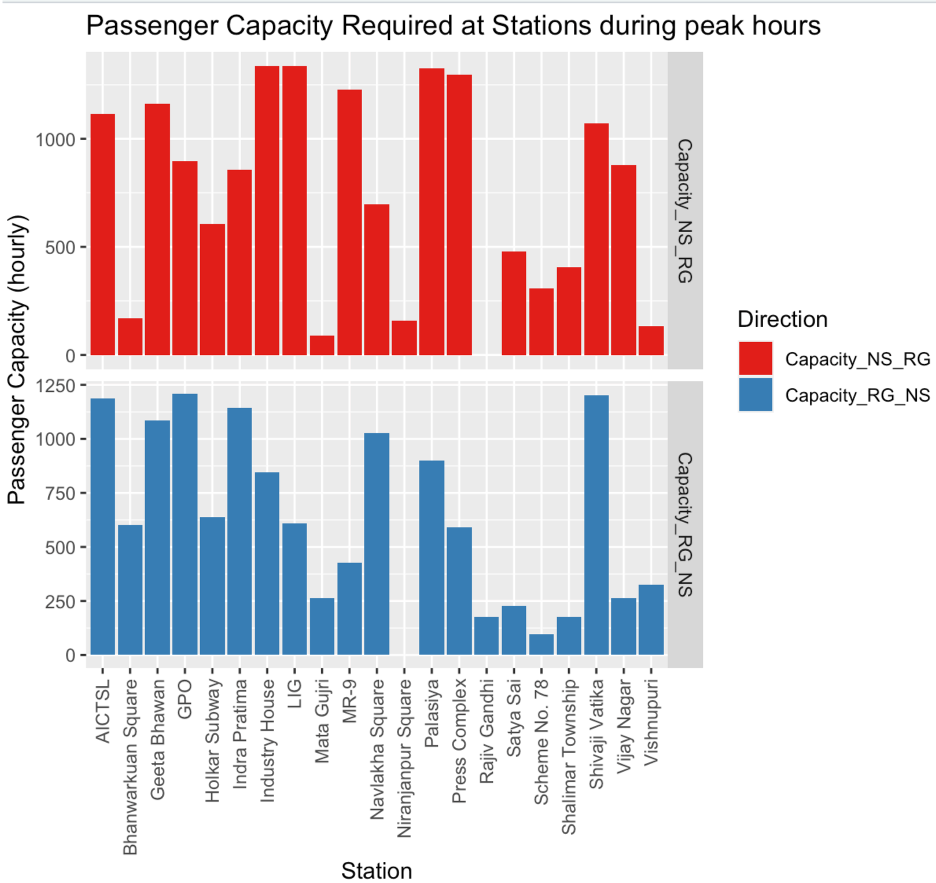
Mid-Term plan

- This can be implemented in 2-3 years
- Battery-operated minibuses to increase the frequency, and capacity in high-demand stops
- BRTS app which aids in live tracking, ticket purchasing, emergency dial-up

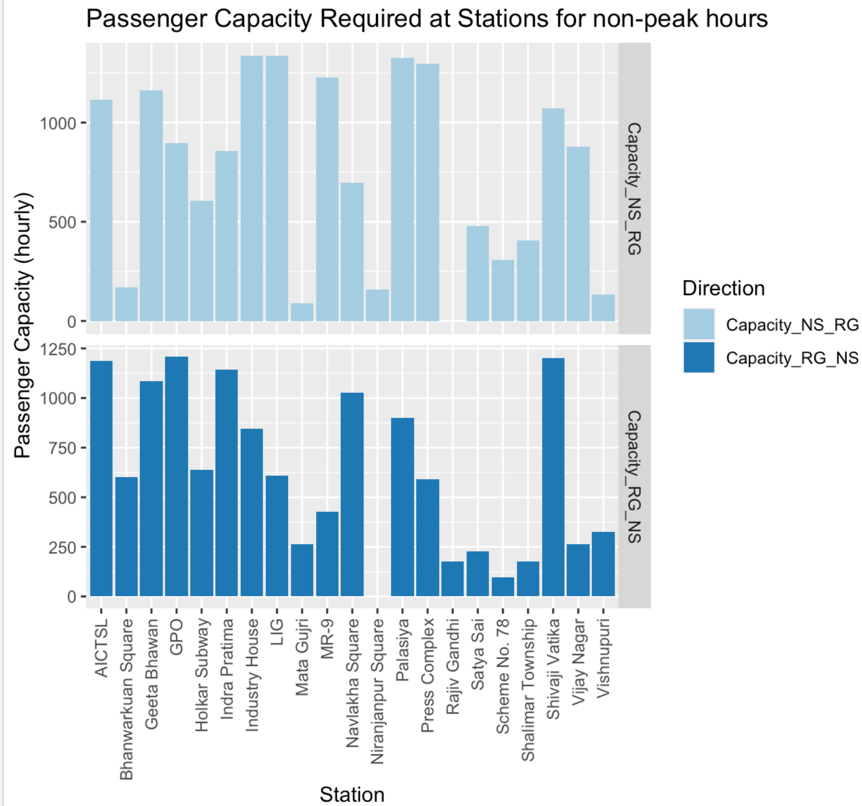
Growth Plan

- This is a 5–8-year strategy
- Urban population is expected to grow at 58% thereby increasing the demand
- Metro Rail

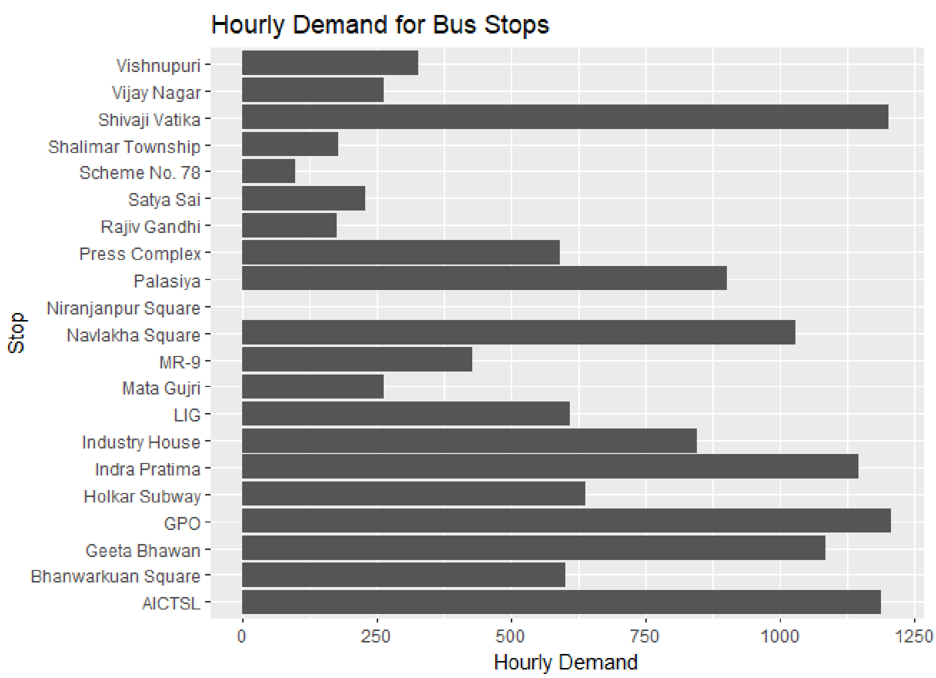
Appendix- A



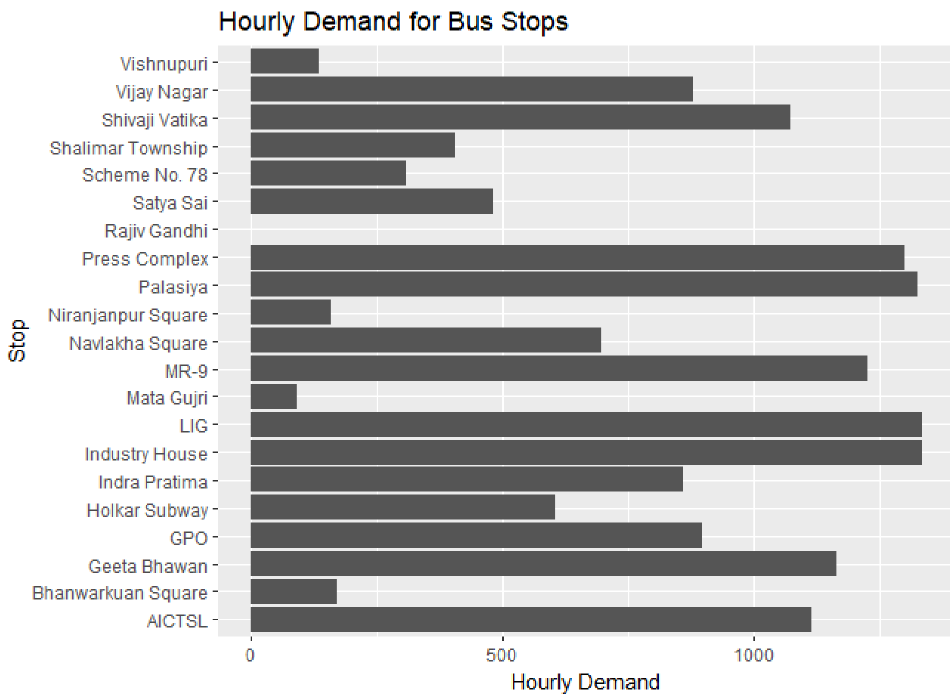
Passenger Capacity Required at Stations during peak hours
Passenger Capacity (hourly)
0
500
1000
0
250
500
750
1000
1250
Capacity_NS_RG
Capacity_RG_NS
Direction
Capacity_NS_RG
Capacity_RG_NS
AICTSL
Bhanwarkuan Square
Geeta Bhawan
GPO
Holkar Subway
Indra Pratima
Industry House
LIG
Mata Gujri
MR-9
Navlakha Square
Niranjanpur Square
Palasiya
Press Complex
Rajiv Gandhi
Satya Sai
Scheme No. 78
Shalimar Township
Shivaji Vatika
Vijay Nagar
Vishnupuri
Station



Rajiv gandhi to Niranjanpur Square



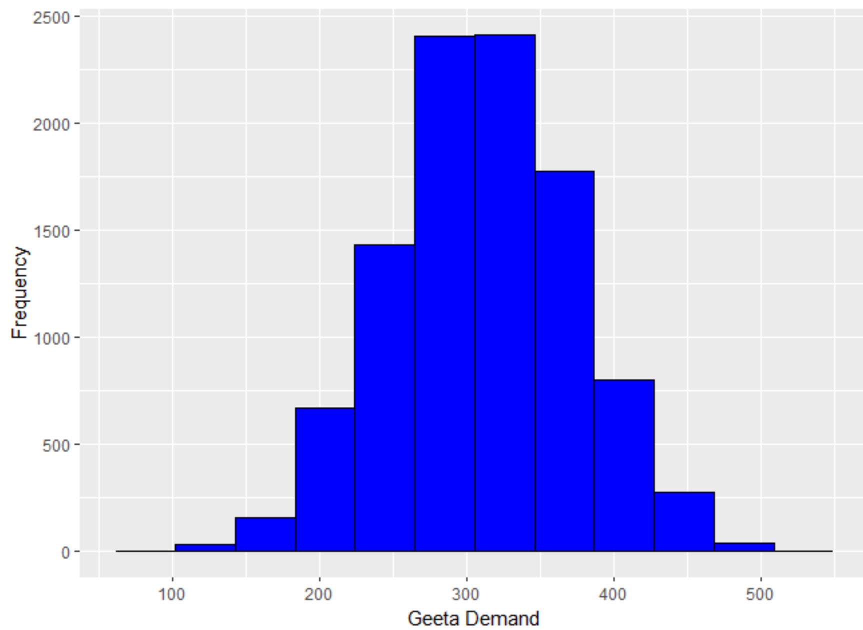
Niranjanpur Square to Rajiv gandhi

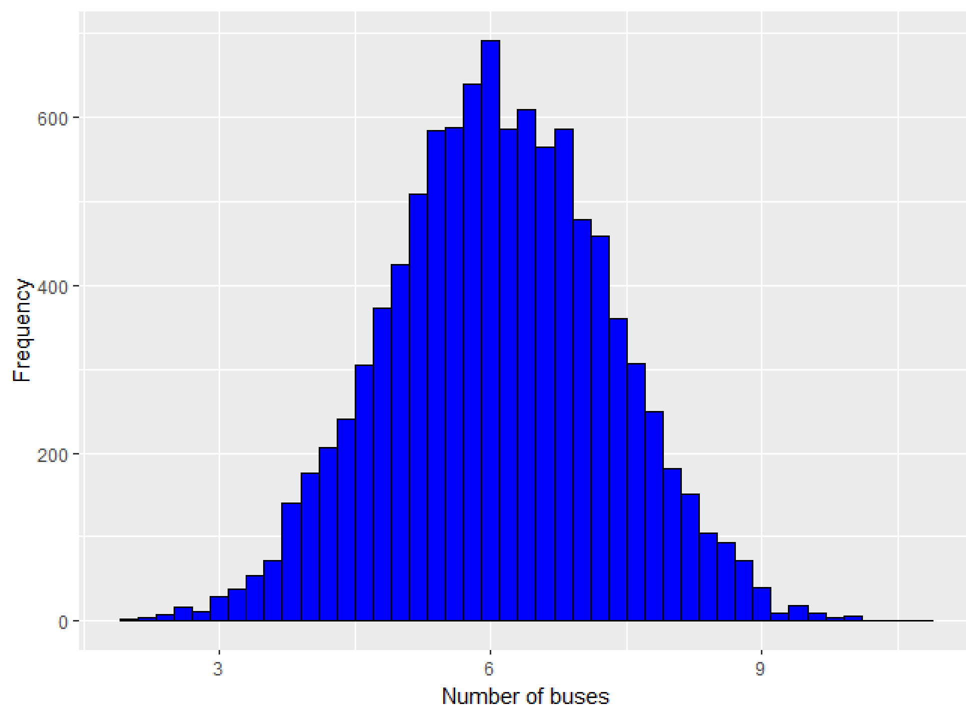


Appendix- B

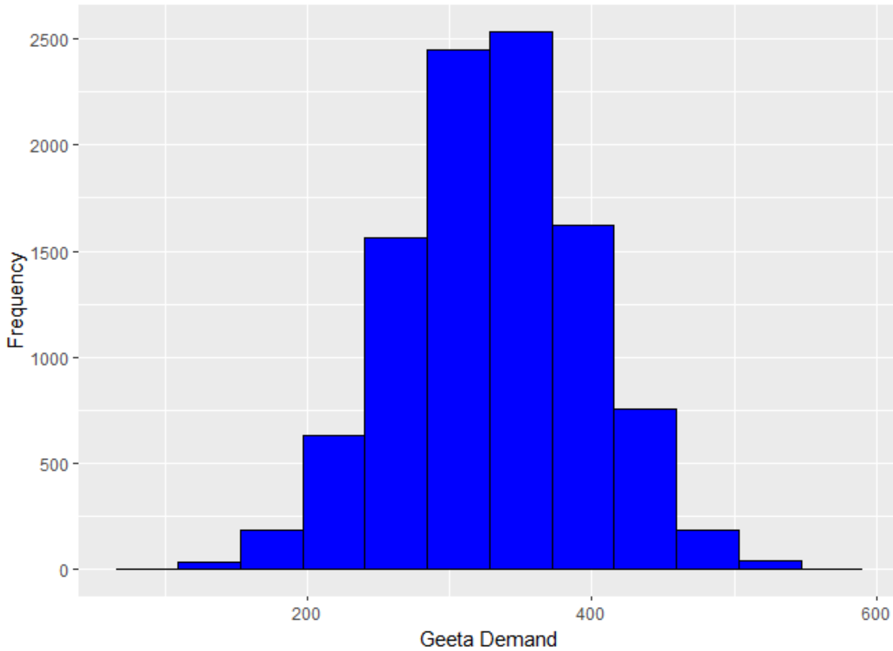
Non-Peak Time

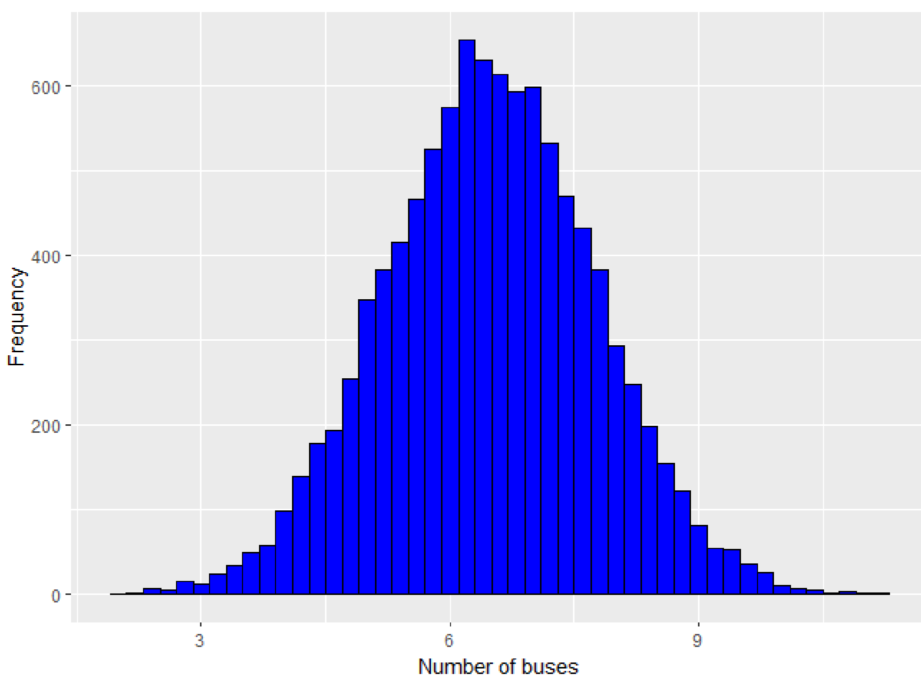
Onward Journey Results





Return Journey Results


2500
2000
1500
1000
500
0
Frequency
200
400
600
Geeta Demand


600
400
200
0
Frequency
3
6
9
Number of buses

Appendix-C

Bus Stop Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Bus Stop Name	Rajiv Gandhi	Mata Gujri	Vishnupuri	Bhanwarkuan Square	Holkar Subway	Navlakha Square	Indra Pratima	GPO	Shivaji Vatika	AICTSL	Geeta Bhawan	Palasiya	Industry House	LIG	Press Complex	MR-9	Vijay Nagar	Satya Sai	Shalimar Township	Scheme No. 78	Niranjanpur Square
	Distance (in km)	0	0.75	1.2	1.7	2	3	3.3	3.7	4.4	4.9	5.4	6.1	6.6	7.2	7.5	8.2	8.9	9.5	10.4	10.9	11.4
1	Rajiv Gandhi	0	7	5	52	19	30	16	71	24	40	100	80	30	61	16	50	39	9	13	16	23
2	Mata Gujri	15	0	4	43	8	24	14	24	15	15	43	37	12	23	5	30	22	8	9	11	10
3	Vishnupuri	8	6	0	21	10	17	9	25	8	16	45	31	0	20	6	21	16	5	4	4	8
4	Bhanwarkuan Square	24	11	7	0	22	53	27	119	32	73	232	176	40	169	13	91	82	12	18	20	26
5	Holkar Subway	8	4	3	31	0	12	5	18	10	11	26	38	14	30	4	9	12	5	6	6	5
6	Navlakha Square	25	20	20	182	47	0	66	145	33	58	299	316	58	223	29	201	133	24	23	42	46
7	Indra Pratima	18	11	9	66	20	52	0	69	21	47	89	78	39	87	13	55	36	15	9	20	25
8	GPO	17	11	6	127	21	72	16	0	30	43	152	131	24	140	12	79	67	8	11	13	15
9	Shivaji Vatika	6	4	3	26	14	13	7	31	0	11	32	20	15	21	4	11	8	4	6	9	7
10	AICTSL	14	5	3	57	19	20	23	39	18	0	61	43	18	47	7	27	21	5	6	16	10
11	Geeta Bhawan	21	10	9	246	34	75	28	102	36	49	0	231	53	169	22	88	36	12	13	17	17
12	Palasiya	30	13	10	243	33	119	31	128	26	44	205	0	35	150	12	112	82	8	13	20	22
13	Industry House	9	5	0	44	14	21	10	40	10	26	53	42	0	41	8	18	13	6	5	10	9
14	LIG	21	11	9	141	22	77	26	95	31	44	186	172	43	0	15	97	75	5	10	19	17
15	Press Complex	13	7	6	43	25	35	18	32	18	24	46	51	15	48	0	26	28	11	10	10	13
16	MR-9	32	20	17	150	40	220	60	146	27	58	364	188	77	268	26	0	124	26	30	37	50
17	Vijay Nagar	30	23	13	220	39	122	46	201	50	49	174	287	57	214	27	162	0	16	28	45	43
18	Satya Sai	7	6	9	38	16	21	12	23	11	16	44	29	18	27	4	22	15	0	12	10	10
19	Shalimar Township	15	8	7	30	20	19	11	43	13	25	56	39	12	50	12	32	24	7	0	8	16
20	Scheme No. 78	26	11	7	85	25	42	13	36	17	34	41	70	36	71	10	45	38	8	14	0	22
21	Niranjanpur Square	20	9	9	63	21	29	27	56	16	28	85	45	17	51	16	45	40	10	17	25	0

Stop	Before Entering	Boarded	Got off	Passenger Capacity required at station	Passenger Capacity required at station (hourly)
Niranjanpur Square	0.0	627.9	0.0	627.9	157.0
Scheme No. 78	627.9	628.5	25.0	1231.4	307.9
Shalimar Township	1231.4	423.0	30.9	1623.5	405.9
Satya Sai	1623.5	319.1	24.6	1918.1	479.5
Vijay Nagar	1918.1	1713.5	117.0	3514.6	878.6
MR-9	3514.6	1694.9	305.1	4904.5	1226.1
Press Complex	4904.5	382.1	94.3	5192.3	1298.1
LIG	5192.3	878.8	728.0	5343.1	1335.8
Industry House	5343.1	274.8	274.4	5343.5	1335.9
Palasiya	5343.5	881.7	923.8	5301.4	1325.4
Geeta Bhawan	5301.4	608.9	1253.7	4656.6	1164.2
AICTSL	4656.6	197.5	397.0	4457.2	1114.3
Shivaji Vatika	4457.2	104.5	273.4	4288.3	1072.1
GPO	4288.3	271.0	973.9	3585.4	896.3
Indra Pratima	3585.4	176.5	329.3	3432.5	858.1
Navlakha Square	3432.5	293.5	937.9	2788.2	697.0
Holkar Subway	2788.2	45.5	410.8	2422.8	605.7
Bhanwarkuan Square	2422.8	41.4	1790.6	673.6	168.4
Vishnupuri	673.6	13.7	148.8	538.4	134.6
Mata Gujri	538.4	15.0	194.8	358.6	89.7
Rajiv Gandhi	358.6	0.0	358.8	-0.2	0.0