PROJECT REPORT UNDER ELITE FELLOWSHIP
On
COMPARTMENTAL MODEL FOR TRAFFIC CONGESTION

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Objectives of the Project:-

- To understand the causes of traffic congestion.
- To develop a compartmental model.
- To simulate word equation and differential equation systematically.
- To use data for solving and propose idea based on the values.

Abstract:-

Traffic in Mega Cities has become a major problem particularly over the last 10 years. In order to improve this situation in the future it is necessary to gain a good understanding of the processes involved. Some way of predicting how the situation may improve (or decline) as a result of current management is vital. To this end we need to be able to predict how the number of vehicles or concentrations varies over time and under different management strategies. We will try to solve the problem of traffic by constructing a compartmental model on a particular road.

Introduction: -

Delhi is the capital of India and its borders touches two Indian states viz. Haryana on the north, west & south and Uttar Pradesh to the east. Five National Highways connects Delhi viz. NH-1: Delhi-Amritsar, NH-2: Delhi-Agra, NH-8: Delhi-Jaipur, NH-10: Delhi-Rohtak and NH-24: Delhi-Lucknow. Although Delhi has good connectivity through railways, there are five main railway stations in Delhi viz. New Delhi Railway Station, Old Delhi Railway Station, Nizamuddin Railway Station, Anand Vihar Railway Station and Sarai Rohella Railway Station, but Delhi is predominantly dependent on road based transport systems as the railways caters to only about 1% of local traffic demand. In terms of traffic volumes, it is second to Mumbai, and handles annually about an approx. of 36 million passengers and 0.56 million tonnes of cargo traffic a year. [1]

Being a political and economic hub of the nation, Delhi attracts people for employment opportunities from whole country. The transport infrastructure is overloaded, roads are saturated, volume to capacity (V/C) ratio on the Delhi roads has crossed to 1; even many places it crossed 2 also.[1] Public Transport System is also inadequate for the uncontrollable traffic. Presently Delhi Metro is providing a slight relief to the city.

Causes of Traffic Congestion: -

- The road length in Delhi has increased at the rate of 4.53% per year, which, of course, is not in pace with the growing population. It is reported that the road density in Delhi is around 155 km per 100,000 populations and about 80 vehicles per km.[2]
- There has been a substantial increase in the number of vehicles on Delhi roads in recent years. In fact, studies have shown that more than a lakh vehicles are plying almost every day on most of the important corridors in Delhi. [2]
  The number of private vehicles (car and two wheeler) has grown exponentially between the years 2003 and 2010. [1]

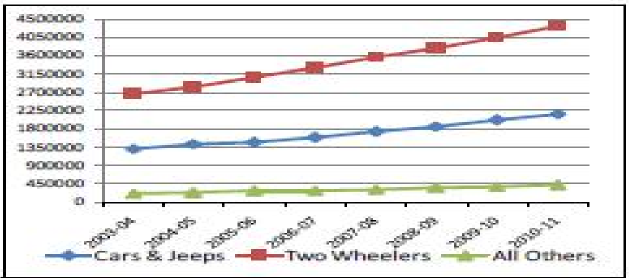


Figure 3.2: Vehicular Growth in Delhi (Category-wise)

- At the intersections, the cycle time ranges from 120 to 180 seconds which leads to long queues, especially in the peak hours.[2]
- Increase in the growth of the population in Delhi, which includes the growing number of workforce, is another important cause.
  As per census 2011, the population of Delhi is 1.68 cr with population density of 225 persons per hectare. The population of Delhi has increased with a decadal growth of 21.6% between 2001 and 2011, which is expected to further rise to 2.3 cr by 2021*(Master Plan for Delhi-2021).* [1]
- There has been an inadequate public transport system in Delhi. In spite of metro and bus services, the transport system has not been able to keep pace with the growing population, as a result of which, more and more people use their private vehicles, leading to increased congestion on the roads.[2]
- Another major cause is that Delhi roads are characterized by mixed traffic, which includes personal vehicles, buses, trucks, three wheelers, two wheelers, including animal driven carts and pedestrians. This creates problems in smooth functioning of the traffic.

Outcomes:-

- Traffic congestion results into unnecessary delays and reduction in speed.
- It has resulted into high rate of road traffic fatalities, making travelling and driving very unsafe in Delhi. Traffic congestion has also led to an increase in the number of accidents on the roads. In fact, Delhi has the highest accident rate in India and third-highest in the world.[2]

  The road accident trend has been shown in the figure: [3]

Road Accidents Trends on Delhi roads

- Traffic rules, red lights, lane driving are not followed which are both the causes and effects of traffic congestion in Delhi.
- Traffic congestion leads to obvious wastage of fuel which further adds in pollution and gives rise to myriad of diseases.
- Increased traffic congestion also leads to increased road rage.
- Traffic congestion also interferes with the passage of emergency vehicles etc.
- The total number of motor vehicles in the Delhi NCR roads was 109.86 lakh on March 31, 2018, showing growth per cent of 5.81 to the previous year. [7]

  Due to population explosion, the no. of vehicles has surged unexpectedly; [6]

S.No.	City	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1.	Delhi	3635	3699	3971	4237	4186	4487	5492	5899	6302	6747	7228	7350	7785	8293	8851

(In thousands)

- Delhi is severely impacted by vehicular pollution. Correlating high-traffic periods with the level nitrogen dioxide in the air, Centre for Science and Environment (CSE) has found that as more vehicles come on to the roads, reducing average speed, pollution levels increase significantly.

  "CPCB's (Central Pollution Control Board) real time monitoring data for NO_2 from Anand Vihar, RK Puram, Mandir Marg and Punjabi Bagh shows that when the average morning peak speed of 28 km/hr drops to 25 km/hr in the evening, NO_2 levels increase from 68 microgram/cubic metre to 94 microgram/cubic meter (an increase of 38 per cent). [4]

GLOSSARY UESD:-[5]

(As per described by Report issued by **Indian Road Congress, 1990**)

- **SPEED: -**Speed is the rate of motion of individual vehicles of a traffic stream. It is measured in meters per second or more generally as kilometers per hour. Two types of speed measurements are commonly used in traffic flow analysis; viz
  - **Time Mean Speed: -** The mean speed of vehicles observed at a point on the road over a period of time.
  - **Space Mean Speed: -** The mean speed of vehicles in a traffic stream at any instant of time over a certain length (space) of road. In other words, this is the average speed based on the average travel time of vehicles to traverse a known segment of roadway. It is slightly less in value than the time mean speed.

- **VOLUME:** - Volume or flow is the no of vehicles at a given point on the road during a designated time interval. Since roads have a certain width and a number of lanes are accommodated in that width, flow is always expressed in relation to the given width (i.e. per lane or per two lanes etc.). The time unit selected is an hour or a day. ADT is Average Daily Traffic when measurements are taken for few days. AADT is Annual Average Daily Traffic when measurements are taken for 365 days of the year and averaged out.

- **DENSITY:** - Density (or Concentration) is the number of vehicles occupying a unit length of road at an instant of time. Density is expressed in relation to the width of the road (i.e. per lane or per two lanes etc.). When vehicles are in a jammed condition, the density is maximum. It is then termed as the **Jamming Density.**

- **CAPACITY:-** Capacity is defined as the maximum hourly volume at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under the prevailing roadway, traffic and control conditions.

- **DESIGN SERVICE VOLUME:-** Design Service Volume is defined as the maximum hourly volume at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under the prevailing roadway, traffic and control conditions while maintaining a designated level of service.

S.No.	Typology of the Road	Capacity (PCUs/hr.)	Lane Capacity (PCUs/hr.)	Design Service Volumes (PCUs/hr.)
1.	Two-lane Undivided	2400	1200	1680
2.	Four-lane Divided	5400(2700)	1350	3780(1890)
3.	Six-lane Divided	8400(4200)	1400	5880(2940)
4.	Eight –lane Divided	13600(6800)	1700	9520(4760)
5.	Ten-Lane divided	20000(10000)	2000	14000(7000)

(INDIAN HIGHWAY CAPACITY MANUAL, CSIR)

- **PEAK HOUR FACTOR: -**Peak hour Factor is defined as the traffic volume during peak hour expressed as a percentage of the AADT. The peak hour volume in this case is taken as the highest hourly volume based on the actual traffic counts.

- **PASSANGER CAR UNITS: -** Urban Roads are characterized by mixed traffic conditions, resulting in complex interaction between various kinds of vehicles. To cater to this, it is usual to express the capacity of urban roads in terms of a common unit. The unit generally employed is the 'Passenger Car Unit (PCU), and each vehicle type is converted into equivalent PCUs based on their relative interference value.

  The Equivalent PCUs of different vehicles categories do not remain constant under all circumstances. Rather, these are a function of the physical dimensions and operational speeds of respective vehicle classes. In urban situations, the speed difference among different vehicle classes is generally low, and as such the PCU factors are predominantly a function of the physical dimensions of the various vehicles. Nonetheless, the relative PCU of a particular vehicle type will be affected to a certain extent by increase in its proportion in the total traffic. Considering all these factors, the conversion factors as shown are recommended for adoption.

Recommended PCU Factors For Various Types OF Vehicles on Urban Roads

VEHICLE TYPE	EQUIVALENT PCU FACTORS PERCENTAGE COMPOSITION OF VEHICLE TYPE IN TRAFFIC STREAM	
	5%	**10% AND ABOVE**
FAST VEHICLES		
1. Two wheelers Motor cycle or Scooter etc.	0.5	0.75
2. Passenger car, pick-up van	1.0	1.0
3. Auto-rickshaw	1.2	2.0
4. Light commercial vehicle	1.4	2.0
5. Truck or Bus	2.2	3.7
6. Agricultural Tractor Trailer	4.0	5.0
SLOW VEHICLES		
7. Cycle	0.4	0.5
8. Cycle Rickshaw	1.5	2.0
9. Tonga (Horse drawn Vehicles)	1.5	2.0
10. Hand cart	2.0	3.0

MATHEMATICAL MODEL:-

❖ IDEA OF COMPARTMENTAL STUDY: -

The compartmental model framework is an extremely natural and valuable means with which is used to formulate models for processes that have inputs and/or outputs over time. Many processes may be considered as compartmental models: that is, the process has inputs to & outputs from a compartment over time.

Our example of this compartmental notion is based on a particular road data (i.e. no. of vehicles per unit length). Here, the compartment is the road (where vehicles are passing through).
The input of number of vehicles can be through many different ways into the compartment.

BALANCE LAW:-[10]

Suppose we are modeling the number of vehicles or the size of population, each of which is changing with time.
We can think of the amount of substance (i.e. number of vehicles at any time at given place or population) as occupying the compartment &
THE RATE OF CHANGE can be considered as "RATE IN" minus "RATE OUT". Thus, we have what is called the BALANCE LAW. In words this is

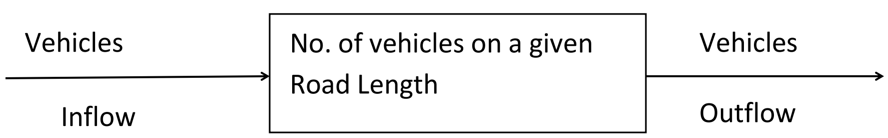
{Net rate of Change of substance} = {Rate in} – {Rate out}

FORMULATING THE DIFFERENTIAL EQUATIONS: -

First of all, we make few assumptions and then, based on these, shall develop a model to describe the process:-

- We assume different average speeds of entry and exit of vehicles from the considered road lengths.
- We nullify all other disturbances which would affect the speed of vehicles.
- We assume that the length of the road is known.
- The vehicles are continuously well distributed so that the concentration is uniform throughout.

We return now to the problem:-
Let C (t) be the concentration of vehicles on the road at any time t. Let S_1be the speed at which vehicles enter the road length.
C_{in} is the concentration of vehicles entering the road length where the compartment is being developed.
Let us suppose speed of vehicles leaving the road length is S_2.
Therefore,
[Inflow speed of vehicles]= S_1 ; [Outflow speed of vehicles] = S_2



Input –Output compartmental diagram for number of vehicles on the road

Then, by applying the B**alance Law** to the number of vehicles, this can be described by the word equation:-

$$\left\{\begin{array}{c}\text{Rate of change}\\ \text{Of no of vehicles}\\ \text{On the road}\end{array}\right\} = \left\{\begin{array}{c}\text{Rate at which}\\ \text{vehicle enters}\\ \text{the road}\end{array}\right\} - \left\{\begin{array}{c}\text{Rate at which}\\ \text{vehicles leaves}\\ \text{the road}\end{array}\right\}$$

The rate at which the number of vehicles is added is the flow rate multiplied by the concentration of incoming mixture.

$$\left\{\begin{array}{l}\text{Rate at which}\\ \text{Vehicles enter}\\ \text{The road}\end{array}\right\} = \text{Inflow Speed of Vehicles x } C_{in}$$

Similarly, the rate at which the vehicles are leaving the road is the outflow speed of vehicles multiplied by the concentration of vehicles on the road.

$$\left\{\begin{array}{l}\text{Rate at which}\\ \text{Vehicles leave}\\ \text{The road}\end{array}\right\} = \text{Outflow Speed of Vehicles x C}$$

This translates into the differential equation for changing no of vehicles on the road:-

$$N'(t) = S_1 C_{in} - S_2 C(t) \text{ where } C(t) = N(t)/L$$

Where C_{in} is the concentration of vehicles entering the road.

Since $N(t) = C(t) L$

Thus, Differential Equation for concentration of vehicles on the road is given as

$$\frac{dC}{dt} = \frac{S_1 C_{in}}{L} - \frac{S_2 C}{L}$$

Now, we assume that concentration at entrance (C_{in}) is given and so is the speed associated with it i.e. S_1 , therefore ($S_1 C_{in}$) is constant.

$$\frac{dC}{dt} = \frac{1}{L}(S_1 \ C_{in} - S_2 C)$$

$$\int \frac{dC}{S_1 C_{in} - S_2 C} = \frac{1}{L}\int dt$$

$$-\frac{1}{S_2}\ln|S_1 C_{in} - S_2 C| = \frac{t}{L} + k(where\ k\ is\ constant\ )$$

$$\ln|S_1 C_{in} - S_2 C| = -\frac{S_2}{L}t + k$$

At t=0, C=C_o;

$$\ln|S_1 C_{in} - S_2 C_0| = k$$

Therefore using initial condition, we have our equation in the form

$$\ln\left|\frac{S_1 C_{in} - S_2 C}{S_1 C_{in} - S_2 C_0}\right| = \frac{-S_2 t}{L}$$

$$\frac{S_1 C_{in} - S_2 C}{S_1 C_{in} - S_2 C_0} = e^{\frac{-S_2 t}{L}}$$

$$C = \frac{S_1}{S_2}C_{in} - \frac{1}{S_2}(S_1 C_{in} - S_2 C_0)e^{\frac{-S_2 t}{L}}$$

When rate in is zero:-

When there is red signal on traffic, the incoming concentration will be zero, and only outflow of vehicles will be going out of the compartment i.e. road then we have: -

$$C = C_0 e^{\frac{-S_2 t}{L}}$$

Also from the differential equation we have

$$\frac{dC}{dt} = -\frac{S_2 C}{L}$$

$$\int \frac{dC}{C} = -\frac{S_2}{L} \int dt$$

$C = C_0 e^{\frac{-S_2 t}{L}}$; Where C_0 is the initial concentration on the road.

CASE STUDIES:-

Road Name: ITO Barrage Bridge Location: ITO

Location	Duration (in hours)	Traffic Volume (in PCUs)	Peak Volume	Peak Time	DESIGN SERVICE VOLUME[9] (in PCUs/hr)
ITO Bridge	24	178333	16289	18:00- 19:00	4760

(Source:-Megacity Logistics: Metrics, Tools and Measures for Sustainability (MEGALOG); CRRI)
Dated :(09/07/17)

Length of the bridge, L = 552 meters

Number of lanes (one way) = 4

According to data available;

Total PCUs passing through the bridge in 24 hours = 178333 PCUs

∴Average PCUs passing per hour through the bridge = $\frac{178333}{24}$ PCUs/hr

Average PCUs passing per hr through 4-lanes (one-way) = $\frac{178333}{48}$

=3715.27 PCUs/hr

At peak hour [from 18:00 – 19:00]

PCUs passing through the bridge (4-lanes one way) = $\frac{16289}{2} = 8144.5$

Design Service Volume for four lanes (one way) = 4760 PCUs/hr [9]

We assume, the initial concentration on the bridge is the average concentration flowing on the road i.e. at t=0, C_0 = 3715.27/L PCUs/hr
At peak hour,

Concentration entering the bridge (C_{in})= 8144.5/L PCUs/hr km

We wish to let this concentration enter the bridge until the concentration on the bridge equals its design service volume.
So, we need to find a time t such that traffic flows smoothly according to Design Service Volume per unit length.

Suppose the constant entry speed and the constant exit speed of the vehicles is 45 km/hr and 36 km/hr respectively (these values might vary).

Using the equation,

$$C = \frac{S_1}{S_2} C_{in} - \frac{1}{S_2}(S_1 C_{in} - S_2 C_0) e^{\frac{-S_2 t}{L}}$$

We can find the required time, t.
On placing the values and solving,

$$\frac{4760}{0.552} = \frac{45}{36} \text{x} \frac{8144.5}{0.552} - \frac{1}{36\text{x } 0.552}(45 \text{ x } 8144.5 - 36 \text{ x } 3715.27) e^{\frac{-36\,t}{0.552}}$$

We get t approximately equal to 10 seconds; this means that after 10 seconds the volume on the bridge will be equal to the design service volume per unit length.
We need to stop traffic after 10 seconds.
Now, the rate in (traffic entering the road) =zero.
We can find time for which concentration drops back to average concentration by using the equation.

$$C = C_0 e^{\frac{-S_2 t}{L}}$$

Here, when t = 0, $C_0 = \frac{4760}{L}$ PCUs/hr km
The speed is same as taken in the first case.
On placing the values and solving,

$$\frac{3715.27}{0.552} = \frac{4760}{0.552} e^{\frac{-36\,t}{0.552}}$$

We get time approximately equal to 14 seconds, this means that after 14 seconds the traffic can again be allowed to enter the bridge and the cycle can repeat.

Conclusion: To maintain a comfortable flow of traffic on ITO Bridge during peak hour, the traffic lights should be designed in such a way as to let vehicles enter for 10 seconds and stop for 14 seconds.

Road Name: Ring Road Location: Rajghat

Location	Duration (in hours)	Traffic Volume (in PCUs)	Peak Volume (in PCUs)	Peak Time	DESIGN SERVICE VOLUME[9] (in PCUs/hr)
Rajghat	24	143270	11585	18:00- 19:00	4760

(Source:-Megacity Logistics: Metrics, Tools and Measures for Sustainability (MEGALOG); CRRI)

Date: - (09/07/17)

Considered length of the road (L) = 1 km

Number of lanes to one way = 4

Total PCUs passing through the road length in 24 hours = 143270 PCUs

Average PCUs passing per hour through the road length = $\frac{143270}{24}$ PCUs/hr

Average PCUs passing per hr through 4-lanes (one-way) = $\frac{143270}{48}$

= 2984.792 PCUs/hr

At peak hour [from 18:00 – 19:00]

PCUs passing through road length on 4-lanes (one way) = $\frac{11585}{2}$

$= 5792.5 \text{ PCUs/hr}$

Design Service Volume for four lanes (one way) = 4760 PCUs/hr [7]

We assume, the initial concentration on the bridge is equal to the average concentration flowing on the road i.e. at t=0, C_0 = 2984.792/L PCUs/hr

At peak hour,

Concentration entering road length= $\frac{5792.5}{L}$ PCUs/hr km

We wish to let this concentration enter the road until the concentration equals its design service volume per unit length.

So, we need to find a time, t such that traffic flows smoothly.

Suppose the entry speed and the exit speed of the vehicles is 45 km/hr and 36 km/hr respectively (these values might vary).

Using the equation,

$$C = \frac{S_1}{S_2} C_{in} - \frac{1}{S_2}(S_1 C_{in} - S_2 C_0) e^{\frac{-S_2 t}{L}}$$

We can find the required time, t.

On placing the values and solving,

$$4760 = \frac{45}{36} \text{x } 5792.5 - \frac{1}{36}(45 \text{ x } 5792.5 - 36\text{x } 2984.792) e^{-36\,t}$$

After calculating, we get approximately equal to 54 seconds; this means that after 54 seconds the volume on the road will be equal to the design service volume per unit length. We need to stop traffic after 54 seconds.
Now, the rate in (traffic entering the road)=zero.

We can find time for which concentration drops back to average concentration by using the equation.

$$C = C_0 e^{\frac{-S_2 t}{L}}$$

Here when t = 0, $C_0 = \frac{4760}{L}$ PCUs/hr km
The speed is same as taken in the first case.
On placing the values and solving,

$$2984.792 = 4760\ e^{-36\,t}$$

After calculating, we get time approximately equal to 47 seconds, this means that after 47 seconds the traffic can again be allowed to enter the road length and the cycle can repeat.

Conclusion: To maintain a comfortable flow of traffic at Rajghat (Ring Road) during peak hour, the traffic lights should be designed in such a way that the vehicles enter for 54 seconds and stop for 47 seconds.

Road Name: Connaught Place Location: Regal Cinema (CP)

Location	Duration (in hours)	Traffic Volume (in PCUs)	Peak Volume (in PCUs)	Peak Time	DESIGN SERVICE VOLUME[9] (in PCUs/hr)
Connaught Place	24	70533	5239	18:00- 19:00	1890

(Source:-Megacity Logistics: Metrics, Tools and Measures for Sustainability (MEGALOG); CRRI
Date: - (09/07/17)

Considered length of the road = L = 1 km
Number of lanes to one way = 2
Total PCUs passing through the road length in 24 hours = 70533 PCUs
Average PCUs passing per hour through the road length = $\frac{70533}{24}$ PCUs/hr
Average PCUs passing per hour through 2-lanes (one-way) = $\frac{70533}{48}$
=1469.4375 PCUs/hr

At peak hour [from 18:00 – 19:00]

PCUs passing through road length on 2-lanes (one way) = $\frac{5239}{2}$

=2619.5 PCUs/hr

Design Service Volume for two lanes (one way) = 1890 PCUs/hr [9]

We assume, the initial concentration on the bridge is equal to the average concentration flowing on the road i.e. at t=0,C_0=$\frac{1469.4375}{L}$PCUs/hr

At peak hour,

Concentration entering the road length = $\frac{2619.5}{L}$PCUs/hr km

We wish to let this concentration enter the road length until the concentration equals its design service volume per unit length.

So, we need to find a time, t such that traffic is allowed to enter smoothly.

Suppose the constant entry speed and the constant exit speed of the vehicles is 45 km/hr and 36 km/hr respectively (these values might vary).

Using the equation,

$$C = \frac{S_1}{S_2}C_{in} - \frac{1}{S_2}(S_1C_{in} - S_2C_0)e^{\frac{-S_2t}{L}}$$

We can find the required time, t.

On placing the values and solving,

$$1890 = \frac{45}{36}\text{x } 2619.5 - \frac{1}{36}(45\text{x } 2619.5 - 36\text{x } 1469.4375)e^{-36\,t}$$

After calculation, we find t approximately equal to 27 seconds; this means that after 27 seconds the volume on the road length will be equal to the design service volume per unit length.

We need to stop traffic after 27 seconds.

Now rate in (traffic entering the road) = zero

We can find time for which concentration drops back to average concentration by using the equation.

$$C = C_0 e^{\frac{-S_2 t}{L}}$$

Here when t = 0, C_0 = 1890/ L PCUs/hr km

The speed is same as taken in the first case.

On placing the values and solving,

$$1469.4375 = 1890\ e^{-36\,t}$$

After calculating, we find time approximately equal to 25 seconds, this means that after 25 seconds the traffic can again be allowed to enter the road length and the cycle can repeat.

Conclusion: To maintain a comfortable flow of traffic at Regal Cinema (Connaught Place) during peak hour, the traffic lights should be designed in such a way that the vehicles enter for 27 seconds and stop for 25 seconds.

Road Name: (Ring Road) Location: Naraina

Location	Duration (in hours)	Traffic Volume (in PCUs)	Peak Volume (in PCUs)	Peak Time	DESIGN SERVICE VOLUME[9] (in PCUs)
Naraina	24	214228	15849	19:00- 20:00	7000

(Source:-Megacity Logistics: Metrics, Tools and Measures for Sustainability (MEGALOG); CRRI)

Date: - (09/07/17)

Considered length of the road (L) = 1 km

Number of lanes to one way = 5

Total PCUs passing through the road length in 24 hours = 214228 PCUs

Average PCUs passing per hour through the road length = $\frac{214228}{24}$PCUs/hr

Average PCUs passing per hr through 4-lanes (one-way)=$\frac{214228}{48}$

= 4463.0833 PCUs/hr

At peak hour [from 19:00 – 20:00]

PCUs passing through road length on 4-lanes (one way) = $\frac{15849}{2}$

$$= 7924.5 \text{ PCUs/hr}$$

Design Service Volume for four lanes (one way) = 4760 PCUs/hr [9]

We assume, the initial concentration on the bridge is equal to the average concentration flowing on the road i.e. at t=0, C_0 = 4463.0833/L PCUs/hr

At peak hour,

Concentration entering road length=$\frac{7924.5}{L}$PCUs/hr km

We wish to let this concentration enter the road until the concentration equals its design service volume per unit length.

So, we need to find a time, t such that traffic flows smoothly.

Suppose the entry speed and the exit speed of the vehicles is 45 km/hr and 36 km/hr respectively (these values might vary).

Using the equation,

$$C = \frac{S_1}{S_2} C_{in} - \frac{1}{S_2}(S_1 C_{in} - S_2 C_0) e^{\frac{-S_2 t}{L}}$$

We can find the required time, t.

On placing the values and solving,

$$7000 = \frac{45}{36} \text{x} 7924.5 - \frac{1}{36}(45 \text{ x} 7924.5 - 36 \text{x } 4463.0833) e^{-36\, t}$$

After calculating, we get approximately equal to 63 seconds; this means that after 63 seconds the volume on the road will be equal to the design service volume per unit length.

We need to stop traffic after 63 seconds.

Now, the rate in(traffic entering the road) =zero.

We can find time for which concentration drops back to average concentration by using the equation.

$$C = C_0 e^{\frac{-S_2 t}{L}}$$

Here when t = 0, C_0=$\frac{4760}{L}$ PCUs/hr km

The speed is same as taken in the first case.

On placing the values and solving,

$$4463.0833 = 7000 e^{-36\, t}$$

After calculating, we get time approximately equal to 45 seconds, this means that after 45 seconds the traffic can again be allowed to enter the road length and the cycle can repeat.

Conclusion: To maintain a comfortable flow of traffic at Naraina (Ring Road) during peak hour, the traffic lights should be designed in such a way as to let vehicles enter for 63 seconds and stop for 45 seconds.

❖ Measures for Improving the Capacity of Roads: -

In the event of traffic on a road section exceeding the design service volume at the desired level of service, the operating conditions will deteriorate. If so, the available practical capacities can be improved through application of traffic engineering techniques besides enforcement.

Some of the measures that could be considered for enhancement of capacity are as under:

I. Prohibiting on-street parking of vehicles, and simultaneously developing off-street parking facilities;
II. We must improve traffic discipline such as correct over-taking, through appropriate road markings, education and publicity;
III. Provision of adequate facilities for pedestrians and cycles;
IV. Provision of segregated right-of-way for slow moving vehicles such as animal drawn carts, rickshaws/ Tongas etc.;
V. Designing a well-maintained and well-developed public transport system.
VI. Designing separate roads or lanes to control speeds and vehicles of different sizes, weights and velocities.

WEB BIBLIOGRAPHY:-

1. https://shodhganga.inflibnet.ac.in/bitstream/10603/90948/6/chapter%203.pdf
2. https://www.mapsofindia.com/my-india/society/traffic-congestion-in-delhi-causes-outcomes-and-solutions/attachment/traffic-congestion-in-delhi.
3. https://timesofindia.indiatimes.com
4. https://www.thehindubusinessline.com/economy/logistics/congestion-low-traffic-speeds-worsen-pollution-in-delhi/article9768721.ece
5. https://thelibraryofcivilengineer.files.wordpress.com/2015/09/irc-106-1990-guidelines-for-capacity-of-urban-roads-in-plain-areas.pdf
6. http://mospi.nic.in/statistical-year-book-india/2017/189
7. https://economictimes.indiatimes.com/news/politics-and-nation/number-of-vehicles-on-delhi-roads-over-1-crore-with-more-than-70-lakh-two-wheelers-economic-survey/articleshow/68128689.cms

BIBLIOGRAPHY:-

8. Megacity Logistics: Metrics, Tools and Measures for Sustainability (MEGALOG); CRRI DATE: - 09/08/2017
9. INDIAN HIGHWAY CAPACITY MANUAL, CSIR
10. Belinda Barnes and Glenn R. Fulford, Mathematical Modelling with Case Studies, A Differential Equation Approach Using Maple, Taylor and Francis, London and New York,2002.