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Minimization of Traffic Congestion by Using Queueing Theory

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Abstract:*Traffic congestion is a phenomenon of increased disruption of the traffic movement. In India, with increasing vehicles on the road, traffic congestion is quickly increasing. Much has been written about the queueing theory technique and its powerful application. This paper is an attempt to analyze the contribution and application of queueing theory in the field of traffic congestion. For this Bhagwanpur Golambar intersection of Muzaffarpur city (located in India) is chosen. The paper summarizes a range of queueing theory results in the following areas: waiting time, utilization analysis and system design. The traffic congestion follows a repeatable pattern during the day, and the locals accept it as a daily routine.*
Keywords:*queueing theory, system design, traffic congestion, utilization analysis, waiting time.*

I. Introduction

Operational research is a scientific approach to analyze problems and making powerful decision. In operational research, queueing theory is a mathematical technique to minimize the waiting time of a particular queueing system. Whenever, the problem of congestion arises in the course of traffic management, the queueing theory and its application always comes into picture. Traffic congestion is a situation on road networks which occurs as its use increases, and is characterized by slower speeds, longer trip times and increased vehicular queueing. Congestion can also happen due to non-recurring highway incidents, such as a crash or road works, which may reduce the capacity of road below normal levels. Thus, congested roads can be seen as an example of the tragedy of the commons.

When vehicles are fully stopped for a period of time then this phenomenon is known as "traffic jam" or "traffic snarl-up". Traffic congestion can lead to drivers becoming frustrated and engaging in road rage. It occurs when a mass of traffic requires space greater than the available road capacity. There are a number of specific circumstances which aggravate congestion; most of them reduce the capacity of a road at a given point or over a certain length, or increase the number of vehicles required for a given volume of people or goods.

Traffic research still cannot fully predict under which condition "traffic jam" may suddenly occur. Because of the poor correlation of theoretical models to actual observed traffic flows, transportation planners and highway engineers attempt to forecast traffic flow using empirical models. Their working traffic models typically use a combination of macro – micro mesoscopic features and may add matrix entropy effects by platooning group of vehicles and by randomising the flow pattern within individual segments of the network. These models are then calibrated by measuring actual traffic flows on the links in the network and the baseline flows are adjusted accordingly.

II. Few Negative Impact Of The Traffic Congestion

- Wasting time of drivers and passengers in blocked traffic affect the economic health of the nations.
- Wasted fuel increasing air pollution and carbon dioxide emission owing to increased idling, acceleration and braking.
- Due to blocked traffic, emergency vehicles may delay in reaching to their destination where they are urgently needed.
- Spill over effect from congested main routes to secondary roads and side street as alternative routes are attempted which affect colony amenity and real estate prices.
- Delays, which may result in late arrival for employment, meetings and education, resulting in lost business, disciplinary action or other personal losses.

III. Steps Preventing Traffic Congestion

It consists of the amalgamation of a number of procedures listed below:-

TRAFFIC FLOW MEASUREMENT
↓
TRAFFIC CONGESTION ANALYSIS
↓
PREVENTION TECHNIQUE

↓
FINAL EVALUATION
↓
RESULTS

IV. Representationof The Bhagwanpur Golambar Intersection Traffic Flow Model Using Queueing Theory

(Single Server as a Traffic Police)

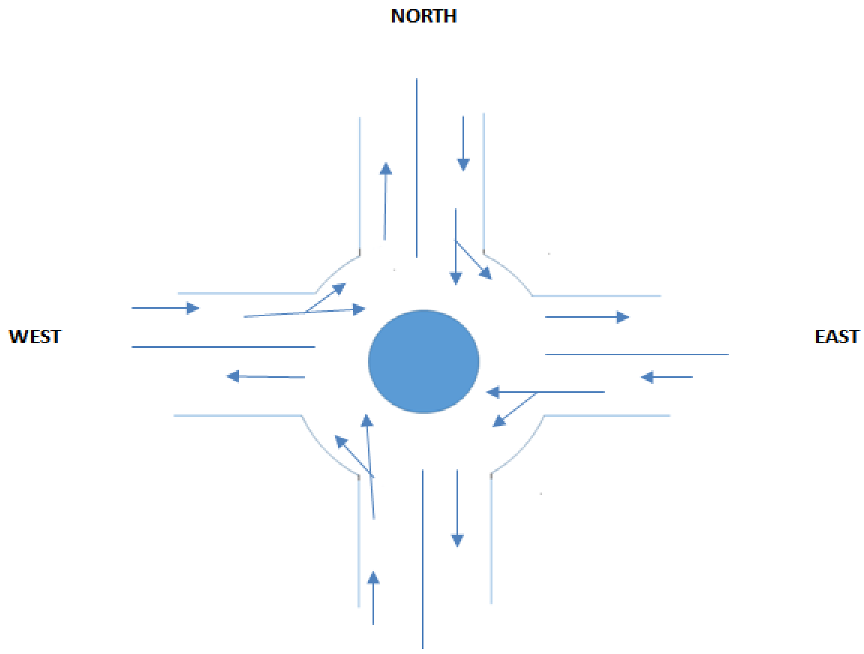


fig::Typical representation of the Golambar intersection

In the above figure, round shape in the middle represents the Bhagwanpur Golambar and incoming arrows to the Golambar represent the arrival of vehicles. NORTH indicates the channel, Rewa Road to Bhagwanpur Golambar Intersection. SOUTH indicates the channel, Gobarsahi to Bhagwanpur Golambar Intersection. EAST indicates the channel, Bairiya to Bhagwanpur Golambar Intersection and WEST indicates the channel, Maripur to Bhagwanpur Golambar Intersection.

V. Description Of The Model(M/M/1): (∞/Fif0)

This research is based on the M/M/1, most widely used queueing system. This queueing system assumes Poisson arrival process with rate λ and the service time for customers are negative exponentially distributed (i.e. generated by Poisson process) with parameter μ. In this system, it is assumed that all customers are independent i.e. their decisions to use the system are independent of other users.

VI. Assumptions Of The Model

This research is based on the following assumptions

I. The arrival of a customer follows Poisson arrival process andthe service time follows negative exponential distribution.
II. The queueing discipline is general i.e. the first customer goes to the server which is ready for the service.
III. The number of customers in the system is very large.
IV. The impact of a single customer for performance of the system is very small, that is a single customer consumes a very small percentage of the system resources.
V. All customers are independent i.e. their decision to use the system are independent of other users.

According to the foremost assumptions it is observed that vehicles entering a channel (or, road) could follow that

a) Total number of car drivers or motorists on the highway is very large.
b) A single car uses a very small percentage of the highway resources.

c) The decision to enter the highway is independently made by each car driver.

VII. Mean Performance Parameter forthemodel
(M/M/1: ∞/FIF0)

7.1 Traffic Intensity
The average number of customers being served is the ratio of arrival and service rate

$$\text{i.e. } \rho = \frac{\lambda}{\mu}$$

For a stable system the service rate μ should always exceed the arrival rate λ and thus ρ should always be less than one. Therefore, it is also known as utilization factor of the server.

7.2 Average Number of Customer in the System
The average number of customer in the system is equal to the average number of customer in the queue together with those being serviced.

$$L_s = \frac{\lambda}{(\mu-\lambda)}$$

7.3 Average Number of Customer in Queue
It can be viewed as average queue length that is, the average number of customers who are waiting in the queue. It is defined as

$$L_q = \frac{\lambda^2}{\mu(\mu-\lambda)}$$

7.4 Average Time Spent in the System
The average time spent in the system is equal to the total time that a customer spends in a system i.e. waiting time plus the service time. It is given by

$$W_s = \frac{1}{(\mu-\lambda)}$$

7.5 Average Waiting Time in Queue
The average waiting time in queue is the average time a customer waits in queue forgetting service. It is expressed as

$$W_q = \frac{\lambda}{\mu(\mu-\lambda)}$$

8. TABLE 1
Tabular Representation of the View of the Traffic Situation at the Bhagwanpur Golambar Intersection

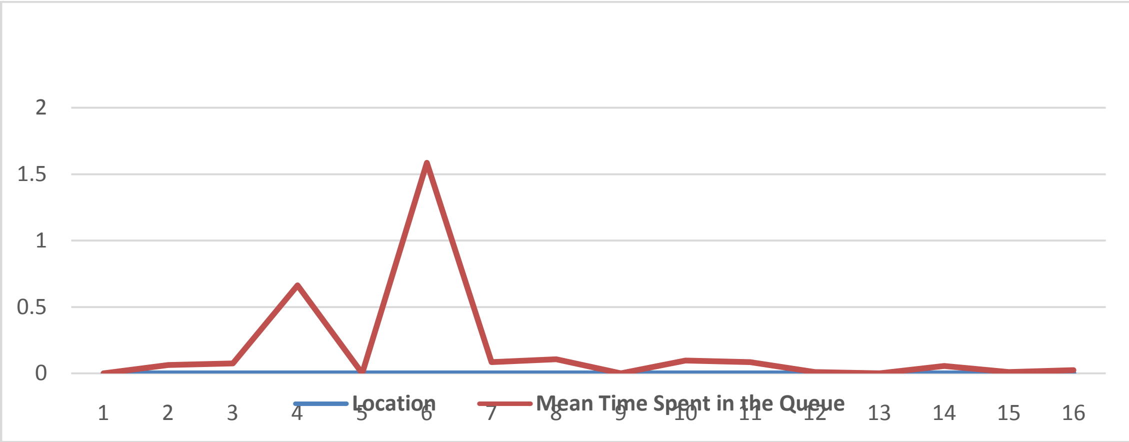
Location	Timing	Arrival		Service		Arrival Rate	Service Rate	Traffic Intensity
		Vehicle	Min	Vehicle	Min			
Bairiya to Bhagwanpur Golambar Intersetion	Morning	25	1.19	32	1.01	21	32	0.6631
	Afternoon	22	2.55	17	1.07	9	16	0.5430
	Evening	**31**	**1.16**	**29**	**1.03**	**27**	**28**	**0.9492**
Gobarsahi to Bhagwanpur Golambar Intersetion	**Morning**	**26**	**2.32**	**17**	**1.44**	**11**	**12**	**0.9493**
	Afternoon	21	1.33	24	1.01	16	24	0.6645
	Evening	19	1.31	21	1.0	15	21	0.6907
Maripur to Bhagwanpur Golambar Intersetion	Morning	17	2.02	15	1.04	8	14	0.5835
	Afternoon	29	1.59	28	1.06	18	26	0.6905
	Evening	51	8.09	42	1.45	6	29	0.2176
Rewa Road to Bhagwanpur Golambar Intersetion	Morning	28	1.25	35	1.02	22	34	0.6528
	Afternoon	29	2.3	49	1.19	13	41	0.3062
	Evening	55	4.55	65	2.25	12	29	0.4184

9. Graphical Representation of Traffic Intensity at Different Channels Leading to Bhagwanpur Golambar Intersection

10. TABLE 2Tabular Representation of the View of the Traffic Situation at the Bhagwanpur Golambar Intersection

Location Or Channel	Session	Arrival Rate	Service Rate	Traffic Intensity	Mean No.of Vehicles waiting in the system	Mean No.of Vehicles waiting in Queue	Mean Time Spent in the System	Mean Time Spent in the Queue
		λ	μ	P	L_s	L_q	W_s	W_q
Bairiya to Bhagwanpur Golambar Intersetion	Morning	21	32	0.6631	2	1	0.0937	0.0621
	Afternoon	9	16	0.5430	1	1	0.1377	0.0748
	Evening	**27**	**28**	**0.9492**	19	18	0.6987	0.6632
Gobersahi to Bhagwanpur Golambar Intersetion	**Morning**	**11**	**12**	**0.9493**	19	18	1.6704	1.5857
	Afternoon	16	24	0.6645	2	1	0.1254	0.0833
	Evening	15	21	0.6907	2	2	0.1539	0.1063
Maripur to Bhagwanpur Golambar Intersetion	Morning	8	14	0.5835	1	1	0.1665	0.0971
	Afternoon	18	26	0.6905	2	2	0.1223	0.0845
	Evening	6	29	0.2176	0	0	0.0441	0.0096
Rewa Road to Bhagwanpur Golambar Intersetion	Morning	22	34	0.6528	2	1	0.0839	0.0548
	Afternoon	13	41	0.3062	0	0	0.0350	0.0107
	Evening	12	29	0.4184	1	0	0.0595	0.0249

11. Graphical Representation of Average Time Spent in the Queue at Different Channels Leading to the Bhagwanpur Golambar Intersection



VIII. Brief Explanation of the Sampled Data at Different Channels Leading to the Bhagwanpur Golambar Intersection at Different Times:

Data is collected (i.e. the arrival rate & service rate) of vehicles at the Bhagwanpur Golambar intersection for 10 days in peak hours of Morning, Afternoon and Evening i.e. 9:00 - 11:00, 1:30 – 3:00 and 5:00 – 6:30 respectively. Then the average of the arrival and service rate is calculated for 10 days and this can be seen in the Table-I. Finally parameters of the traffic flow based queueing model represent the actual situation of traffic flow at Bhagwanpur Golambar intersection. Explanation of the observed traffic flow at different channels leading to the Bhagwanpur Golambar intersection at different time is given below in the Description of Table I and Table II respectively.

Description of Table-I

While following the data of this table, it is observed that traffic in channels leading to Bhagwanpur Golambar intersection from Bairiya and Gobarsahi route during peak hour of Evening and Morning respectively, the traffic intensity is approaching I.Thus, queueing theory presents the above mentioned traffic situation as a imperfect traffic system.

Description of Table-II

This table represents the traffic flow model of queueing theory in mathematical terms. Further we will discuss the traffic flow situation at different channels in different time.

Morning Session

Bairiya to Bhagwanpur Golambar

The arrival rate and service rate were 21 and 32 according to the collected data and hence traffic intensity becomes 0.6631 which revealed a stable traffic situation but not a smooth and good traffic flow.

Gobarsahi to Bhagwanpur Golambar

The arrival rate and service rate according to the collected data were 11 and 12 respectively. Thus the traffic intensity becomes 0.9493 which is approaching 1. Therefore, revealed a really unstable and critical condition of traffic flow.

Maripur to Bhagwanpur Golambar

The arrival rate and service rate were 8 and 14 according to the sampled data and traffic intensity calculated was 0.5835 which revealed a smooth and stable traffic flow.

Rewa Road to Bhagwanpur Golambar

The arrival rate and the service rate according to the data collected were 22 and 34 respectively and traffic intensity calculated was 0.6528 which represents a fairly stable traffic flow situation.

Afternoon Session

Bairiya to Bhagwanpur Golambar

`The arrival rate and service according to the data collected were 9 and 16 and hence traffic intensity becomes 0.5430 which represented a better traffic flow situation in comparison to all the other three channels leading to Bhagwanpur Golambar in afternoon session.

Gobarsahi to Bhagwanpur Golambar

The arrival rate and the service rate were 15 and 24 respectively according to the data collected and the calculated traffic intensity was 0.6645, which represented a stable traffic flow situation but not a smooth and a good traffic flow.

Maripur to Bhagwanpur Golambar

The arrival rate and service rate according to the sampled data were 18 and 26 respectively and traffic intensity calculated was 0.6905 which revealed a stable but not a smooth traffic flow.

Rewa Road to Bhagwanpur Golambar

The arrival rate and the service rate according to the sampled data were 13 and 41 respectively and traffic intensity calculated was 0.3062 which revealed a fantastic traffic flow condition, the best traffic situation in comparison to all other channels leading to Bhagwanpur Golambar Intersection in all the three session.

Evening Session

Bairiya to Bhagwanpur Golambar:-

The arrival rate and the service rate according to the data collected were 27 and 28 respectively and the traffic intensity calculated was 0.9492 which approached 1.Thus, represented the worst condition of traffic as compared to all other channel and in all the three sessions. The traffic observed was seriously unstable and critical.

Gobarsahi to Bhagwanpur Golambar

The arrival rate and the service rate were 15 and 21 respectively according to the data collected and the traffic intensity was 0.6907 as calculated, which revealed a stable traffic flow situation but not a smooth and a good traffic.

Maripur to Bhagwanpur Golambar

The arrival rate and the service rate were 6 and 29 respectively according to the sampled data and the traffic intensity was 0.2176 as calculated, which revealed a marvellous traffic flow condition, the traffic flow situation and smooth vehicle flow in comparison to all other channels and in all sessions.

Rewa Road to Bhagwanpur Golambar

The arrival rate and the service rate were 12 and 29 respectively according to the data collected and the traffic intensity was 0.4184 which represents a good, stable and smooth traffic flow situation.

IX. Results And Discussion

a) Acute analysis of the data collected at Bhagwanpur Golambar intersection revealed proximity to a under perfect system.
b) It is observed that in some of the channels leading to the intersection, the arrival rate reached in proximity to the respective service rate i.e. traffic intensity is approaching 1.
c) It is also observed that there is no fixed time interval between the signals given by server (traffic police signals to the traffic flow).
d) Bairiya and Gobarshahi route leading to the intersection is the most congested route during the evening and morning respectively.
e) Road side hawkers and parking at unauthorized places are also responsible for the traffic congestion to some extent.
f) It is observed that in the morning, drivers of commercial transports take advantage of the situation, they park and off load/on load passenger at unauthorized places very closed to the intersection, impeding the flow of the traffic when server resumed work.
g) It is observed that after installation of equipment for measuring the pollution level in the air, the pollution level has already been crossed the danger level. It is also a matter of concerned for the designers of the pollution free smart city Muzaffarpur. The prevailing "jam" phenomenon in this city is also responsible in raising the pollution level.

   Thus the present study will be a helping tool for the architects of the pollution free proposed smart city Muzaffarpur.

X. Conclusion

The queueing theory is an effective mathematical technique for solving various acute problems of any organization or system. As queueing theory focuses on representation of traffic situation by using mathematical terms and formulas, its application cover a wide range of present situation including the traffic congestion. City planning and urban designpractices can have a huge impact on levels of future traffic congestion. The present work is based upon the actual survey of traffic flow at various times and at different location of Bhagwanpur Golambar intersection of Muzaffarpur City. The application of the queueing theory is exploited to minimize the traffic congestion leading to a well-known situation "Traffic Jam" at a particular time. The study will be a helping tool for the designers of the forthcoming "Smart City" Muzaffarpur which is a dream project of the people of Muzaffarpur with a hope of "Jam free traffic". We find that the following steps can be taken to avoid the congestion.

I. It can be reduced by either increasing road capacity or by reducing traffic.
II. We can provide separate lanes for specific user groups.
III. Variable message signs can be installed along the roadway to advice road users.
IV. Increasing width of the channel of congested route or building up of highways.
V. Widening the channel of Bairiya and Gobarshahi route by removing the roadside hawkers.
VI. Introducing public transport such as busses and office cabs.
VII. There must be parking restriction for the motor vehicles by the roadside (i.e. at unauthorized place), so that congestion can be reduced.

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