A Novel Framework for Prioritizing Emergency Vehicles through Queueing Theory

Parul Choudhary, Rakesh K. Dwivedi, Umang

Abstract: Traffic congestion is a mess on the road networks as it reduces the speed elongates trip time and lengthens vehicular queuing. It leads to a chaotic situation wherein the usage of traffic increases and resources are wasted. As according to name Emergency vehicles must be prioritized to reach their destination at the earliest.Emergency vehicles reaching destination on time can be very critical for saving lives. This paper attempts to analyze the dual problem of traffic congestion and fast commuting of emergency vehicles through a novel applicationof Queueing Theory. The manuscript reports implementation of proposedM/M/1: ∞/prioritymodel in Rohini's Sai Baba Chowk to prioritize emergency vehicles over others. The same framework was also found to suit different roads on different patterns at different time slots.

Keywords: Queueing Theory, Traffic Density, Interarrival rate, Service rate, Turnaround Time

I.INTRODUCTION

The pathetic situation of the traffic congestion is a mess on the road network as it reduces the speed, trip time becomes longer and vehicular queuing increases[1]. It leads to a chaotic situation wherein the usage of traffic increases and resources are wasted[2]. The other factors which add on to this problem of traffic congestion are the incidents on the roads for example accidents or constructions work which further decreases the capacity of the road networks even below the existing levels[2]. To further aggravate this condition, there are other specific situations as well. These situations can vary from reducing the capacity of the road at any given time or at a stretch to increase the number of vehicles on the road that carry a particular lot of people or goods[3]. The analysis of delay is one of the major problems in the analysis of any traffic system[4]–[6]. Delay being a more delicate concept can be defined as the difference between the ideal time to travel a particular road segment and the actual time to travel the same[7]–[9]. With this, a new question is raised as to what actually the ideal travel time is? In the real scenario, the actual travel time depends on the situation. However, there are two mechanisms which perfectly fit the frame to compare the actual travel time with the ideal. These two are travel time taken when there is free flow of the vehicles and the travel time at the higher capacity[10][11].

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But, as per the recent researches done[12]–[14], the results vary in case of the roads, as in there is slight difference in both the speeds. If such is the case, then the focus is on the delay which results when demand is greater than the capacity[15]. Such a delay is known as queuing delay and the same can be studied further by a theory called queuing theory[16]. This whole concept of the queuing theory involves the study of queuing system that includes a server, stream of customers who demand the services and the ones who get served[17].Emergency vehicles implies vehicles like ambulance, fire trucks etc which are supposed to respond to an emergency situation [18], [19]. Hence to reach the destination at the earliest is of utmost importance. Emergency vehicles reaching destination on time can be very critical for saving lives.[8], [9], [20], [21]. As the name suggests, emergency vehicles should be prioritized. Not only traffic congestion leads to increase in the time taken to reach the destination, but the probability of accident also increases. The emergency vehicles in a haste to reach a destination quickly drives at a higher speed on a red light can prove as a danger to other vehicles and can even lead to accident[22]. This manuscript attempts to analyze the dual problem of traffic congestion and fast commuting of emergency vehicles through a novel application of Queueing Theory.[16]. The rest of the manuscript is framed as follows: Section II discusses the basic idea of queuing theory which has been used as the base to design the traffic congestion minimization and emergency vehicle prioritization framework. Section III discusses the proposed framework. Section IV elaborates on the results obtained after model implementation. Section V delves upon the results and findings. Section VI concludes the work by discussing the future work and extensions.

II.QUEUING THEORY

Queuing Theory analyses traffic congestion mathematically. Through mathematical modelling we estimate the increase of traffic which leads to the increase of waiting time of vehicle. It helps in analyzing every aspect of all vehicles waiting in queue to get served[23], [24]. All this includes; process of the arrival; process of the service; servers, system places and customers involved in actual numbers. There are three input parameters in the queuing system: Mechanism of the arrival:This mechanism describes the rate at which vehicles arrive at the server. The inter arrival pattern of vehicles depends upon the inter arrival time and size of input source. Protocols about queuing:It describes the pattern in which vehicle will be served next eg.FIFO (first in first out), FILO (first in last out), SIRO (served in random order), scheduling the priorities or time sharing.

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Mechanism regarding the services:This mechanism involves the details of the resources required and if received, then how much time is taken to service a request. It also describes available servers and whether it takes any action to prevent vehicles of low priority above vehicles of high priority.

III.MODELLING

Queueing systems depend upon numerous queue characteristics to form variant Queueing models[25]. Different models rely on different source platform, arrival pattern, service distribution, number of servers, queue protocols,etc.

According to M/M/1 Queue Model the vehicles arrive in Poisson distribution with interarrival rate λ, which is exponentially distributed. This distribution could be appliedbycounting number of vehicle that reach intersection between start and end of red light.Arrival of one vehicle does not affect the other and the number of time slots at which vehicles are counted is fixed.Number of vehicles that cross the junction on green signal are those which are getting serviced while rest stay back in queue. This time is also exponentially distributed at service rate μ. Since all roads meet at single junction which acts as a server, so this manuscript proposes single server.

This manuscript proposes M/M/1 model with priorities. This means that in this model we have two classes of vehicles. All emergency vehicles lie in Class 1and rest of the vehicles in class 2. Vehicle of each class arrive in poissondistribution fashion with inter arrival rate λ1, and λ2, respectively and vehicle of each class are independent of each other. The time in servicing these vehicles is exponentially distributed at service rate μ.

The system shows regular flow of traffic if

$\rho_1 + \rho_2 < 1$;

where $\rho_i = \lambda_i / \mu$ where i = 1, 2.

The proposed model assumed that emergency vehicles of class 1 have priority over the rest of vehicles belonging to class 2. Since this model follows preemptive execution of vehicles, the execution of a vehicle belonging to class 2 is never allowed if there is a vehiclebelonging to class 1 in the system. Emergency vehicle will first avail green signals than any other normal vehicle. If any vehicle of class 2 is getting executed, it will be stopped in midst of its execution and will be resumed only after class 1 vehicle gets executed.

Assumptions of The Proposed Model (M/M/1: ∞/priority)

The manuscript assumes following queue characteristics to carry the research

The inter arrival time of vehicles follow probabilistic arrival which allow Poisson method

The Service of vehicles at junction follow negative exponential distribution

The discipline followed by queue model is Preemptive priority.

The size of the source is too large. The number of vehicles on the road is too large.

The number of vehicles arriving or leaving queue in an interval is k, where k=0,1,2,3…

The arrival of one vehicle does not affect the occurrences of second vehicle which shows that vehicles are independent.

A single vehicle consumes a very small-time span of the entire turnaround time of the system. That means the impact of one vehicle on the output of entire system is very less

According to the above assumptions, k is taken as Poisson variable taken randomly

Evaluation of the performance for the proposed model (M/M/1: ∞/priority) can be measured by following parameters

Density of Traffic: It is defined as ratio of arrival rate by service rate i.e $\rho = \lambda / \mu$. Since the research work applies(M/M/1: ∞/priority) queueing model, there is different interarrival time for each class i.eλ_1, and λ_2. To achieve a stability in system service rate must be greater than arrival rate of each class such that $\rho_1 + \rho_2 < 1$, where $\rho_i = \lambda_i / \mu$; i = 1; 2.

Average Number of Emergency vehicles waiting in the System: Average of emergency vehicles standing in queues and those getting serviced is the average number of emergency vehicles in the system which is given by $E(N1)= \rho_1/(1-\rho_1)$, where $\rho_1 = \lambda_1/\mu$.

Average Number of Normal Vehicles waiting in the system: Average of normal vehicles standing in queues and those getting serviced is the average number of normal vehicles in the system which is given by $E(N2)= \rho_2/((1-\rho_1)(1-\rho_1-\rho_2))$, where $\rho_1 = \lambda_1/\mu$, $\rho_2 = \lambda_2/\mu$.

Turnaround time for emergency vehicles: Turnaround time for emergency vehicle is the average time spent by emergency vehicle in waiting and getting service which is given by

$E(T1)=(1/\mu)/(1-\rho_1)$

Turnaround time for Normal vehicles: Turnaround time for normal vehicle is the average time spent by normal vehicle in waiting and getting service which is given by

$E(T2)=(1/\mu)/((1-\rho_1)(1-\rho_1-\rho_2))$, where $\rho_1 = \lambda_1/\mu$, $\rho_2 = \lambda_2/\mu$)

IV. REPRESENTATION AND ANALYSIS OF TRAFFIC FLOW MODEL OF SAI BABA CHOWK IN ROHINI USING QUEUE THEORY

Sai Baba Chowk in Rohini has generally heavy flow of traffic. Following figure represents Sai BabaChowk of Rohini in Delhi.

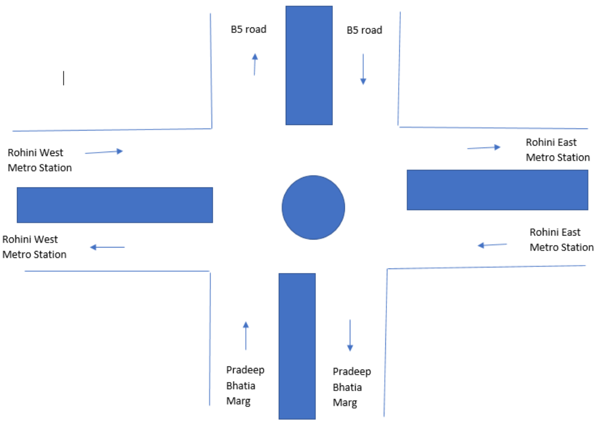

Figure 1: Representation of Sai Baba Chowk in Rohini

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Live data of running vehicles at Sai Baba Chowk is collected for 15 days in three different time slots. Traffic is maximum in peak hours of Morning between 9.00a.m. to 11.00a.m., becomes lean in afternoon between 1.00p.m.-2.30p.m. and again increases in evening between 6.00pm-8.00pm. The videos collected from the data site shows the number of emergency vehicles and normal vehicles arriving and leaving the lane per unit time. Data of 15 days is averaged and tabulated in Table I and Table II.

Number of vehiclesarriving on different roads at different time slots leading to Sai Baba Chowk is given below in Table I. Number of vehicles crossing green signals (or getting serviced) on different roads at different time slots leading to Sai Baba Chowk is given below in Table II. Traffic density is ratio of Inter-arrival to that of rate of servicing. Table III calculates traffic density for emergency vehicles and normal vehicles on different roads at different time slots leading to Sai Baba Chowk. Table IV calculates the average number of emergency vehicles waiting in the system, average number of normal vehicles waiting in the system, turnaround time of emergency vehicles and turnaround time for normal vehicles on different roads at different time slots leading to Sai Baba Chowk.

Table I : Vehicles arriving on different roads at different time slotsleading to Sai Baba Chowk

Direction	Time Slot	No of EV's arriving at junction	No. of Normal Vehicle arriving at junction	Time taken by vehicles in arrival(min)	Rate of arrival ofEV's (λ 1)	Rate of arrival of Normal Vehicle(λ 2)
Rohini East Metro station to Sai Baba Chowk	Morning	1	60	1	1	60
	Afternoon	0	38	1.2	0	32
	Evening	2	66	1	2	66
Rohini West Metro station to Sai Baba Chowk	Morning	1	60	1.3	0.77	46
	Afternoon	2	30	1.18	1.69	25
	Evening	0	52	1.1	0	47
Pradeep Bhatia Marg to Sai Baba Chowk	Morning	1	22	1	1	22
	Afternoon	0	25	1	0	25
	Evening	2	35	1.15	1.74	30
Road 5 to Sai Baba Chowk	Morning	1	33	2	0.5	17
	Afternoon	1	18	2	0.5	9
	Evening	0	43	2.1	0	20

Table II: Number of vehicles crossing green signals (or getting serviced) on different roads at different time slots leading to Sai Baba Chowk

Direction	Time slot	No of vehicles getting service	Time taken by vehicles in service	Rate of service
Rohini East metro station to Sai Baba Chowk	Morning	80	1.10	72.7
	Afternoon	60	1.20	50
	Evening	100	1.10	90.9
Rohini West metro station to Sai Baba Chowk	Morning	80	1.20	66.7
	Afternoon	70	1.10	63.6
	Evening	39	0.47	83
Pradeep Bhatia Marg to Sai Baba Chowk	Morning	25	0.50	50
	Afternoon	32	1	32
	Evening	33	1	33
Road 5 to Sai Baba Chowk	Morning	25	0.30	83.3
	Afternoon	27	0.45	60
	Evening	37	0.45	82.2

Table III: Traffic density for emergency vehicles and normal vehicles on different roads

Direction	Time slot	Traffic density of EV	Traffic density of Normal Vehicle
Rohini East metro station to Sai Baba Chowk	Morning	0.0138	0.825
	Afternoon	0	0.633
	Evening	0.022	0.726
Rohini West metro station to Sai Baba Chowk	Morning	0.0115	0.692
	Afternoon	0.0266	0.4
	Evening	0	0.57
Pradeep Bhatia Marg to Sai Baba Chowk	Morning	0.02	0.44
	Afternoon	0	0.781
	Evening	0.0527	0.922
Road 5 to Sai Baba Chowk	Morning	0.006	0.198
	Afternoon	0.0083	0.15
	Evening	0	0.249

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at different time slots leading to Sai Baba Chowk.

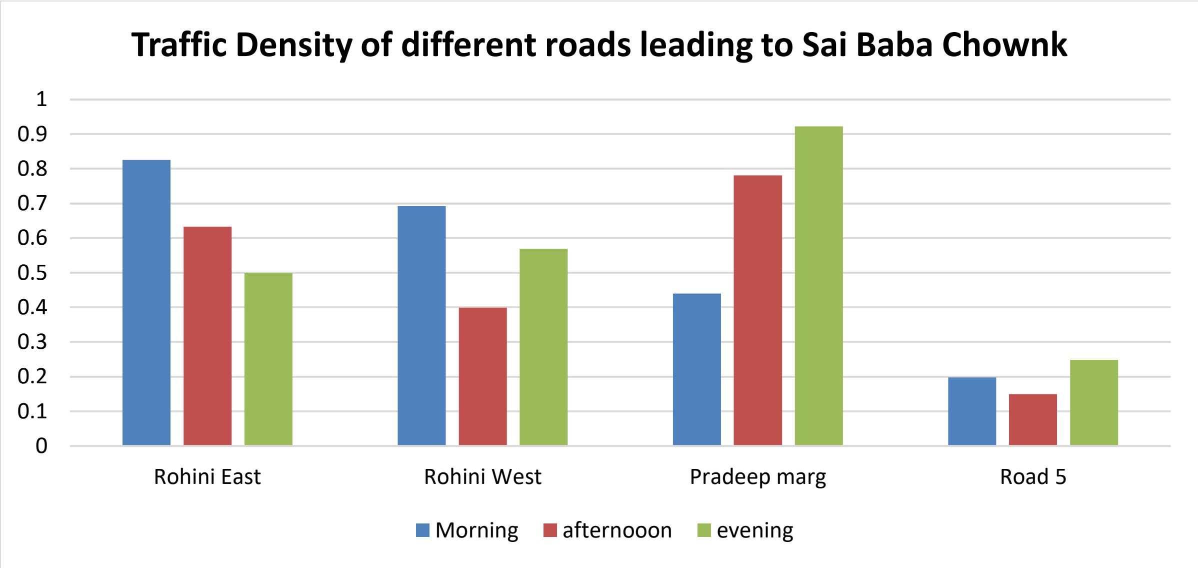

Figure II: Traffic density of different roads at different time slots leading to Sai Baba Chowk for normal Vehicles

Table IV: Average number of emergency vehicles waiting in the system, average number of normal vehicles waiting in the system, turnaround time of emergency vehicles and turnaround time for normal vehicles on different roads at different time slots leading to Sai Baba Chowk

Direction	Time Slot	E(N1)	E(N2)	E(T1)	E(T2)
Rohini East metro station to Sai Baba Chownk	Morning	1	6	0.014	0.086
	Afternoon	0	2	0.02	0.055
	Evening	1	3	0.011	0.045
Rohini West metro station to Sai Baba Chownk	Morning	1	3	0.015	0.051
	Afternoon	1	1	0.016	0.028
	Evening	0	2	0.012	0.028
Pradeep Bhatia Marg to Sai Baba Chownk	Morning	1	1	0.02	0.038
	Afternoon	0	4	0.031	0.143
	Evening	1	39	0.032	1.278
Road 5 to Sai Baba Chownk	Morning	1	1	0.012	0.015
	Afternoon	1	1	0.017	0.02
	Evening	0	1	0.012	0.016

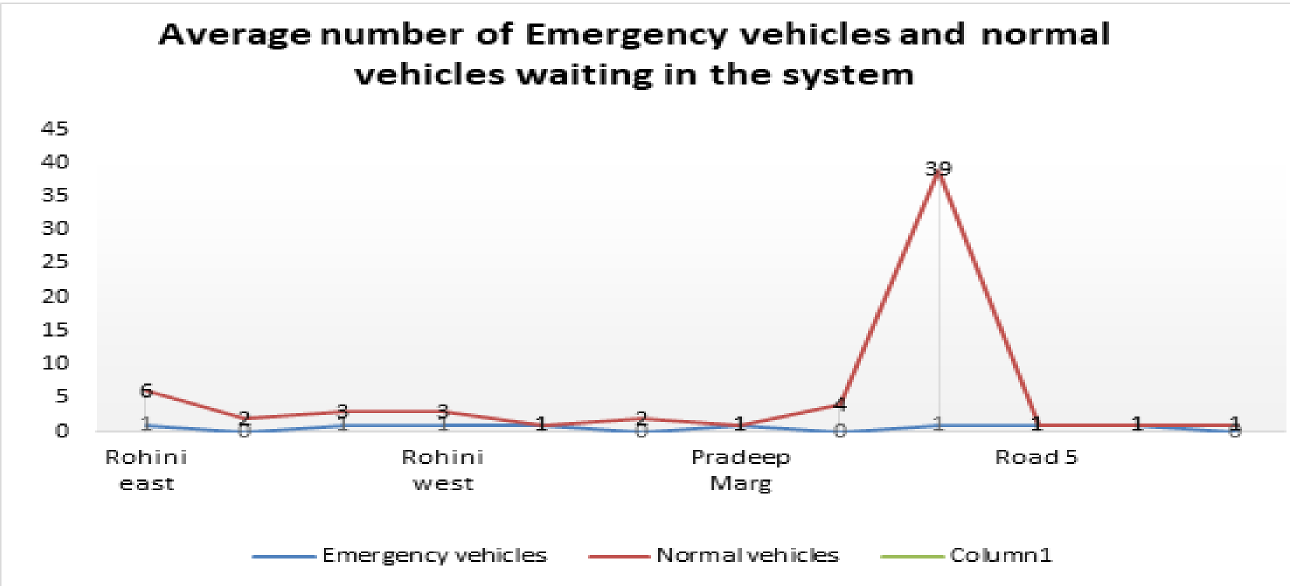

Figure III: Average number of Emergency and normal vehicles waiting in the system

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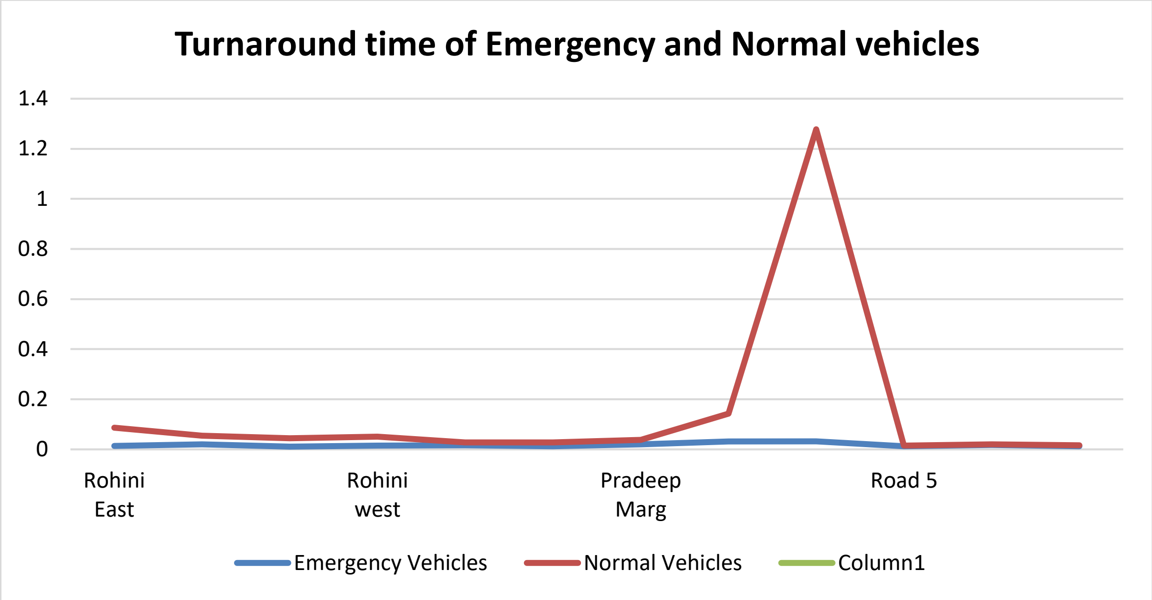

Figure IV: Turnaround time of Emergency and normal vehiclesin the system

V.FINDINGS

Traffic density of different roads leading to chowk explains the flow of traffic across our site of investigation Analysis of figure II shows different traffic pattern for different roads. Road leading from Rohini East metro station to Sai Baba chowk shows maximum traffic density among morning time span of all roads. This depicts that in morning maximum volume of traffic is of those vehicles leaving for offices at peak hours between 9.00a.m.to 11 a.m. Traffic density decreases in lean hours of afternoon and even decreases in evening as vehicle leave for residential areas. There is smooth flow of traffic in afternoon and evening whereas in morning system is slow. Road leading from Rohini west metro station to Sai Baba Chowk shows high traffic density in peak hours of morning and evening both whereas low in lean hours of afternoon. Traffic moves slow in morning and rest of the time it is manageable. Road leading from Pradeep Bhatia Marg to Sai Baba Chowk is showing a complete new pattern as it is a shopping hub. Generally, shops get opened by 11a.m. onwards so traffic density is less in morning and reaches to its maximum level by evening. In evening it is approaching 1 which makes the system very sluggish and slow.

Road 5 is a silent residential area where traffic density remains low throughout the day. However, a slight difference in morning, afternoon and evening is visible. Average number of vehicles both Emergency and normal explains the hindrance caused by waiting vehicles in the flow of traffic. A close analysis of figureIII shows comparison of vehicles waiting in system at different time slots. Number of vehicles waiting in system are more in peak hours of morning and evening as compared to afternoon on our main road connecting Rohini East metro station to Rohini West Metro Station. Both roads show similar pattern except the fact that Rohini east shows more number of waiting vehicles in morning than in evening whereas Rohini west shows visa versai.e. more number of waiting vehicles in morning as compared to evening. The difference suggests that the road from Rohini east metro station leads to areas of work which has high occupational index as compared to the other. Road leading from Pradeep Bhatia Marg goes from a shopping hub of Rohini so the pattern shows a sudden rise in number of vehicles waiting in system from morning to evening. Shops generally open late as compared to offices so this road shows lean period in morning. Number of vehicles waiting in system at evening time slot suggests heavy traffic congestion on the road. Road 5 is a residential complex, so the traffic remains generally smooth but not ideal. Through our modelling we have given priority to emergency vehicle as compared to normal vehicle thus showing very few number of emergency vehicles waiting on road but again its not ideal. Close analysis of figure IVshows turnaround time of vehicles which is sum of time spent in waiting and servicing on the road. This graph also shows the same pattern as figure III.

VI.CONCLUSION AND FUTURE SCOPE

Queueing theory helps in modelling traffic flow on roads with close analysis of congestion causing delay. We used M/M/1: ∞/priority model in Rohini's Sai Baba Chowk to prioritize emergency vehicles over others. A close analysis shows that different roads show different pattern at different time slots. These roads do not show characteristics of a perfect system because the time span of traffic lights are not customized according to the need of commuters. Future scope remains in customizing these traffic lights according to the road pattern to get a stable system with least congestion minimizing delay.

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