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Level of Service & Throughput Maximization at Operational Toll Plazas

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Abstract - *The Toll Collection on National Highways /Expressways usually have serious repercussions on their operation and management. Performance evaluation depends on operating characteristics of toll plaza. The operating characteristics toll plazas are service capacity of toll gates, vehicles arrival patterns, availability of number of various type gates, driver lane choice behavior & stability of performance. The optimal toll plaza is one which minimizes expected time a driver must spend while travelling through a system. Operational performance of two toll plazas namely Thikaria and Badgaon on Jaipur-Kishangarh expressway part of National Highway-8 were studied and it is concluded that level of service for toll area traffic plays an important role in maximization of throughput & determination of optimal toll lane configuration of toll plazas. Numerous measures of effectiveness including density, Volume to capacity ratio & delay are available to evaluate level of service. The delay is very important and identifiable measure of effectiveness which represents drivers level of inconvenience. The average queue length and average time spent at toll collection system seriously influence the delay so used to classify the level of service into six levels. Based on the research studies it is concluded that toll operations are stable if average queue length at toll gate does not exceed by three vehicles, when average queue length exceeds by ten vehicles, the operations become unstable & undesirable. The essential features of the recommended methodology of evaluation of level of service are presented.*

Key Words: **Capacity, Congestion, Pollution, Toll roads.**

1. Introduction

India has an extensive road network with around 54,72,144 Km. in 2017, the second largest in the world. It is estimated that more than 70% freight & 85% passengers traffic in the country being handled by the roads. While National Highways/Expressways constitutes about 2% (1,15,435 Km. length in 2017) of all roads. Yet they carry about 40% of road traffic leading to strain in the capacity. So improvement of the National highways capacity to international standard become the prime necessity. This requires huge financial requirements which cannot be meet by regular budgetary system of the country. To meet such huge financial requirement Toll operate transfer (TOT) models e.g. PPP, BOT, BOLT etc. are adopted to include privately finance investors. In TOT models entire finance for construction operation & maintenance is arranged by the entrepreneur. The entrepreneur is permitted to recover investment through levy of toll fees from the user of facility at the capping rate prescribed by the Govt. of India from time to time in the concession period awarded to the entrepreneur. After completion of the concession period the facility is return back to the Government.

The toll plaza is a structure built on a highway segment where vehicle has to pay toll fee. The aim of the toll plazas on National highway/expressways is to allow uninterrupted & high speed flow. Present day the traffic congestion become a major problem at toll plazas, which causes travel time delay, increase in Vehicle operation cost VOC & air pollution and decrease in level of service at toll plazas. The objective of this paper is to established methodology for evaluation of level of service at toll plazas by studying operating characteristics & vehicle arrival pattern of toll plazas.

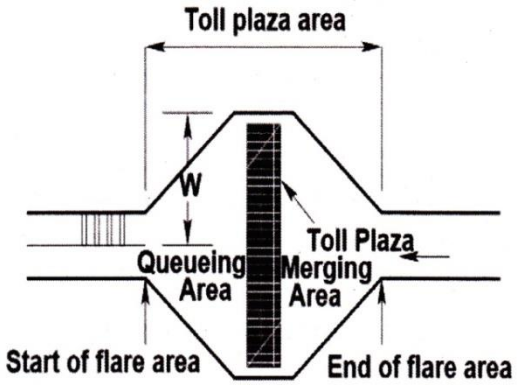

fig-1 : Toll Plaza Geometry

2. Operating Characteristics of toll plazas

2.1 Service Capacity

Currently, the study conducted at the tolls on the Jaipur-Kishangarh expressway NH-8. Both tolls have Manual Toll Collection (MTC), & Electronic toll Collection (ETC) gates. The toll gates are classified in five categories according to vehicle type & method of payment. For convenience the types are taken as type 1, type, 2 type 3, type 4 and type 5. Type 1 Automatic toll collection gate which is based on Automatic coin machine, type 2 gates are Electronic Toll Collection gates based on RFID technology, type 3 are MTC gates serve small vehicles that required change transaction,

type 4 are MTC gates serving single unit trucks and buses, type 5 is manual toll collection gate service for multi axle oversize vehicles. The tolls at Jaipur-Kishangarh expressway have type 2, type3, type 4, & type 5 gates. Capacity of a toll gate may be defined as the maximum number of the vehicles that can be expected to go through the gate in 1 hour under prevailing roadway & traffic condition. The service time required to process non queuing vehicles through a gate is defined as the elapsed time from the moment a driver is in a position to pay toll until the rear end of the vehicle crosses the electronic operated boom barrier installed on reference line ahead the booth. The service time of a queueing vehicle can be measured from the moment the rear end of the vehicle ahead crosses a electronic operated boom barrier installed on reference line drawn from the toll both until the moment the rear end of the subject vehicle crosses the same line. The service capacity of a toll booth is influenced by the time required to process the queueing vehicle through the toll gates. IRC recommends that, the service time of the vehicle, as 10 sec for ACM, 15 sec for MTC & 3 sec for ETC transactions. So capacity of ACM, MTC & ETC gates is about 360 vehicles per hour, 240 vehicles per hour & 1200 vehicles per hour respectively. Time of day and weather conditions acceleration & deceleration characteristics of vehicles can also affect the capacity of toll plaza.

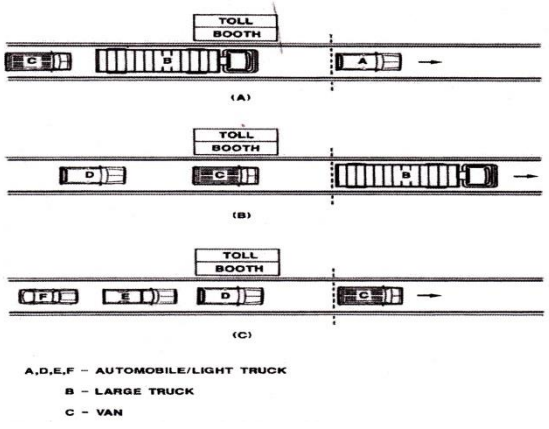

Fig -2 Vehicle movement at toll booth

2.2 Toll lane choice

Toll lane choice of automobile driver significantly affect the efficiency of toll collection. Field observations reveals that, factor affecting driver lane choice behavior are (i) Driver chooses a lane that has smaller queue length (ii) Driver chooses a queue, which is moving at faster speed and (iii) Driver chose a lane on which their time in the queue is minimized.

2.3 Stability of performance

The traffic operation at a toll gate can be classified into stable, meta stable and unstable states. The measure of effectiveness of stability of performance is average queue length which depends on arrival flow rate, flow duration and volume to capacity ratio.

2.4 Effects of number of gates for given type gate

For a given class of vehicles either single or multiple gates can be available at toll plaza as per their requirements. Driver lane choice behavior provide flexibility in multiple gates, so each gate can be used more efficiently than when single gate is available. The V/C ratio that will yield smaller average queue length under single gate than that under multiple gate operations. For planning purposes this difference is recommend be under about 0.03.

2.5 Effects of Temporal Variation in Flow Rate

For a given traffic volume, an arrival flow pattern with a constant flow rate will result in better gate performance than one with a variable flow rate.

3. Methodology of Level of Service analysis

3.1 Measures of Effectiveness

Measure of effectiveness MOE are density, V/C ratio and delay. Density is found to be in appropriate MOE for use as a comprehensive method of evaluation of LOS because toll plaza exhibit a wide range of densities among lanes, as lanes with different transactions types shows different densities. The V/C ratio is also not adequate method for evaluating LOS because the capacity dependent upon the service time which influenced by payment type & volume is a point measure i.e. with respect to a fixed reference line. If the movement of vehicles across the reference line is interfered by the down stream congestion, V/C ratio will be small while severe congestion is present at down stream. The delay is very important and identifiable measure of effectiveness. The delay for toll plazas are queueing delay & toll payment processing time (Service time & headway time) delay. Delay may depends on drivers reaction time, type of payment accepted in toll lane and performance of individual toll collectors, this delay influences average queue length and average time in the system so average queue length and average time in the system at toll plaza are chosen as the measures of effectiveness for assessing gate operation.

3.2 Level of Service criteria

Level of Service (LOS) is a qualitative measure describing operational conditions within a traffic stream and their perception by motorists. LOS varies widely in terms of both the users perception of service quality and the variable used to describe the operational conditions. The toll plaza is seen a bottleneck in which traffic is regulated by the capacity of the toll plaza. Before incoming traffic reaches the capacity of the toll plaza, toll booths are able to accommodate all traffic as represented in zone A, when traffic approximates the capacity of the toll plaza, delays occur. This conditions is indicated as an unstable zone B in the figure. If traffic exceed capacity, the plaza can only serve at its capacity, as shown in Zone C.

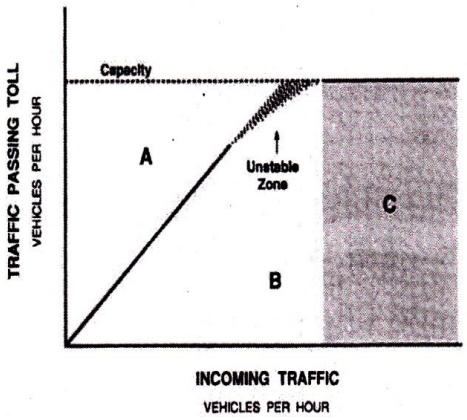

Fig-3 Traffic passing toll versus incoming traffic

There are no existing criteria based on service time in the system, stopped delay similar to time in the system for toll plaza operations has been commonly used to define level of service associated with the interrupted flow conditions. IRC codes recommends, service time should not be more than 10 sec per vehicle at peak flows. So we can take 15 sec as time in system per vehicle including vehicles acceleration & deceleration time, therefore it is suggested that as an interim measure, average time in the system be divided into some ranges for classifying the level of service. Stable operation stage can usually occur when V/C ratio is <0.93, at this stage average queue length of vehicle is upto 3 vehicles. Meta stable operations can occur when V/C ratio varies between 0.93 to 0.97, at this stage average queue length is less than 10 vehicles, when V/C ratio exceeds 0.97 the operation become unstable & undesirable at this stage average queue length is more than 10 vehicles.

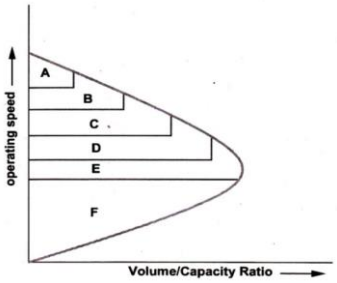

Figure -4 Level of Service A to F

Stable operation are good service and may be assigned as level A, B & C. Meta stable operations can be assigned as level D & Level E where as unstable and undesirable can be the assigned as level F services. The relations among operations speed, V/C ratio and level of service is shown in figure 4. The level of service criteria suggested on the basis of these discussions are summarized in table 1.

Table 1 : Level of Service Criteria

LOS (1)	Average queue length, *L* vehicles (2)	Average time in system, *T* s per vehicle (3)
A	≤1	≤15
B	1<*L*≤2	15<*T*≤30
C	2<*L*≤3	30<*T*≤45
D	3<*L*≤6	*45<T*≤90
E	6<*L*≤10	90<T≤150
F	>10	>150

3.3 Procedure of determination of LOS

i) **Data Collection**

Data collection shall consist of Number. & type of toll gates available at toll plaza. Recognition of problems affecting service capacity of toll plaza. Consecutive seven days traffic count survey on National Highway just at upstream of toll plaza. Twenty Four hours vehicle survey at toll plaza. Approaching traffic characteristics or vehicle mix and Service capacity of different type of gates.

ii) **Data Analysis**

The data analysis shall be done by the using following equations of relationship:

D = 0.92T (3.1)
T = (1605 + 3250 L)/C for L ≤ 15 (3.2)
T = (8748 + 2776 L)/C for L > 15 (3.3)
D = (2060 + 2980 L)/C for L ≤ 15 (3.4)
D = (8244 + 2570 L) for L > 15 (3.5)
L\= 0 if (V/C) ≤ *0.5* (3.6)

L= 7 V/C - 3.5 if 0.5 < V/C ≤ *0.93* (3.7)

L=3[1+6.29{(v/c)-0.93}{(C/360)-1}*[1+{14 (V/C) 13}2*t] if V/C > *0.93* (3.8)

L_{max} = 7 + 1.7L if $L \leq$ 10 (3.9)

L_{max} = 11 + 1.3L if $L >$ 10 (3.10)

D = Delay
T = Time in system
L = Average queue length, in vehicles
L_{max} = Maximum queue length, in vehicles
C = Capacity of Toll gate in vehicle per hour
V = Volume of the vehicle passing through the gate, in vehicle per hour
t = Flow duration

4. Case Study

Toll plaza Jaipur-Kishangarh Expressway located at Km. 286+700 on NH-8

4.1 Data Collection

Total gate at toll plaza = 16, ETC gate = 6, MTC gate = 8, Toll free gate =2

Fig 5 - Toll Plaza at Km. 286+700
on NH-8 Jaipur-Kishangarh Expressway

Recognition of problem

The problem observed at toll plaza are driver pay with monitory amounts, MTC toll collector influences time by their performance in serving the customer, increasing intensity of traffic during peak hours creates congestion and congestion usually occurs six-eight hours per day and when vehicals enter in ETC land with insufficient balance in RFID tags.Payment is made by the driver by cash transaction. so ETC lane does not work as dedicated lane.

4.2 Traffic count survey

Traffic count survey of seven consequent days from 11.10.2017 to 17.10.2017 was conducted. Average daily traffic (ADT) is shown in table no. 2 and 3.

Fig. 6 - Traffic Count Survey on Toll Plaza at Km. 286+700 on NH-8 Jaipur-Kishangarh Expressway

Table 2 Average daily traffic 11-10-2017 to 13-10-2017

Time/Date	11-Oct-17	12-Oct-17	13-Oct-17
Car/Jeep Class 3	9,506	9,216	9,098
LCV Class 4	1,928	1,936	1,962
Bus Class 5	1,605	1,622	1,534
Truck (2 Axle) Class 6	1,999	2,152	1,802
Multi Axle Class 7	12,306	12,265	13,148
Jcb/Crane Class 7s	11	5	2
Total	27,355	27,196	27,546

Table 3 Average daily traffic 14-10-2017 to 17-10-2017

Time/Date	14-Oct-17	15-Oct-17	16-Oct-17	17-Oct-17
Car/Jeep Class 3	9,122	9,084	9,038	9,132
LCV Class 4	1,930	1,946	1,986	1,997
Bus Class 5	1,590	1,565	1,535	1,514
Truck (2 Axle) Class 6	1,919	1,933	1,943	1,980
Multi Axle Class 7	12,814	12,755	12,355	12,818
Jcb/ Crane Class 7s	21	5	12	13
Total	27,396	27,288	26,869	27,454

4.3 Twenty four hours vehicle survey at toll plaza

Twenty four hours vehicle survey was conducted on 13.10.2017 at toll plaza. Peak hour traffic was 1492 vehicle per hour between 20.00 to 21.00 Hours as shown in table no. 4. Design traffic is taken as peak hour projected traffic for 5 years at the growth rate of 8%. Design traffic = 1492 $(1+0.08)^5$ = 2200 veh/hour

Table 4 24 Hours vehicle survey on 13.10.2017

Hour Time	Traffic Total	Hour Time	Traffic Total
00.00 - 01:00	935	12:00 - 13:00	1326
01:00 - 02:00	780	13:00 - 14:00	1193
02:00 - 03:00	829	14:00 - 15:00	1213
03:00 - 04:00	709	15:00 - 16:00	1248
04:00 - 05:00	739	16:00 - 17:00	1358
05:00 - 06:00	808	17:00 - 18:00	1429
06:00 - 07:00	855	18:00 - 19:00	1300
07:00 - 08:00	969	19:00 - 20:00	1441
08:00 - 09:00	1176	20:00 - 21:00	1492
09:00 - 10:00	1280	21:00 - 22:00	1328
10:00 - 11:00	1282	22:00 - 23:00	1344
11:00 - 12:00	1354	23:00 - 24:00	1158
			27546

4.4 Approach Traffic Characteristics or Vehicle mix

Vehicle mix is determined by propionate traffic of different class groups of vehicles from traffic count survey of 13.10.2017 shown as below;
Vehicles Class 3 & 4 = 40%
Vehicles Class 5 & 6 = 12%
Vehicles Class 7 & 7s = 48%
The toll manager record was observed and found that ETC payment users are 50% of total users. So ETC and MTC users are 1100 vehicles.

Service capacity of various toll gates

To determined service capacity service flow rate survey was conducted on ETC and MTC gate. The detail of Service capacity (volume)serve by different type gates is shown in table no. 5.

Table 5 Service capacity (volume) serve by different type gates

Sr. No.	Type of gate	Average Service flow rate (second)	Capacity vehicle per hour (number)
2	ETC	9	400
3, 4 & 5	MTC	25.4	142

Fig. 7 Incoming Traffic survey Toll Plaza at Km.286+700 on NH-8 at Jaipur Kishangarh Expressway

4.5 Determination of Level of Service

Estimation of V/C ratio based on available number of gates
$(V/C)_{ETC}$ = 1100/6x400 = 0.46
$(V/C)_{MTC}$ = 1100/8x142 = 0.98

Average queue length (L) is based on V/C ratio for ETC gate V/C ≤ 0.5 so use equation (3.6) and for MTC gate V/C > 0.93 so use equation (3.8) for determine average queue length (L). The average queue length calculated for ETC gates is 0 and for MTC gates is 8.

Maximum queue length (L_{max}) is based on average queue length. For ETC and MTC gate L ≤ 10 so use equation (3.9) to calculate L_{max} The maximum queue length calculated for ETC gates is 7 and for MTC gates is 21.

Estimating average time in the system (T) is based on average queue length. For ETC and MTC gate L ≤ 15 so use equation (3.9) to calculate average time in the system (T). The average time in the system calculated for ETC gate is 4.01 sec. and for MTC gate is 194 sec.

Level of service for ETC and MTC gates determined from table 1 and shown in table 6.

Table 6 Level of service on existing toll lane configuration

Sr. No.	Type of gate	Average queue length (vehicles)	Average time in system (in sec)	Level of service
2	ETC	0	4.01	A
3, 4 & 5	MTC	8	194	F

4.6 Proposed toll lane configuration

Data Collection

Total gate at toll plaza = 16, proposed ETC gate = 8, ACM gate = 6, Toll free gate = 2. As ETC gate increased from 6 to 8 so ETC user shall become (8/6)x50=67%. So ETC user vehicle shall be 1475 & ACM user vehicle shall be 725.

4.7 Service capacity

Service capacity of ETC gate shall be as per table 5 is 400 (vph) and for ACM gate is 240 (vph) as average processing time is taken 15 sec for level of service of level A from table 1.

4.8 Determination of Level of Service

Estimation of V/C ratio based on available number of gates

$(V/C)_{ETC}$ = 1466/8x400 = 0.46

$(V/C)_{ACM}$ = 725/6x240 = 0.51

Average queue length (L) is based on V/C Ratio. for ETC and ACM gate V/C ≤ 0.5 so use equation (3.6). The average queue length calculated for ETC and ACM gate is 0.

Maximum queue length (L_{max}) is based on average queue length. For ETC and ACM gate L ≤ 10 so use equation (3.9) to calculate L_{max} The maximum queue length calculated for ETC and ACM gate is 7.

Estimating average time in the system (T) is based on average queue length. For ETC and ACM gate L ≤ 15 so use equation (3.9) to calculate average time in the system (T). The average time in the system calculated for ETC gate is 4.01 sec. and for ACM gate is 6.69 sec.

Table 7 Level of service on proposed lane configuration

Sr. No.	Type of gate	Average queue length (vehicles)	Average time in system (in sec)	Level of service
2	ETC	0	4.01	A
3, 4 & 5	MTC	8	6.69	A

Various performance indicators shows that in proposed lane configuration minimizes expected time of a driver while travelling through the system by 187 sec and level of service improved from level F to level A. So proposed toll plaza configuration is optimal toll plaza configuration.

Conclusions

Toll plazas are seen as bottlenecks can seriously disrupt traffic movement at National highways. The traffic operations at toll plaza are affected by operational characteristics such as approaching traffic characteristics, number & capacities of toll gates, geometry design of toll plaza on the basis of field studies it is concluded that stability of performance depends upon V/C ratio. V/C <0.93 the operation is stable and average queue length is maximum upto 3 vehicles. V/c ratio varies between 0.93-9.07. operations become meta stable & average queue length is upto 10 vehicles. V/C ratio exceeds 0.97, average queue length exceed 10 vehicles and operations becomes unstable & undesirable.

Based on existing practice of toll management & characteristics of traffic operations, measures of effectiveness of level of service are average queue length & average time in the system. On the basis of these MOE the level of service is classified into six levels in accordance with criteria given in table 1. Criteria for level of service may vary from country to country. The study concluded factors of delay are method of payment, cash transaction with monitory amount, Toll collector behaviors. Insufficient balance conditions arises in RFID prepaid tags & mix use of toll gates by vehicles irrespective their categories. In the research case study proposed toll lane configuration reduces the delay by 187 sec. which result in travel time saving by 6% and VOC saving by 3%, between two adjoining toll plazas located at 74 km. distance on the same highway. Other benefits are improvement LOS from level F to Level A, reduction of environmental pollution, driver stresses, operational cost of toll plaza & increases efficient use of highway segment.

Recommendations

Based on the studies following suggestions are recommended:

a) Cash transaction at Toll booth should be discouraged by providing facility to convert cash in ACM token or coupons in advance of toll booth.
b) RFID tags should be linked with vehicle owner account.
c) Use necessary vehicle algorithm so vehicle uses proper category gates.
d) Most of toll plazas are congested for 6 to 8 hours a day leaving reminder of the day with excess toll plaza capacity. Variable toll rate should be used during peak hours to reduce congestion in peak hours.

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