Determination of Stream Equivalency Factor for Toll Plaza

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Abstract— The main disadvantage of building a toll plaza is that it increases the traffic on highway. Therefore, the aim of our study is to introduce a new concept of Toll booth Equivalency Factor (TEF) at toll plaza similar to that of PCU for mixed traffic conditions. The mixed traffic is converted into flow equivalent in passenger car units (PCU) and then multiplying them with number of each vehicle class by their respective PCU values and then adding them up. The PCU is a complex parameter and it depends upon multiple factors. Vehicle arrival at a toll booth is random inspite of the lane assigned to a particular vehicle category. Such mixed traffic in the same lane causes the variation in service time and hence reduces capacity. The vehicles in the lane are divided into four classes and mathematical models are developed to determine service time of a vehicle type based on approach volume and composition of traffic in the same lane. The service time is further used to determine TEF. The variation in TEF is explained on the basis of service time due to random arrival of vehicle and approach traffic volume. Further a concept of Stream Equivalency Factor (SEF) proposed will be useful to convert heterogeneous traffic volume in veh/hr to homogenous traffic volume in TEF/hr without actually determining the TEF factors for individual vehicle types at tollbooths. This work will be helpful for quick estimation of capacity. There are multiple phases in which study is carried out for identification of the problem, collection of the data, data analysis, then Paliyekkara toll plaza situated in NH 544 was selected to do the analysis. The current operational effectiveness can be drawn using data analysis and the parameters such as the Arrival Rates, Service Rates and the Number of toll booths are determined for estimating the Toll Booth Equivalency Factor of the toll plaza.

Keywords: Stream Equivalency Factor for Toll Plaza, PCU, TEF

I. Introduction

A. General

Toll plazas are built on highways to recover the cost of construction and maintenance from road users in the form of user fee. Toll booths are built such that dedicated lanes are provided for different categories of vehicles to expedite the process of toll collection. Vehicles enter into lanes irrespective of the type of vehicle assigned to those particular toll lanes. This may lead to heterogeneous traffic in the same lane which affects the toll booth operator's performance in terms of service time required to collect toll from vehicles. The operator expects the arrival of same category of vehicles in a lane, but due to the heterogeneity in traffic arising from encroachment of vehicles, he or she will have to collect different amounts of toll tax which increase service time and the consequent reduction in capacity. Here the capacity is the number of vehicles passed through a particular toll booth in an hour. The Indian Roads Congress (IRC) specifies clearance time of 5 sec per vehicle at peak flow, irrespective of the vehicle type and a capacity of 240 vehicles/hour (veh/h) for semi-automated toll lane while considering a service time of not more than 10 seconds (sec) per vehicle.

Field observation also depicts that generally heterogeneous traffic present at tollbooths. The capacity of tollbooth may be reduced due to diverse maneuverability of different sized vehicle which consequently affect the service time at the tollbooth. When these different types of vehicles with varying static and dynamic characteristics are allowed to mix and move on the same traffic lanes, expressing traffic volume in terms of vehicles per hour per lane is irrelevant, as the traffic is heterogeneous. One way of representing heterogeneous traffic flow is to express in terms of passenger car unit (PCU) as known in India or passenger car equivalent (PCE) world-wide. The concept of PCU/PCE was firstly introduced in Highway Capacity Manual (HCM). Afterwards, many researchers attempted to estimate PCU to convert mixed traffic into homogenous under different traffic conditions for estimating PCU to convert mixed traffic into homogenous. Different measures of effectiveness are considered by researchers to estimate PCU are delay, speed, headway, density, and queue discharge under different traffic conditions. To introduces a new concept of Toll booth Equivalency Factor (TEF) at toll plaza similar to that of PCU for mixed traffic conditions.

B. Objective

The main objectives of this study is to determine the Tollbooth Equivalency Factor (TEF) at toll plaza similar to that of PCU for mixed traffic conditions and also to evaluate the present scenario of Paliyekkara toll plaza. This main objective can be achieved with the help of following sub objectives i.e development of service time models and development of a cumulative trend chart for clearance Time.

C. Scope of study

The study focus on identifying the issues related to the toll booths, helpful for quick estimation of capacity and measuring the efficiency of tollbooth in the field. Different measures of effectiveness are considered by researchers to estimate PCU are delay, speed, headway, density, and queue discharge under different traffic conditions. To introduces a new concept of Tollbooth Equivalency Factor (TEF) at toll plaza similar to that of PCU for mixed traffic conditions.

II. Literature Review

V.N. Yogeshwar, et. al (2016)[1], developed a concept of Stream Equivalency Factor to measure of heterogeneous traffic at tollbooths in India. They introduce the new concept of Tollbooth Equivalency Factor (TEF) at toll plaza similar to that of PCU for mixed traffic conditions. Vehicle arrival at a tollbooth is random inspite of the lane assigned to a particular vehicle category. Such mixed traffic in the same lane causes the variation in service time and hence reduces capacity. Videographic data collected at three toll plazas located in India. The vehicles are divided into seven classes and mathematical models are developed to determine service time of a vehicle type based on approach volume and composition of traffic in the same lane. TEF for different vehicle types are determined with the help of service time. The TEF values range observed for big car is 0.84 to 2.25,1 to 4.15 for buses whereas 3.73 to 8.74 is observed for trailer. Stream Equivalency Factor (SEF) concept will be useful to convert heterogeneous traffic volume in vehicle/hour (veh/hr) to homogenous traffic volume in TEF/hr without actually determining the TEF factors for individual vehicle types at tollbooths The present work will be helpful for quick estimation of capacity and measuring the efficiency of tollbooth in the field. This study is also useful for planners for maintaining the performance evaluation of toll plaza.

Ashish Dhamaniya et.al (2013) [2] proposed a new procedure for converting heterogeneous traffic stream into homogenous by employing an SEF rather than PCU values of individual vehicle types. Field data collected on six sections of six-lane divided urban arterials are used to derive a relation between SEF and traffic composition traffic volume on the road. The relation was found to be dependent on the number and types of vehicle categories in the traffic stream Microscopic simulation program Vissim is utilized to generate the speed and volume data for different categories of vehicles in the stream. The simulated data are used to present a generalized method obtain the value of SEF for any.

Y.V Navandar et.al (2017), [3] studied on Present work introduces a new concept of Tollbooth Equivalency Factor (TEF) at toll plaza similar to that of PCU for mixed traffic conditions. Vehicle arrival was random at the toll booth inspite of the lane assigned to a particular vehicle category. Videography data was collected for three toll plazas and vehicles in the lane are divided into seven classes. Mathematical models are developed to determine service time of a vehicle type based on approach volume and composition of traffic in the same lane. Service time used to determine TEF for different vehicle types. The ratio of traffic volume in TEF/hr and volume in veh/hr is referred to as SEF. It is related to traffic volume (arrived at tollbooth) and traffic composition through regression analysis. This work will be helpful for measuring the efficiency and also for quick estimation of capacity of tollbooth in the field.

Cao N. Y. et. al (2012),[4] Proposed the motorcycle equivalent unit (MEU) in place of PCU for urban roads in Hanoi, Vietnam. They developed a methodology for deriving MEUs in mixed traffic flow by considering the characteristics of moving vehicles, such as speed and effective space. The effective space of each kind of vehicle is computed with consideration of the influences of speed, physical size of the subject vehicle, and the surrounding motorcycles. The MEU values of cars, buses, minibuses, and bicycles were found to be 3.4, 10.5, 8.3 and 1.4 respectively.

Al-Kaisy A et.al (2015)[5] proposed this study as an attempt to circumvent this problem of determining PCU factors for individual vehicle type to convert a heterogeneous traffic stream into a homogenous equivalent. The objective of the convert heterogeneous traffic volume in vehicles per hour to homogenous traffic volume in PCU per hour without actually determining the PCU factors for individual vehicle types.

III. METHODOLOGY

A. General

Toll tax is gathered to recover the complete expenditure of assets that involves building costs, repairs, maintenance, toll operating expenses and outlay interest. The new facility thus built should provide decreased travel time and enhanced service level. Most road projects in India are provided on a PPP-based basis, i.e. Public partner- ship in the private sector. In this, the private organization gains profit in the form of toll tax and builds the facility and recovers the assets from the customers. After the facility is surrendered to the public, this tax is gathered for a reasonable moment.

B. Study location and details

The study was decided to conduct at the Paliyekkara toll plaza which is currently run by company named Guruvayoor Infrastructure Private Limited (GIPL) situated in NH 544. National Highway 544, frequently referred to as NH 544 (ancient number NH 47), is a 340- kilometer-long national highway in South India linking the town of Salem in Tamil Nadu with the town of Kochi in Kerala. It's also called the Salem-Kochi Highway. The highway passes through the states of Kerala and Tamil Nadu, connecting numerous major cities and towns such as Salem, Coimbatore, Palakkad, Thrissur and Kochi. It is a spur of National Highway 44, which forms India's National Highway North South Corridor. It runs west of coimbatore. The plaza location is shown in the Figure1

Fig. 1: Paliyekara Toll-Plaza

Data were extracted for twelve lanes at the Paliyekkara toll plaza, by rewinding the video on a large screen monitor. Fig 3.1 shows the study locations and survey details. In order to achieve the desired degree of precision, time was noted up to two decimals of seconds. In the spreadsheet, data like lane number, vehicle class, their entry and exit time at the toll booth (exactly at the toll window for the transaction) were entered. Service time is calculated by obtaining the difference in exit and entry time of the vehicles at a particular toll booth. Clearance time is the difference of exit time of leading vehicle and entry of following vehicle in the system. All vehicles in traffic at the tollbooth were divided into four classes and the analysis part was carried out.

The video graphic survey was done on a peak working day. Data were extracted for all lanes at the toll plaza by rewinding the video. In order to achieve the desired degree of precision, time was noted up to two decimals in the spreadsheet, data like lane number, vehicle class, there entry and exit time at the toll booth were entered. Service time is calculated by obtaining the difference in exit and entry time of the vehicles at a particular toll booth. Clearance time is the difference of exit time of leading vehicle and entry of following vehicle in the system. After analyzing the service time delay caused to each vehicle can be easily obtained. Finally, the stream equivalency factor can be obtained. At last various models can be prepared to evaluate the various performance evaluation parameters of toll plaza and thus complete system analysis can be done. Further studies on the models developed will helps to suggest improvement measures that can be applied on the plaza to reduce the congestion at the plaza point.

IV. Data Analysis

A. General

Analysis of data was done using Statistical Package for the Social Sciences (SPSS) software and it is a widely used program for statistical analysis in social science. Many organizations and researchers uses this software like marketing organizations, market researchers, survey companies, government, education researchers, health researchers, data miners, and others. Data management (case selection, le reshaping, creating derived data) and data documentation are also the features of this base software, in addition to statistical analysis

B. Service time analysis

Time spent by a vehicle at toll booth for paying toll is referred as service time. It has been observed that service time is varying in a wide range for all categories of vehicle and even in same vehicle class. In order to capture this variation in service time, the cumulative distribution plot has been drawn from the extracted data as shown in Figure 2.

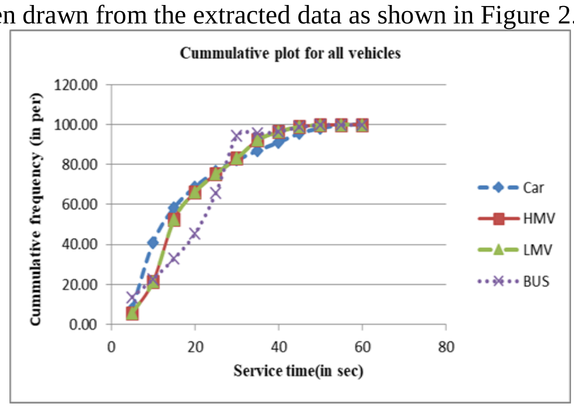

Fig. 2: Service time cumulative plot for all vehicle category

Mean service time for car is 12.31sec, whereas that for HMV is 28.74 sec, LCV is 21.33 sec and bus is 24.78 sec respectively from the figure 4.1. The field observation showed that service time of a vehicle at toll booth is not a constant value, but varies in a wide range. The observed value shows that under mixed traffic condition, the service time is more than 10sec whereas the value specified by IRC is not more than 10 sec irrespective of the payment method. This variation might be due to mixed traffic conditions, the varying toll rate for different vehicle classes and the random arrival of same vehicles at the toll booth. Further, the exact change of the toll amount given by drivers and efficiency of tollbooth operator may also lead to variations in service time.

C. Log normal distribution curves

There are four log normal distribution curves that shows variation in service time for CAR, BUS, HMV and LMV and these are shown below.

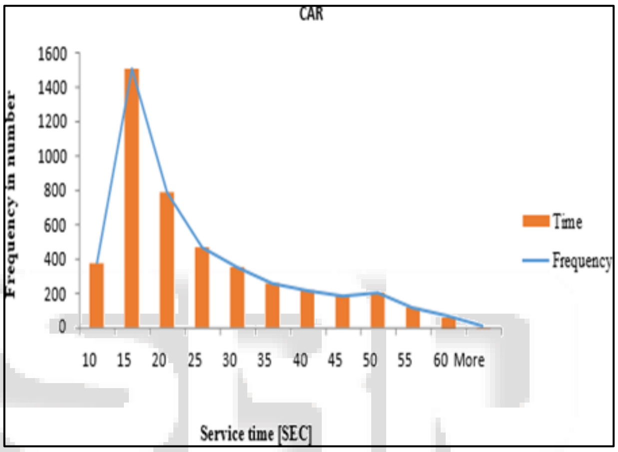

Fig. 3: Log Normal Distribution For CAR

In the above figure the variation of service time with frequency for car is shown and the frequency is maximum i.e 1500 at a service time of 15 sec.

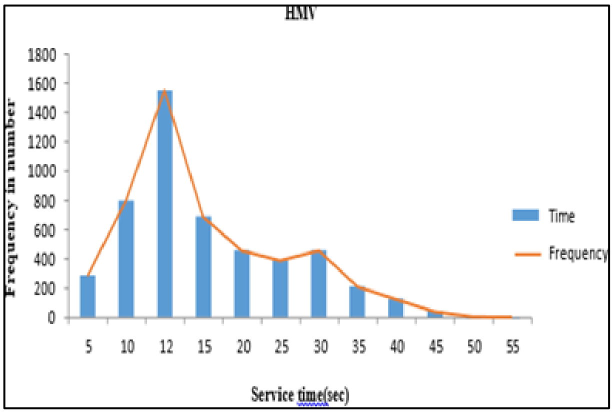

Fig. 4: Log Normal Distribution For HMV

In the above figure the variation of service time with frequency for HMV is shown and the frequency is maximum i.e nearly 1600 at a service time of 12 sec and as the service time goes on increasing the graph of frequency goes to negligible.

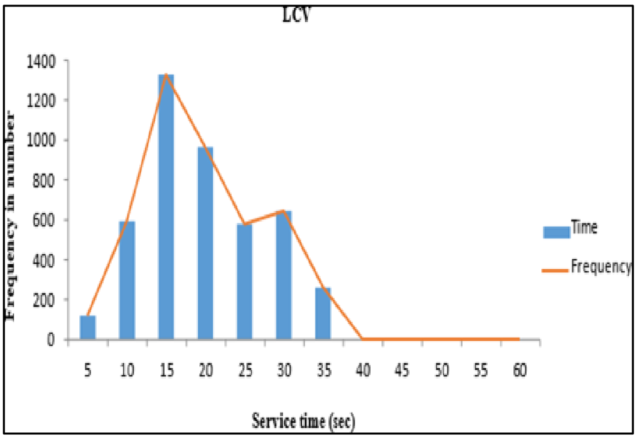

Fig. 5: Log Normal Distribution for LCV

In the above figure the variation of service time with frequency for LCV is shown and the frequency is maximum i.e nearly 1300 at a service time of 15 sec and as the service time goes on increasing the graph of frequency goes to negligible i.e after a service time of 35 sec there is no LCV being served.

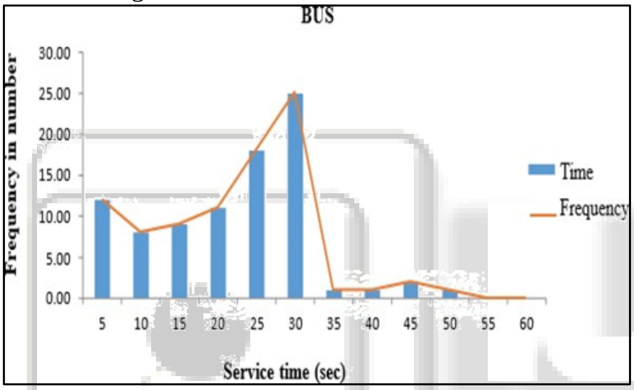

Fig. 6: Log Normal Distribution for BUS

In the above figure the variation of service time with frequency for BUS is shown and the frequency is maximum i.e nearly 25 at a service time of 30 sec and as the service time goes on increasing the graph of frequency goes to negligible i.e after a service time of 50 sec the number of BUS is zero.

D. Clearance time analysis

Clearance time means the time required to clear the toll booth for a vehicle after paying toll, which depends upon the length of vehicle that indicates its maneuverability and acceleration capability at toll booth. The field observation showed that as the vehicle size increases in terms of its physical length in comparison to SC, its clearance time increases. It can be explained on the basis of relative clearance time of a vehicle type with respect to that of SC. Vehicle size larger than SC requires more clearance time to clear the toll booth owing to its length as compared to SC.

In present study 85th percentile clearance time consider for estimation of TEF. The reason may be due to maximum vehicle clear the tollbooth within this time.

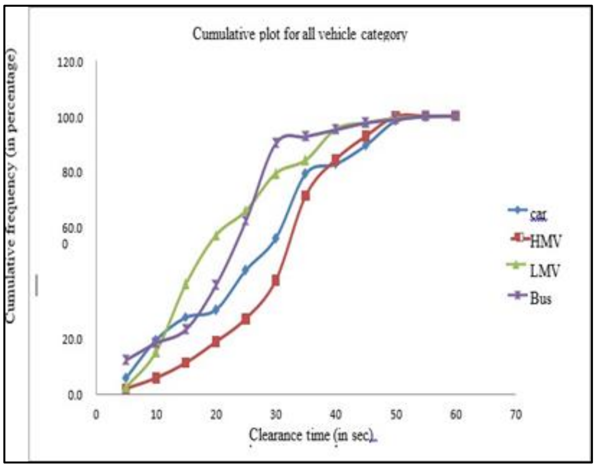

Fig. 7: Clearance time cumulative plot for al vehicle Category

The figure shown above is this the cumulative trend chart for clearance time and the clearance time for Car, HMV, LCV, Bus is shown and the85th percentile clearance time consider for estimation of TEF.

E. Analysis of field observed values

Service time and clearance time of vehicles are used to determine its TEF value and total volume is converted to equivalent number of TEFs per hour. The ratio of these two flows is termed as stream equivalency factor (K) in the present study. It is given by Equation

$$\log(K) = (\text{Flow in TEF/hour}) / (\text{Flow in Veh/hour})$$

The data points are quite staggered, having many values of flow in TEF per hour corresponding to the same value of flow in veh/hr and vice-versa. The value of K in the data set varies from 0.99 to 1.27. This is attributed to the varying traffic compositions observed in different time intervals on tollbooths. The value of K seems increasing exponentially as the proportion of heavy vehicles increases at the tollbooth. It can be explained on the basis of TEF of all vehicles is more than one as compared to standard car (SC).

V. RESULTS AND DISCUSSION

A. General

This chapter includes all the results that is obtained from the analysis part.it also includes the results obtained from modelling through SPSS software. The results include the service time values, clearance time values, toll booth equivalency factor values and stream equivalency factor values.

VEHICLE TYPE	SAMPLE SIZE	MEAN OF SERVICE TIME(SEC)	MINIMUM VALUES (SEC)	MAXIMUM VALUES (SEC)	STANDARD DEVIATION
CAR	4517	18.02	1.28	45.62	4.71
HMV	5014	11.56	3.89	59.21	7.99
LMV	4458	34.37	2.31	38.33	21.78
BUS	88	35.8	1.91	53.16	21.75

Table 1: Service time values obtained from model

The table 1 shows the service time values obtained from modelling for different vehicle type and from this table we can come to a conclusion that the mean service time and the standard deviation for LMV is much more than other vehicle type.

VEHICLE TYPE	SAMPLE SIZE	MEAN OF SERVICE TIME(SEC)	STANDARD DEVIATION	R SQUARE VALUE
CAR	4517	12.31	0.98	0.975
HMV	5014	28.74	1.12	0.844
LCV	4458	21.33	1.51	0.968
BUS	88	24.78	1.92	0.921

Table 2: R^2 values obtained from model

The table 2 shows the R square values obtained from modelling for different vehicle type and from this table we can come to a conclusion that the mean service time for HMV is much more than other vehicle type while its R square value is the least as compared to other vehicle type.

VEHICLE TYPE	SAMPLE SIZE	PERCENTILE CLEARANCE TIME IN SEC			STANDARD DEVIATION
		15th	50th	85th	
CAR	3645	9	28	42	9
HMV	6513	18	32	40	21.78
LMV	5097	10	18	35	9.19
BUS	82	7	23	29	4.71

Table 3: Clearance times values obtained from models

The table 3 shows clearance time values obtained from modelling for different vehicle type and from this table we can come to a conclusion that the standard deviation for HMV is much more than other vehicle type and the 85th percentile speed is higher for car as compared to other vehicle type.

	AVERAGE TEF VALUES				STANDARD DEVIATION			
LANES	CAR	HMV	LMV	BUS	CAR	HMV	LMV	BUS
1-12	1	1.30	1.13	1.23	0.31	1.02	0.91	0.78

Table 4: Field observed TEF values

The table 4 shows field observed tollbooth equivalency factor values both average TEF values and SD values are obtained for different vehicle type and from this table we can come to a conclusion that the average TEF value and the SD value for HMV is much more as compared to other vehicle type.

Time interval (in h)	Flow in (veh/h)	Flow in (TEF/h)	K value
3-4	3660	4016.85	1.0975
6-7	3250	3985.20	1.226215
8-9	2987	3781.50	1.265986
11-12	4250	4215.18	0.991807
1-2	3845	4110.31	1.069001
4-5	3235	3899.12	1.205292
7-8	3580	3913.21	1.093075

Table 5: Obtained stream equivalency factor (K) values

VI. CONCLUSION

A. General

The main disadvantage of building a toll plaza is that it increases the traffic on highway. Therefore, the aim of this study is to observe the present situation of traffic congestion at a highway toll plaza and determine the stream equivalency factor for the toll-plaza. There are multiple phases in which this study is carried out in identification of the problem, collection of the data and data analysis.

B. Findings

After analyzing the videos collected some preliminary findings were made and is as follows:

1) Dedicated lanes provided for each type of vehicle are not used properly, that is each lane have mixed traffic condition which is observed to be the prime reason for the queue.
2) Proper sign boards are not provided for the dedicated lanes prior to the entry of vehicles
3) The fast tag lane markings are also not provided properly, which creates con- fusions among the drivers.

Mixed traffic condition is prevalent in Indian roads. This is also observed at toll plazas, as vehicles do not follow lane discipline. Analysis of heterogeneous traffic is usually carried out using PCU values. The present work introduces the concept of TEF instead of PCU. The present study proposes a procedure for converting mixed traffic into homogenous traffic using SEF, rather than TEF values of individual vehicle types at tollbooths. Field data collected from toll plaza were used to derive a relation between SEF, traffic composition, and volume at tollbooths. The exponential relation is found to be dependent on the type of vehicle class and number of vehicles present at tollbooth exponentially. This is due to the fact that TEF of all vehicle class is more than unity as compared to standard car. The proposed SEF method is easy to convert non-homogeneous traffic volume measured in veh/hr at tollbooth to equivalent volume in TEF/hr without making use of TEF values. It will reduce the effort and cost of data collection, without compromising on the accuracy of the analysis. The concept of SEF at tollbooth has not been studied extensively, and hence, the study is useful for toll plaza planners and management authorities for estimating capacity at tollbooths.

REFERENCES

[1] N. N and M. Arundhathi, Analysis of traffic behavior at the toll plaza around Bangalore. IRJET, 2017, vol. 4.

[2] A. Dhamaniya and S.Chandra, “Concept of stream equivalency factor for hetero- geneous traffic on urban arterial roads,” Journal Of Transportation Engineering, vol. 139, pp. 1117–1123, 2013.

[3] Y.V.Navandar and A.Dhamaniya, “Concept of stream equivalency factor: A measure of heterogeneous traffic at tollbooths in india,” TRB 2018 Annual Meet- ing, 2017.

[4] C. N. Y and sano k, “Estimating capacity and motorcycle equivalent units on urban roads in hanoi, vietnam,” Journal of Transportation Engineering, vol. 138(6), pp. 776–785, 2012.

[5] J. y. Al-Kaisy A and R. H, “Developing passenger car equivalency factors for heavy vehicles during congestion,” Journal of Transportation Engineering, vol. 131(7), pp. 514–523, 2013.