New Traffic Congestion Analysis Method in Developing Countries (India)

Tsutomu Tsuboi*
Global Business Development, Nagoya Electric Works Co., Ltd., 29-1 Mentoku Shinoda, Ama Aichi, Japan

Keywords: Traffic Flow, Traffic Density, Traffic Congestion.

Abstract: This manuscript describes introducing new traffic congestion analysis for developing country in India. In generally, it is challenge to show how traffic congestion occurs, especially in developing countries such as in India because its traffic is consisted of various kinds of transportation like two wheelers, three wheelers, and sometimes animals on the roads. There is a chance to collect real traffic flow data in Ahmedabad of Gujarat states of India since October 2014. The traffic monitoring system there consist of 14 traffic monitoring cameras and the system is capable to monitor traffic density, traffic volume, average vehicle speed, and occupancy at the each location. In this manuscript, there are three types of traffic congestion analysis. One is based on its observation traffic flow, in which it compares daily traffic volume and its average vehicle speed. The second one is based on the judgement of occupancy parameter, which uses as one of traffic congestion parameter in general. The third one is based on estimation from "social loss" calculation which comes from the traffic flow theory but is challenge to analyse in the developing countries. The social loss calculation is proven in the traffic theory but it is difficult to define the traffic demand curve, the social cost curve, and the traffic supply curve. Author shows how to make the practical "social loss" calculation and its validation compared with the actual traffic congestion condition.

1 INTRODUCTION

According to rapid economic growth in developing countries such as India and China, it becomes big issues of negative impact by transportations. An economic growth requires transporting not only people but also commercial goods and material exporting to other countries and or importing as well. In general, developing countries don't spend enough infrastructure improvement budget compared growing economics. Therefore they have traffic congestion, more accidents, environment problems like air pollution, and untuneful energy consumption. It is able to say that those issues are occurred by poor infrastructure development and growth of traffic. And it is not easy to manage proper traffic condition under this situation, particularly to analyse traffic condition of developing countries. There are not so many study of traffic flow analysis for the developing counters. The traffic flow analysis is introduced by Goutham.M, Chanda.B in " Introduction to the selection of corridor and requirement, implementation of IHVS (Intelligent Vehicle Highway System) In Hyderabad. This research took only few days data collection. And the other one is headway parameter analysis in India by Salim.A, Vanajakshi.L, Subramanian.C but its data is based on only four days measurement.

Author have a chance to manage intercity traffic by ITS or Intelligent Transport Systems business in one of major city of India 2014. The city is Ahmedabad which is located in Gujarat State of west Side of India. The system of ITS (Intelligent Transport System) has fourteen traffic monitoring cameras and four traffic information display which is called "VMS" or Variable Message Sign board. Traffic condition such as traffic volume, traffic density, gaps between vehicles are observed by the system and traffic congestion level is provided through VMS to drivers. Therefore motivation is to analyse Indian traffic condition on the basis of one month measurement in June 2015 from the ITS system in Ahmedabad. The detail ITS system

*https://www.nagoya-denki.co.jp/en/

Tsuboi, T.
New Traffic Congestion Analysis Method in Developing Countries (India).
DOI: 10.5220/0009766501450151
In *Proceedings of the 6th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2020)*, pages 145-151
ISBN: 978-989-758-419-0

configuration and location are described in the next section.

2 TRAFFIC FLOW ANALYSIS

2.1 Measurement Field and Data

The ITS system in Ahmedabad consists of 14 CCTV or traffic monitoring cameras and for VMSs in the city. The Figure 1 shows the location of each CTV and VMS in the city. In Figure 1, Cam#1 means CCTV number 1 and Cam#1 has one CCTV with pole on the street. The VMS#1 means VMS number 1 and it also has CCTV with Traffic Sign board.

The traffic data is measured by the CCTV and measures traffic flow data such as number of vehicles, average vehicles speed, traffic density. In this paper, it is used this traffic flow data in June 2015 one month data by every minutes. The total traffic flow data for each CCTV becomes more than 40,000 points and author took 11 camera data through camera number 1 to 10 and VMS number. In this paper, we take eleven CCTV data because VMS#1 and VMS#2 data are missing during measurement by communication network error.

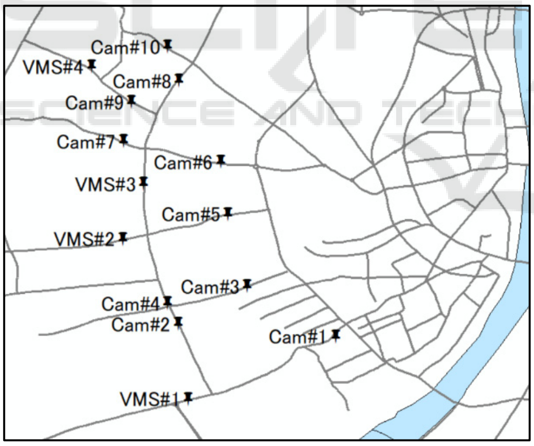
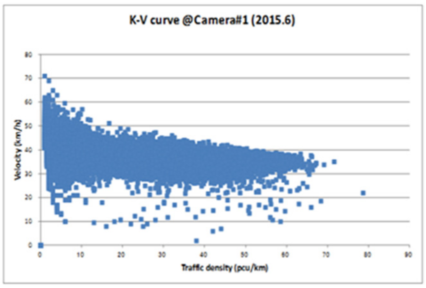
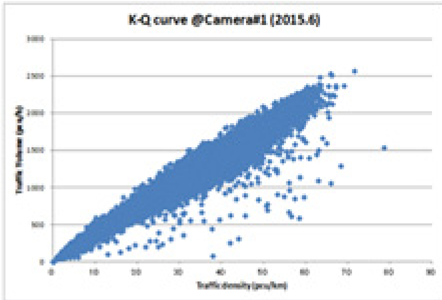


Figure 1: Traffic monitoring camera location in Ahmedabad city.

In terms of measurement data, Figure 2 shows two typical traffic flow characteristics—traffic density (k) to vehicle average speed (v) and traffic density (k) to traffic volume (q) of Cam#1 in June 2015.
In terms of traffic measurement value, all these value are generalized as one lane of each road for the comparison of traffic condition level among the different number of lanes roads. The two lanes of road is at through Cam#1 to Cam#7 and through VMS#1 to VMS#4. The three lanes is at through Cam#8 to



(a) k - v curve at Camera #1.



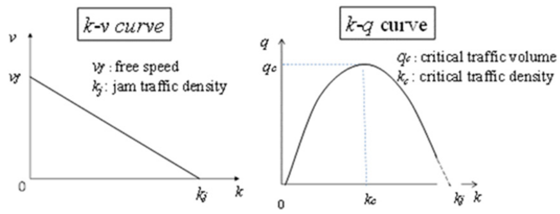
(b) k - q curve at Camera #1.

Figure 2: Traffic Flow Characteristic of Cam#1.

Cam#10. Therefore the actual value of .traffic volume and density are the described value times by each number of lanes.

2.2 Traffic Flow Theory

In the traffic flow theory, there are typical characteristics which are defined relationships traffic density (k) and traffic volume (q) —$k – q$ curve— and traffic density (k) and average vehicle speed (v)—$k – v$ curve— which are illustrated in Figure 3. In terms of $k – v$ curve, there are three major curves e.g. Greenshields, Greenburg and Underwood. In this paper, we use most typical Greenshields one.



(a) $k – v$ curve (b) k- q curve

Figure 3: Traffic Flow Characteristic of Cam#1.

From the traffic flow theory, the $k – v$ curve and $k – q$ curve are provided by equation (1) (2) (3) and (4).

$$v = v_f\left(1 - \frac{k}{k_j}\right) \tag{1}$$

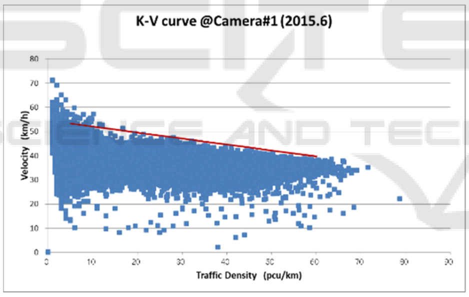
$$q = -\frac{v_f}{k_j}\left(k - \frac{k_j}{2}\right)^2 + \frac{v_f k_j}{4} \tag{2}$$

$$q_c = \frac{v_f k_j}{4} \tag{3}$$

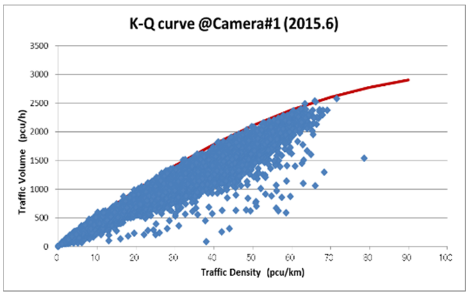
$$k_j = 2k_c \tag{4}$$

where v_f is free vehicle speed, k_j is jam traffic density, q_c is critical traffic volume, and k_c is critical traffic density.

From Figure 2 (a) and (b), we see there is boundary line in each curve and there is no data over its boundary line. Therefore this boundary line means each traffic flow characteristics. There are similar kind of characteristics in all other CCTVs. From this observation method, we have traffic flow parameters fitting by equation (1) and (2). Figure 4 shows each boundary line on both *k–v* curve and *k–q* curve. From this observation method, the boundary line is able to be drawn by using equation (1) and (2). Based on this observation method, it is able to get traffic flow parameters —v_f, *kj*, and *qc*— and curve equation (1), (2). The summary of all CCTV data is shown in Table 1.



(a) *k* - *v* curve at Camera #1 with boundary edge line.



(b) *k* - *q* curve at Camera#1 with boundary edge line.

Figure 4: Traffic Flow Curve with boundary line.

Table 1: Summary of Traffic flow equation and parameters.

Location	Data analysis					
	v f/k j	*k c*	*q c*	*v c*	Formula	*v f*
Cam#1	0.2479	110	3,000	27	-0.2479(*k*-110)^2+3000	54.545
Cam#2	0.1556	150	3,500	23	-0.1556(*k*-150)^2+3500	46.667
Cam#3	0.2153	120	3,100	26	-0.2153(*k*-120)^2+3100	51.667
Cam#4	0.3200	100	3,200	32	-0.3200(*k*-100)^2+3200	64.000
Cam#5	0.3704	90	3,000	33	-0.3704(*k*-90)^2+3000	66.667
Cam#6	0.2367	130	4,000	31	-0.2367(*k*-130)^2+4000	61.538
Cam#7	0.2361	120	3,400	28	-0.2361(*k*-120)^2+3400	56.667
Cam#8	0.3200	100	3,200	32	-0.3200(*k*-100)^2+3200	64.000
Cam#9	0.4898	70	2,400	34	-0.4898(*k*-70)^2+2400	68.571
Cam#10	0.3438	80	2,200	28	-0.3438(*k*-80)^2+2200	55.000
VMS#3	0.2361	120	3,400	28	-0.2361(*k*-120)^2+3400	56.667

2.3 Traffic Congestion

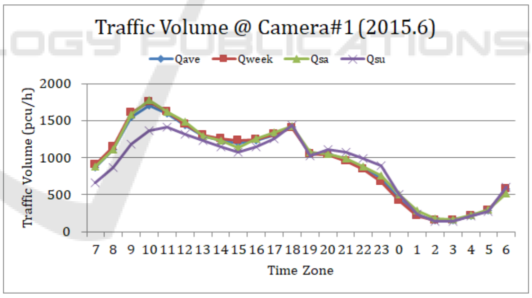
In order to analyse the traffic congestion from measurement data, there are several method.

- Observation from daily traffic flow
- Judgement from occupancy parameter
- Judgement by Social Loss calculation

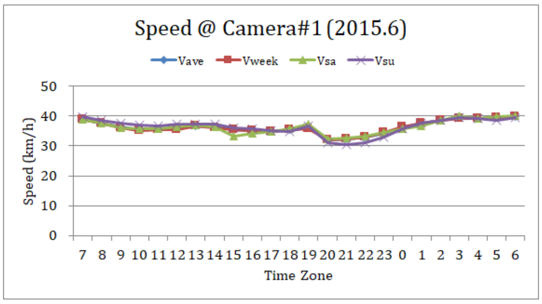
From the next section, each analysis is described.

2.3.1 Observation from Traffic Flow

This observation is to define the traffic congestion by comparing daily number of vehicle and average speed for each hour. Figure 5 shows an example of Cam#1 traffic flow daily data and (a) shows time zone basis number vehicle trend and (b) shows average vehicle speed.



(a) Traffic volume of Camera#1.

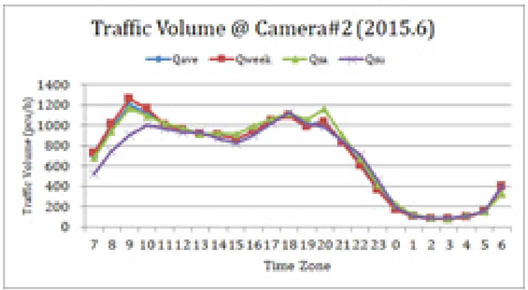


(b) Traffic average speed of Camera#1.

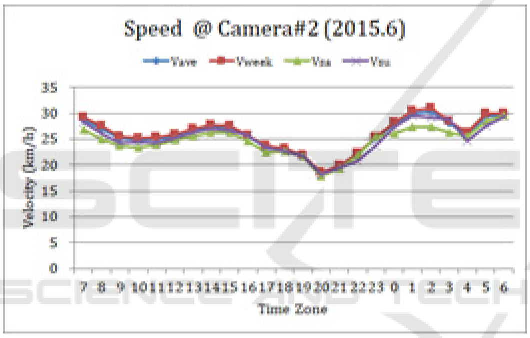
Figure 5: Traffic Flow Time Zone basis Measurement.

From Figure 5 (a), there are two peeks of number of traffic volume in the morning from 9:00 to 11:00 and the evening from 17:00 to 19:00. Form Figure 5 (b), the average vehicle speed seems to be stable or not so much drop at those two traffic peeks. The vehicle speed in the evening peek is relatively lower than in the morning peek. From this observation, there is no traffic congestion at Cam#1 in June 2015.

On the other hand, Figure 6 shows the case of Cam#2.



(a) Traffic volume of Camera#2.



(b) Traffic average speed of Camera#2.

Figure 6: Traffic Flow Time Zone basis Measurement.

From Figure 6 (a), there are two traffic number of vehicle as same as Cam#1. But from Figure (b), there is big speed drop in the evening, which means there is traffic congestion.

2.3.2 Judgement from Occupancy

In this section, occupancy (*OC*) is introduced as one of traffic flow parameter for traffic congestion indication. From traffic flow theory, (*OC)* is defied by equation (5).

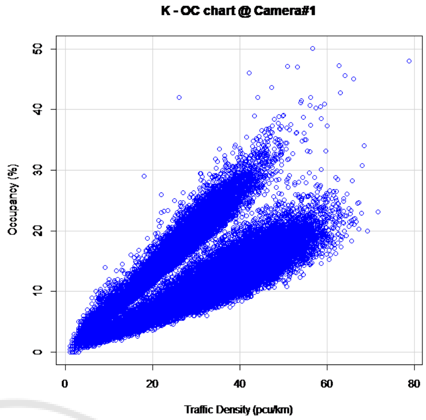
$$OC = \frac{1}{T}\sum_{i} t_i \times 100\ (\%) \tag{5}$$

where T is time of measurement, t_i is detected time of vehicle i.

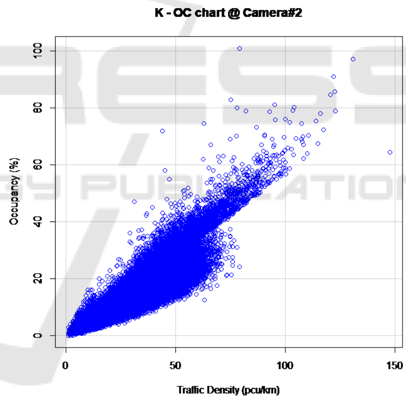
When number of existing vehicle a certain section is N, average length of vehicle is $\bar{l}$, formula (6) is given.

$$OC = 100\frac{q}{v}\bar{l} = 100\,k\bar{l} \tag{6}$$

Therefore occupancy (OC) is proportional to traffic density (K) and traffic volume (q).From the one month measurement data of Cam#1 and #2 in June 2015, traffic density (k) to occupancy (OC) relationship are shown in Figure 7. According to Figure 7, the relationship between (k) and (OC) is proportional but the dispersion of data is seen.



(a) *k-OC* characteristics of Cam#1.



(b) *k-OC* characteristics of Cam#2.

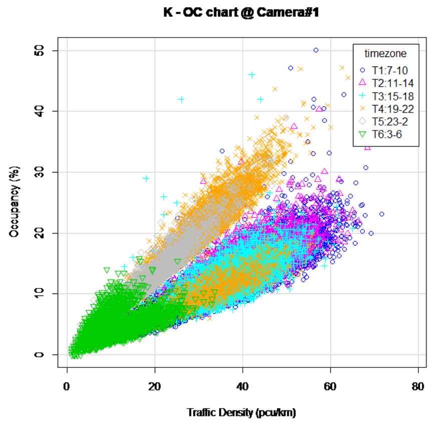
Figure 7: Example of *k-OC* characteristics.

In order to identify time zone basis characteristics, six time zone is introduced from T1 to T6 as shown in Table 2.

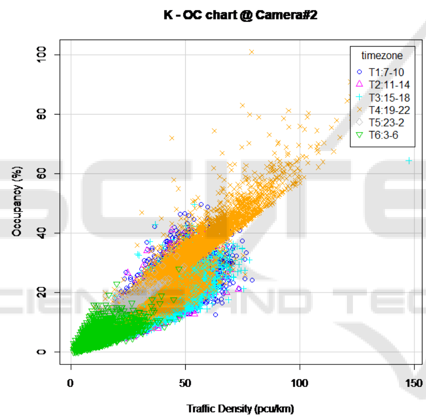
Table 2: Time Zone Classification.

Zone Name	Time Zone
T1	7:00 – 10:59
T2	11:00 - 14:59
T3	15:00 - 18:59
T4	19:00 - 22:59
T5	23:00 - 2:59
T6	3:00 - 6:59

By using Time Zone in Table 2 for Figure 7, then Figure 8 is obtained. From Figure 8, it is clear that T4 is most congested condition and the condition of (OC) over 30% is congested.



(a) Time Zone based $k - OC$ chart at Cam#1.



(b) Time Zone based $k - OC$ chart at Cam#2.

Figure 8: Time Zone based of *k-OC* characteristics.

2.3.3 Judgement from Social Loss

Finally, Social Loss is introduced in this section. According to the traffic flow theory, the Social Loss caused by traffic congestion is defined the Traffic Road Service Market Model. The theoretical Social Loss is calculated by area CE*E in Figure 9.

In Figure 9, the supply curve line rises to the right from travel time ($1/v_f$) to ($1/v_c$), which means private cost curve for transportation. And when (v) becomes small (travel time (t) becomes large), the value in blanket becomes negative and the supply curve drops to the right, which corresponds to private cost curve.

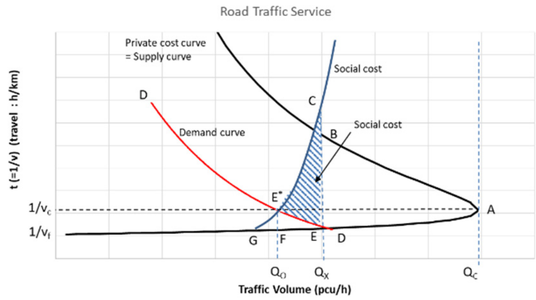


Figure 9: Traffic Road Service Market Model.

The point A is called hyper congestion condition at critical traffic volume (q_c) when traffic volume becomes larger beyond point A, travel time takes more because of traffic congestion. There are two travel time (t) except point A. In case of travel time longer at point B, there is travel service loss in terms of transport efficiency because travel time takes more than that of point E same which has equivalent traffic volume. If traffic demand curve D-D is given, the point E is cross point between demand curve D-D and supply curve which provides balance condition between traffic demand and supply condition. When social cost curve is given, the point E* becomes balance point between traffic demand and social cost. Then area CE*E provides traffic service cost loss caused by traffic congestion because infrastructure should cover at the level of traffic volume (Q_x) at the point E and social cost rises at the point C where its traffic volume (Q_x) is same as that of at the point E. Therefore area CE*E is defined as "Social Cost" by traffic congestion.

In our previous work of traffic flow analysis in CODATU November 2017, the critical vehicle speed (v_c) is 2/3 times of free speed (v_f). Therefore Figure 8 shows the result of measurement plot of Camera#2. In order to get the graph, we use the following condition.

- Demand curve: it is set on the boundary approximate line of all measurement plots
- Social cost: it is defined by linear line between point E* and point B. The traffic volume at point B is equal to that of point E. The point E is cross point of supply curve and boundary approximate line of measurement data.

On the basis of the above conditions, we define area BE*E as social cost. This definition is not exactly same as that of Figure 9 but it is enough to use this parameter as equivalent of social cost because we want to have relative comparison among measurement result in Ahmedabad traffic with common parameter—equivalent social cost. According to the definition of point E*, it should be cross point of supply curve at the travel time level ($=1/v_c$) at point A in Figure 9. But we already see the threshold between congested traffic flow condition and free flow condition is at threshold point of which inverse of vehicle velocity equals to $1/(2v_f/3)$. Therefore point E* in Figure 10 is set at $t = 1/(2v_f/3)$. Under these conditions, social cost of each road is obtained by area BE*E in Figure 10.

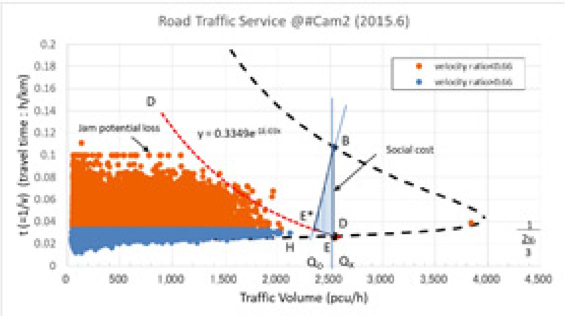


Figure 10: Traffic Road Service Market at Cam #2.

Table 3 shows the summary of Social Loss value of each CCTV.

Table 3: Social cost and speed ratio comparison.

Location	v_{ave}/v_f	Social loss
Cam#1	0.66	3.3
Cam#2	0.57	8.1
Cam#3	0.66	3.1
Cam#4	0.69	3.2
Cam#5	0.69	2.0
Cam#6	0.63	2.2
Cam#7	0.69	1.3
Cam#8	0.73	0.2
Cam#9	0.69	1.6
Cam#10	0.67	2.4
VMS#3	0.72	0.7

The correlation between speed ratio and social loss is shown in Figure 11 and calculated Social Loss is able to be representative value of traffic congestion (the decision factor R^2=0.825).

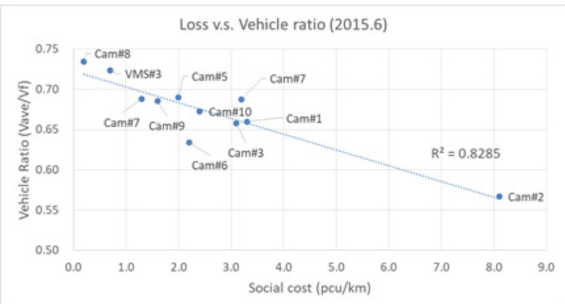


Figure 11: Correlation between Social cost and Vehicle ratio.

3 CONCLUSIONS

In this paper, author provides three types of traffic congestion analysis by typical traffic flow measurement observation, occupancy judgement, and Social Loss calculation. From these analysis, we know the total hourly number of vehicle of each road is not always explained the traffic congestion. From traffic flow measurement observation, the second number of vehicle peek point in the evening is most congested condition. From occupancy judgement, T4 (which means the time frame from 19:00 to 22:59) is most congested time zone. This is the same as traffic flow observation. In Social Loss calculation, calculated Social Loss is able to define the one of traffic congestion parameter.

This research continues to collect traffic flow data in Ahmedabad and a whole year analysis brings us more detail thought about Indian traffic congestion analysis. After this research, we will find out the traffic condition reason. The more traffic flow parameter value comparison is required in future work. Some future work introduction is described in Appendix. It is also necessary to make spatial analysis after collection all traffic flow data collection points.

ACKNOWLEDGEMENTS

This research is part of SATREPS program 2017 (ID: JPMJSA1606)) between India and Japan.

REFERENCES

Goutham.M, Chanda.B, 2014 , *Introduction to the selection of corridor and requirement, implementation of IHVS (Intelligent Vehicle Highway System) In Hyderabad*, International Journal of Modern Engineering Research, Vol.4, Iss.7, pp.49-54

Salim.A, Vanajakshi.L, Subramanian.C, 2010, *Estimation of Average Space Headway under Heterogeneous Traffic Conditions*, International . of Recent Trends in Engineering and Technology, Vol. 3, No. 5

Greenshields B.D., 1935, *A Study of Traffic Capaci, Proc.H.R.B.*, *14*, pp.448-477

Greenberg, H. 1959, *An analysis of traffic flow. Operation Research*, pp.79-85

Underwood, R. T. 1961, *Speed, Volume, and Density Relationship. Quality and Theory of Traffic Flow, Yale Bur. Highway Traffic, New Haven, Connecticut*, pp.141-188

Tsuboi.T , Yoshikawa.N, : Traffic Flow Analysis in Emerging Country (India), CODATU XVII, Nov.2017.

Tsuboi.T, Oguri.K 2016, *Journal of Society of Information Processing Engineers, Vol. 57 No. 12*, pp. 2819-2826 (in Japanese).
Matsuoka.Y, et al, 2013, *Fluid Mechanics —Fundamentals and Exercises—*, Corona Publishing C. Book, pp.119-121.
Kuroda.T, et al, 2008, *Urban and Regional Economics*, Yuhikaku Book, pp. 265-268.

APPENDIX

In Social Loss research, the following Figure A shows time zone basis characteristics. Form the Figure A, it is clear that T4 time Zone is critical for traffic demand curve.

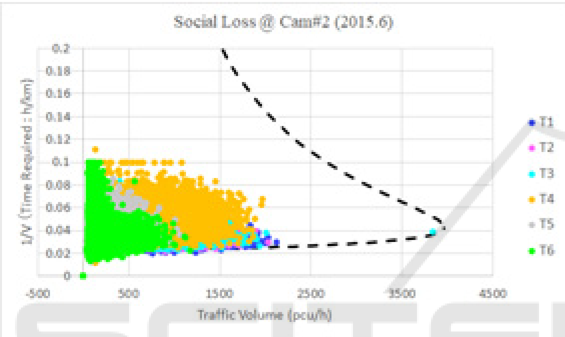


Figure A: Time Zone basis Traffic Road Service Market at Cam #2.

In case of traffic density histogram of Cam#2, there are two peeks: one is low density point in T5 and T6, the other is high density in T1 and T2 (Figure B).

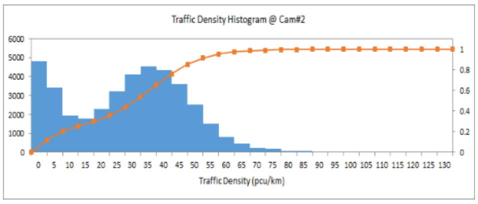


Figure B: Traffic Density Histogram at Cam #2.

In terms of the traffic density in T4, Figure C shows its histogram.

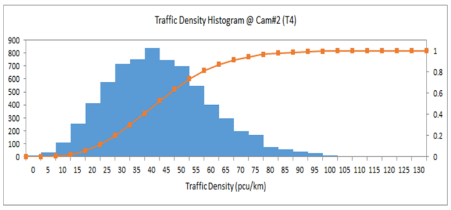
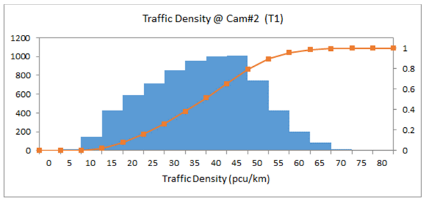
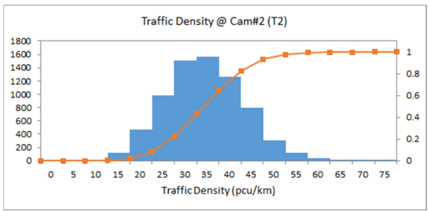


Figure C: Traffic Density Histogram in T4 at Cam #2.

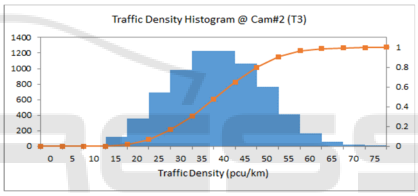
From those two histograms of Figure B and C, the traffic congestion condition courses under the condition of traffic density which is from 20 to 60. From Figure C, the traffic density histogram looks the normal distribution. In Figure D, it shows other time zone basis traffic density histograms as the reference.



(a) Traffic Density Histogram in T1 of Cam#2.



(b) Traffic Density Histogram in T2 of Cam#2.



(c) Traffic Density Histogram in T3 of Cam#2.

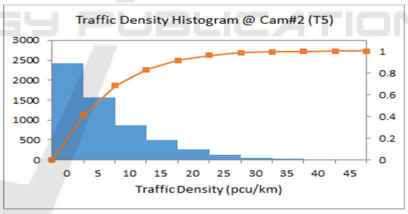
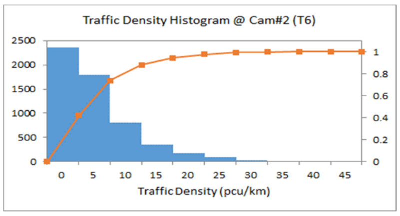


Figure D.



(e) Traffic Density Histogram in T6 of Cam#2.

Figure D: Traffic Density Histogram in each Time Zone.

Here is some notice about traffic flow values.
The value of the traffic density is generalized value which is mentioned in section 2.1. Therefore the number of lanes at Cam#2 is two lanes. So the real traffic density here becomes two times.