Lane Effect of Traffic Flow Analysis in India

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Keywords: Traffic Flow Analysis, Road Lanes Effect, Emerging Country Traffic.

Abstract: The aim of this research is to develop quantitative analysis method for emerging countries, especially focusing on major city in India where they are facing negative impact by transportation such as CO2 emission growth, many traffic fatalities, large fuel consumption, and air pollution as a result. In this research, we installed more than ten traffic monitoring traffic counter cameras in Ahmedabad city of Gujarat state of India. The monitoring cameras detect traffic vehicle and capture several traffic data such as vehicle numbers, vehicle speed, traffic occupancy, vehicle density, gap length between vehicle to vehicle and so on. And each data is collected by every minutes per roads. Therefore the collected data becomes more than 432,000 points per months. In order to analyse the traffic data, author recognize special features of the collected traffic data and the Envelope Observation (EO) for traffic flow characteristics by measurement data is useful for obtaining traffic flow equation. The unique feature of emerging counties traffic data is widely spread plots at the traffic basic characteristics such as traffic density to speed curve and traffic density to traffic volume curve. But there is clearly boundary line in those curves. Author uses EO analysis to fit traffic flow parameters to these boundary lines. By defining traffic flow parameters, it is able to obtain the traffic flow value such as free speed traffic flow, critical traffic volume, and critical traffic density. After obtaining traffic parameters, it is able to create traffic flow equation for each measured road and even each lane of its road. The uniqueness of this research is extension of analysis for the road lane effect for the traffic congestion by correlation ratio analysis between driving lane and passing lane of each road. As the result of this analysis, it becomes clear that congestion condition of roads makes the different traffic flow characteristics by driving and passing lane. This is the first time to explain the lane effect for traffic congestion on the basis of the EO method.

1 INTRODUCTION

1.1 Background

This manuscript describes traffic flow analysis method in emerging county based on one month probe big data. In general, it is a challenge how to collect real traffic probe data in emerging country and how to analyse traffic flow from its data. Author has a chance to collect total two months traffic probe data by using traffic monitoring cameras in Ahmedabad city of Gujarat State in India. This is a part of Japan International Cooperation Agency or JICA project for providing traffic information to the drivers in the city as Indian ITS business since October 2014. In this project, there are fourteen traffic monitoring cameras and four electric traffic information sign boards so called Variable Message Sign (VMS) are installed in Ahmedabad city. In this paper, one month prove data in June 2015 is used as lane effective analysis.

In Author's previous research, we introduced traffic flow analysis of Ahmedabad city in India and showed traffic congestion condition by using Envelop Observation (EO) method in which traffic characteristics is obtained by utilizing the Envelope Observation for each measurement traffic data. It is described in the next section. According the previous research, speed ratio which is average speed of vehicles to free flow speed which is obtained from EO.

The following steps are our traffic flow analysis in this paper.

At first, we start traffic flow analysis for each roads by EO method and obtain traffic basic traffic flow characteristics such as the traffic density (k) to speed (v) curve (*K-V* curve). From each *K-V* curve, it is able to define free flow speed (v_f).

As the next step, we calculate a speed ratio (V.R.) which is the average speed (v_{ave}) to the free flow speed (v_f). When the critical speed is described as (v_c), its value is the half of free flow speed (v_f) from the

Tsuboi, T.
Lane Effect of Traffic Flow Analysis in India.
DOI: 10.5220/0007239302680276
In *Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2019)*, pages 268-276
ISBN: 978-989-758-374-2

theory. Therefore the traffic condition under less than 0.5 V.R. area means congested condition. The V.R. becomes important parameter for congestion condition of the roads.

As the third step, we investigate lane effect against each traffic condition and this analysis is main study in this paper. In order to analyze the lane effect to traffic congestion, we compare the variance of traffic congestion between driving lane and passing lane. In this study, we have three measured data of the roads—speed (v), traffic density (k), and traffic volume (q). For the traffic condition variance, two value of them are enough for the variance comparison because there is the relationship among them—$q=k\times v$. So we chose (v, k) parameter set as representative traffic characteristics for each lane. Since the V.R. is congested condition parameter, the correlation between V.R. and the (v, k) parameter set of each lane provides lane effectiveness for its traffic condition.

And finally we show a certain lane effect between driving lane and passing lane by *K-Q* curve of each lane.

This is the first traffic flow analysis in emerging country in terms of the following features.

- Use one month traffic flow big data among 10 locations
- Introduce traffic flow equation by EO method
- Show lane effectiveness by *K-Q* curve characteristics

1.2 Related Study

In terms of traffic analysis, there are new challenges by using advanced sensing technology such as the probing data with Global Positioning System (GPS) in side vehicles. This study is estimation by using probing vehicle behaviour but this case study is limited number of probe data and a study in the advanced country i.e. Italy. For probing technology based traffic analysis, there are many case studies in the vehicular ad hoc network (VANET) environment. These research are useful to estimation traffic safety application especially in the congested traffic condition. In VANET environment, the advanced communication technology is sued such as Dedicated Short Radio Communication (DSRC), Cellular phone network like Long term Evolution (LTE), 3G, 4G, 5G etc. Most of the advanced network communication technology has just been released in the advanced countries and will be installed in new manufacturing vehicles in future.
Therefore the classical traffic monitoring technology with monitoring cameras is still valid especially for study of traffic flow analysis in the emerging countries. In case of traffic analysis in emerging countries such as India, there are several studies these days. Goutham.M has proving data analysis at National Highway in Hyderabad. It shows trend of traffic condition and comparison with Indian Road standard IRC-106-1990 but measurement points are only two Highways and volume is two days with five CCTVs. In Salim.A et al study, it describes traffic congestion condition by headway measurement in Chennai. But measurement point is only one city road and four days data with one hour for each. It is also limited measurement data.

2 ENVIRONMENT OF TRAFFIC DATA MEASUREMENT

2.1 Location

As mentioned in Introduction, the Indian ITS project has been started since October 2014. The ITS business operates in Ahmedabad city of Gujarat states in India, where it is located west region of India and it has about 8 million population. There are fourteen traffic monitoring cameras which collect traffic parameters such as traffic density, traffic volume, and speed.

The Figure.1 shows total ITS cameras installation location in the city. The “Cam” in Figure.1 means Traffic Monitoring Camera and “VMS” means Various Message Sign board. The main purpose of VMS is display of traffic condition to drivers after traffic condition analysis.

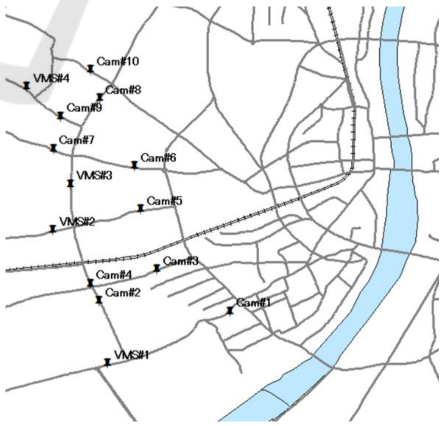


Figure 1: Indian ITS system installation location.

2.2 System Configuration

The Indian ITS system has three components—traffic monitoring camera, traffic information board, traffic management system. The management system is operated by cloud system through internet access. The total system configuration is shown in Figure.2. The traffic data is captured through traffic monitoring camera and transferred to the data base via Internet Cloud. After collecting traffic data, the traffic condition is shown at the VMS as the result of traffic analysis. The traffic condition information is shown by the simple three level like conditions such as heavy, slightly heavy, and smooth.

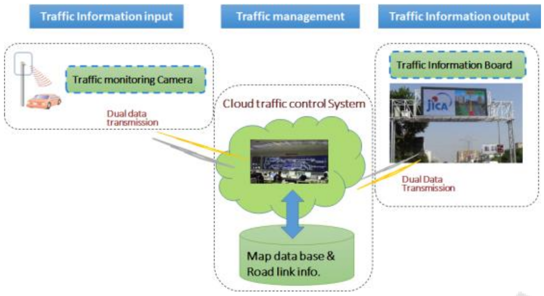
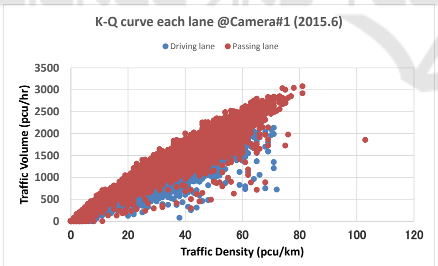


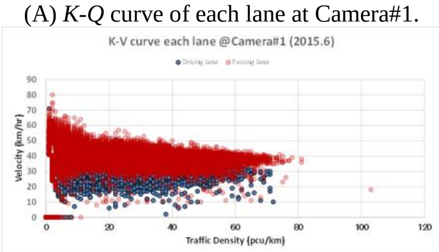
Figure 2: Indian ITS system configuration.

2.3 Traffic Measurement Data

The traffic monitoring cameras measure and collect the traffic data every minute. Figure.3 (A) and (B) show an example of *K-Q* curve and K-V curve of each lane at Camera#1. The plotted data is measured during June 2015. The road at Camera#1 has two lanes for both direction of its roads.



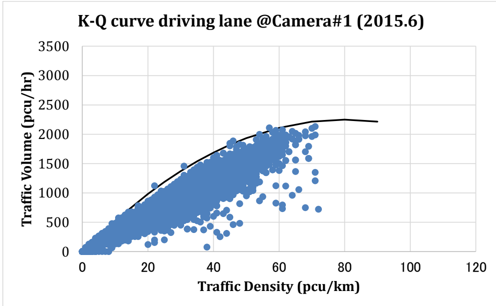
(A) *K-Q* curve of each lane at Camera#1.



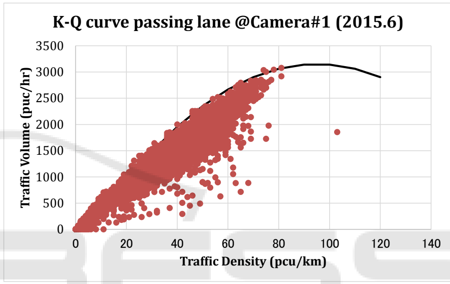
(B) *K-V* curve of each lane at Camera#1.

Figure 3: Example of traffic characteristics at Camera#1.

According to all measured traffic data, shape of curve at each location is quite similar configuration. There is boundary line in each *K-Q* curve and *K-V* curve clearly. There are no measured data out of its boundary line. Therefore it is able to consider that the boundary line shows traffic capacity of the road at least under the measurement time period. Figure.4 (A) and (B) show *K-Q* curve for driving lane and passing lane at Camera#1 for example.



(A) *K-Q* curve of driving lane at Camera#1.



(B) *K-Q* curve of passing lane at camera#1.

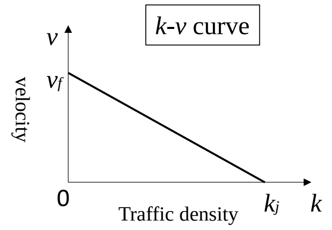
Figure 4: *K-Q* curve of each lane at Camera#1.

3 ENVELOPE OBSERVATION METHOD

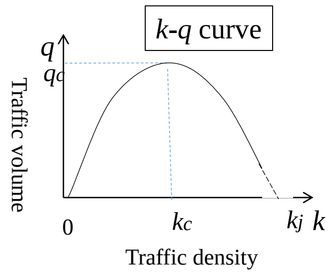
In this section, it is explained how to obtain the traffic characteristics by using the Envelop Observation (EO) method.

3.1 Traffic Flow Equation

From the traffic flow theory, typical *K-V* and *K-Q* curve are described like in Figure.5 (A) and (B). As we see the boundary line in previous section, the line is consistent with the envelopment curve. Therefore when we consider that the boundary line provides the road capacity of each road, it is able to obtain traffic parameters from this curve.



(A) Theoretical *K-V* curve.



(B) Theoretical *K-Q* curve.

Figure 5: Traffic Flow Theoretical curve.

The Figure.5 (A) shows one of general *K-V* curve which is called Greenshields. It is obtained by equation (1).

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

where (v_f) is free flow speed and (k_f) is traffic density at free flow condition.

From traffic flow continuity of the traffic flow theory, equation (2) is given.

$$q = k \times v \tag{2}$$

where (q) is traffic volume, (k) for traffic density, (v) for speed.

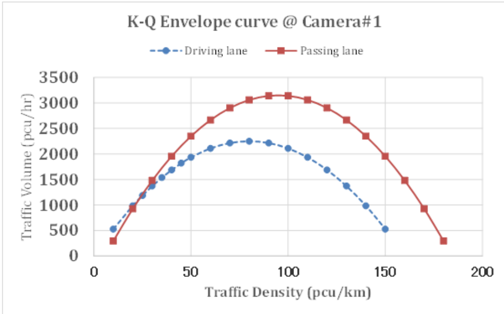
The following equation (3) is obtained by eliminating (v) from equation (1) and (2).

$$\begin{aligned} q &= k \times v_f \left(1 - \frac{k}{k_f}\right) \\ &= \mathrm{k} \times v_f - \frac{k^2}{k_f} \\ &= -\frac{v_f}{k_j}\left(k - \frac{k_j}{2}\right)^2 + \frac{v_f k_j}{4} \end{aligned} \tag{3}$$

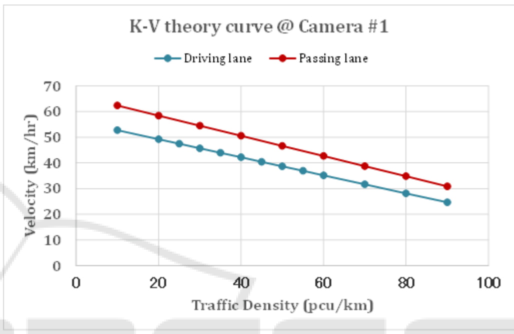
where (k_j) is jam traffic density and $k_j = 2\ k_c$.

3.2 Traffic Flow Characteristics by EO Method

When we use equation (1) and (3), it is able to obtain traffic parameters by matching the envelopment line with its calculated curve by its traffic parameters. The envelopment curve at Camera#1 in Figure.6 (A) and (B) as an example.



(A) Envelopment curve of *K-Q* curve at Camera#1.



(B) Envelopment curve of *K-V* curve at Camera#1.

Figure 6: Envelopment curve of Traffic Flow Characteristics of Camera#1.

By using EO method for all measurement traffic data in Ahmedabad, Table 1 shows the summary of the analysis result at each location.

Table 1: Traffic Parameters at each Location by EO Method.

Location	Lane	v f/kj	kc(pcu/km)	qc(pcu/hr)	vc (km/hr)	K-Q curve Formula	vf (km/hr)
Cam#1	DL	0.35156	80	2250	28.13	-0.3516(k-80)^2+2250	56.3
	PL	0.34903	95	3150	33.16	-0.3951(k-95)^2+3150	66.3
Cam#2	DL	0.17355	110	2100	19.09	-0.1736(k-110)^2+2100	38.2
	PL	0.22222	120	3200	26.67	-0.2222(k-120)^2+3200	53.3
Cam#3	DL	0.24377	95	2200	23.16	-0.2438(k-95)^2+2200	46.3
	PL	0.26446	110	3200	29.09	-0.2645(k-110)^2+3200	58.2
Cam#4	DL	0.39446	85	2850	33.53	-0.3945k-85)^2+2850	67.1
	PL	0.35000	100	3500	35.00	-0.3500(k-100)^2+3500	70.0
Cam#6	DL	0.21607	95	1950	20.53	-0.2161(k-90)^2+1950	41.1
	PL	0.28733	115	3800	33.04	-0.2873(k-115)^2+3800	66.1
Cam#7	DL	0.24793	110	3000	27.27	-0.2479(k-110)^2+3000	54.5
	PL	0.28099	110	3400	30.91	-0.2810(k-110)^2+3400	61.8
VMS#3	DL	0.24306	120	3500	29.17	-0.2431(k-120)^2+3500	58.3
	PL	0.28099	110	3400	30.91	-0.2810(k-110)^2+3400	61.8
Cam#8	DL	0.25620	110	3,100	28.18	-0.2562(k-110)^2+3100	56.4
	1PL	0.35000	100	3,500	35.00	-0.3500(k-100)^2+3500	70.0
	2PL	0.41975	90	3,400	37.78	-0.4198(k-9 0)^2+3400	75.6
Cam#10	DL	0.28906	80	1850	23.13	-0.2891(k-80)^2+1850	46.3
	1PL	0.37500	80	2400	30.00	-0.3750(k-80)^2+2400	60.0
	2PL	0.42857	70	2100	30.00	-0.4286(k-70)^2+2100	60.0

DL: Driving Lane, PL: Passing Lane, 1PL: 1st Passing Lane, 2PL: 2nd Passing Lane

The data of Camera#5 and #9 are eliminated because of measurement trouble. The number of lane of Camera#1 to #7 and VMS#3 is two lane and that of Camera#8 and #10 is three lanes for each side of the road.

4 LANE EFFECT ANALYSIS

4.1 Congestion and Speed Ratio

In the previous research, it is concluded that there is strong relationship between traffic congestion and speed ratio (V.R.) which is average speed (v_{ave}) to free flow speed (v_f). When $k=k_c=k_j/2$ in equation (1), $v=1/2v_f$. And the critical traffic volume (q_c) is obtained when k=k_j/2. The road condition over (q_c) becomes congestion condition which is shown in Figure.7.

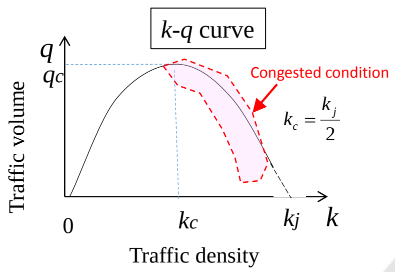


Figure 7: Traffic density and Traffic Volume relationship.

The Figure.8 shows the summary of V.R. of each location. In Figure.8, DL means the driving lane, 1PL is the first passing lane, and 2PL is the second passing lane.

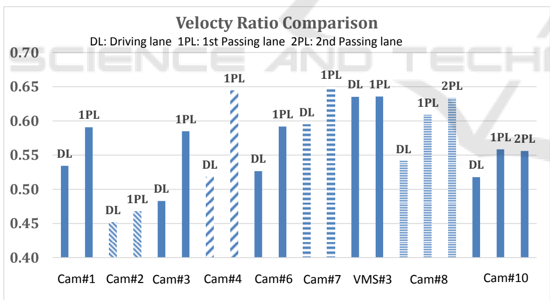
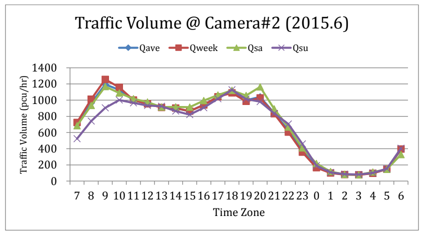


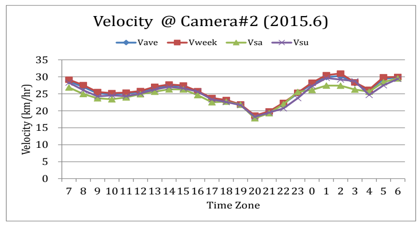
Figure 8: Speed ratio (V.R.) at each Location.

As it is shown in Figure.8, the condition at Camera#2 is congested of both the driving lane and passing lane. The driving lane condition at Camera#3 is also congested.

In order to understand the condition at Camera#2, the time zone based traffic volume and speed at Camera#2 are shown in Figure.9. In Figure.9 (A), we see two heavy traffic volume time zones which are around 9:00 am and 8:00 pm.



(A) Time zone base Traffic Volume at Camera#2.



(B) Time zone base Speed at Camera#2.

Figure 9: Time zone traffic characteristics at Camera#2.

As for the time zone based speed in Figure.9 (B), the speed at 8:00 pm drops down under 20km/hr which means the traffic condition is congested.

The actual *K-Q* curve from the measured data at Camera#2 is shown in Figure.10.

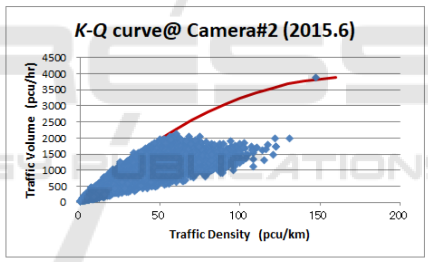


Figure 10: The Actual *K-Q* curve from the measured data at Camera#2.

According to Figure.10, there is no measured data over the critical traffic volume. This shows there is another new congested area except the area with over traffic critical volume. Figure.11 shows this condition.

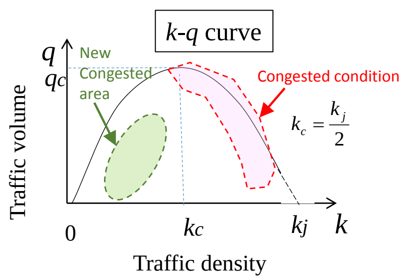


Figure 11: New congested area in Indian traffic.

The Figure.11 explains that the value of traffic volume does not always provides the traffic congestion condition, which we have already seen the traffic condition around 9:00 am in Figure.9 (A). Therefore it is able to say that V.R. is valid parameter which defines traffic congestion.

4.2 Lane Effect

As it is shown in Figure.8, the traffic conditions of each road and each lane are different. In order to understand their lane effect for traffic flow, we calculate the variance of measurement data set with the elements of traffic density (k) and Speed (v). Here we define data set of the driving lane is DL(k, v) and the passing lane data set is PL(k, v). The correction ration between driving lane (DL) and passing lane (PL) are shown in Table 2. The data set of the 1st passing lane is (1PL) and the 2nd passing lane is (2PL).

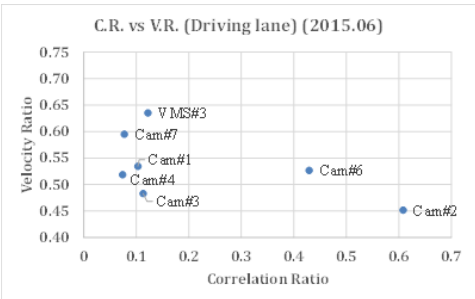
Table 2: Correlation Ratio at Each Location.

	Cam#1	Cam#2	Cam#3	Cam#4	Cam#6	Cam#7	Cam#8	Cam#10	Cam#10	VMS#3
DL-PL	0.103	0.608	0.113	0.074	0.429	0.077	0.073	0.153	0.153	0.122
1PL-2PL							0.013	0.144	0.144	
DL-2PL							0.114	0.067	0.067	

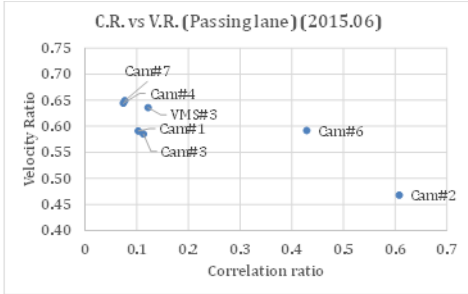
According Table 2, the value of correlation ratio at Camera#2 is highest score, which means the traffic condition of the driving lane and the passing lane are both congested. This is what it has been already shown that the traffic condition at Camera#2 is most congested (refer to Figure.8 (B)).

4.3 Correlation Ratio and Speed Ratio

In this section, we investigate relationship between correlation ratio (C.R.) and speed ratio (V.R.). Figure.12 shows the relationship for each lane.



(A) C.R. vs V.R in driving lane



(B) C.R. vs V.R in passing lane

Figure 12: Relationship between C.R. and V.R

From Figure.12, the lower speed ratio which means traffic congestion condition, the higher correlation ratio which means different traffic characteristics between driving lane and passing lane. Figure.13 shows K-Q envelopment curve at VMS#3, Camera#6 and Camera#2.

4.4 Comparison Traffic Characteristics

In previous section C, K-Q characteristics curve at VMS#3, Camera#6 and Camera#2 is described. As it is shown in Figure.9, traffic condition atVMS#3 is smooth flow compared with that of camera#2 and Camera#6 is middle.

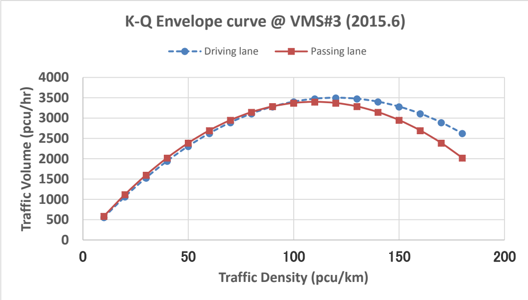
From Figure.13, it is clear different traffic characteristics between the driving lane and the passing lane based on congestion condition.

For the summary for lane effect to traffic characteristics, it is possible to the following conclusion.

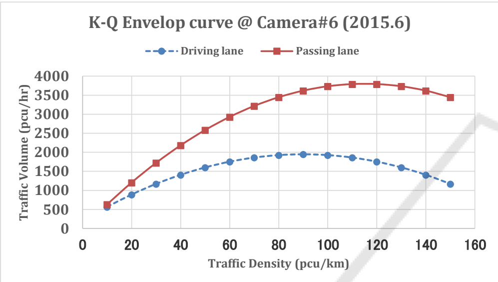
i) In free flow condition: there is no particular different between driving lane and passing lane (Figure.13 (A))
ii) Medium congested condition: there is a certain different especially in low traffic density condition (Figure.13 (B))
iii) Congested condition: there is big difference between driving lane and passing lane (Figure.13 (C))

The above summary is illustrated in Figure.14. The different characteristics between driving lane and passing lane becomes clearer according to congestion level of the road. From the beginning of traffic congestion, traffic volume difference becomes bigger at lower traffic density condition (A point in Figure.14). Then when traffic condition becomes more congested, traffic volume difference at higher traffic density becomes bigger (point B in Figure.14).

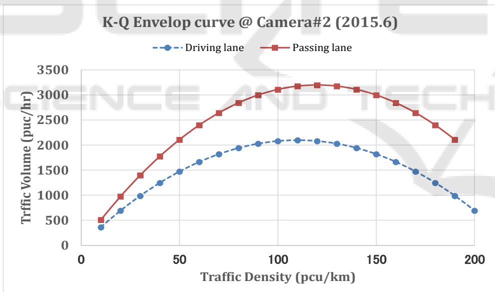
In terms of lane effect research, Uchida.H announced highway level analysis in Japan. But this is based on simulation model analysis and lane effect shows up in high traffic density area.



(A) *K-Q* characteristics curve at VMS#3.



(B) *K-Q* characteristics curve at Camera#6.



(C) *K-Q* characteristics curve at Camera#2.

Figure 13: *K-Q* characteristics curve at typical location.

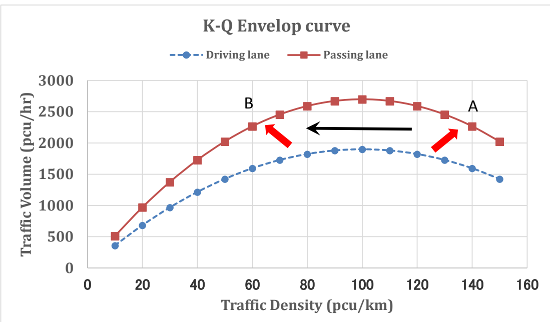
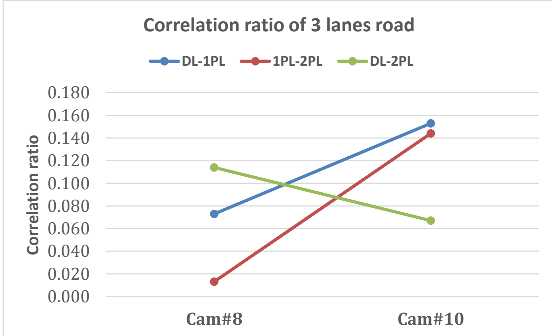


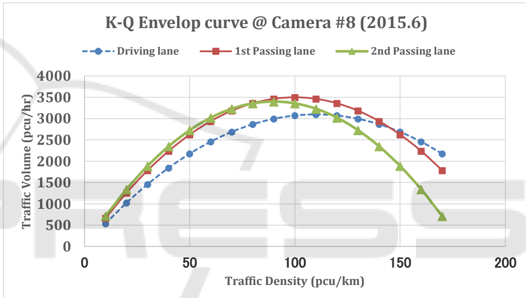
Figure 14: Lane Effect in K-Q envelopment curve.

4.5 Three Lane Analysis

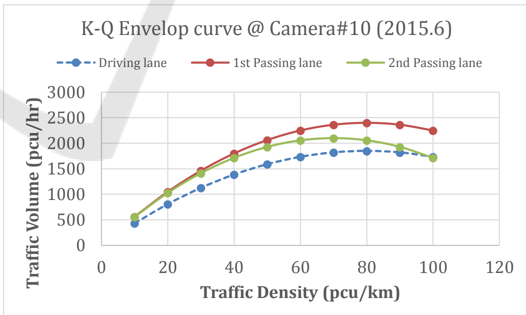
In case of three lane case study, we only have data of Camera#8 and #10. Figure.15. The correlation ratio and vehicle ratio relationship, *K-Q* envelopment curve at Camera#8 and #9 are shown in Figure.15.



(A) Correlation ratio at Camera#8 and #10



(B) *K-Q* characteristics curve at Camera#8.



(C) *K-Q* characteristics at Camera#10.

Figure 15: Three lane traffic characteristics Comparison.

There is no significant characteristics difference among three lanes because correlation ratio is small and traffic condition is relatively smooth.

5 DISCUSSION

In this section, it is more detail discussion about the Envelop Observation method. The Figure.16 shows *K-V* curve at driving lane of Camera#1 with approximate line by Envelop Observation method and Least Square method. The Least Square method is generally used in Statics Analysis for understand the trend of measurement data. From Figure.16, the equation by Least Square method is right rising curve, which does not follow the traffic flow theory. On the other hand, the equation by Envelop Observation method is right downward curve and follows the traffic flow theory. In this example, the Envelop Observation method shows the traffic flow limitation of each road.

In case of *K-Q* curve at Camera #1, the traffic flow characteristics is shown in Figure.17. The Envelop Observation equation of *K-Q* curve is $q = -0.3516(k - 80)2+2250$. Therefore the jam density $k_j=160$. From equation (3), the free speed $v_f=56.25$. When the Least Square equation of k-q curve from Figure.17, $q = -0.022k^2+31.213k+4.689=-0.022(k-709.4)^2+503233.2$. The jam density $k_j=1418.772$. Then free speed $v_f = 31.21$. It does not match with v_f of Figure.16.

As the result, it is able to say that the Least Square method shows the trend of traffic measurement data but it does not provide the traffic parameter data such as jam density and free speed.

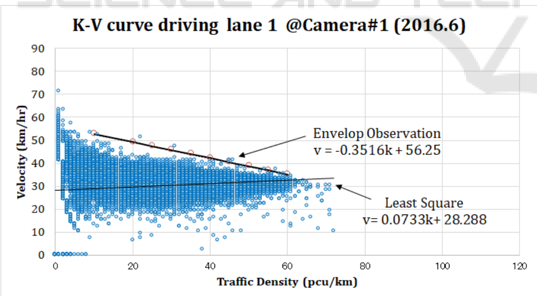


Figure 16: *K-V* curve driving lane at Camera#1.

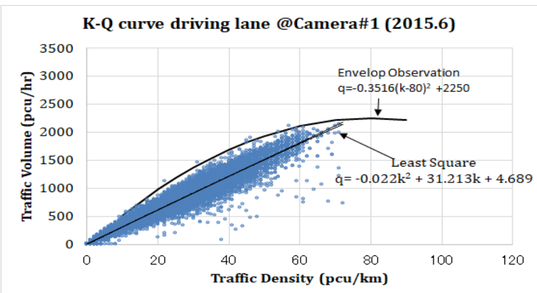


Figure 17: *K-Q* curve driving lane at Camera#1.

6 CONCLUSIONS

Author introduce Envelop Observation (EO) method for emerging country traffic flow study based on one month big data of traffic at a city in India. By using EO method, it is able to get traffic flow parameters such as free flow speed. From the free flow speed, we are able to get Speed Ratio (average speed to free flow speed) as indication of traffic congestion level. After validation of EO method and Speed Ratio is confirmed, we look into traffic flow difference for driving lane and passing lane as a lane effect by correlation ratio between traffic flow condition of driving lane and passing lane. And we reach the following conclusion for traffic flow lane effect.

1) Under free flow condition: There is no different about traffic flow condition. We are able to confirm this by *K-Q* curve characteristics.
2) Under light congested flow condition: There is traffic flow volume different between at driving lane and passing lane. The traffic volume at passing lane is larger than that of driving lane, especially high traffic density condition.
3) Under congested flow condition: There is clear difference in traffic volume not only at high traffic density condition but also small traffic density condition.

In this research, we show that EO analysis method and correlation ratio comparison for multiple lane road is useful for the analysis of traffic flow condition. So we consider this analysis method to other case study such as time zone base, season base, and location base in future.

ACKNOWLEDGEMENTS

This research is a part of SATREPS (Science and Technology Research Partnership for Sustainable Development) program 2016 (ID: 16667556).

Special appreciation to Mr.Kikuchi.C and Mr.Mallesh.B of Zero-Sum ITS India for providing traffic data in Ahmedabad.

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