Lane Distribution Behavior in Three Lane Uni-Directional Freeway

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1. Introduction

The movement of motorized within a freeway facility is a special area of traffic operation with several unique characteristics. One of such an area is 'analysis of traffic distribution into the individual lane in a multi-lane freeway', which become as a major research area in traffic operation at present. Identifying the phenomena of traffic distribution is very useful in application of new traffic operation strategies. The recent researches have identified that the traffic distribution in each lane of a multi-lane freeway is not uniform among each other, and it became major concern for the capacity improvement of freeways' operations. Since, locations of on and off ramp are highly influence the lane distribution near to those facilities, in this study, only uninterrupted segments are considered for analysis. Further, even though there are many factors affecting the traffic distribution, in this analysis it is decided to examine the effect of geometry changes, such as specific grade (up and down), curvature together with effect of mix of heavy vehicle and light condition on lane distribution, by identifying a suitable models. Therefore, the objective of this study is to develop a model for lane distribution and to provide some insights into how these factors might affect the lane distribution.

2. Site Selection

Five different geometry conditions, such as leveled straight segment, upgrade straight segment, downgrade straight segment, leveled curved segment with right turning movement and left turning movement were examined. Data from eight different sites in Tomei expressway was collected by detectors, as shown in Table 1. Among this data set, three sites (A-II, B-II, C-II) were selected for the analysis for the locational effect of lane utilization. As shown in Table 1, the sites A-I and A-II are considered as leveled and straight segment. Similarly, B-I and B-II, C-I and C-II, are considered as upgraded straight and downgraded straight segment. The site D is leveled curved segments with right hand turning curvature, while, sites E is leveled curved segments with left hand turning curvature.

Table 1. Detail of Selected Sites for Lane Utilization Analysis

Geometry		Site	Direction to	km Post	Grade(%)	Radius (m)
Leveled and Straight		A-I	Nagoya	21.52	-0.06	2,800
		A-II	Tokyo	32.69	0.22	2,800
Up Grade and Straight		B-I	Tokyo	14.98	3.00	2,000
		B-II	Nagoya	16.35	2.83	3,000
Down Grade and Straight		C-I	Nagoya	12.50	-2.91	2,500
		C-II	Tokyo	16.77	-2.83	3,000
Leveled and Curved	RT	D	Tokyo	02.47	0.00	900
	LT	E	Nagoya	02.40	0.00	900

Note : RT means right turning movement and LT means left turning movement

The data were collected through out the period (i.e., 24 hours per day) during August 1990. The total volume, total heavy vehicle, corresponding average speed, and percentage of occupancy of each lane for every 5 minute were obtained. There are very few data on congested condition. Since, the lane utilization in congested region is not an objective of this paper, congested data were removed by identifying the critical speed and critical level of occupancy.

3. Modeling of Lane Distribution

The lane distribution analysis was carried out by considering various traffic parameters, such as volume, traffic composition and speed. Among various model configurations tested for the modeling of lane distribution, the two most suitable form of models are given by the following eq 1[(1)], eq 2.

Model I $P_i = a_{1i} + b_{1i} \ln Q + c_{1i} \ln Q_{hv} + d_{1i} \ln V$ (i=1,2,3) (1)

Model II $P_i = a_{2i} + b_{2i} Q + c_{2i} Q^2$ (i=1,2,3) (2)

Where; P_i is the percentage of lane distribution in lane i (i=1,2,3), Q is the total traffic flow rate (vph), Q_{hv} is the total heavy vehicle in the traffic stream, V is the average speed of the traffic stream, a_{1i}, $a_{2i(i=1,2,3)}$ are constants $b_{ji((j-1,2)i=1,2,3)}$, $c_{ji((j-1,2)i=1,2,3)}$ and $d_{1i(i=1,2,3)}$ are coefficients. This analysis shows that, the model I is the better description for lane distribution for three lane uni-directional freeway than model II. The value of the R^2 values, the estimated coefficients, the t-values for each coefficient are given in Table 2. Due to the limitation of the space, except R^2 other model II details are not presented here.

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Table 2. Statistical Results of Lane Utilization Model (Model I)

Site		R^2	a_{1i}	b_{1i}	c_{1i}	d_{1i}	t_{a1}	t_{b1}	t_{c1}	t_{d1}	F	R^2 for Model II
A-I	P2	0.78	84.49	-10.814	0.7479	8.158	13.51	-68.57	8.47	6.57	1,723	0.71
	P3	0.87	-182.94	18.801	0.9942	14.735	-23.59	96.10	9.07	9.57	3,240	0.77
A-II	P2	0.81	88.72	-11.364	1.3942	7.210	13.22	-58.27	17.97	6.10	2,913	0.75
	P3	0.90	-166.66	18.374	1.5969	11.011	-23.22	85.13	18.60	8.42	3,848	0.67
B-I	P2	0.85	146.59	-12.275	0.0596	-2.534	29.09	-64.85	6.90	-2.96	2,739	0.80
	P3	0.88	-184.10	18.401	0.5441	16.258	-28.19	78.44	6.60	15.30	3,186	0.81
B-II	P2	0.80	105.37	-11.372	0.1753	4.973	17.86	-68.30	2.12	4.34	1,865	0.80
	P3	0.88	-172.18	18.528	1.4913	12.359	-25.35	96.51	15.68	9.37	3,594	0.87
C-I	P2	0.79	89.23	-10.826	0.2295	7.439	14.11	-67.94	2.83	5.92	1,783	0.79
	P3	0.86	-162.02	18.516	1.7357	9.921	-19.41	88.06	16.25	5.99	2,969	0.85
C-II	P2	0.86	106.61	-11.231	0.5861	3.732	20.33	-69.70	8.95	4.00	3,106	0.84
	P3	0.90	-181.83	18.291	0.4019	16.302	-28.99	94.94	5.13	14.61	4,234	0.89
D	P2	0.79	168.28	-12.720	-0.2353	-6.496	25.84	-68.89	-2.91	-5.27	1,738	0.50
	P3	0.68	-188.06	11.903	2.3845	24.749	-18.69	42.40	19.42	13.20	658	0.67
E	P2	0.84	160.48	-10.902	-0.8813	-6.448	27.59	-80.21	-11.74	-5.59	2,589	0.83
	P3	0.91	-256.28	18.424	1.1640	31.148	-38.24	117.64	13.46	23.42	5,095	0.88

Eventhough, the lane 1 (shoulder lane) results (P1) not shown in this Table, it was found out that the R^2 value for lane 1 in every site are less than the other two lanes. This may be due to higher percentage of heavy vehicle and their irregular vehicle moment in lane 1 is higher than it for other lanes. Therefore, in future, it is better to forecast the model for P_2 and P_3 and then P_1 can be obtained from $P_1 = 100 - P_2 - P_3$. Further, '*t*' value for each parameter shows that all of them are statistically significant at 95% level. This shows that the traffic distribution in a three lane uni-directional freeway is affected not only by the total traffic flow but also by the amount of heavy vehicles in the traffic and the average speed. However, it is better to mention here that a similar analysis for two lane uni-directional freeway lane distribution analysis shows that the model II is better for describing it's lane distribution, i.e., the lane distribution is not depending either on average speed or percentage of the heavy vehicle in the traffic stream.

The percentage of lane traffic distribution against total traffic flow in vph for site A-I is shown in Figure 1. From this the lane distribution can be classified into three categories, such as, $P_2 > P_1 > P_3$, $P_2 > P_3 > P_1$ and $P_3 > P_2 > P_1$. Also similar to the other studies, it is identified from theses groups that the shoulder lane utilization has never been highest for any flow condition in a six lane freeway. From this Figure, at the maximum flow condition, the different in lane distribution between lane 1 and lane 3 is about 35%. This value is about 17% between lane 1 and lane 2. On the other hand it is very interesting to see that the usage in lane 3 at maximum flow condition is equal to other two lanes. Therefore it is very important to improve the utilization of other lanes by the suitable measures, which will be discussed slightly in the section 5.

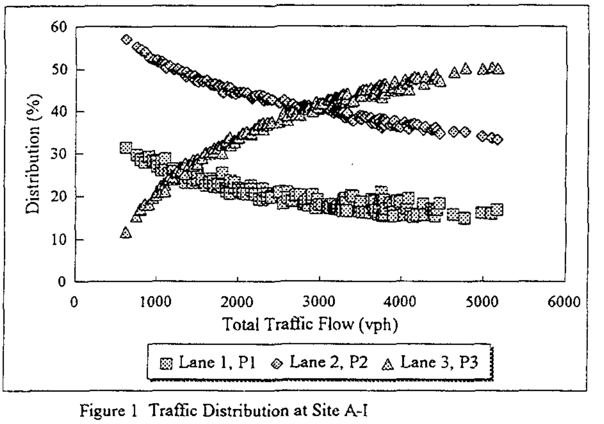

Figure 1 Traffic Distribution at Site A-I

4. Analysis of the Lane Distribution

(1) Effect of Location

The locational effects on lane distribution were compared between geometrically identical sites, such as between A-I and A-II, similarly B-I and B-II, C-I and C-II. Results show that there is no significant difference between the same geometry sites for the level of 95% significant. Also, Chi-square (χ^2) value for lane 2 comparison is very much less than other two lane, i.e., the lane distribution in lane 2 is more identical for each locations than others. On the other hand, it can be say that, the lane 2 traffic utilization is more stable than the other lanes.

(2) Effect of Geometry

In this section, first effect due to site slopes and curvature was analyzed, then combined effect together with upstream and downstream section was taken into account, and discussed in three separate paragraphs as follows.

Statistical test for differences in lane distribution manner in upgrade and downgrade freeway segment (about 3% or -3%, respectively) was compared with straight level freeway segment. Results show that, even though there are no significant different for 95% level for any flow condition, the trends in individual lane usage have unique different in their behaviors, as can see from Figure 2. The differences in lane distribution was calculated as the traffic distribution in a lane at the site under consideration minus the same lane traffic distribution in a straight leveled segment. Therefore as can see from the Figure 2, when gradient is changing regardless of up or down, the usage in lane 1 and lane 3 is increasing while the usage in lane 2 is decreasing. The reason for this phenomena in lane utilization might be due to expected gravitational effect on the vehicle speed by steep slope. By which, some vehicles in lane 2 are changing their lane to shoulder lane, while some passenger car in the lane 2 is changing their positions to faster lane. Further, when the total flow is higher, for the similar reason, the amount of increase is much more in lane 1 when comparing this to lane 3, but for the lower range of total traffic flow the amount of increase in lane 3 is higher than it for lane 1.

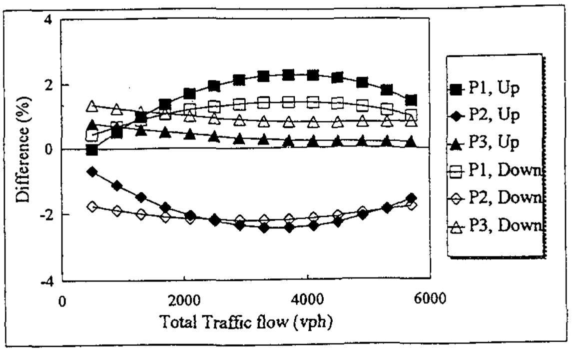

Figure 2 Differences in Site B and Site C with Site A-I

A similar statistical test was carried out to find the effect due to right and left turning curved freeway segment with straight freeway segment. Because of limitation of sites, acceptable existing two sites were considered for this analysis with the segment radius of 900 m, as detail given in Table 1. Results show, there are no significant differences for the level of 95% for left turning curvature (Site E). This shows the left turning moments is much familiar for the divers. But for the right turning moments (Site D), the differences in lane usage with site A-I, is more than an acceptable level, as can see from Figure 3. Further, the result of an individual lane analysis for site E, with respect to typical lane usage of a straight leveled segment can be seen from Figure 4. The value of P_3 increases for lower flow rate and decreasing for higher flow rate condition with a decreasing rate. The reason for increase in lane 3 is due to the willingness of usage of shortest path. Further, at moderate to higher flow rate condition, the increases in P1 may be due to effect of centrifugal force on vehicle expected by the driver.

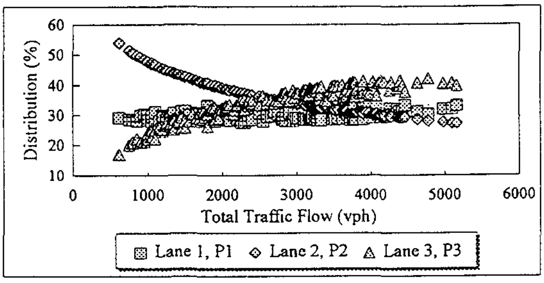

Figure 3 Traffic Distribution at Site D

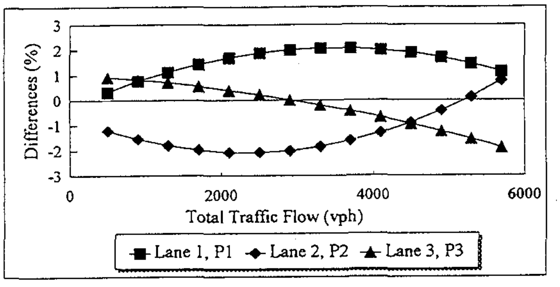

Figure 4 Differences in Site E Distribution with Site A-I

When comparing the Site D lane distribution behavior with other sites, it is surprising that the values are differ very widely, as shown in Figure 3. The lane 3 utilization is decreasing very much while lane 1 is increasing. The reason might be identified as effect due to downstream configuration, i.e., by looking the site configuration there is a 'S' type of segment in the downstream site freeway configuration with in a distance from 400 m to 800 m and the freeway meets an arterial road at a distance of 2.47 km. Further as an example, a vehicle traveling in this Site D with a speed of appr., 90 kmph has to meet an exit with in 2 minute period. Therefore this site results are not exactly represent the uninterrupted flow condition as expected. However, it can be conclude that the lane distribution is heavily depend on both sides (upstream and downstream) of the freeway profile. Therefore, it is often necessary consider an extended length in both directions containing a number of upgrades, downgrades, and level segments together with the change in curvature, as a single uniform segment, which left for the future.

(3) *Effect of Heavy Vehicles*

Distribution of total volume into each lane was analyzed for different percentage of heavy vehicle condition, by grouping into four categories such as 5%, 15%, 25% and 35%. Each groups are cover the range of ± 5% from the stated value. The following model was identified form regression analysis for the traffic distribution.

$$P_i = a_i + b_i Q + c_i \ln V \quad (i=1,2,3) \qquad (3)$$

Where; P_i is the percentage of lane distribution in lane i (i=1,2,3), Q is total directional traffic flow rate, V is average speed a_i is constant b_i and c_i are coefficients. The results show that, R^2 values for each group are ranging from 0.49 to 0.73

for shoulder lane (lane 1), from 0.61 to 0.85 for middle lane (lane 2) and 0.66 to 0.88 for median lane (lane 3). The tendency in lane distribution is shown in Figure 5. Statistical test shows that, there is no significant difference in lane distribution between these four groups for an acceptable level of 95%. However, the traffic distribution tendency in middle lane (lane 2) shows that, there is a slight higher level of usage for more heavy vehicle percentage than it for the lesser percentage of heavy vehicle as shown in Figure 5. It seems that if there is higher percentage of heavy vehicle in the total traffic, the heavy vehicles traveling in lane 1 increases and the other vehicles tend to change their lane to middle lane. Because with densely occupied higher percentage of heavy vehicle in lane 1, the divers of other small vehicles try to avoid this lane by changing their position to lane 2.

(4) Effect due to Light Condition

Similarly, the effect due to light condition was analyzed for leveled straight freeway segment data, and the data was separated as day time from morning 6:00 am to evening 5:00 pm and night time from 8:00 pm to 4:00 am. The typical differences in lane distribution in night time with respect to the day time are shown in Figure 6. In night condition, the amount of usage in lane 1 and lane 2 is decreasing. A check of average speed values related to low traffic volumes showed that speeds were most often lowest during the night, because of darkness. Due to this, drivers try to use median lane than shoulder lane, similarly for other lanes. The usage reduction in lane 2 is less than it for lane 1, this may be due to higher percentage of heavy vehicle changing their lane from shoulder lane to meddle lane in night condition.

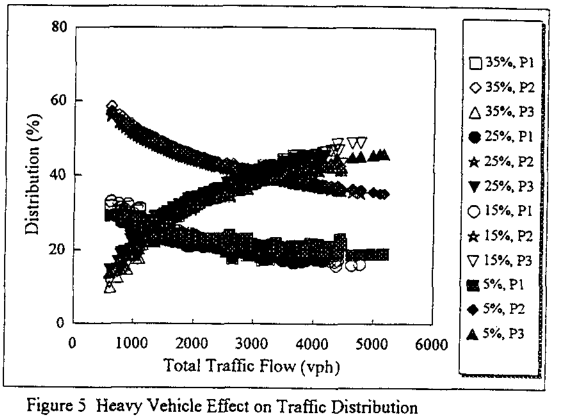

Figure 5 Heavy Vehicle Effect on Traffic Distribution

5. Measures for Capacity Improvement

Identifying the measures which can improve the freeway capacity is very useful for the system managers. Therefore the following are considered as capacity improvement measures such as, introducing a short passing lane with the shoulder lane, restricting the lane changes from lower utilized lane to higher utilized lane by road marking, and increase the width of the low utilized lane with respected to higher utilized lane. However these measures need field validation, which have to be left for the further analysis.

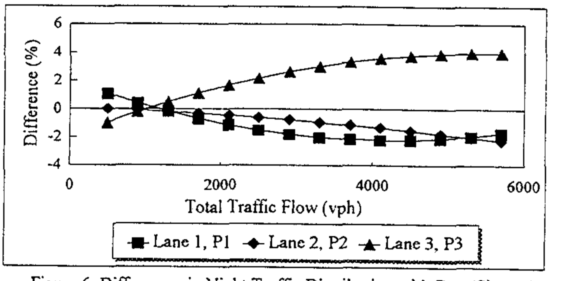

Figure 6 Differences in Night Traffic Distribution with Day (Site A-I)

6. Conclusions

Analysis of lane utilization for an uninterrupted flow condition in three lane uni-directional freeway was carried out for different locations with five geometrical characteristics. A modeling results show that lane utilization has very strong correlation with the total traffic flow, the heavy traffic composition and average speed. Also, it shows that there are no significant difference in lane utilization due to the variation in location between the identical sites such as leveled straight or up and down gradient of a straight segment. Further, the curved freeway configuration was analyzed by taking as two sites namely right hand turning site (site D) and left hand turning sites (site E). Analysis shows, the left hand turning site has no significant difference in lane distribution with a straight leveled segments. But, the selected right hand turning site is not exactly represent the ideal uninterrupted flow condition due to down freeway profile and an exit at a distance of 2 min of travel. Further, analysis of changes in trend in individual lane distribution with a straight level segment was considered against all other sites. Results show the lane usage in shoulder lane is increasing for any changes in geometry. This result concluded that, if there is a small irregularity in geometry condition from a straight leveled segment then shoulder lane utilization is increasing. On the other hand, results from the night flow condition show that the lane utilization in lane 1 is decreasing. Reason identified as, because of darkness the average speed in each lane falls slightly, therefore a higher percentage of night divers try to use faster lane than what they prefer in the day time. Finally, three measures which can increase the freeway capacity were suggested, which need further research.

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