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Analysis of Traffic Characteristics at Multi-lane Divided Highways, Case Study from Cairo-Aswan Agriculture Highway

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Abstract:- This paper presents an analysis into traffic characteristics on rural multi-lane highways. Empirical data from study sites on Cairo-Aswan agriculture four-lane divided highway were used in this investigation. Four separate however relevant analyses are presented in this paper. The first analysis investigates the impact of lane position (Median Lane (ML), Shoulder Lane (SL)) on Average Travel Speed (ATS). The second analysis looks at the relationship between ATS and different traffic characteristics. The third analysis examines the impact of lane position on traffic stream relationships. The fourth and last analysis inspects the impact of lane position and traffic level on headway characteristics. It was found that the lane position has a significant impact on ATS. The best model that shows the relationship between ATS and traffic characteristics include density, percentage of heavy vehicles and lane position variables. The lane position also has a significant impact on traffic stream relationships. Finally lane position and traffic level have a considerable impact on headway characteristics.

Keywords:- Multi-lane Highways; Average Travel Speed; Headway; Traffic Stream Relationships; Land Position; Headway Characteristics.

I. INTRODUCTION

Rural multi-lane highways are an important type of un-interrupted flow facilities. In such facilities there is no obstruction to the movement of vehicles along the roadway. These facilities represent the majority of the highway system in Egypt. Highway Capacity Manual (HCM) (TRB, 2000) uses density in terms of passenger cars per kilometer per lane as the primary measure for level-of-service (LOS) on multi-lane highways. Traffic analysts are required to be familiar with different traffic characteristics on multi-lane highways. These characteristics are important in the evaluation of traffic performance, examination of highway safety, setting appropriate traffic control devices and speed limits, and development of simulation programs, etc. In multi-lane highways, lane position is considered one of the most important factors affecting traffic performance and characteristics. Estimation of highway capacity is extremely concerned with lane position and number of lanes. Most of traffic design manuals assume that average capacity per lane on different highways is equal. However, through empirical research, studies showed that average capacity per lane decreases with increasing number of lanes (Yang & Zhang, 2005). This could be due to that each lane has its own characteristics that influence drive behavior and traffic characteristics. Therefore, Traffic performance and characteristics may be differed from one lane to another on the same multi-lane divided highway.

In this paper, a detailed statistical analysis was carried out to examine the traffic characteristics on the selected field sites. More specifically, the analysis was carried out for the following objectives:

- To investigate the impact of lane position (Median Lane (ML), Shoulder Lane (SL)), for four-lane divided highway, on Average Travel Speed (ATS);
- To model the relationship between ATS and different traffic characteristics of four-lane divided highways;
- To examine the impact of lane position on traffic stream relationships; and
- To inspect the impact of lane position and traffic level on headway characteristics.

II. BACKGROUND STUDIES

Previous studies on the analysis of traffic Characteristics at multi-lane highways were reviewed. Examples of these studies are presented in this section.

Ali et al. (Ali et al., 2007) investigated the relationship between free-flow speed, posted speed limit, and geometric design variables along 35 four-lane urban streets in Virginia. Results showed that posted speed, median width and segment length had a significant impact on free-flow speed on urban streets.

Fitzpatrick et al. (Fitzpatrick et al., 2003) investigated speed relationships and agency practices related to speed. They modeled operating speeds at 78 suburban/urban sites in Arkansas, Missouri, Tennessee, Oregon, Massachusetts, and Texas. Only the posted speed limit was found to be a statistically significant predictor of 85th percentile speed on urban–suburban arterials.

Figueroa and Tarko (2005) examined the relationship between various roadway and roadside design features and operating speeds on four-lane roadways in Indiana. A regression model was used to estimate operating speed. The model showed that increasing the posted speed limit resulted in higher operating speeds. It also showed that speeds are higher in rural areas.

Yang and Zhang (2005) found that based on an extensive field survey of traffic flow on multi-lane highways in Beijing and subsequent empirical model development the average roadway capacities per hour per lane on four-lane, six-lane and eight-lane divided highways are 2104, 1973 and 1848 passenger car unit, respectively. This implies a marginal decrease of average capacity per lane with increasing number of lanes on highway.

The speed-flow characteristics on different types of multi-lane highways in India as well as capacity estimation had been studied based on traditional and microscopic simulation models by Velmurugan et al. (2010). Another study was conducted in India by Arasan and Arkatkar (2011) to investigate the effect of variation of traffic composition, road width, magnitude of upgrade and its length on highways capacity. It was found that highway capacity significantly changes with change in traffic volume composition, width of roadway, magnitude of upgrade, and its length.

The time headway between vehicles is an important traffic flow characteristic affecting safety, level of service, driver behavior, and capacity of a transportation system (May, 1990). Regarding headway studies, Al-Ghamdi (2001) analyzed the time headways of vehicle arrivals on urban roads in Riyadh based on lane-wise traffic data collected under different volume levels. It was found that negative exponential, shifted exponential and gamma distributions reasonably fitted time headways at low and medium flow rates on freeways, whereas the Erlang distribution was found to be appropriate in high traffic flows. Also, Arkatkar and Arasan (2010) determined that vehicle arrivals could be fitted well into the Poisson distribution, whereas inter-arrival times could be fitted well into negative exponential distribution.

In Egypt, Semeida (2013) carried out a study to investigate the relationship between roadway factors and operating speed at multi-lane highways. It was found that the most influential variables on operating speed are pavement width, followed by median width and existence of side access along road section. It is also found that the posted speed limit has a very small effect on the operating speed. In another study by Semeida (2013a) aimed at investigating the impact of road geometric characteristics and heavy vehicles on level-of-service and capacity in rural multi-lane highways in Egypt. Semeida found that the most influential variables were heavy vehicles, lane width, and existence of side access.

III. STUDY SITES AND FIELD DATA

3.1 Study Sites

The study sites were located on a major highway that runs north/south (Cairo-Aswan agricultural highway). This highway is a four-lane divided highway, with a posted speed limit of 90 km/h. The chosen sites are located on straight sections with level terrain to avoid the effect of the longitudinal gradient and to minimize the influence of geometric features of the highway, and far from the influence of intersections, driveways and horizontal curves. The sites were also selected at least 2 km away from any traffic signal and at least 250 m away from any left turn. Also, the chosen sites have relatively similar geometry characteristics (pavement and shoulders widths). The average pavement width for each direction is about 7.5 m and the average shoulder width is about 1.5 m.

Two locations were selected, the first location is on the southbound approach (from Cairo to Aswan) and the second location is on the northbound approach (from Aswan to Cairo). Figure 1 shows the study locations on Cairo-Aswan agricultural highway.

Figure 1. Study locations on Cairo-Aswan agricultural highway

3.2 Traffic Data

Digital video camera was used to collect the traffic and speed data used in this paper. Data collection was carried out in working days, during daylight hours. During all data collection periods, the weather was clear and the pavement was dry and in a good condition. To determine vehicles speed from recorded videos, before recoding, two transverse white lines, the distance between them were 10 meters, were painted across the span of the lanes on the pavement surface, for each carriageway/direction. Vehicle speeds were calculated by dividing the distance between the two lines (10-meter) over the elapsed time, which can be determined from the videos with a high degree of accuracy. At each study location, a minimum two hours of continues recording, at the peak traffic periods, was used. The collected data was assumed to be adequate to perform the required analysis at the study locations. The speeds measured are typically spot speeds.

IV. DATA ANALYSIS

4.1 Impact of lane position on speed and traffic characteristics

In this section, the analysis was carried out to investigate the impact of lane position on different traffic characteristics. As the data was collected from four-lane divided highway sites, two lane positions can be identified as Shoulder Lane (SL) and median Lane (ML), as in Figure 2.

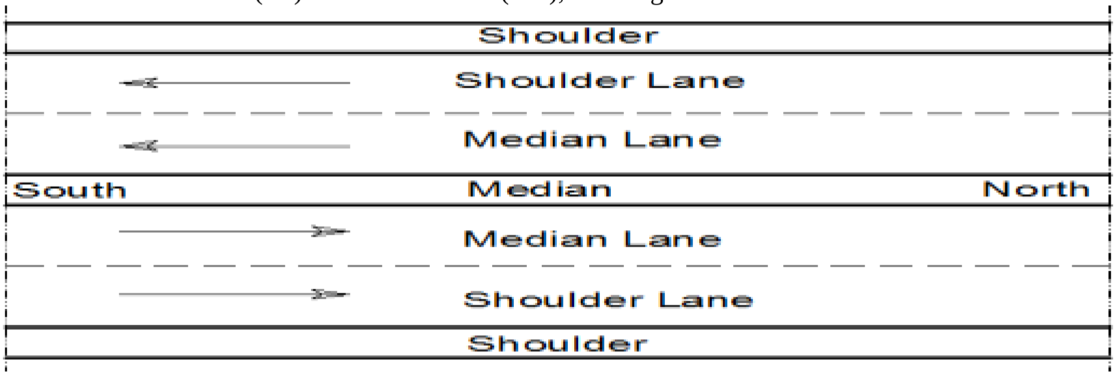

Figure 2. Lane positions for each direction of travel on four-lane divided highway

Dataset at each lane for each direction of travel on each site was divided into 5-minutes intervals. This creates 48 time intervals for the 2-hours duration of data collection, for each lane position. In each interval vehicle counts were multiplied by twelve to convert them into flow rates (q). The average travel speed (ATS) and average headway (Ahdy) were calculated for each time interval. The density can be calculated from the following equation: Density (K) = Flow Rate (q) / Average Travel Speed (ATS). The percentage of heavy vehicles (HV) was also calculated by dividing the number of heavy vehicles (buses and trucks) by the total vehicle counts at each interval. Description of resulting data including ATS, Ahdy, flow rates, density and HV for each lane position is provided in Table 1. For this table it is clear that the median lanes usually have higher speeds, higher flow rates, higher densities, lower percentages of heavy vehicles and lower headways than those of shoulder lanes. Such results are consistent with the hypothesized logical relationships.

Table 1. Summary statistics of the traffic characteristics for sites under study.

Variable	Lane	N	Maximum	Minimum	Mean	SD
ATS (Km/h)	ML	48	81.56	64.74	74.53	4.69
	SL	48	79.73	56.47	65.53	5.01
Ahdy (sec.)	ML	48	14.07	5.44	9.16	2.02
	SL	48	17.61	7.43	10.71	2.10
Flow Rate (veh/h)	ML	48	672.00	264	411.75	89.12
	SL	48	480.00	204	347.50	63.45
Density (veh./km)	ML	48	9.75	3.42	5.58	1.41
	SL	48	7.29	3.17	5.30	0.89
HV (%)	ML	48	20.00	0	7.16	5.39
	SL	48	30.80	2.5	13.35	6.89

More analysis was carried out to investigate the influence of traffic lane position (Median/Shoulder) on speed and traffic behavior by applying t-test for comparing means. T-test tests the difference between the means of two groups. A t-test was carried out by looking at the difference in different traffic characteristics (average travel speed distributions, average headway distributions, flow, heavy vehicle percentages) for the two lanes position of traffic. The results, as in Table 2, show that there was a statistically significant difference between the different traffic characteristics for the two-lane positions (Median/Shoulder), as the sig. values are usually equal 0.00. Moreover, the signs of the mean differences are in the expected direction.

Table 2. T-test results of the impact of lane of traffic position on traffic characteristics behavior.

Variable	Lane	Mean	T-Test		
			Mean Diff.	T-value	Sig.
ATS	ML	74.53	8.99	9.08	0.000
	SL	65.53			
Ahdy	ML	9.15	-1.55	-3.70	0.000
	SL	10.71			
Flow	ML	411.75	64.25	4.07	0.000
	SL	347.50			
HV (%)	ML	7.16	-6.19	-4.91	0.000
	SL	13.35			

4.2 Relationship between ATS and traffic characteristics

Table 3 contains an analysis describing the correlations between different traffic characteristics. The results show strong correlations between the majority of the variables, as expected. Results that are significant at the 5% significance levels are presented in bold in this table. Generally, the signs of the correlation coefficients are in the expected directions. For example, the table shows that ATS has a significant negative correlation with average headway (Ahdy), HV and lane position. This indicates that as the percentage of heavy vehicles and average headways increase the average travel speeds decrease. The results also indicate that the median lane has higher ATS. This table also shows that negative correlation exists between average headways and flow. Moreover, in the case of lane position there is a positive correlation with HV, indicating that the shoulder lane has higher HV than median lane.

Table 3. Correlation coefficients between different traffic characteristics.

Variables	ATS	Ahdy	Flow	Density	HV (%)	Lane
ATS	1.00	**-0.21***	0.20	-0.19	**-0.57***	**-0.68***
Ahdwy		1.00	**-0.94***	**-0.86***	**0.25***	**0.36***
Flow			1.00	**0.92***	**-0.25***	**-0.39***
Density				1.00	-0.02	-0.12
HV%					1.00	**0.45***
Lane						1.00

*Correlation is significant at the 5% level (2-tailed).

Lane (Dummy variable) =0 for median lane, and 1 for shoulder lane.

Certainly, ATS is a good indicator for traffic performance as it relates well to road user perceptions of the quality of traffic flow. To gain more insights into the impact of different traffic characteristics and especially lane position on ATS, a stepwise linear regression analysis was conducted. The objective is to produce the best relationship between ATS and different traffic characteristics. The criteria used to assess the accuracy of the produced models were (Hashim and Abdel-Wahed, 2011):

- Each of the independent variables should have regression coefficients that are significantly different from zero (based on the significance level of the t-test), and whose sign should logically explain the effect of this variable on the dependant variable (i.e. ATS).
- The coefficient of determination R^2 must be as high as possible and significant at the 95% confidence level. R^2 values only give a guide to the ‘‘goodness-of-fit’’ and do not indicate whether an association between the variables is statistically significant. This is determined by the significance level of the F statistic. For a confidence level of 95%, if the F statistic is associated with a probability of <0.05, there is a statistically significant association between dependent and independent variables

Having applied these criteria the best model was selected. Details of the regression analysis of the best model are shown in Table 4.

Table 4. Results of the best regression model for ATS at multi-lane divided highways.

Variable	Coefficient	T	Significance	R^2	Significance of F statistic
Constant	85.11	39.83	0.000	0.83	0.000
Density	-1.50	-4.17	0.000		
HV	-0.31	-4.82	0.000		
Lane	-7.50	-7.91	0.000		

This model can be written as follows:

$$ATS = 85.11 - 1.50 Density - 0.31 HV - 7.50 Lane$$

where:

ATS = Average travel speed (km/h);
Density = Density in (veh./Km); and
HV = Percentage of heavy vehicles
Lane = A dummy variable for lane position (Lane = 0 for median lane and 1 for shoulder lane).

The resulting coefficient of determination (R^2) and significance of the F statistic are equal to 0.83 and 0.000 respectively. For coefficients of the independent variables, it can be noticed from Table 4 that the hypothesis that each of the coefficients are equal to zero can be rejected at the 95% confidence level, as the t values are greater than ±1.96. The model has a logical explanation for the effect of the independent variables on the prediction of ATS. The negative signs of the independent variables density and HV means that drivers tend to decrease their speeds as density and HV increases. The dummy variable Lane was significant and has a negative sign. The dummy variable equals 1 for shoulder lane and 0 for median lane. This means that vehicles traveling in shoulder lanes are slower than vehicles traveling in median lanes. This is consistent with the hypothesized logical expectations.

4.3 Impact of lane position on traffic stream relationships

Traffic stream variables include speed, flow and density. Speed is defined as the rate of motion in distance per unit of time. Flow is defined as the number of vehicles that pass a point on a highway or a given lane or direction of a highway during a specific time interval. Whereas, density is defined as the number of vehicles occupying a given length of highway or lane (Mathew, 2006). Figures 3, 4, and 5 present the main relationships of traffic flow parameters for median lane and shoulder lane. The figures show the three relationships (Average travel speed (ATS) - Density), (Flow Rate -ATS) and (Flow Rate - Density). The relationships show that the traffic stream is in un-congested state, as the maximum flow rate is less than 700 veh./h/l. From these relationships, it is clear that the variation of ATS with traffic flow rate is relatively low. However, the variation of density with traffic flow rate is much clearer and proportional. These relationships depict the impact of lane position on traffic flow characteristics. The figures show that ATS of median lane is higher than that of shoulder lane at the same density. Also, flow rate of median lane is higher than that of shoulder lane at the same density. Moreover ATS of median lane is higher than that of shoulder lane at the same flow rate.

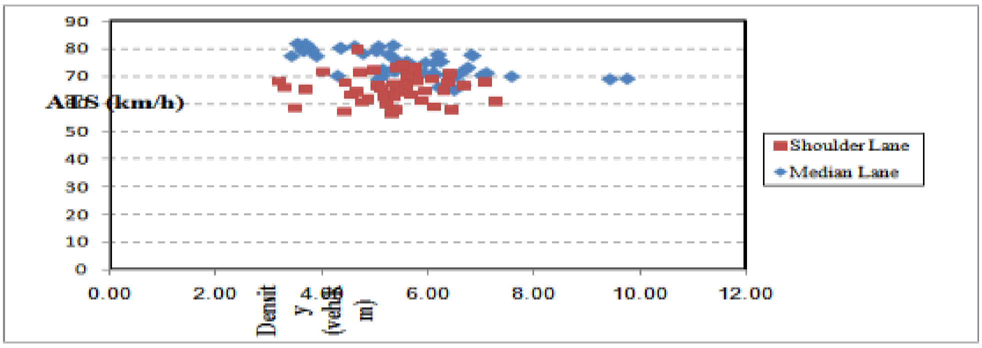

Figure 3. Relationship between ATS and Density for Median Lane and Shoulder Lane

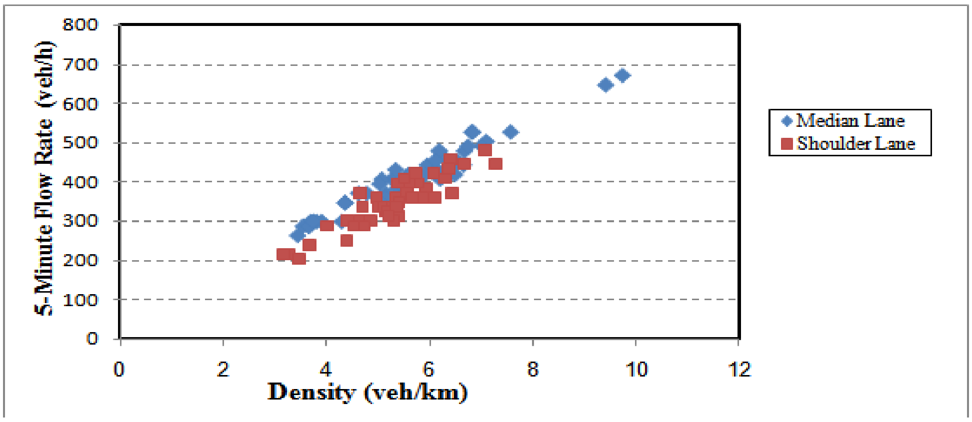

Figure 4. Relationship between Flow Rate and Density for Median Lane and Shoulder Lane

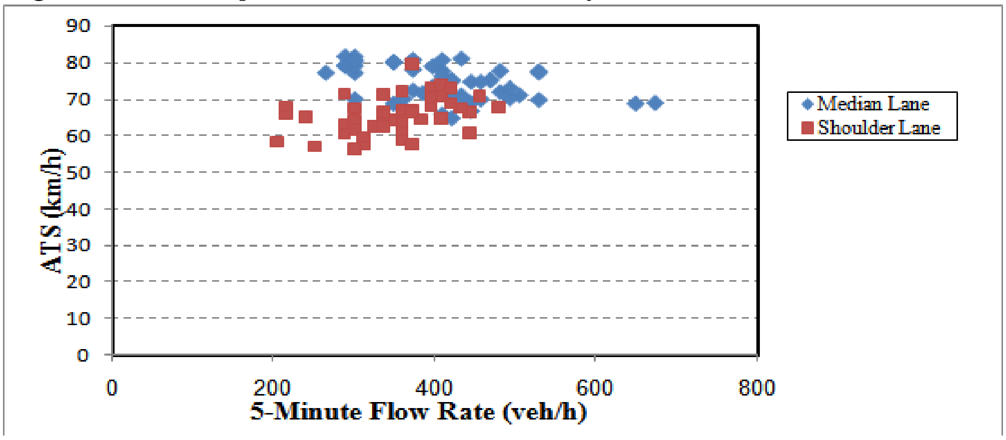

Figure 5. Relationship between ATS and Flow Rate for Median Lane and Shoulder Lane

4.4 Impact of lane position and traffic level on headway characteristics

Headway is the time in seconds between two successive vehicles as they pass a point on a road, measured from the same common feature of both vehicles (TRB, 2000). The determination of headway characteristics and distributions are of great importance for, planning, designing, analyzing and operating roadway facilities (Abtahi et al., 2011). Therefore, it must be analyzed as accurate as possible based on real behavior of roadway drivers (Kerner 2009). Traffic analysts should be well aware of real behaviors of drivers in choosing the desired headways.

In this section of analysis, collected headway data were subjected to analysis in order to determine the proper characteristics that reasonably described the data. The headway data for each lane position were considered separately. Moreover, three flow levels as described in the literature (Al-Ghamdi, 2001) were defined as follows:

- Low flow: less than 400 veh./h/ln
- Medium flow: 400 – 1200 veh./h/ln
- High flow: more than 1200 veh./h/ln

In order to classify the collected headway data, the flow scopes with the levels defined above were defined for each lane and the headways belonging to each 5-minutes time interval were put into the corresponding flow level. Two flow levels (low and medium) were defined for median and shoulder lanes, as no high flows were found in the collected data. Therefore the resulting groups can be classified as follows:

- Median lane with low flow (ML)
- Median Lane with median flow (MM)
- Shoulder lane with low flow (SL)
- Shoulder lane with medium flow (SM)

Table 5 shows some of the descriptive statistics for speed and headway at different lane positions and flow levels. The descriptive statistics include the sample size, maximum, minimum, mean, median, and standard deviation (SD) values of headway for all lane positions and flow levels as well as for each lane position separately and also for all data as one dataset . According to the Table 2, the increase in the flow rate resulted in a decrease in the mean and standard deviation of headways. With comparison of mean and median values for each group, it is shown that the median value was less than mean value for different groups. This indicates the large concentration in short headways so that 50% of the drivers choose the headway which are less than the mean of the headways.

Table 5. Descriptive statistics of speed and headway at different lane positions and flow levels.

Lane Position	Flow Rate Level (veh./h)	Sample Size	Headway (Sec.)				
			Max.	Min.	Mean	Median	SD
Median	<400 (Low)	632	84.39	0.10	10.45	7.31	10.77
	≥400 (Medium)	1087	42.08	0.10	7.70	5.24	7.25
	All	1719	84.39	0.10	8.71	6	8.891
Shoulder	<400 (Low)	1023	106.51	0.72	11.08	8.44	9.32
	≥400 (Medium)	358	46.18	0.38	8.40	6.52	7.27
	All	1381	106.51	0.38	10.38	7.91	8.91
Both	Total Flow	3100	106.51	0.1	9.46	6.86	8.89

Analysis of variance (ANOVA) was carried out to examine the effect of lane position and traffic level on headway characteristics by comparing the differences between the mean headway values. ANOVA tests the difference between the means of three or more groups, while the t-test measures the difference between the means of two groups.

The ANOVA was carried out using the values of headway at four different levels (ML, MM, SL, and SM). Table 6 shows the ANOVA results, the most important part concerns the ANOVA test, showing the F statistic and the corresponding significance value. Here, the significance value is equal to 0.00 (less than 0.05) which means that there was a statistical difference between the mean headways of different lane positions and flow levels.

Table 6. ANOVA results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7026.69	3	2342.23	30.50	0.00
Within Groups	237653.68	3095	76.77		
Total	244680.38	3098			

Table 7 confirms these findings, showing that the comparisons of mean differences between groups are mostly significant. However, some of the results show that there was no significance difference between ML (median lane with low flow) and SL (shoulder lane with low flow), and between SL (shoulder lane with low flow) and MM (median lane with medium flow). Generally, the results verify the necessity for such classification and grouping to study headway classifications and distributions.

Table 7. Multiple comparisons of significance values lane positions and flow levels.

Lane Position & Flow Level (veh./h)	Headway			
	ML	MM	SL	SM
ML	-	**0.000**	0.450	**0.002**
MM		-	**0.000**	0.560
SL			-	**0.000**
SM				-

V. SUMMARY OF FINDINGS AND RECOMMENDATIONS

The current paper presented analyses which addressed four different aspects of traffic characteristics on rural multi-lane divided highways, using data from Cairo-Aswan four-lane divided highway. Such traffic characteristics are important in the evaluation of traffic performance, examination of highway safety and development of simulation programs, etc. The most important findings of this paper are:

1. Empirical observations showed that there was a statistically significant difference between the different traffic characteristics for the two-lane positions (Median/Shoulder). Such characteristics include average travel

speed, average headway, density, percentage of heavy vehicles. Moreover, the signs of the mean differences between the traffic characteristics for both lanes are in the expected direction.

2. Correlation and regression analysis were used to investigate the relationship between average travel speed (ATS) and different traffic characteristics. The results show that most traffic characteristics have significant correlations with ATS. However density, percentage of heavy vehicles and lane position are the major contributing variables in the regression model.

3. The paper examines the three fundamental relationships (Average travel speed (ATS) - Density), (Flow Rate - ATS) and (Flow Rate - Density). These relationships depict the impact of lane position on traffic flow characteristics. It was found that the ATS of median lane is higher than that of shoulder lane at the same density. Also, the flow rate of median lane is higher than that of shoulder lane at the same density. Moreover the ATS of median lane is higher than that of shoulder lane at the same flow rate.

4. Statistical analysis showed that a significant difference between the mean headways of different lane positions and flow levels was existed. This means that the driving behavior in terms of headway is different from lane position to another. However, more analysis is needed to investigate this issue using more data and other statistical and distribution techniques.

5. Generally, the results presented here confirmed that lane position in rural multi-lane highways has a significant impact on traffic performance and characteristics. Therefore, it is recommended to consider each lane separately of multi-lane highway when performing different traffic studies.

Finally, Future research should be conducted to extend all aspects of this research using comprehensive field data for congested and un-congested traffic flow conditions from various regions and governorates in Egypt not only for rural highways but also for urban highways.

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