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The Impact of Lane Discipline on Speed and Time Headway

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Abstract: **Lane discipline has a major impact on traffic density, speed, and time headway. In this paper, three-dimensional (3D) centre lane marking is used to enforced lane discipline. Traffic congestion mitigated with three dimensional lanes marking as the speed and headway increased. The Camlytics is used to observe the egress and ingress time. The statistics analysis noticed an increase in speed and headway after 3D lane marking. Gamma and Lognormal distributions are found the best fit for speed before and after 3D marking, respectively. Normal and Weibull distributions are the best fit for headway in the absence and presence of 3D lane markings, respectively. These distributions can be used for traffic flow characterization. This study recommends strictly enforcement of lane discipline to counter traffic congestion.**

Index Terms- **3D Lane Marking, Lane Discipline, Statistic Analysis, Time headway, Speed.**

I. NTRODUCTION

Lane discipline is imperative for the safe movement of heavy urban traffic. A road capacity is the maximum traffic flow potential on a road. The capacity and operation of a road mainly depends on driver behavior and lane discipline [1]. Road markings have a dominant role in directing traffic [2]. Heterogeneous traffic does not follow lane discipline. It results in traffic breakdown (congestion) [3]. Weaving maneuvers on the roads are the main cause of speed reduction [4] or the development of road congestion. Traffic congestion is one of the worldwide urban problem, which affects travel time, increases energy consumption due to excessive delay [5], aggravates environmental pollution as well as results in traffic accidents [6]. In Dhaka, Bangladesh, congestion costs USD 3.868 billion per year [7]. Lives are often lost due to road accidents that occur as a result of poor traffic management [8]. Converting traffic congestion into smooth flow reduces travel time delay, energy consumption, noise, and air pollution [9], and improves public safety. The aim of dividing a road into lanes is to improve traffic flow conditions [10]. A painted centre line was used to control vehicle lateral movement [11]. Rumble strips alert a driver by producing vehicle vibrations. Centerline rumble strips used to prevent vehicles drift off [12]. According to a recent American Association of State Highway and Transportation Officials (AASHTO) report, every 21 minutes a death on a highway occurs as a result of drift off from a lane [13]. Fabrizio and Alessandro used three different colors marking for speed reduction in which red markings were found most effective. Speed was reduced up to 6 km/h along the curve [14]. Direction arrows on a two-way road improve directional traffic movement [10]. Cambridge and Nicole studied the reduction of speed at an uncontrolled crosswalk with the help of 3D illusion marking. Yielding to pedestrian increased to 2% and 3%, respectively at site 1 and site 2 [15]. Migletz studied that travel time, traffic flow, and exposure to ambient weather are the main factors which decrease the retro reflectivity of pavement markings [16]. In the United States, $2 billion is spent annually on pavement markings [13]. Deceleration mark in the road center is an effective way to increase the sense of speed [17]. Road marking plays an imperative role in directing autonomous vehicles because map with visible marking can be very effective for navigation and anticipation of road condition [18]. Parallelogram-shaped pavement markings decreased both the frequency and the intensity of pedestrian crosswalk accidents and substantially reduced vehicle-pedestrian accidents [19].
Kolmogorov-Smirnov test and P-values are used to determine the best fit distribution of speed and time headway at various traffic density [20]. Lognormal distribution is considered best fit for low density traffic while for high density log-logistic seems best suited [21-22].

In Peshawar, Pakistan traffic management is a major issue. A lot of time is wasted on the roads due to the new bottlenecks development along the rapid bus transit route in Peshawar, in 2019. In this paper, traffic flow and speed are analysed by ensuring lane discipline through three dimensional (3D) centre lane markings on a 60 m road section in Peshawar.

Density, speed and time headway were observed on Monday, Tuesday and Wednesday before and after the 3D markings. 3D markings restrict driver lateral movement. It was noticed that speed increased and headway between vehicles was reduced.

Gamma and Lognormal distributions are considered the best fit for speed before and after marking as per KS test and P-value. However, Normal and Weibull are considered best fit for density and speed after 3D marking.
The remainder of this paper is organized as follows. Section II represents the methodology. The statistical data is explained in Section III and the best fit distribution of speed and time headway are given in Section IV.

II. METHODOLOGY

Heterogeneous traffic behavior results in traffic flow congestion. This is the major societal concern in Peshawar which needs to be solved by applying management techniques. For this study, an effective management technique is practically applied on a 60 m road section. A three dimensional centre lane road marking is drawn on the road near Bab-e Peshawar fly over having coordinates as 34o16’54’’ N and 71o41’17’’ E, as shown in Fig. 1.

FIGURE 1: Google map location of 60 m road section.

The main problem on the selected site is the development of congestion in peak hours due to a U-turn. Three dimensional centre lane markings are drawn to mitigate congestion. Traffic was recorded with 30.000 Frames Per Second (FPS) digital camera from Babe-e Peshawar fly over having height 26 m for three days that is Monday, Tuesday and Wednesday. Camlytics software gives, entrance and exit time on 60 m road section shown in Figure 2. Traffic flow observed before and after 3D centre lane marking is shown in Fig. 3.
Speed is calculated by dividing the time difference of entering and leaving on 60 m. Density p is determined by counting the number of vehicles in a given lane section. Time headway is the time gap of arrival between two consecutive vehicles which is determined at the exit reference line as shown in Fig. 2.

FIGURE 2: Entrance and Exit Time (Camlytics)

FIGURE 3: Recorded Frames Before and After 3D Road Marking

In the recorded data, 230 different observations were made for each day. To analyze speed and time headway changes, best fit distributions are used [20]. The Kolmogorov Smirnov (KS) test and P-value are used to find best fit distributions of speed and time headway. In the KS test, the maximum variance between the expected cumulative distribution function (ECDF) and the cumulative distribution function (CDF) of observed data is determined. The CDF is determined from the observed data by measuring the actual probability with the help of their corresponding frequencies while ECDF is representing the expected probability such that,

$$S_N(x) = \frac{n(i)}{N} \qquad (1)$$

where, $n(i)$ represents the value of i-th number starting from 1 to N (total number of count). Mathematically KS test is expressed as;

$$D = \max |F_o(x) - S_N| \qquad (2)$$

where, $F_o(x)$ shows the actual cumulative distribution function. The KS critical value relies on the level of significance, α and the sample size n [21-23]. In this paper the KS test is performed at 5% level of significance, such that KS critical value is 1.36/√n [24]. The P-value shows whether null hypothesis (observed data follow specified distribution) is true. A P-value less than α (0.05) reflect a strong evidence against null hypothesis

III. STATISTICAL DATA OF DENSITY, SPEED AND TIME HEADWAY

The descriptive statistics of density, speed and time headway in the presence and absence of 3D centre lane marking is shown in Table I. The mean is obtained by dividing the sum of all observed value on the total number of observation, that is, 230. The median represents the middle value after the organization of data in ascending order. The standard deviation shows that how the observed data (density, speed and time headway) is spread from the mean. The Day-1, Day-2, and Day-3 represent the days of data collection, that is, Monday, Tuesday and Wednesday, respectively in Tab. I (a), (b) and (c).

TABLE II (a): Statistical data of density, speed and time headway

Data Set	**Density, ρ (Veh/m) Without Marking**	**Density, ρ (Veh/m) After Marking**
Observation	230.00	230.00
Mean Day-1	6.18	4.52
Mean Day-2	7.00	5.28
Mean Day-3	6.31	4.93
Median Day-1	6.00	5.00
Median Day-2	7.00	5.00
Median Day-3	6.00	5.00
Std.dev Day-1	1.71	1.40
Std.dev Day-2	1.73	1.46
Std.dev Day-3	1.83	1.46

TABLE III (b)

Data Set	**Speed, v (Veh/m) Without Marking**	**Speed, v (Veh/m) After Marking**
Observation	230.00	230.00
Mean Day-1	7.94	11.66
Mean Day-2	7.88	11.55
Mean Day-3	7.83	11.66
Median Day-1	7.85	11.70
Median Day-2	7.70	11.30
Median Day-3	7.70	11.70
Std.dev Day-1	1.49	1.90
Std.dev Day-2	1.50	1.80
Std.dev Day-3	1.48	1.91

Table I (b) shows that the average speed after 3D marking is greater than speed observed in the absence of 3D centre lane road painting. The maximum average difference between the speed observed before and after the marking is 3.83 m/s. This indicates that with lane discipline traffic flow is improved while the congestion is reduced. The travel time improved due to 3D marking as the average speed observed on Monday, Tuesday and Wednesday without marking are 7.935 m/s, 7.879 m/s and 7.826 m/s which increased to 11.660, 11.547 and 11.658 m/s after 3D centre lane marking shown in Table I (c).

TABLE IV (c)

Data Set	**Time headway, s (Veh/m) Without Marking**	**Time headway, s (Veh/m) After Marking**
Observation	230.00	230.00
Mean Day-1	21.47	2.35
Mean Day-2	2.21	2.38
Mean Day-3	2.14	2.36
Median Day-1	2.10	2.40
Median Day-2	2.20	2.40
Median Day-3	2.20	2.40
Std.dev Day-1	0.59	0.61
Std.dev Day-2	0.63	0.64
Std.dev Day-3	0.58	0.63

The density decreased due to 3D centre lane marking so the time headway increased due to speed improvement. Headway noticed on Monday, Tuesday and Wednesday before marking are 2.147 s, 2.211 s and 2.141 s, respectively. However, after 3D marking, time headway increased to 2.346 s, 2.378 s and 2.364 s, respectively. The larger time headway shows that a driver has more time to adjust vehicle speed to forward traffic conditions. The median of density after marking for all three days is equal to 5 veh/m shown in Tab. I (a). However, before marking we noticed on Monday and Tuesday median is 6 veh/m while on Tuesday it is 7 veh/m. The maximum standard deviation which reflects the spread of data from the mean is noticed in the absence of 3D marking for density while for speed and time headway it is minimum. On Wednesday, the maximum spread for density in the absence of 3D marking observed is 1.834. Headway without marking show minimum standard deviation on Wednesday that is 0.582. In case of speed after marking we observed maximum spread across the mean on Wednesday that is 1.911.

IV. BEST-FIT DISTRIBUTION FOR SPEED AND TIME HEADWAY

The Kolmogorov Smirnov (KS) and P-value are used to rank distributions of density and speed before and after the 3D center lane marking [21-23]. The null hypothesis is rejected when KS value exceeded from the critical value while P-value observed is lower than the significant value. The critical value of KS is 0.089 which is determined by $\mathbf{1.36/\sqrt{n}}$ [24]. Generally, Gamma and Lognormal distributions are best fit for speed before and after the marking while Normal and Weibull distributions are best fit for time headway data obtained before and after the marking. The speed and time headway data observed on Monday, Tuesday and Wednesday before and after 3D road marking having sample size 230.

A. Distribution of speed without 3D marking

Table II shows that on Tuesday and Wednesday Gamma distribtion is considered best fit for speed in the absence of 3D road marking having KS statistics and P-value of 0.039 and 0.043, and 0.875 and 0.789, respectively. Lognormal is the second most best fit distribution for speed data observed on Tuesday and Wednesday having KS and P value of 0.040

and 0.0.046, and 0.847 and 0.706, respectively. Speed data observed on Mondays shows that Lognormal followed by Birnbaum-Saunder is the best fit distribution as per KS and P-value of 0.044 and 0.045, and 0.755 and 0.753, respectively. The P-value is greater than 0.05 so there is no reason to reject null hypothesis. Hence, the observed data follow the specified distribution. The histograms of speed data observed in absence of 3D road marking on Monday, Tuesday and Wednesday are shown in Fig. 4. The maximum frequency is 7.5 m/s which reflect the mean value of speed observed in the absence of 3D road marking.

TABLE V: Speed distribution on Monday, Tuesday and Wednesday without 3D marking

Speed (m/s)	Type of Distribution	KS value	Critical KS Value	P-value
Monday	Lognormal	0.044	0.089	0.755
	Birnbaum-Saunders	0.045		0.733
	Inverse Gaussian	0.045		0.731
	Log-logistic	0.046		0.707
	Gamma	0.049		0.638
Tuesday	Gamma	0.039	0.089	0.875
	Lognormal	0.04		0.847
	Birnbaum-Saunders	0.041		0.841
	Inverse Gaussian	0.041		0.837
	Log-logistic	0.043		0.799
Wednesday	Gamma	0.043	0.089	0.789
	Lognormal	0.046		0.706
	Birnbaum-Saunders	0.047		0.699
	Inverse Gaussian	0.047		0.696
	Log-logistic	0.05		0.605

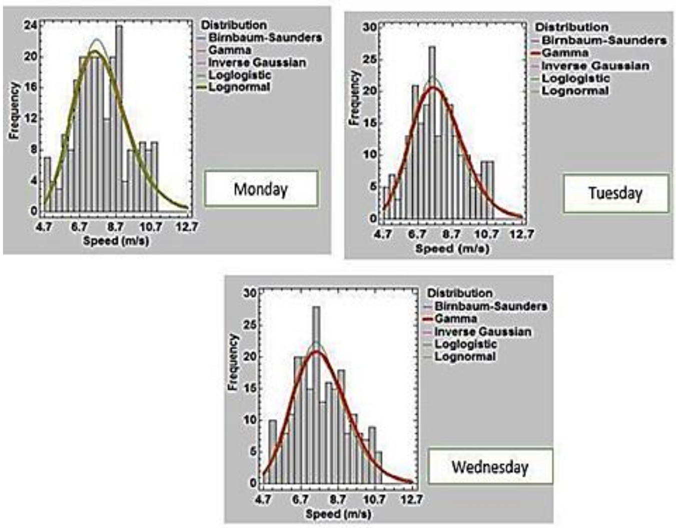

FIGURE 1: Distribution of speed before 3D marking

B. Distribution of speed after 3D marking

Table III shows that on Monday and Wednesday, Lognormal distribution is considered best fit for speed after 3D road marking with KS statistic and P-value of 0.068, 0.066, and 0.284, 0.295, respectively. Normal distribution is best fit for speed observed on Tuesday with KS and P-value of 0.0672 and 0.282, respectively. Birnbaum-Saunders is the second best fit for speed data noticed on Monday and Wednesday with KS statistics and P-value of 0.068, 0.066, and 0.279, 0.292, respectively.

TABLE VI: Speed distribution on Monday, Tuesday and Wednesday after 3D marking

Speed (m/s)	Type of Distribution	KS value	Critical KS Value	P-value
Monday	Lognormal	0.068	0.089	0.284
	Birnbaum-Saunders	0.068		0.279
	Inverse Gaussian	0.068		0.278
	Gamma	0.069		0.261
	Log-logistic	0.073		0.208
Tuesday	Normal	0.0672	0.089	0.282
	Lognormal	0.0672		0.282
	Log-logistic	0.0675		0.277
	Birnbaum-Saunders	0.0676		0.275
	Inverse Gaussian	0.0676		0.274
Wednesday	Lognormal	0.066	0.089	0.295
	Birnbaum-Saunders	0.066		0.292
	Inverse Gaussian	0.066		0.291
	Gamma	0.067		0.271
	Log-logistic	0.07		0.223

Generally, Lognormal distribution is considered best for speed data after marking. The KS statics and P-values concludes that the obdserved data follow the specified distribution. When 3D marking was drawn on road to restrict vehicles for traveling within a lane, improvement in vehicle speed as the average value of speed increased from 8 to 11.5 m/s. The histogram of speed data after 3D road marking on Monday, Tuesday and Wednesday shows that Lognormal distribution is best fit as shown in Fig. 5. The average value of speed observed On Monday Tuesday and Wednesday, is 11.5 m/s which reflect the mean value of speed observed after 3D road marking.

C. Distribution of time headway without 3D marking

Normal distribution is considered best fit for time headway data observed on Monday, Tuesday and Wednesday without 3D road marking having KS statistic and P-value of 0.067, 0.063 and 0.071, and 0.249, 0.315 and 0.196, respectively. On Monday, logistic distribution is the second most best fit for headway as per KS statistic and P-value of 0.074 and 0.161 respectively.

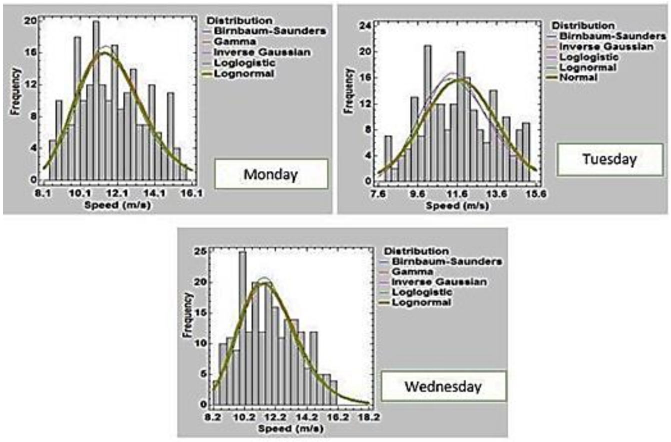

FIGURE 2: Distribution of speed after 3D marking

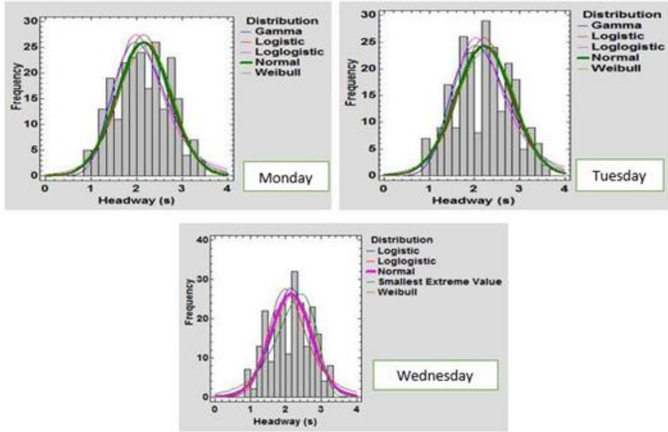

FIGURE 3: Distribution of time headway before 3D marking

Weibull distribution is the second best fit distribution for headway on Tuesday and Wednesday with KS statistics and P-value of 0.065, 0.072 and 0.287, 0.185, respectively. Generally, normal distribution is considered best for headway data in the absence of 3D road marking. The KS statistics is less than crtical value of 0.089 and P-value is greater than 0.05 so there is no reason to reject null hypothesis. Hence, the observed data follow the specified distribution. The histogram of time headway data observed in absence of 3D road marking on Monday, Tuesday and Wednesday are shown in Fig. 6.

TABLE VII: Time headway distribution on Monday, Tuesday and Wednesday without 3D marking

Time Headway (s)	**Type of Distribution**	**KS value**	**Critical KS Value**	**P-value**
Monday	Normal	0.067	0.089	0.249
	Logistic	0.074		0.161
	Weibull	0.074		0.158
	Log-logistic	0.081		0.099
	Gamma	0.084		0.075
Tuesday	Normal	0.063	0.089	0.315
	Weibull	0.065		0.287
	Logistic	0.071		0.192
	Log-logistic	0.074		0.161
	Gamma	0.08		0.102
Wednesday	Normal	0.071	0.089	0.196
	Weibull	0.072		0.185
	Logistic	0.08		0.103
	Log-logistic	0.09		0.049
	Smallest Extreme Value	0.095		0.032

D. Distribution of time headway without 3D marking

Table V shows that Weibull distribution is best fit for headway data observed on Monday, Tuesday and Wednesday after 3D road marking having KS statistic and P-value of 0.053, 0.065, 0.053 and 0.543, 0.287, 0.555, respectively. Logistic distribution is the second best fit for headway data observed on Monday and Wednesday with KS statistics and P-value of 0.062, 0.058, and 0.335, 0.437, respectively.

TABLE VIII: Time headway distribution on Monday, Tuesday and Wednesday after 3D marking

Time Headway	**Type of Distribution**	**KS value**	**Critical KS Value**	**P-value**
Monday	Weibull	0.053	0.089	0.543
	Logistic	0.062		0.335
	Normal	0.07		0.208
	Smallest Extreme Value	0.071		0.191
	Log-logistic	0.088		0.05
Tuesday	Weibull	0.065	0.089	0.287
	Normal	0.072		0.178
	Logistic	0.073		0.176
	Smallest Extreme Value	0.087		0.061
	Log-logistic	0.088		0.058
Wednesday	Weibull	0.053	0.089	0.555
	Logistic	0.058		0.437
	Normal	0.07		0.216
	Smallest Extreme Value	0.072		0.187
	Laplace	0.079		0.116

The KS statistics and P-value for Weibull distribution shows that the null hypothesis is rejected and data followed specified distribution as P-value is greater than 0.05. After 3D marking drawn, time headway increased from 2.14 to

2.35 s. The histogram of headway data after 3D road marking on Monday, Tuesday and Wednesday shows that Weibull distribution is best fit as shown in Fig. 7. The average value of headway observed on Monday, Tuesday and Wednesday is 2.35 s.

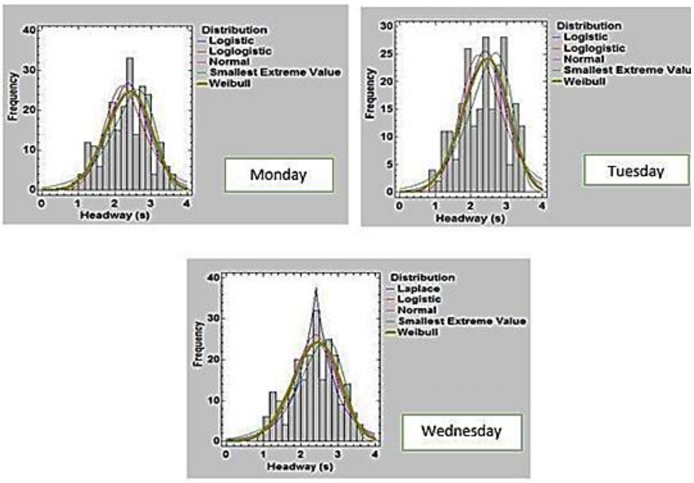

FIGURE 4: Distribution of time headway after 3D marking

V. CONCLUSION

In this research we analyzed that traffic flow can be improved by enforcing lane discipline. In order to restrict the lateral movement of driver, 3D center lane road marking was employed which improved traffic break down. Speed increased which improved the travel time. Time headway increases due to traffic flow improvement as the gap between two consecutive vehicles increase due to speed improvement. The difference between the average speed observed before and after the marking is 3.5 m/s and the headway difference is 0.23 s. The maximum and minimum speed before 3D marking are 11 m/s and 5 m/s, respectively while after 3D marking the maximum and minimum speed noticed are 15 and 8 m/s respectively. The maximum and minimum headway before and after 3D marking are 3.6 s and 1 s, respectively. The KS statistics and P-value are used to identify best fit distribution for density and speed data observed. Gamma and Lognormal distributions are generally considered best fit for speed before and after 3D marking. In headway distribution, Normal and Weibull is considered best fit for headway before and after the 3D road marking. The best fit distributions can be used to characterize traffic flow.

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