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CHARACTERISTICS OF FUNDAMENTAL DIAGRAMS DUE TO SHOCKWAVE BY NON-LANE BASED HETEROGENEOUS TRAFFIC

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If the global context of traffic flow researches are highlighted, it is observed that many researches have already been conducted with the Fundamental Diagrams of traffic flow for lane based homogeneous traffic. Studies related to propagation of shockwaves are being conducted as well. But for developing countries such as Bangladesh, it is predominant that non-lane based heterogeneous traffic exists in most of the roads. Firstly there is scarcely any lane concept among the drivers at all. Moreover frequent lane changing is a common phenomenon. For these reasons, responses of Fundamental Diagrams' shape are quite distinctive from already established shapes. Thus the main concern is to trace the deviation of the prevailing traffic flow parameters of traffic flow from those established equations. Video footage has been taken of roadway section marked suitably for measurement. Shockwaves due to lane changing for non-lane based and heterogeneous synchronized traffic flow has been accomplished and modelled using R and MATLAB analysis for a highway of Dhaka city, Bangladesh. After modeling the calibration and validation are done accordingly to distinguish the variation from ideal models and to verify that the study outcomes converge as well. It has been detected that shockwave induces significant decrement in flow and speed in case of specified traffic condition.

Keywords: Developing country, Lane changing, Peak hour, Three phase traffic, Traffic breakdown, Bottleneck, Phase transitions.

1 INTRODUCTION

As the increment of ever growing traffic demand has been noticed substantially large all over the world, addressing the attributes of traffic behavior i.e., traffic parameters on the route is essential for proper planning and solution. Moreover, shockwave is considered to be an afflictive phenomenon which reduces desired traffic quality also denoted as traffic flow breakdown. In case of Bangladesh where the traffic is non-lane based and heterogeneous on the road, the condition is rather terrible. Traffic congestions eat up 3.2 million working hours each day and drain billions of dollars annually from the city's economy (Rosen 2016). Hence fundamental diagrams of traffic flow is the basis for modeling, designing and implementing measures to any roadway. World Bank states that Bangladesh is among the top 12 developing countries with a population of over 20 million, who achieved six plus percent growth in 2016 (World Bank 2016). It can be easily concluded from the above statements that as a developing country the number of traffic vehicles would increase with the economic growth as well as the congestions. Figure 1 shows the actual scenario of abrupt lane changing and propagation of shockwave in a typical highway of Bangladesh. The most alarming fact is that with more than 18 million population in Dhaka (World Population Review 2016) only 9% of roadway and 6% of pavement area is available (Mahmud *et al.* 2008). Meanwhile road is 16% of total city area in Tokyo and 25% of total area in majority of other developed cities (Mahmud *et al.* 2013). In this paper, fundamental diagrams have been modeled analyzing video footage data. At the same time, changes of traffic parameters due to shockwave have been addressed to compare the variation on the plot.

Figure 1. Shockwave generating due to lane changing in Bangladesh.

2 GOVERNING EQUATIONS

Based on kinematic waves LWR (Lighthill *et al.* 1955) and (Richards 1956) model has been developed, which can be used to determine the shockwave hereafter. This theorem denotes an analogy between flow of fluids and the flow of traffic. Assuming a small interval of road as shown in Figure 2, it can be assumed that total change between inflow and outflow is equal to the storage i.e., equation of continuity, law of the conservation of vehicles.

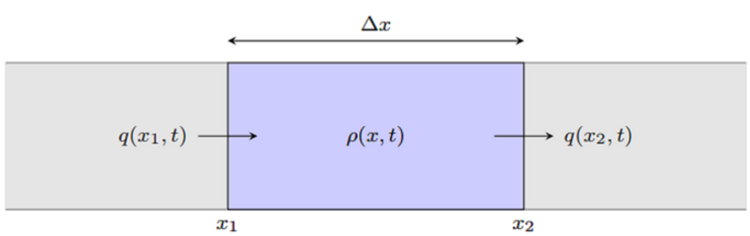

Figure 2. Segment of road for depicting LWR model (Lustri 2010).

Expressing flow, q as a function of density, ρ the LWR equation Eq. (1) can be written as:

$$\frac{\partial \rho}{\partial t} + q'(\rho)\frac{\partial \rho}{\partial t} = 0 \tag{1}$$

Using methods (Ockendon *et al.* 2003) for determining the jump conditions from the original conservation equation, it is established that the shock speed is given by:

$$\frac{dx}{dt} = \frac{[q]}{[\rho]} = \frac{q(\rho_1) - q(\rho_2)}{\rho_1 - \rho_2} \tag{2}$$

Here, ρ_1 and ρ_2 denoting density of the upstream and the downstream respectively. Eq. (2) actually represents the slope of the flow vs. density curve of the fundamental diagrams.

3 METHODOLOGY

As cited earlier in the introduction chapter that developing countries like Bangladesh have non-lane based heterogeneous traffic movement, measurement technique of density and speed is tough. Video footage has been collected to analyze the data. Moreover, there are some difficulties even using video footage. One of those is perspective correction of the camera angle. This phenomenon has been well illustrated for India (Sen *et al.* 2013). The perspective correction has been conducted according to Figure 3, to get the accurate measurement of speed and density hereafter.

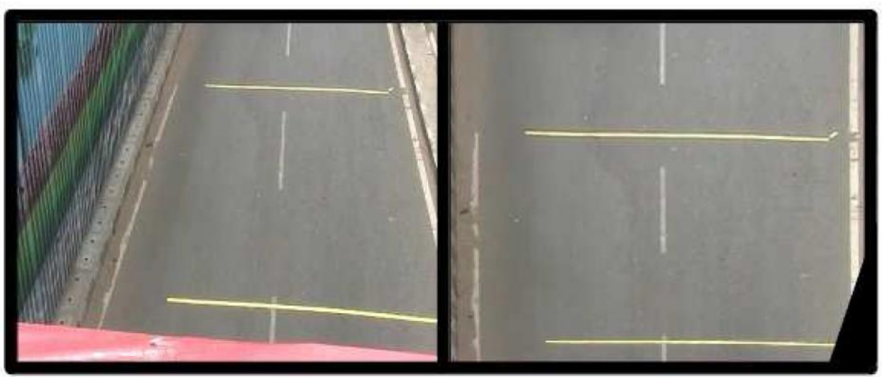

Figure 3. Road before (left) and after (right) perspective correction (Sen *et al.* 2013).

It can be concluded that as roadway traffic condition is similar for Bangladesh to India, the methodology might give accurate measurement and results thereby. Dhaka-Mymensing Highway, one of the major highways of megacity Dhaka has been chosen for the study. Data for different peak hours of the day has been collected through video camera and accumulated accordingly. Road segments have been marked with 20 m spacing for analysis. Renowned software for statistical analysis R and MATLAB are used to analyze the data and obtaining the equations of fundamental diagrams which will be demonstrated later on.

4 RESULTS AND DISCUSSIONS

Results have been obtained using methodology described earlier. Two major aspects of the results are fundamental diagrams' characteristics and the shockwave speed on the diagrams.

4.1 Plot of Fundamental Diagrams

Differentiating free flow and congested flow in different peak hours of the day for both directions of the road, the plot of fundamental diagrams is made using R. For convenience accumulated data for both directions have been summarized here. Figure 4, Figure 5 and Figure 6 well represent the interrelations between traffic parameters as it can be seen from the plot. Car, bus, motorbike, paratransit were taken as reference vehicles on the road except non-motorized vehicles. PCU (Passenger Car Unit) equivalents for different vehicles are used as per Indian practice for rural conditions (IRC 1990).

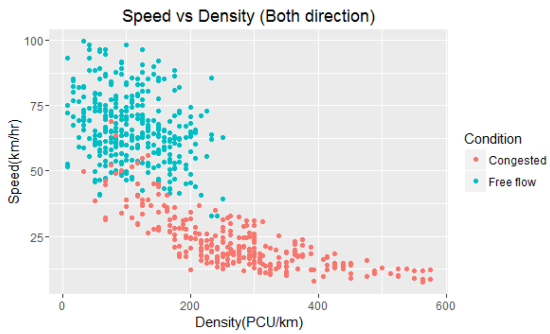

Figure 4. Speed vs. density plot.

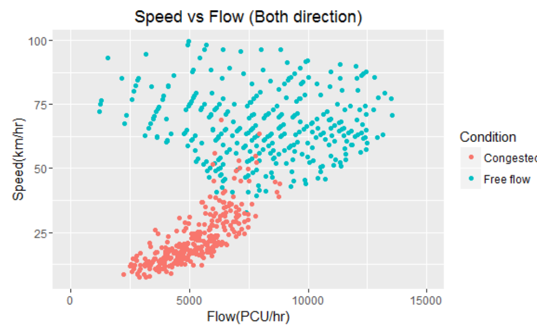

Figure 5. Speed vs. flow plot.

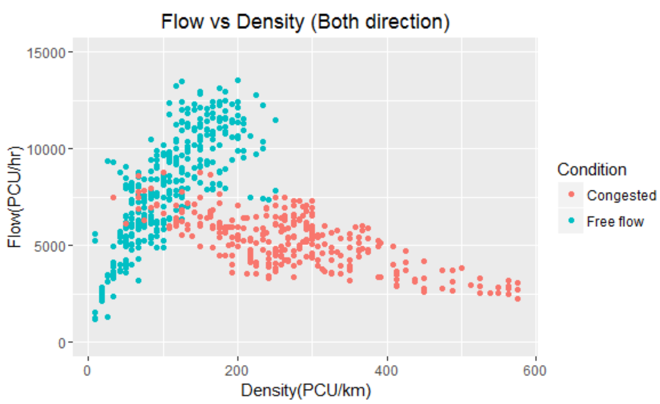

Figure 6. Flow vs. density plot.

From the above figures the shape of the fundamental diagram could easily be detected. For convenience the data of congested and free flow condition are separated from the video footage and shown distinctively in the above figures. Figure 4 shows scatter in speed value for short range of density. The plots are calibrated using R with the best suit models and also validated afterwards with different data. Hence it is vindicated that the result yields. The exponential fit suits best for this plot regarding equation $v = 89.93e^{-0.005*\rho}$, units are specified as per figure. Figure 5 also shows a scattering for free flow condition, it indicates that speed varies even for same flow rate of vehicles. However, speed with respect to flow could be illustrated by the equation $v = 22.17 + 0.3*q + 11.4*q^2 + 0.14*q^3$. Here, q is flow rate, v is instant speed and ρ is the corresponding density. Finally the Figure 6 depicts the flow vs. density diagram which is identical to the currently established three phase traffic theory (Kerner 1999). The plot of flow vs. density indicates change of phase from F→S i.e., traffic breakdown to admit synchronized flow from free flow. Hence, the relationships between traffic parameters including phase transitions are obtained for Non-lane based heterogeneous traffic vehicles which is used to calculate the speed of shockwave described later on.

4.2 Plot of Shockwave on Calibrated Fundamental Diagrams

The equation obtained from the fundamental diagrams using best fit combination via R, used to match with the shockwave speeds on the relationships using MATLAB. The following graphs have been encountered shown in Figure 7 and Figure 8 using Eq. (1) and Eq. (2). It can be easily seen that the speed drastically reduces in case of shockwave as well as in F→S phase transitions.

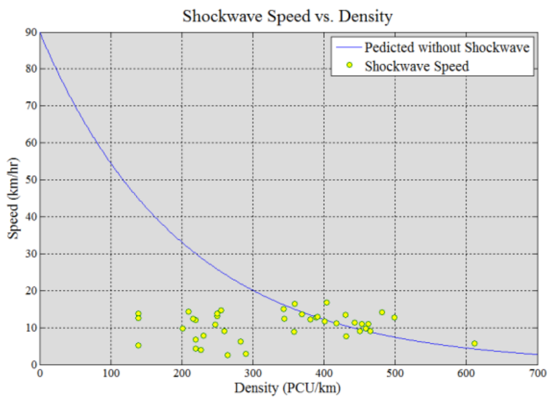

Figure 7. Shockwave speed vs. density plot.

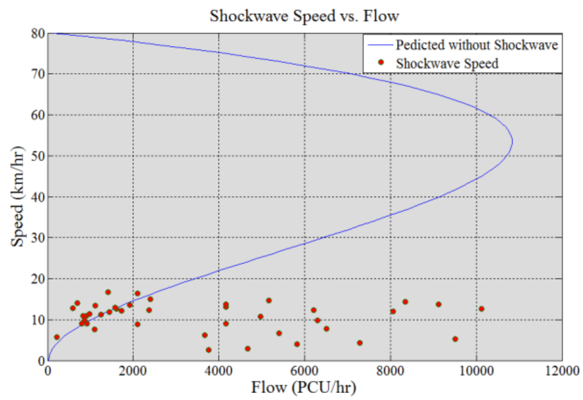

Figure 8. Shockwave speed vs. flow plot.

Figure 7 shows that in case of low density when shockwave occurs, the speed lies below 20 km/hour although in normally predicted equation speed should have been well upon the values represented by the blue line. In addition to that it is observed that the shockwave speeds on high density almost coincide with the predicted equation. For the interpretation of this outcomes, it should be remembered that while in saturated flow, non-lane based traffic behavior eclipses the shockwave phenomenon which can be compared to the lane changing in bottleneck. Hence, the speed of shockwave is identical to the speed in congested flow of non-lane based heterogeneous traffic. Also in Figure 8, it can be noticed that shockwave speed is well below 20 km/hour which shows a large deviation from originally predicted speed at high flow rate albeit in congested flow where operating speed due to frequent lane changing is similar to the shockwave speed.

5 CONCLUSIONS

From the above discussions it can be concluded that delay is significant while shockwave occurs due to lane changing. Moreover operating speed is tragic in case of congested flow as frequent lane changing still prevails and stimulate a situation alike shockwave all the time. Hence, transportation networks and operations are becoming dilapidated.

In this study traffic parameters are calibrated for the particular roadway mentioned in the methodology chapter and validated. Thus, the model can be used to predict traffic flow and also could be used as a prototype for the non-lane based heterogeneous traffic containing roadway for future planning, simulation and assessment purpose as it is already discussed on the introduction chapter that there lies an enormous possibility that the traffic demand and number of vehicles would increase in the near future here.

For sustainable traffic management restriction on lane changing might be imposed and enforced on the roadway. Another comprehensive study might have been undertaken to determine the delay and cost of delay on the roadway of developing countries where heterogeneous traffic prevails and lane concepts are absent. The relationships established by the model in this paper might act as a stimulant for the study.

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