EFFECTS OF RICKSHAWS AND AUTO-RICKSHAWS ON THE CAPACITY OF URBAN SIGNALIZED INTERSECTIONS

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Non-motorized vehicles (i.e. rickshaws) and small size motorized vehicles (i.e. auto-rickshaws) are popular para-transit modes that provided door-to-door service in congested parts of Dhaka metropolitan area. Improper design of signal timing at signalized intersections is one of the reasons of traffic congestion in Dhaka metropolitan area. For capacity analysis, to convert the mixed traffic flow into basic traffic flow passenger car equivalents plays an important role. In Bangladesh for signal design purposes passenger car equivalents value of rickshaws and auto-rickshaw are assumed by the traffic engineers as there is no widely acceptable method to estimate PCE values of rickshaws and auto-rickshaws, which is likely to result in unnecessarily long queues and additional delays or, in other words, inefficient intersection control. The objective of this study was to analyze the effects of rickshaws and auto-rickshaws on the capacity of signalized intersections. This study also aimed at developing an estimation method of passenger car equivalent of rickshaws and auto rickshaws at signalized intersections by a macroscopic approach. Data of four intersections of Dhaka metropolitan were used for development of PCE values. Passenger car equivalent values of rickshaws and auto-rickshaws are recommended for capacity analysis of urban signalized intersections with a mixed traffic flow. The results indicated that the estimated PCE value of rickshaws and auto rickshaws of this study are different from the assumed PCE values that are presently used by traffic engineers of Bangladesh.

Key Words: Passenger car equivalents (PCE), Rickshaws, Auto-rickshaws, Signalized intersections, Capacity analysis

1. INTRODUCTION

The analysis of traffic flow at signalized intersections has long been recognized as one of the most important concerns facing the traffic engineering profession, since the amount of delay that can occur at such intersections can render an otherwise excellent highway design inadequate. The presence of non-motorized vehicles and small size motorized vehicles in the traffic stream affects vehicular performance and reduces actual capacities of the highway facilities. These effects are severe at signalized intersections as all vehicles have to stop when the signal turns to red. Road transport in metropolitan Dhaka, Bangladesh is predominated by non-motorized vehicles (three wheeler rickshaws) and small size motorized vehicles (auto-rickshaws). In the past, these modes of transport were given very little consideration, both in planning and research.

Hossain[1] conducted a study in metropolitan Dhaka on the effect of non-motorized transport on the performance of road traffic. The authors concluded that mobility (persons/hr) on some selected road sections decreased as the proportion of non-motorized vehicles increased. They also concluded that modal share of total accidents (fatality, injury and property damage) showed that non-motorized vehicles share of accidents was lower than the share of motorized vehicles. However, when only fatalities are concerned, the share of non-motorized vehicles becomes much higher than that associated with motorized vehicles. Gallagher[2] made a study on rickshaw, rickshaw-owners and rickshaw users of Bangladesh. The author investigated the impact of rickshaws on the total transport system and road accidents. Sarna[3] made a study regarding the importance of non-motorized modes in mixed traffic in Indian cities. Reploge[4] made a comprehensive study on the non-motorized transport of many mixed traffic Asian cities and concluded that transport in most parts of Asia has focused principally on the motorized transport sector and has often ignored the needs of non-motorized vehicles. Liu[5] conducted a study on the capacity of highways with a mixture of bicycle traffic and developed a set of coefficients to discount the capacity per motor lane on the road with mixture of bicycle traffic. Tiwari[6], in his study on planning for non-motorized traffic, concluded that if the infrastructure design does not meet the requirements of non-motorized transport, all modes of transport operate at sub-optimal conditions. Marwah and Singh[7] attempted to provide a classification of level of service for urban heterogeneous traffic conditions. The operating characteristics considered to define what LOS are: journey speeds of cars and motorized two-wheelers; concentration; and road occupancy. Parikesit[8] conducted a study in Yogyakarta, Indonesia on the characteristics of non-motorized public transport service and concluded that non-motorized vehicles operation finds it difficult to cope with a "modern" traffic management scheme developed to suit the needs of motorized vehicle. Steuart and Shin[9] made a comprehensive study on the effect of small cars on the capacity of signalized urban intersections and concluded that the capacity of a signalized intersection is increased by up to 15% for a stream of small cars over a stream of full-sized cars.

An overall review of the studies suggested that past efforts on determining the effects of non-motorized and small size motorized vehicles has concentrated on the total transport system, importance of these modes and some limited cases on mixed traffic performance. Very few studies considered the capacity analysis of mixed traffic flow. Furthermore, no study was found which considered the effects of rickshaws and auto-rickshaws on the capacity of intersections and PCE estimation procedure of these modes. Presently there is no widely acceptable guide line for traffic engineers of Bangladesh to estimate the PCE values of rickshaw and auto-rickshaws for capacity analysis of signalized intersections, furthermore, assumed PCE values of rickshaws and auto-rickshaws result in long queues in some intersections which leads to traffic congestion in Dhaka metropolitan area. The objective of this study was to analyze the effects of rickshaws and auto-rickshaws on the capacity of signalized intersections. This study also aimed at developing an estimation method of a passenger car equivalent of rickshaws and auto rickshaws at signalized intersections by a macroscopic approach.

2. DATA COLLECTION PROCEDURE

All field data were collected from the signalized intersections located in the Dhaka metropolitan area in Bangladesh. Four signalized intersections were selected for the study. The following criteria were used in the selection of study sites: minimum proportion of turning vehicles, no parking allowed, level terrain, and road surface in good conditions, high traffic volume and insignificant disturbance from bus stops. Figure 1 represents the geometric configuration of study sites. Data of non-motorized vehicles (rickshaws) and small size motorized vehicles (auto-rickshaws) were collected from intersections 1, 2 and intersections 3, 4 respectively.

Data collection was performed by a two person team. Two types of data were collected for intersections 1 and 2: total number of passenger cars and rickshaws in the specified queue length, and time required to discharge

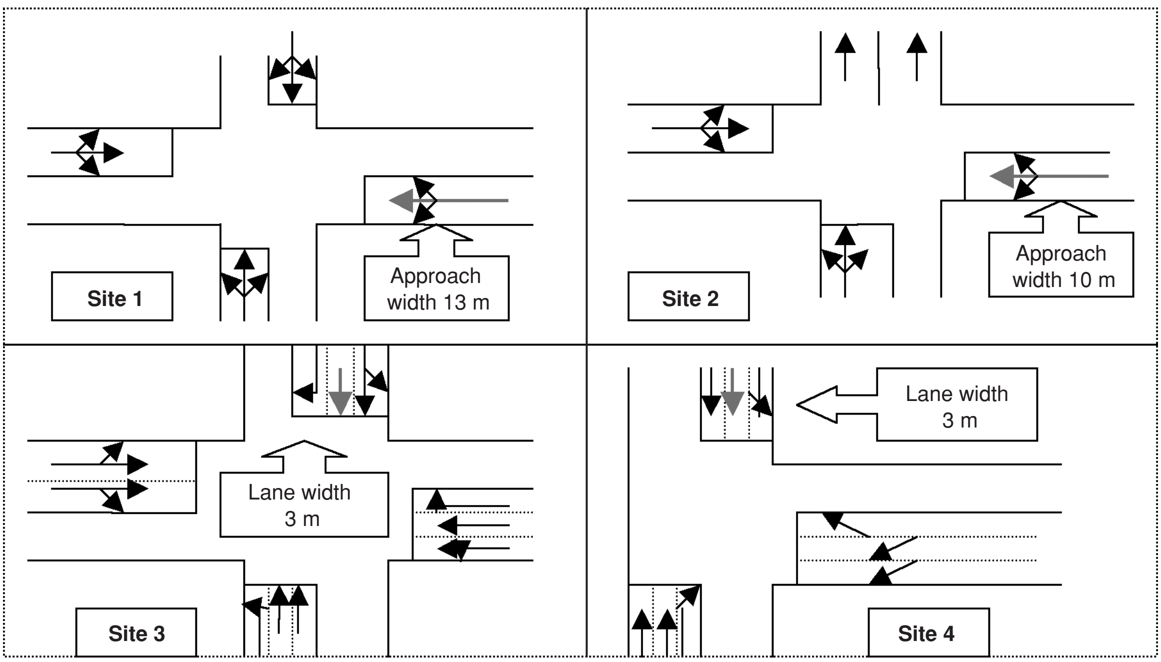

Fig.1 Geometric configuration of study sites

these queued vehicles. A total number of queued vehicles within this queue length were counted during the red interval. Time required to discharge these queued vehicles was recorded by stop watch. For intersections 3 and 4, total number of passenger cars and auto-rickshaws were counted which were discharged during a specified green period. Data were collected for two different green periods of 20 sec and 25 sec intervals because during the data collection phase it was observed that average discharged time to clear all the queued vehicles was about 23 sec. For intersections 1 and 2 data were collected for queue length of 50 meters and 40 meters because during data collection phase it was observed that the average length of queued vehicle was about 46m. All data were collected during morning peak period. In all, more than sixteen hours data were collected for this study. To determine the basic flow the queue which contained only passenger cars was recorded. To avoid the impact of other types of vehicles on passenger car equivalents, data were recorded for only those queues which contained passenger cars and rickshaws or passenger cars and auto-rickshaws.

3. EFFECTS OF RICKSHAWS AND AUTO-RICKSHAWS

Figure 2 and Figure 3 represent the effect of rickshaws and auto-rickshaws on the discharge rate of mixed

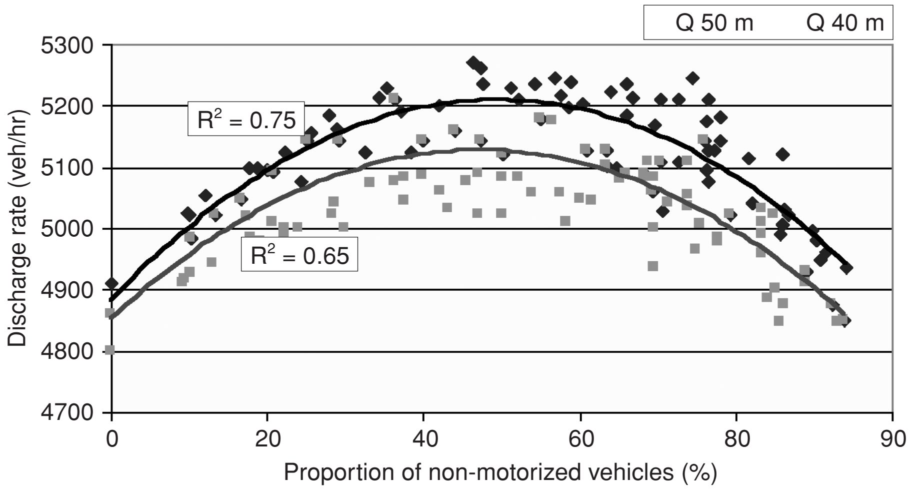

Fig. 2 Relationship between discharge rate and proportion of rickshaws

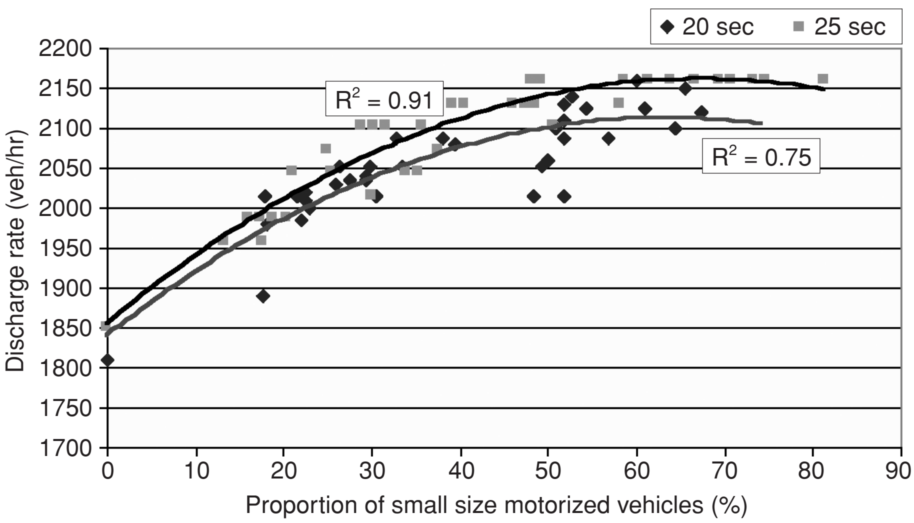

Fig. 3 Relationship between discharge rate and proportion of auto-rickshaws

flow at signalized urban intersections.

As shown in Figure 2 the discharge rate of mixed flow of passenger cars and rickshaws increases as the proportion of rickshaws increases and after certain proportion of rickshaws (about 50%) the discharge rate gradually decreases as the proportion of rickshaws, increases. This seems to us that a lower proportion of rickshaws the passenger car are dominant and the discharge rate is higher due to their higher speed and at a higher proportion of rickshaw discharge rate is slow due to the lower speed of rickshaws which required more time to cross the stop line. This tendency is similar for both the 50 meter and 40 meter queue lengths and the discharge rate of the 50 meter queue lengths is more than that of the 40 meter queue length as more vehicles are involved in a bigger queue length. The pattern of relationship between discharge rate and proportion of auto-rickshaws is somewhat different from that of rickshaws. As shown in Figure 3, the discharge rates of mixed flow of passenger cars and auto-rickshaws at urban signalized intersections increased with the increase of proportion of auto-rickshaws. This seems to occur due to the size of auto-rickshaws being smaller and almost half that of a passenger car and those headway values are smaller than passenger cars which results in an increase in discharge rate.

4. PCE ESTIMATION METHODS AT INTERSECTIONS

The term passenger car equivalent (PCE) was first introduced in 1965 Highway Capacity Manual (HCM)[10]. The concept of estimating passenger car equivalent is to estimate the number of passenger cars displaced by each vehicle other than a passenger car in mixed traffic flow. Considerable research effort has been directed toward the estimation of PCE value at signalized intersections by various researchers.

Greenshields et al.[11] estimated PCE value by a headway ratio method, which is also known as the basic method and currently the most commonly used method. In this method, PCE of any vehicle class (i) is estimated by the ratio of average headway value of vehicle class (i) to the average headway of a passenger car (c) according to the equation (1).

$$PCE_i = H_i / H_c \qquad (1)$$

Molina[12] developed a method to estimate the PCE value of large trucks at signalized intersections based on the increased headways caused by a large truck. Molina's method is based on the headway method and estimate PCE using equation (2).

$$PCE_j = 1 + \frac{Dh}{H_b} \qquad (2)$$

Where: PCE_j = passenger car equivalents of large vehicle type j;
D_h = increased headway of the queue caused by vehicle type j (sec);
H_b = saturation flow headway of passenger car (sec).

Zhao[13] developed a delay-based passenger car equivalent method for heavy vehicles at signalized intersections using headway data according to the equation (3).

$$D - PCE_i = 1 + \frac{Dd_i}{d_o} \qquad (3)$$

Where: $D\text{-}PCE_i$ = delay-based PCE for vehicle type i;
Dd_i = additional delay caused by vehicle type i (sec);
d_o = average delay of passenger car queue (sec).

Rahman et al.[14] developed a new method for estimating passenger car equivalents for large vehicles at signalized intersections based on the increased delay caused by the large vehicle. This method includes the effects of a large vehicle's position in the queue to estimate the PCE value. The authors estimate PCE using equation (4).

$$PCE_{LVj} = 1 + (d_{LGj} / D_o) \qquad (4)$$

Where: PCE_{LVj} = passenger car equivalents for a large vehicle at j-th queue position;
d_{LGj} = increased delay due to the large vehicle at j-th queue position;
D_o = base delay of a passenger car when all the queued vehicles are passenger car.

An overall review of the studies suggested that past efforts on determining the PCE value concentrated mainly on the large vehicle i.e. motorized vehicles. No study considered PCE estimation method for non-motorized vehicles and small size motorized vehicles at signalized urban intersections. The methods mentioned above cannot be directly used to estimate PCE of non-motorized and small size motorized vehicles, as flow characteristics of these types of vehicle is completely different and complex in nature. Furthermore, most of the intersections rickshaws and passenger cars form a scattered queue, so it is difficult to estimate the individual headway of vehicles.

5. PCE OF AUTO-RICKSHAWS AND RICKSHAWS

The passenger car equivalent (PCE) of a rickshaw or auto-rickshaw represents the number of passenger cars (basic vehicles) displaced by each rickshaw or auto-rickshaw in the mixed traffic stream under specific conditions of flow. Consider the relationship between some measure of impedance along a length of roadway and the flow rate along the same roadway for two different traffic streams. There are several variables that may be used as a measure of impedance. For this study, in the case of rickshaws fixed queue length and auto-rickshaws the fixed green time period is considered as a measure of impedance to relate two traffic streams. The flow-impedance relationship is shown in Figure 4, in which the basic curve represents a stream consisting solely of basic vehicle (passenger cars) and the mixed curve represents a stream with proportion of rickshaws or auto-rickshaws p and of basic vehicles (1-p).

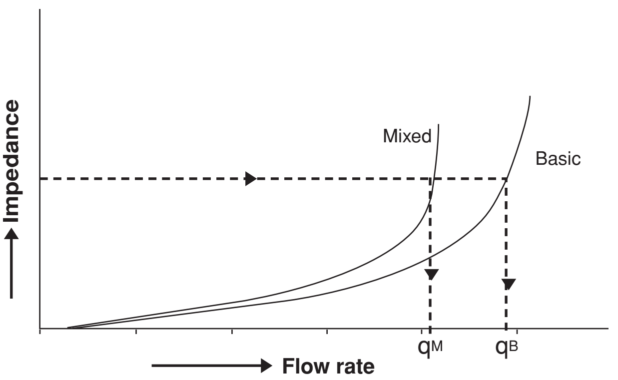

Fig.4 Flow-impedance relationship[15]

As shown in Figure 4, as the flow rate q increases, the impedance increases; the increase in impedance is at a greater rate for the mixed flow. For any given impedance it is possible to calculate the corresponding flow rate q_B and q_M. These flow rates for the basic and mixed streams will produce identical measures of level of service and can then be equated so that $q_B = (1\text{-}p)\ q_M + p\ q_M\ (PCE)$. Solving for PCE, the result is

$$PCE = (1/p)\ [(q_B / q_M) - 1] + 1 \quad \text{.......................... (5)}$$

Where: PCE = passenger car equivalent of rickshaws or auto-rickshaws;
p = proportion of rickshaws or auto-rickshaws in mixed traffic flow;
q_B, q_M = flow rate for basic and mixed traffic streams respectively.

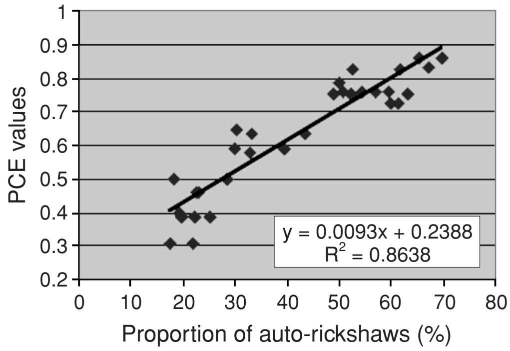

Fig. 5 Relationship between PCE and proportion of auto-rickshaws (Site 3, 20 sec green time period)

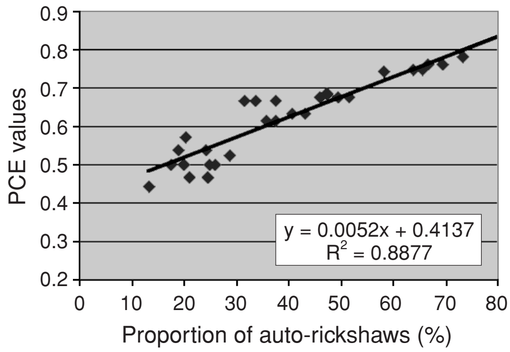

Fig. 6 Relationship between PCE and proportion of auto-rickshaws (Site 3, 25 sec green time period)

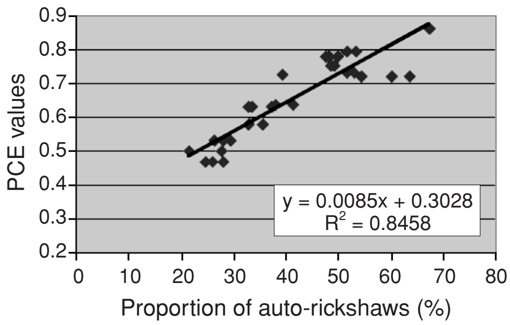

Fig. 7 Relationship between PCE and proportion of auto-rickshaws (Site 4, 20 sec green time period)

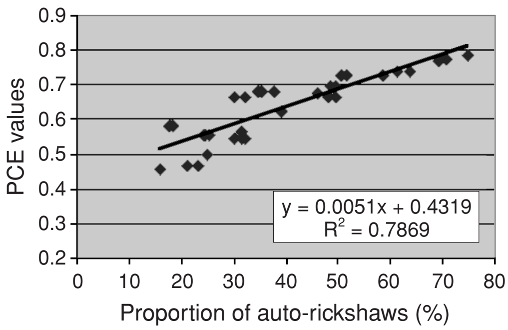

Fig. 8 Relationship between PCE and proportion of auto-rickshaws (Site 4, 25 sec green time period)

The concept of passenger car equivalent (PCE) estimation method of auto-rickshaws is that first basic flow for a fixed green time period is determined, and then mixed flow for a various proportion of auto-rickshaws is determined for the same green period. From the collected data p, q_B, and q_M are estimated for various proportions of auto-rickshaws. Basic flow rate q_B, and mixed flow rate q_M were estimated by dividing the number of vehicles passing during the observed green time period. In the first phase of data analysis PCE values are estimated for various proportions of auto-rickshaws using Eq. (5) for two different green time periods. Passenger car equivalent values and corresponding proportions of auto-rickshaws are plotted for site 3 in site 4 in Figures 5 to 8.

After examination of the data patterns presented, linear regression models were recommended to present the relationships between passenger car equivalents of auto-rickshaws (PCE_{AR}) and the proportion of auto-rickshaws (PAR). A linear regression model was applied as the plotted data showed a linear relationship between PCE values and proportion of auto-rickshaws. The general format of the linear model was as follows:

$$PCE_{AR} = a + b * PAR \quad (6)$$

In the second phase of analysis one way analysis of variance (ANOVA) tests were conducted to determine the effect of a fixed green time periods on the PCE values, as data were collected for different green time period. The principal of an ANOVA table is to compare the F value and $F_{critical}$ value at a given confidence level. If $F > F_{critical}$ the null hypothesis will be rejected. Since the purpose of the test was to evaluate whether the fixed green time period had a significant impact on the PCE values, the statistical basis for the ANOVA test was as follows:

- H_o: The fixed green time period does not have a significant impact on the PCE value of auto-rickshaw at signalized intersections.
- A confidence level of 95% ($\alpha = 0.05$) was set for the test.

Results of the ANOVA of the PCE values on the green time period are presented in Table 1. As shown in Table 1, the null hypothesis H_o was accepted, so it could be concluded that the effects of a fixed green time period on PCE value of auto-rickshaws is insignificant. So we can combine all the data for further analysis. In the case of rickshaws, a similar approach used for determination of PCE values and examined the effect of approach width and fixed queue length on PCE values of rickshaws has been done. Rahman et.at.[16] described the detailed of this procedure.

Table 1 ANOVA results of PCE on fixed green time period

Parameter	F	$F_{critical}$	H_o
Green time (20 sec)	0.025	4.00	Accepted
Green time (25 sec)	0.022	3.98	Accepted

6. RESULTS AND DISCUSSION

Regression results based on combined data are shown in Table 2. Considering the R^2 and t-values as shown in Table 2, regression models provide very good predictions of PCE for both auto-rickshaws and rickshaws. The critical t-value for 95% significance level for the data set is about 1.65. All values show a significant value as this significance level. Comparison of observed

Table 2 Regression results of PCE models

Vehicle type	R^2	Co-efficient		t-value		F
		a	b	t_a	t_b	
Auto-rickshaw	0.78	0.3485	0.0069	23.86	21.26	452
Rickshaw	0.89	0.7508	0.0026	232.36	47.27	2234

PCE and predict PCE of auto-rickshaws and rickshaws from regression equations are shown in Figure 9 and Figure 10 respectively.

As shown in Figure 9 the regression model can predicts the PCE value of auto-rickshaws more authentically at a higher proportion of auto-rickshaws than a lower proportion. This seems to us to have occurred because at a lower proportion of auto-rickshaws the discharge rate varies considerably depending on the position of auto-rickshaws in the queue. The Discharge rate increases if auto-rickshaws are at the beginning of the queue and decreases if they are at the end of the queue, this causes scatter of estimated PCE value.

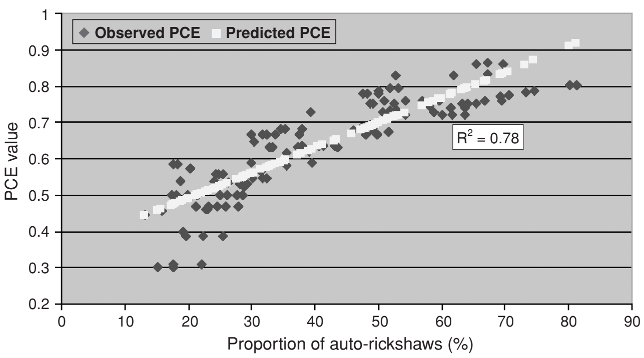

Fig. 9 Comparison of observed PCE and predicted PCE value of auto-rickshaws

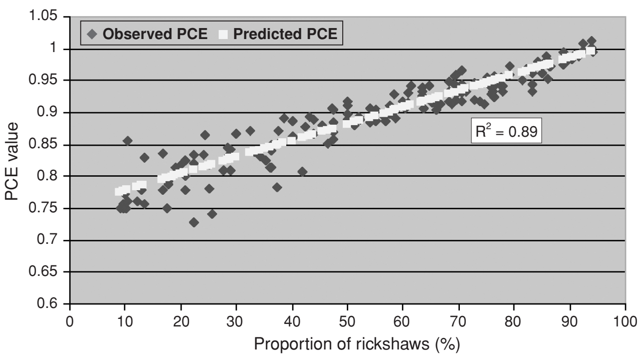

Fig. 10 Comparison of observed PCE and predicted PCE value of rickshaws

As shown in Figure 10 the regression model can predict the PCE value of rickshaws authentically at all proportions of auto-rickshaws. There is a linear relationship between PCE value and proportion of rickshaws. PCE value increases as the proportion of rickshaws increases. Maximum effect due to rickshaws occurrs at signalized intersections when their proportion is high. This seems to us to occurre because at a higher proportion of rickshaws, discharg time increases due to slow moving

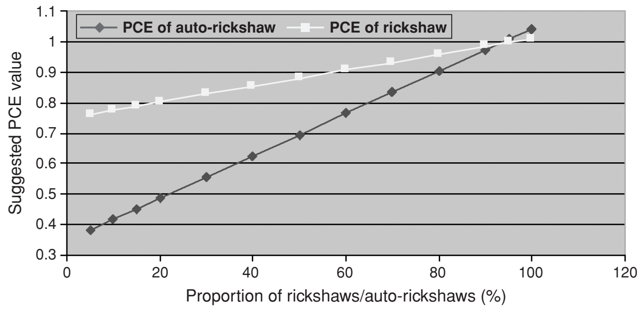

Fig. 11 Suggested PCE value of auto-rickshaws and rickshaws for capacity analysis

capabilities of rickshaws which decreased the flow rate of mixed traffic. A similar effect was also observed for auto rickshaws. In the regression analysis we assumed that there was a linear relationship between estimated PCE values and the proportion of rickshaws and auto-rickshaws. However, other relationships might be considered in future to account for possible non-linear relations.

Figure 11 represents the PCE value computed from the prediction model for various proportions of rickshaws and auto-rickshaws. For capacity analysis or signal design for mixed traffic flow, from field observations we have to determine the proportion of rickshaws or auto-rickshaws in mixed flow. Then PCE value of Figure 11 will be used to convert the mixed flow into basic flow in the analysis. As shown in Figure 11, at lower proportion of rickshaws in the mixed flow affects the flow more adversely than auto-rickshaws and at higher proportion of vehicles the effect is similar. The suggested PCE value of rickshaws and auto-rickshaws varies from 0.75 to 1 and 0.35 to 1 respectively depending on the proportion of vehicles in mixed traffic flow. This result is applicable for capacity analysis of any intersection with a mixed flow of passenger cars and rickshaws or auto-rickshaws. In DITS[17] report they assumed and used a constant PCE value of rickshaws and auto-rickshaws 1 and 0.75 respectively. No adequate documentation is provided for this assumption. The results show evidence that the estimated PCE value of rickshaws and auto rickshaws of this study varied significantly at lower proportions of vehicles from the assumed PCE values that are presently used by the traffic engineers of Bangladesh. In this paper we considered PCE values of rickshaws and auto-rickshaws separately. It is possible to estimate the PCE a value of a mixture of rickshaws and auto-rickshaws by similar approach, but an extensive data source is required for this purpose.

7. CONCLUSIONS

A procedure for estimating passenger car equivalents (PCE) of rickshaws and auto-rickshaws at signalized intersections is presented. Results summarized in this paper are based on field data collected in Dhaka metropolitan area, Bangladesh. Based on the results of this study, the following can be concluded:

At a higher proportion of the rickshaws discharge rate of mixed flow at signalized intersections is smaller than that at a lower proportion of rickshaws. The discharge rates of mixed flow at urban signalized intersections were increased with the increases of proportion of auto-rickshaws. The effect of intersection approach width and fixed queue length on PCE value of rickshaws was insignificant; on the other hand the effect of fixed green time period on PCE value of auto-rickshaws was insignificant. There is a linear relationship between PCE value and proportion of rickshaws and auto-rickshaws. The presence of rickshaws in the mixed flow conditions affect the capacity of signalized intersections more adversely at a lower proportion than that of at a higher proportion of rickshaws. The passenger car equivalents (PCE) of a rickshaw or auto-rickshaw represents the number of passenger cars (basic vehicles) displaced by each rickshaw or auto-rickshaw in the traffic stream under specific conditions of flow.

The PCE values of rickshaws and auto-rickshaws is of utmost importance for capacity analysis of signalized intersections for mixed traffic conditions, as these types of modes are very common and popular in some south Asian countries. Information gathered from this study would not only provide avenues for further research but also help transport planners and decision makers in taking steps forward to solve existing traffic problems at intersections in metropolitan Dhaka and thus evolve a more efficient and safe transport network. In this study, data were collected from a limited number of (four) intersection approaches, a further comprehensive study will required which coveres all factors that affect the PCE value at signalized intersections.

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