2012 International Conference on Traffic and Transportation Engineering (ICTTE 2012)
IPCSIT vol. 26 (2012) © (2012) IACSIT Press, Singapore

Evaluation of Passenger Car Equivalent Values under Rainfall

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Abstract. Passenger Car Equivalent (PCE) values are a convenient way for stating the flow rates of traffic with heterogeneous composition. The basis for PCE evaluation is to compare the number of passenger cars that can be displaced by other vehicle categories especially the heavy vehicles. These have been carried out in normal weather but the study has yet to be conducted under rainfall conditions. Data on vehicle headways was collected on a basic highway section and PCE values were evaluated under varying rainfall intensities. The results indicate marked increases in motorcycle PCE values but decreased values for all other vehicle types. The average values for the motorcycle for both directions of flow are 1.16 and 1.18 respectively. For the medium vehicle categories the average PCE values are 1.22 and 1.36. In the heavy vehicle category, the average PCE values are 1.05 and 1.09 respectively in both directions. All the PCE values decreased with increase in rainfall intensity. Reasons attributed to these include low heavy vehicle content in the traffic stream (3.51%), increase in small vehicle headways under rainfall conditions and the free flow state of the facility throughout the observation period. In the absence bottlenecks and congestion rainfall alone improves the performance of heavy vehicles.

Keywords: Passenger Car Equivalent, Traffic Flow Rate, Rainfall

1. Introduction

Studies on passenger car equivalency (PCE) have centered on points or sections of highways with the greatest vehicular interactions. These include work zones, intersections, and peak periods, areas with high pedestrian-vehicular interactions or non-motorized vehicle content. Ambient conditions such as rainfall may influence traffic behaviour in ways akin to the aforementioned areas. Thus rainfall also brings about high vehicle-vehicle interactions and may therefore add its own dimension to PCE determination. PCE studies have thus far been restricted to normal weather conditions. During rainfall long queues form, delays occur, speed changes are common and the occupancy of vehicles increases. The arguments for PCE evaluation in normal weather equally apply in adverse weather conditions. Thus this paper seeks to examine the effect of rainfall on traffic behaviour and the implications of this on the Passenger Car Equivalents (PCE) values of vehicles. The thrust of the paper is to evaluate PCE values of light, medium and heavy vehicles in no-rain conditions and compare with values evaluated under various rainfall intensity regimes. This is to see if rainfall alone affects PCE of vehicles in the absence of congestion and other known constraints.

Passenger Car Equivalency (PCE) was first mentioned in the 1965 Highway Capacity Manual (HCM) to depict the displacement of the passenger car in traffic flow by trucks, or buses under the prevailing roadway and traffic conditions. It has since been redefined in the 2000 HCM as "the number of passenger cars that are displaced by a single heavy vehicle of a particular type under the prevailing roadway, traffic and control conditions" PCE studies are important because they affect the quality and quantity of traffic flow on highways and freeways. Traffic flow constraints in bottleneck areas such as on-and–off ramps, affect PCE

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values much as they do to capacity. Furthermore, the number of heavy vehicle content in the traffic stream also influences the PCE values. Thus it may be reasonable to link traffic flow features which affect capacity to impact PCE values in a similar way.

2. Literature Review

Traffic flow analysis and design often requires the computation of flow volumes for demand assessment, level of service determination, and upgrading of existing facilities. The heterogeneous nature of the traffic does not often permit the specification of the flow in the conventional units of flow, i.e. volume per hour, volume per day etc. An alternative way is to specify the volumes in passenger car equivalent. The acceleration and deceleration characteristics of heavy vehicles and the large space they occupy on roadways have attracted the most attention in the evaluation of PCE values. When they are stationary, they are slow to start and speed. When caught in high flow situations, they are slow to decelerate to a stop and are unable to maneuver out of congested situations. Furthermore drivers of passenger cars in the vicinity of trucks and other large vehicles have been known to change their behaviour [2]. Thus studies of PCE values have been focused on heavy vehicles at signalized intersections [3], during congestions [4], [5] and at mid-block sections [6]. Different evaluation criteria have been employed in PCE studies. These criteria include speed density or average headway, delay and platoon formation. The evaluation criteria used suggest that vehicle-vehicle interactions must be high and that interaction enable the relationships between passenger cars and other vehicles to be derived. Conditions that bring about high vehicular interactions such as during congestion, rainfall, accidents, extreme pavement distress, might create situations similar to those in which PCE evaluation criteria have been applied. However, such conditions need to be recurring to constitute a problem which might require PCE values of heavy vehicles to be determine for use in capacity analysis. Rainfall and congested roadways meet this criterion. While efforts to minimize or eliminate congestion have persisted, the problems of congestion are still much noticeable on most road networks. Similarly, rainfall is a recurrent traffic related problem and in many parts of the world, precipitation is a common highway management problem. Evidence on the effect of rainfall on traffic flow now clearly indicate that traffic flow contraction and speed reduction are the macroscopic parameters impacted by rainfall. Speeds and headways are similarly affected by rainfall. Highways with high flow rates are disturbed by rain and conditions similar to congested roadways or peak hour flows might form. In tropical countries such as Malaysia, where rainfall is a daily occurrence, drivers would have to contend with traffic disturbances associated with rainfall. No work has yet been dedicated to PCE studies under rainfall conditions. However, Al-Kaisy et al.[5]encountered rainfall events in their field work but dissociated rain effect on the PCE values of heavy vehicles. The headway evaluation criteria could be applied to many traffic situations such as at intersection and basic highway segments or mid-block sections. Whereas headway data can be obtained in the field with relative ease, other evaluation criteria such as delay, density and speed are expensive as such methods based on these adopt the simulation approach. The passenger car equivalency method used in this study is the headway method. The method was first proposed by and involves the following equation

$$PCE_i = \frac{H_i}{H_c} \tag{1}$$

Where PCE_i is the passenger car unit of vehicle class *i*. H_i is the average headway of vehicle class *i* and H_c is the average headway of passenger car. The passenger car equivalency was determined for all headways less than 5secs. This is because according to Alhassan and Ben-Edigbe [7] drivers headways of more than 5secs are not affected by rainfall.

3. Data Collection

The evaluation of PCE's in this study is based on empirical data collection. All data was collected from a basic highway section on J5 in Johor State of Malaysia. An automatic traffic counter was installed on the section, which recorded particulars of vehicles as they traversed the observation point. Information on speed, direction of travel, headway, gap, length of wheelbase, vehicle classification and time and date stamped are

recorded for each vehicle as it passes the observation point. Rainfall intensity data from a nearby weather station was coupled with the traffic data to identify traffic data during rainfall spells. These data were further processed to categorize the traffic into three rainfall intensity regimes. These are light rain, medium rain and heavy rain. The rainfall classification was based on the World Meteorological Organization (WMO) Scheme.

Each category of rainfall data together with the no-rain data were sorted according to the Standard PCE Values currently in operation in Malaysia. The Standard Malaysian PCE values for dry weather and daylight conditions are: motorcycle 0.75; passenger car 1.0; light vans 2.0; Lorries 2.5; and heavy goods vehicle/Buses/Coaches 3.0. The vehicle classifier system used to generate the traffic data is synchronized with several vehicle classification systems across the world but does not include the Standard Malaysian system. There are more vehicle classifications embodied in the F-Scheme than is available in the Standard Malaysian system. For instance, a car with trailer, pickup with trailer, two-axle truck with trailer and three axle truck can all be bundled under light vans in the Standard Malaysian system. Furthermore there is no clear equivalent between the Malaysian classification of "Medium Lorries" and the F-scheme of the Federal Highway Administration. This category and variants of it are captured in the F-Scheme category F7 to F13.in addition to the Heavy Lorries and Buses category of the Malaysian system. Therefore the medium lorry category of the Standard Malaysian system is merged with the Heavy and Bus categories to obtain three classes as in the case of the F-Scheme. The PCE scheme used in this study is grouped into light, medium and heavy to conform to the F-Scheme. In all 99 rainfall events were observed during the three month period of May, November and December 2010 and a total of 1,316,834 vehicles were observed during the period of which 75.80% were cars and 10.23% were motorcycles (Light category). The truck composition (Heavy category) was 3.51% and the remaining vehicles (Medium category) in the traffic stream were 10.46%. The period of the traffic flow which results in the greatest interaction among vehicles is the peak period. The data analysis was carried out for peak periods only, for both conditions of dry and wet weather. The peak period for the Skudai-Pontian direction was from 5-6pm and 6-7pm, while the peak period in the Pontian-Skudai direction was 7-8am.

4. Results and Findings

The results of the PCE evaluation are shown in table 1 and 2 for both directions of flow. Generally, the PCE values of other vehicles decrease with change in weather condition and decreases further with increase in rainfall intensity. The motorcycle mode has a high PCE value in both weather conditions, a value consistently higher than the PCE value of the car. The concept of passenger car equivalency is that vehicles with higher values than the car use more road space than the car during congestion or times of greater vehicular interactions. The implication is that the motorcycle mode in this study has used more road space than the car mode. This is hardly noticeable on the facility because of the provision of a separate motorcycle lane. Even on facilities without a motorcycle lane, the high maneuverability of the motorcycle does not translate into high PCE values. In this case the motorcycle mode travelled with average headways larger than the car in both weather conditions and for all rainfall intensities as shown in tables 3 and 4. Furthermore, considering only 10.23% of the motorcycle mode in the traffic, no significant impact of rain will take place on motorcycle behaviour. The average PCE for motorcycle under rain conditions in both directions are 1.16 and 1.18 respectively. The PCE values of the passenger car mode have remained consistently the same in view of the fact that, the passenger car is the basis for comparison with other modes. However, a wide range of cars now ply the highways and even though they may have similar performance characteristics, varieties in the wheelbase configurations might affect the PCE values of other modes. Furthermore they constitute the bulk of the traffic stream and they could influence the behaviour of other modes rather than being influenced by them.

The light and medium goods vehicles categories have higher PCE values in rain conditions than in no-rain condition except under heavy rain condition in the Pontian–Skudai direction. In the opposite direction the PCE values are lower than the no-rain value except for the medium rain condition. The average PCE value for this mode under rain conditions for the Skudai-Pontian Direction is 1.22 while that of the Pontian-Skudai direction is 1.36. The PCE values computed for this mode under both rain and no-rain conditions are lower than the specifications in the Malaysian Standards. It may thus appear that the PCE values in the

Malaysian Standard are conservative values. Changes in the PCE values embodied in the HCM versions from 1985 to 2000 make comparison difficult. Besides, no study has been solely devoted to PCE studies under rainfall conditions making comparison with similar studies incompatible. The PCE values for heavy vehicles are the most widely researched. The outputs of different research efforts give various values for instance [4]. In this study, the findings on the PCE of heavy vehicles are completely at variance with other results. The average PCE value under rainfall in the Skudai-Pontian direction is 1.05 while in the opposite direction the value is 1.09. This is unlike the results in studies on PCE. The context of this research therefore needs to be explained. All PCE studies have been based on congested conditions at intersections, on-ramps, work zones, peak hour periods or mid-block sections where vehicular interactions are dominant. In this study, to isolate the effects of these bottlenecks areas, a basic section was selected and observed for peak hour flows that are devoid of incidences and to see if rainfall on its own has implications for PCE values of vehicles. Notionally, the speed reduction and flow contraction associated with traffic under rainfall conditions as well as the increases in the microscopic parameter of small headways should influence the PCE values under rain conditions. On the contrary, the influence of rainfall on PCE values in this study is to decrease the PCE as the rainfall intensity increases. This means heavy vehicles tend to behave more or less like cars under rain. Studies that have used the headways approach in the evaluation of PCE values for heavy vehicles have similar findings to this study even though the studies were carried out under no-rain conditions. The widely held view that percentage of heavy vehicle content affects the PCE values might perhaps have influenced this result. In this study the percentage of heavy vehicle content is 3.51%. The evaluations of PCE values of vehicles under rainfall conditions have been studied in this paper. Clearly, rainfall has an effect on PCE values of vehicles. It is thus, an alternative way to state the flow rate of a given section of a roadway. If the traffic mix could be determined, the flow along any section of a highway could be stated as either vehicle per hour or passenger cars per hour per lane etc.

Table 1: Passenger Car Equivalencies under No-Rain and Rain Conditions. Skudai–Pontian Direction.

Vehicle	No Rain	Light Rain	Medium Rain	Heavy Rain
Car	1.000	1.000	1.00	1.00
LGVs	1.268	1.202	1.268	1.201
HGVs	1.148	1.065	1.085	1.001

Table 2: Passenger Car Equivalencies under No-Rain and Rain Conditions. Pontian-Skudai Direction.

Vehicle	No Rain	Light Rain	Medium Rain	Heavy Rain
Car	1.000	1.000	1.000	1.000
LGVs	1.248	1.436	1.549	1.088
HGVs	1.125	1.150	1.025	*NA

*No data for this category of rainfall.

Table 3: Average Headways for Skudai-Pontian Direction

Vehicle	No Rain	Light Rain	Medium Rain	Heavy Rain
Car	1.695	1.773	1.738	2.029
LGVs	2.028	2.132	2.203	2.437
HGVs	1.836	1.888	1.886	2.032

Table 4: Average Headways for Pontian-Skudai Direction.

Vehicle	No Rain	Light Rain	Medium Rain	Heavy Rain
Car	1.581	1.567	1.620	1.831
LGVs	1.974	2.250	2.509	1.993
HGVs	1.776	1.803	1.661	NA

5. Conclusion

As shown in the paper, all the PCE values decreased with increase in rainfall intensity. Reasons attributed to these include low heavy vehicle content in the traffic stream (3.51%), increase in small vehicle headways under rainfall conditions and the free flow state of the facility throughout the observation period. In the absence bottlenecks and congestion rainfall alone improves the performance of heavy vehicles. Heavy vehicles are not easily disturbed during rainfalls and this account for their consistent behaviour under rainfall. So it can be concluded that heavy rainfall has significant impact on passenger car equivalent values of light vans and passenger cars.

6. Acknowledgement

The authors would like to acknowledge with thanks the rainfall data supplied by the Department of Irrigation and Drainage of Malaysia (JPS).

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