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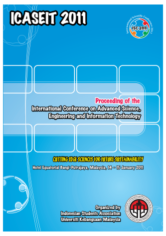

Highway Capacity Loss Induced by Rainfall

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Abstract— **The effect of rainfall on capacity reduction on highways has been investigated. Traffic data was generated for both wet and dry conditions. The data analysis showed that the highway section studied was operating in free flow region. A 2.7% capacity loss was obtained for the road. It is argued that no traffic instability could arise from this situation if the state of traffic remains in the free flow regime. However, in the event of the coincidence of fixed bottlenecks and rainfall, instabilities arising from that could lead to further capacity loss.**

Keywords— **Highways, Rainfall, Traffic Flow , Capacity Loss, Weather.**

I. INTRODUCTION

Freeways and urban road networks require continuous monitoring to minimise the effects of incidences emanating from bottleneck locations and the capacity loss that may accompany such incidences. The value of the capacity of a roadway is useful in seeing if the demand placed on a section exceeds the capacity provided. Thus the performance of a highway section may be jeopardised if the section is operating near capacity or at capacity level. It is therefore of upmost importance to be able to predict or measure the capacity of a given highway section accurately.

Capacity loss is not confined to bottleneck points on freeways and urban road networks; they are also caused by weather elements such as snow, hail, fog, rainfall, and dust storms, [1]. Weather elements are Spatio temporal in nature and can occur in such magnitude and scale, which could inflict serious disruption to traffic flow and cause accidents and death to drivers and other road users. Some weather elements are more prominent than others in different parts of the world. They may also occur in combination to cause dramatic effect on traffic flow.

This paper reports on preliminary findings of a wet weather traffic studies project at the Universiti Teknologi Malaysia on capacity reductions caused by rainfall events. It is a contribution to the study on capacity related problems on highways during adverse weather conditions such as rainfall. Subsequent sections relate to capacity estimation in general and capacity related study under rainfall. The data collection procedure is described next to be followed by the statistical analysis of the data. The last section contains the results and the conclusions drawn therein.

II. LITERATURE REVIEW.

The definition of capacity contained in [2] has been interpreted and used by researchers as a deterministic value. Whereas the definition clearly spelt out ideal conditions for its measurement, no specific measuring technique was suggested. Moreover, ideal conditions seldom occur in practice and factors have had to be applied to compensate for curved sections, grades, traffic composition and inhomogeneity of traffic lanes. Increases in traffic demand on road networks require accurate measurement and prediction of road capacities for performance evaluation. The emergence of the modern computer, in the face of traditional road capacity improvement schemes such as lane addition, and intense environmental concerns clearly shifts the focus of capacity improvement to technical aids. Besides, different researchers have reported different capacity values for roadways of equal lanes, at similar locations such as on- and –off ramps, work zones, etc. Persaud and Hurdle [3] generated traffic flow data on a 3-lane facility for three days and evaluated the capacity of the section. They recommended the mean queue discharge flow as the capacity of the section. Similar work by [4] evaluated capacity from peak period data collected over 52 days. They recommended values for stable flow and post breakdown conditions. Wemple et al [5] recognised the futility of using a deterministic value and fitted capacity data collected at a freeway site to the normal distribution. Also Elefteriadou et al [6] studied the phenomenon of flow breakdown at a freeway ramp. They observed that flow breakdown was independent of site and location but is associated with ramp-vehicle cluster. Evans et al [7] extended this study to predicting the probability of breakdown at freeway-ramp junctions and other freeway sections, while Elefteriadou and Lertworawanich [8] further extended the work by generating speed and flow data at two freeway bottleneck locations to see if the breakdown phenomenon can be supported by empirical evidence. Between non-congested and congested flow, they identified a threshold speed following which breakdown occurs. They then suggested a modification to the capacity definition to incorporate the breakdown phenomenon. In all these studies, four types of capacity values emerged as candidate values to use in measuring highway capacity. They are: mean queue discharge flow, maximum queue discharge flows, breakdown flows and maximum pre-breakdown flows. To see if the capacity flows are similar, [9] studied these flows collected from a freeway in Philadelphia. These were then examined by day of week, time of day and freeway segment type to see if significant differences exist. They concluded that the mean capacity flows were different during different times of the day, reflecting flow variation during the day and were the same during each day of the week, reflecting a flow pattern through the section. Furthermore the flows were not equal at merging, diverging, weaving, and inhomogeneous sections of freeways.

In all these studies, there is no indication of capacity measurement in adverse weather. Weather elements have been known to equally induce capacity loss on freeway segments. Like traffic flow, weather elements are also spatiotemporal in nature and act in combination to cause dramatic and unpleasant consequences on highways. Researchers such as [10], [11], [12] and [13] have all reported a drop in capacity during rainfall. Chung et al [11] found decreases in travel demand by 2.9% during week days and an average of 4.1% during weekends. Keay and Simmons [12] found significant traffic volume decreases of 1.35% and 2.11% respectively for wet and spring periods. Chung et al [13] again reported capacity decreases of up to 4.7% in light rain and 14% in heavy rain.

III DATA COLLECTION

Data for this study was collected on a principal road in Johor State of Malaysia as shown in figure 1. The site is located 23km from Universiti Teknologi Malaysia along the Skudai-Pontian Highway. The highway is a principal link between the southern city of Johor and the north-western part of the Malaysian peninsula.

Fig.1: Data Collect ion Site

Thus traffic avoiding toll on the E2 expressway uses this link as an alternative. The Skudai-Pontian Highway is a two way-two lane facility that is well maintained, marked and all traffic regulatory, guidance and warning devices properly installed and functional. The section has a posted speed limit of 60km/hr.

The observation site is a 2km straight section on which is installed a parallel pneumatic tube connected to a vehicle classifier unit which logs in the traffic data as vehicles traverse the tubes. The road side unit has sensors which detects vehicle presence as air pulses reach them when the tubes are hit by vehicles. The data logged in by the unit is retrieved later for analyses. The unit serially numbers all vehicle hits and records the direction of movement, speed, headway, gap, number of axles, width of wheel base, number of groups of axles etc. This information is processed in a variety of ways to generate traffic flow parameters of interest to this study.

The observation site is located close to a rain gauge station with ID 1534002, 0.75km away. The site was observed for two months during which (May and June 2010) 71 rainfall events were recorded. To minimise variation in spatial distribution of the rainfall in this catchment, an independent observation of the start and end times of rainfall events at the site was instituted and this was correlated with the data from the rain gauge station. The periods of the rainfall events were regarded as wet and traffic flow data were abstracted for these periods. Other periods were regarded as dry. The data for both wet and dry periods were analysed and compared.

IV. RESULTS

No differences were found in the traffic flow patterns in the months of May and June 2010. The general traffic descriptions for the site are shown in figures 2 to 5 for the month of May.

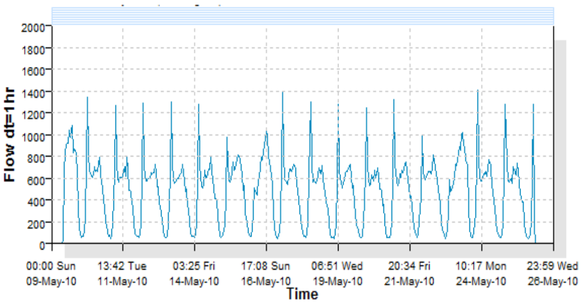

Fig. 2: Traffic Flow Profile for May

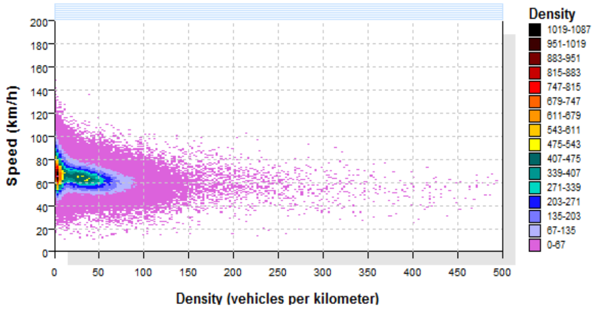

Fig.3: Speed - Density Plot for May

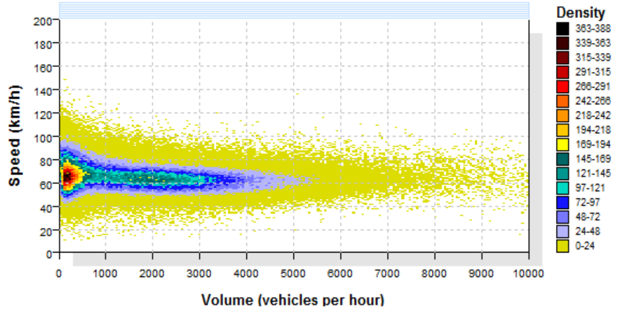

Fig.4: Speed-Volume Plot for May

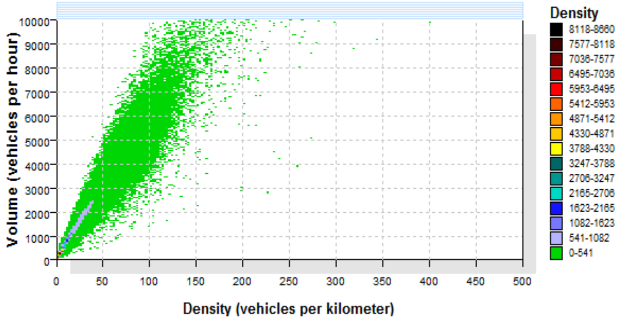

Fig.5: Volume - Density Plot for May

Figure 1 shows the flow profile of the section. It is easy to see that the week day traffic is higher than the week end traffic. Also Mondays sees the highest traffic during the week.

The monthly number of vehicles recorded was 271,322. Of these, 66.6% exceeded the posted speed limit of 60km/hr travelling on average at 69.7km/hr. The mean speed was 64.4km/hr with a standard deviation of 10.5km/hr. The 85% and 95% percentile speeds were respectively 73.8km/hr and 82.8km/hr. Furthermore, the minimum speed recorded was 10.3km/hr and the maximum speed was 147.2km/hr. It is clear from these that the state of the traffic flow is in the free flow regime.

Figures 3 to 5 confirms the traffic state to be in the free flow regime. This can be seen in the density legend to the right side of the plots.

V. CAPACITY LOSS.

To assess the capacity loss in this section of the highway, two traffic flow conditions were identified; wet and dry. Wet flow conditions constitute the traffic flow data recorded during a rainfall event. Dry flow conditions are those for which no rainfall occurred. Thus, if for instance a rainfall event occurred on Monday 8.00am to 11.00am., an equivalent dry period is used for comparison. Figures 6 to 8 show the bivariate relationships between the traffic parameters of speed, volume and density. In all the three plots, there is a contraction of the parameters for the wet condition. For the speed parameter, the vehicles that travel beyond the posted speed limit (PSL) are affected most, as they need to adjust their speed to drive safe. On the contrary, drivers that travel below the PSL, are able to cope with deteriorating sight distance conditions and therefore do not adjust their speed. This results to 5% speed drop to cope with wet weather conditions for this road.

The drop in speed is seen in the volume contraction in the volume-density plot shown in figure 7. It must be mentioned that even in normal weather, the road operates in the free flow regime. This situation did not change in adverse weather. The implication is that a facility operating in free flow condition in normal weather is not likely to experience instability or congestion in the event of a rainfall occurring, unless the rainfall combines with a physical bottleneck to dramatically change the situation. On a facility with higher flow rates, more speed and volume contraction is to be expected during rainfall

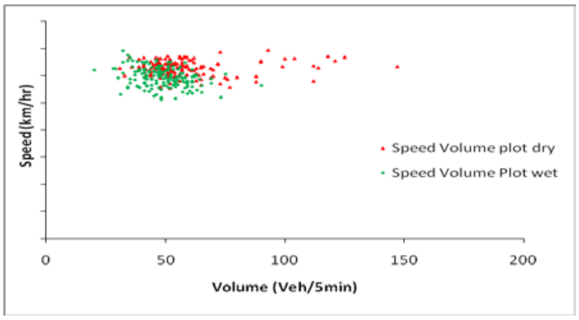

Fig.6: Speed-Volume Plot for Wet and Dry Conditions

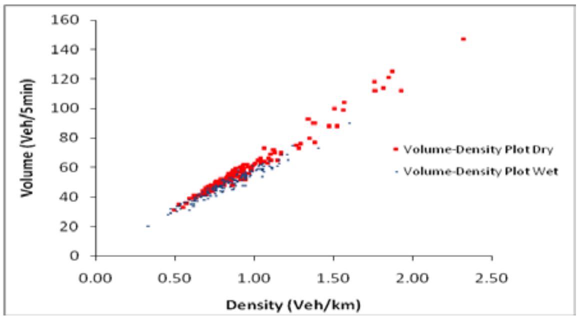

Fig.7: Volume-Density Plot for Wet and Dry Conditions

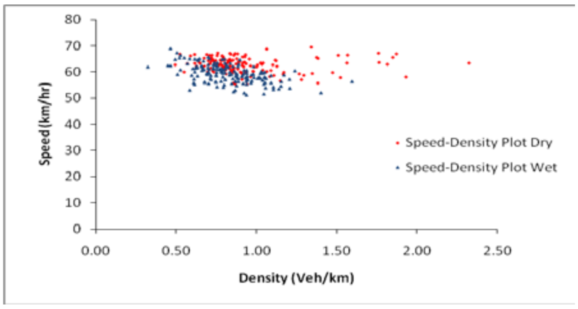

Fig.8: Speed-Density Plot for Wet and Dry Conditions

and this could result to significant capacity loss. Table1 shows the observed traffic flows in both wet and dry conditions. As stated earlier only identical periods are compared. The total flow for the wet condition was 6453vehs while the dry condition yielded 6633vehs in about 10 hours. The drop in flow was 2.72%. Longer duration of rainfall tend to reduce the flow more than short durations. This may be due to higher rainfall intensities during the storm and corresponding sight distance deterioration. Drivers are able to cope with short rainfall events more because they are protected by the roof of the vehicle and the wind screen wiper temporally restores visibility. Moreover, in a free flow regime the risk associated with driving in adverse weather is reduced as vehicle-vehicle interaction is less.

Table 1: Observed Flows in Wet and Dry Weather

	Weather Condition/Traffic Flows		
	Start of Rain	**End of Rain**	**Observed Flows**
Wet Weather June 16,2010	8.05am	14.40pm	3720vehs
Wet Weather June 23,2010	15.50pm	18.10pm	2733vehs
Dry Weather June 9 , 2010	8.05am	14.40pm	4255vehs
Dry Weather June 9 2010.	15.50pm	18.10pm	2378vehs

VI CONCLUSIONS

This paper examined the issue of capacity loss on highways during adverse weather. For a highway section operating in the free flow regime, it is hard to see a significant reduction in capacity unless the rainfall event combines with other bottlenecks to constrain the flow. Results from this study corroborate the existence of capacity loss on highways. Implications for sections operating in the vicinity of capacity and the congested region require investigation to understand the rainfall-vehicle interaction in adverse weather conditions.

ACKNOWLEDGMENT

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