Investigation of Breakdown Event at Merging Section of Federal Highway

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Abstract— **Congestion is an issue that continuously occurs on urban roads which is part of a so-called breakdown phenomenon. Breakdown can be defined as the transition between proper operation and non-acceptable flow conditions. This study was carried out to determine the speed-flow relationship with respect to breakdown event at the Federal Highway as well as to analyse time series for flow rate and speed in order to justify the breakdown occurence. Data consist of speed, traffic flow, density, and several others were collected by the Automatic Incident Detection device. The speed-flow curve was reconstructed using the Greenshields Model. Based on the model obtained, value of maximum flow rate is 1634 veh/hr/ln and the critical speed is 65 km/h. Understanding the breakdown phenomenon at merging sections is a key parameter for more effective geometric design and control strategies.**

Keywords-breakdown; capacity; on-ramp; speed; time-series

I. INTRODUCTION

From a traffic study perspective, the term "capacity" is basically a description of the limit of the vehicle-carrying ability of a roadway. The concept of capacity for expressways plays an important role within the transportation field, since it is applied in the planning, design, and operation states of expressway facility. However, determining capacity has occupied transportation researchers for decades [1]. The numerical value associated with definition of expressway capacity has changed over time. The current published version of the United States Highway Capacity Manual 2010 defines expressway or freeway capacity as "the maximum sustained 15-min flow rate, expressed in passenger cars per hour per lane, that can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction of flow" [2]. Implied in the current definition and understanding of expressway capacity is the notion that the facility will "breakdown" when demand exceeds a specified capacity value. A simple definition of breakdown was introduced by Lorenz and Elefteriadou [1] as transition from an uncongested state to a congested state. Breakdown can also be explained by the duality of capacity on an expressway [3]. Brilon et al. [4] define breakdown as the transition between proper operation and non-acceptable flow conditions. On highway, such breakdown occurs when the average travel velocity is reduced from an acceptable speed level to a much lower value of congested conditions. The suddenness of breakdown, however, may differ from one country to another depending on the general driving culture [4]. Another definition for breakdown is the transition of traffic flow from fluid into congested conditions [5]. At a merging section, two traffic streams conflict each other which are the main stream and ramp flows, where each vehicle of these two streams looks for a space that maximizes its utility. Consequently, breakdowns that start from such sections appear to be an indefinable phenomenon, yet they need to be understood. Previous studies [6] [1] proved that the breakdown events at merging sections are not a direct result of peak traffic volumes. In their studies, the breakdown phenomenon was treated as a probabilistic problem. They found that the breakdown probability is an increasing function of main-stream and on-ramp flow rates. However, the shape of the developed probability models varies among them. According to Shawky and Nakamura [7], breakdown probability functions can best be used to investigate factors that may affect the breakdown phenomenon. If expressway capacity continues to be defined with respect to breakdown conditions, then the definition of capacity should be modified in light of this probabilistic view of expressway breakdown. This paper addresses the breakdown event through an analysis of speed and flow rate data collected at Federal Highway merging section located in Shah Alam, Selangor.

II. DESCRIPTION OF STUDY FACILITY AND SITE

A. *Description of Study Facility*

The Federal Highway 2 is a primary expressway facility located in Kuala Lumpur and Klang Valley, and serves as a major corridor for Kuala Lumpur and Klang Valley travel. Roadway cross-section is six lanes for both directions. The posted speed limit on the expressway is 110 km/h. Free flow speeds during off-peak time periods were found to range between 100 km/h and 150 km/h. Traffic volumes on the expressway system are generally heavy during weekday morning and afternoon peak periods, and breakdowns in traffic flow are typical during these peak times.

B. *Description of Study Site*

One capacity-constrained site along the Federal Highway 2 expressway system in Shah Alam, Malaysia was selected for in-depth analysis. Federal Highway 2 was selected as the study

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facility since detailed speed and volume data from its detector device is archived and made available through the Kuala Lumpur City Hall. The site was selected for study since it is a merging location and instrumented with detector called the Automatic Incident Detection (AID) within the section capable of recording speeds and volumes, as shown in Figure 1.

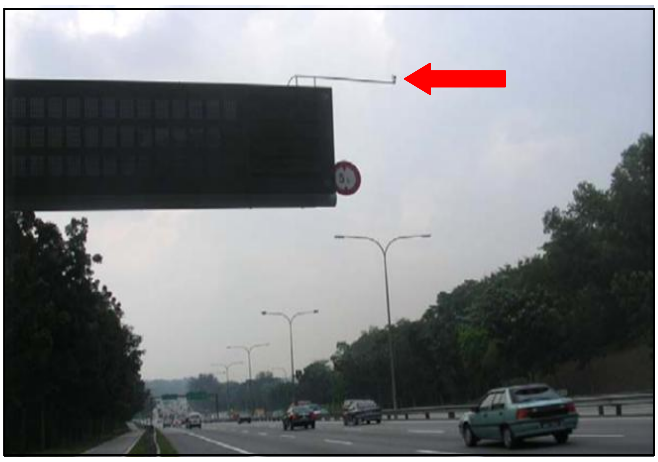

Figure 1. Location of AID

Figure 2 illustrates the lane geometry at study location located in the vicinity of the Bulatan Darul Ehsan interchange. At this site, traffic traveling westbound-to-eastbound in single ramp lane merges with express traffic traveling in two westbound mainline lanes.

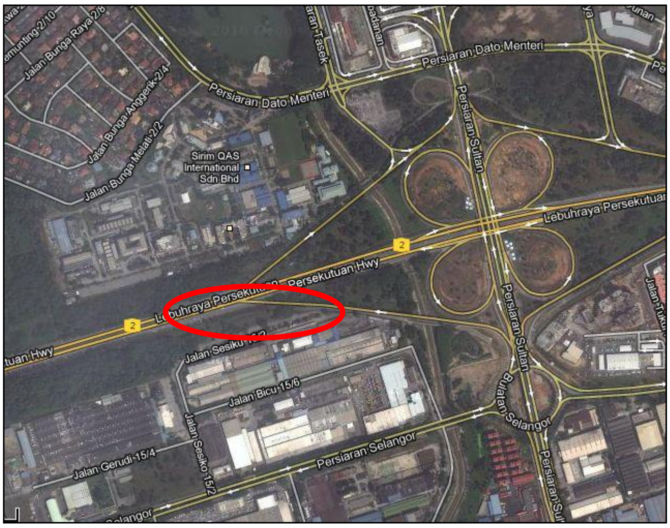

Figure 2. Map of study site

An AID is located approximately 250 meters downstream of the ramp gore point. At both stations, paired detectors are located in the each of the travel lanes and are instrumented to provide vehicle counts and speed estimates continuously at 3-minute intervals. The driver population in the vicinity typically consists of urban commuters and other drivers familiar with the area’s transportation system. Breakdown in traffic flow at study location is common during weekday peak periods.

III. Data Collection and Analysis

A. Data Collection

Traffic data required in this study was recorded using the AID device. The AID has been under the supervision of the Transportation Management Centre of the Kuala Lumpur City Hall (KLCH). The AID devices are installed at several locations along the Federal Highway Route 2 including study site. However, visual observation at the study location is needed to obtain better understanding on actual traffic condition. This observation gives better ideas and understanding with regard to congestion and breakdown phenomenon at study location. The weekdays’ data are extracted from raw AID data for analysis purpose. Tuesday, Wednesday and Thursday are considered as weekdays or working days with normal traffic flow.

B. Data Analysis

1) Time-series of Speed

Each data of study are analyzed separately according to a specific date. The 24 hours speed data have been summarized in a time interval of 3 minutes for each individual travel lane. The speed and flow rate were plotted in time -series over the period of each sample. In these plots, time was displayed on the “x”-axis and speed on the “y”-axis. Figure 3 illustrates a representative time-series speed plot for a data sample collected on August, (on weekdays) at Bulatan Darul Ehsan interchange of federal highway 2.

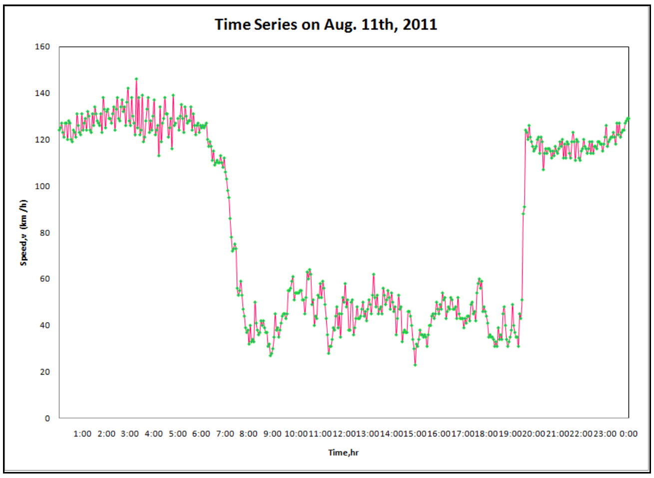

Figure 3. Time-series speed plot on August 11th, 2011

The period of breakdown is easily identifiable in Figure 3. Prior to about 7:00 a.m., the average travel speed across all lanes is relatively high, fluctuating between approximately 100 km/h and 120 km/h. However, at approximately 7:00 a.m., the average travel speed across all lanes drops sharply to below 100 km/h and generally remains well below the 100 km/h threshold until about 7:45 p.m. At this time, speeds rise back to their pre-congestion levels.

Examining the time-series speed plot shown in Figure 3, it is evident that a speed "boundary" or "threshold" of approximately 100 km/h exists between the congested and uncongested regions. When the expressway operates in an uncongested state, average speeds across all lanes generally remain above the 100 km/h threshold at all times. Conversely, during congested conditions, average speeds rarely exceeded 100 km/h, and even then were not maintained for any substantial length of time. This 100 km/h threshold was observed to occur at study site and in all of the daily data samples evaluated as part of this research.

2) Speed-Flow Relationship

Speed, flow, and density are all related to each other. Under uninterrupted flow conditions, speed, density, and flow are all related by the equation (1).

$$q = kv \qquad (1)$$

Where, q = Flow (vehicles/hour)
v = Speed (miles/hour, kilometers/hour)
k = Density (vehicles/mile, vehicles/kilometer)

Because flow is the product of speed and density, the flow is equal to zero when one or both of these terms is zero. It is also possible to deduce that the flow is maximized at some critical combination of speed and density. However, the full relationships between speed and flow are quite difficult to observe in the real world since not everytime the congested condition is occured. The speed-flow relationship in one day of the study period is as shown in Figure 4.

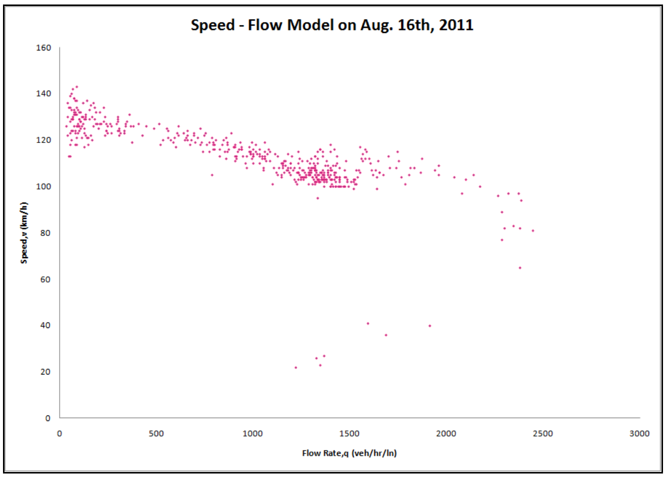

Figure 4. Speed-flow relationship

Referring to Figure 4, through a detailed observation the pattern of data distribution, where the speed in initially is high which is around 110 km/h to 150 km/h, however the pattern of curve is changing due to the reduction of speed and also because of increasing the number of vehicle. Upon reaching a certain period of time, a maximum flow rate can be identified in the figure. This phenomenon so-called the congested condition or non-acceptable flow condition occurs due the increasing of vehicle number and decreasing of speed. Besides that, if number of vehicles continues to the grow and speed are decreasing then the curve will be directed faced to the jam density, when it happens, the speed tend to be zero.

3) Greenshields Model

Greenshields model is the only model that expresses the relationship between speed and density is linear and shown in (2).

$$v = v_f - \left(\frac{v_f}{D_j}\right) D \qquad (2)$$

Where, v = Speed (km/h)
vf = Free flow speed (km/h)
Dj =Jam density (veh/km/ln)
D = Density (veh/km/ln)

Referring to (2), it shows the relationship between speed and density for Greenshields model. The value of free flow speed, v_f and the jam density, D_j must be obtained first before the equation (2) can be used. To produce the curve speed – flow, the value free flowspeed, v_f and the jam density, D_j must be obtained in advance by the equation mentioned at the top.

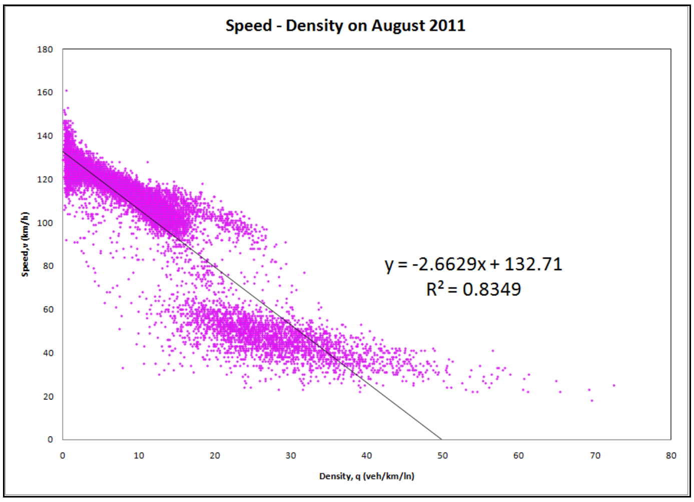

Figure 5. Speed – density diagram

When the value of v_f and D_j available then it could be included in equation (3),

$$Q = D_j v - (D_j/v_f)\, v^2 \qquad (3)$$

Where, Q = traffic flow (veh/h/ln)

Therefore, the following equation (4) can be obtained.

$$Q = 49.84v - 0.38v^2 \quad (4)$$

By using speed data and the observed traffic flow, speed-flow curve can be plotted as shown in Figure 6.

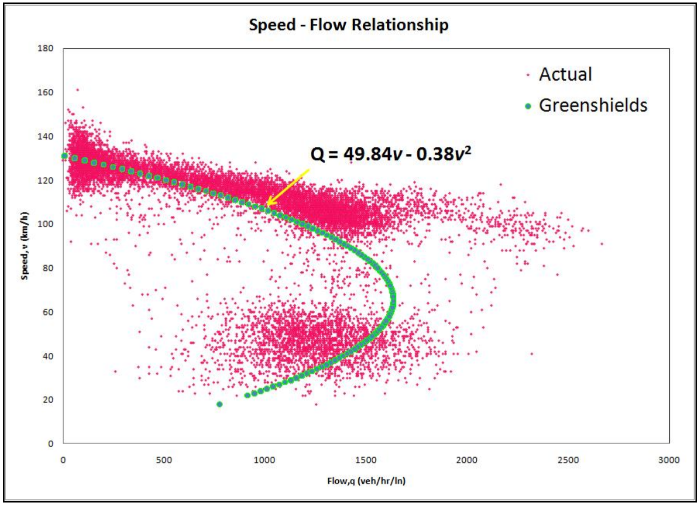

Figure 6. Speed-flow model using Greenshields

Referring to Figure 6, the value of Q_{max} obtained for actual and Greenshield curve are 2700 and 1634 veh/hr/ln, respectively. It shows that breakdown event might happens when capacity is reaching these values. Referring to Greenshield model, the lower value of maximum capacity might be influenced by the data distribution during congested condition which were mostly in range 1000 to 1500 veh/hr/ln.

IV. CONCLUSION

From this study, the conclusions that can be made are as follows:

1. Based on the time-series obtained, the time of breakdown is identified within 7.00 a.m. until 7.00 p.m. and the threshold speed is 100 km/h.
2. Based on the speed-flow analysis, the breakdown speeds are in the range of 20 km/h to 90 km/h. While, the maximum capacity value obtained based on actual and Greenshield model are 2700 and 1634 veh/hr/ln, respectively.

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