

**INVESTIGATION OF BREAKDOWN EVENT AT MERGING
SECTIONS OF FEDERAL HIGHWAY**

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ABSTRACT

Breakdown occurs when there is a change of velocity in a traffic stream due to traffic flow. It happens when the average travel velocity reduce from normal to a lower value of congested conditions while there are still vehicles coming although capacity is reached. Breakdown might frequently happen nearby on-ramp or at merging section. This study aims to investigate the breakdown event at two difference sites near merging section of Bulatan Melawati Interchange at the Federal Highway Route 2. Federal Highway Route 2 is equipped with the Automatic Incident Detection devices which monitored by the Transportation Management Centre of the Kuala Lumpur City Hall to collect traffic data for management purposes. Data from the device are obtained for analysis and presented in a speed-flow relationship model where breakdown speed and capacity at merging section can be determined. Based on developed time series of flow rate and speed, a total of 30 breakdown events have been identified at study locations. Later, Speed-flow models are developed using actual data and Greenshields modelling. Capacity and critical speed using Greenshields modelling are 1756 veh/hr/ln and 33 km/h, and 2380 veh/hr/ln and 77 km/h at Site A and B, respectively. Breakdown phenomenon occurs at study locations are still under control since the breakdown occurrence usually disperses within 1 to 2 hours. This study contributes to better understanding of breakdown phenomenon which benefits in control strategy and effective geometric design in the future.

ABSTRAK

Breakdown berlaku apabila terdapat perubahan halaju pada aliran trafik. Ia berlaku apabila halaju purata perjalanan berkurangan daripada halaju biasa kepada halaju yang lebih rendah pada keadaan sesak dan pada ketika ini juga masih terdapat kenderaan yang datang walaupun kapasiti telah dicapai. *Breakdown* kebiasaannya kerap terjadi berhampiran seksyen percantuman. Kajian ini bertujuan untuk menyiasat fenomena *breakdown* yang berlaku di dua lokasi yang berbeza berhampiran seksyen percantuman di Persimpangan Bulatan Melawati, Lebuhraya Persekutuan 2. Lebuhraya Persekutuan 2 dilengkapi dengan peranti *Automatic Incident Detection (AID)* yang dipantau oleh Pusat Pengurusan Pengangkutan, Dewan Bandaraya Kuala Lumpur. Peranti *AID* digunakan untuk mengumpul data trafik bagi tujuan pengurusan trafik. Data dari peranti yang diperoleh akan dianalisis dan dipersembahkan dalam model hubungan laju-aliran. Melalui hubungan laju- aliran ini, laju semasa *breakdown* berlaku dan kapasiti di seksyen percantuman boleh ditentukan. Berdasarkan graf siri masa bagi aliran dan halaju yang dihasilkan, sebanyak 30 fenomena *breakdown* telah dikenalpasti berlaku di lokasi kajian. Seterusnya, model laju-aliran dihasilkan dengan menggunakan data sebenar dan permodelan Greenshields. Kapasiti dan kelajuan kritikal dengan menggunakan Model Greenshields di Tapak A dan B masing-masing adalah 1756 ukp/jam/lorong dan 33 km/j, dan 2380 ukp/jam/lorong dan 77 km/j. Fenomena *breakdown* berlaku di lokasi kajian adalah masih di bawah kawalan, ini kerana ianya akan kembali pada keadaan trafik biasa dalam masa 1 hingga 2 jam. Kajian ini menyumbang kepada pemahaman yang lebih baik terhadap fenomena *breakdown* yang mana ia akan memberi kebaikan untuk strategi kawalan trafik dan rekabentuk geometri yang berkesan pada masa akan datang.

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CHAPTER I

INTRODUCTION

1.1 Background

In the last few decades, Malaysia has seen rapid development in the transportation sector compare to the other ASEAN countries. Increasing of living standard in Malaysia gives direct impact to the increasing of the number of vehicles on the road. The growth rate of vehicles especially passenger car in Kuala Lumpur and Klang Valley are the highest among other areas. Statistics of cumulative number of motor vehicle by type and state until March 31, 2012 issued by the Ministry of Transport Malaysia proves that Federal Territory has recorded a total of 5.04 million vehicles (JPJ, 2012). The increasing of the vehicles on this road will eventually lead to traffic congestion.

Lebuhraya Persekutuan or Federal Highway Route 2 is a Malaysian highway connecting the capital city of Kuala Lumpur, and Klang, Selangor. The highway starts from Seputeh in Kuala Lumpur to Klang, Selangor. Federal Highway Route 2 has its own functions. Construction history of the highway is proportional to the increase in the number of vehicles in Klang Valley. Begin with series of road linking

Kuala Lumpur and Klang, further upgrading work has made the Federal Highway Route 2 as the first expressways in Malaysia. It serves as a major east-west corridor for local, regional and inter-province travel. Federal Highway Route 2 was originally four-lane highway, but now the whole of this express highway has six lanes.

Similar to the other main roads, Federal Highway is also experiencing traffic congestion. Instead of other factors, the increase in number of vehicles as stated earlier is also contributing to congestion. Congestion that occurs would then lead to a breakdown phenomenon. A simple definition of breakdown was introduced by Lorenz and Elefteriadou (2000) as transition from an uncongested state to a congested state. Breakdown may take place at the bottleneck due to construction activities at basic segment or midblock and might also happen nearby on-ramp or merging section. Usually at merging section, breakdown phenomenon appear when there is a conflict between two traffic streams which are the main stream and ramp flows. The situation also appeared at Exit 213, Bulatan Melawati Interchange at Federal Highway Route 2. Understanding of the breakdown phenomenon especially at merging sections is a key parameter towards effective geometric design and control strategies.

1.2 Problem Statement

Bulatan Melawati Interchange at Exit 213 Federal Highway Route 2 connects traffic from north of Shah Alam and from south of Puchong towards main stream Kuala Lumpur – Klang. Traffic from both directions enters the expressway through merging ramp. The situation has potential to cause a congestion and breakdown especially during peak hours where the number of vehicles in both streams is higher compare when at the normal time. During peak hours, traffic flow on the main stream tends to be slow because of the increasing of the capacity. It becomes worse when the traffic flow from ramp attempting to enter the main stream. At this point the traffic flow will gradually decrease and the density of the flow will increase until it reaches at maximum point which is considered as jam density. According to Vien

and Azai (2010), merging activities in the on ramp of an expressway often cause turbulence and congestion which might be critical if it does not being handled in accordance to specifications and until now, not many research works that has been conducted to access the operational performance of on ramp junction based on Malaysian expressway conditions. Therefore, this study is carried out to comprehend the breakdown event at selected study location.

1.3 Objective

This study embarks on the following objectives:

- i. To analyse time series of flow rate and breakdown speed based on the traffic condition at selected location.
- ii. To analyse speed-flow model at merging sections at selected location.
- iii. To determine the value of maximum flow rate and critical speed from speed-flow curve developed based on traffic condition at selected location.

1.4 Scope Of Work

The purpose of this study is to analyse the breakdown phenomenon at merging section. Therefore, the study will be focused at on-ramps at Bulatan Melawati Interchange at Federal Highway Route 2. Since the definition of breakdown is the transition from uncongested state to congested condition, the period of study will be during off and peak hour for the whole day. Figure 1.1 shows the selected location of case study.

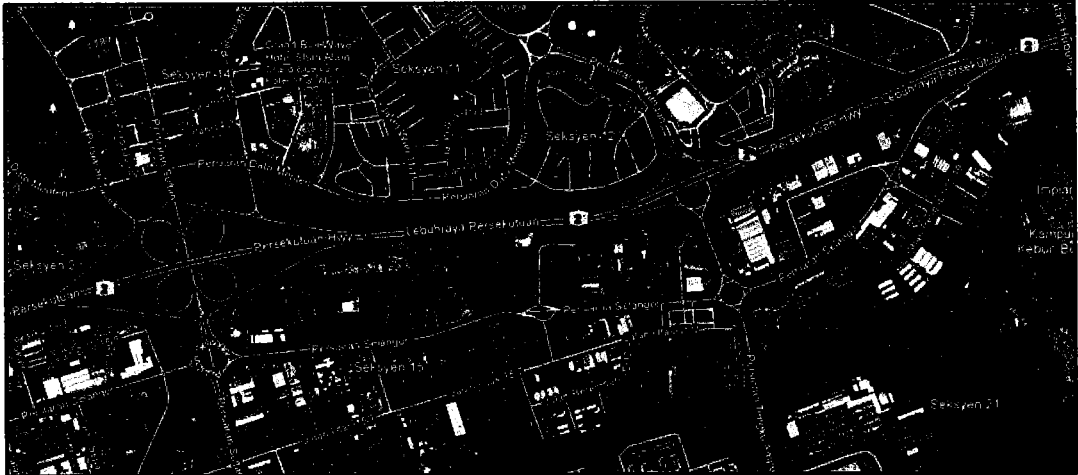


Figure 1.1 : Location of Case Study, Marked with Circle in Red.

Figure 1.2 shows close up of the Bulatan Melawati Interchange.



Figure 1.2: Bulatan Melawati Interchange of Federal Highway Route 2.

1.5 Importance and Contribution of Study

This study may discover new findings in explaining the breakdown phenomenon at merging section and would assist relevant parties in designing proper access or consulting for appropriate control strategy. It is also give new ideas yet can contribute towards solving congestion problems at Federal Highway Route 2 especially when related to merging section. Ramp control management may take place as the strategy to control ramp flows at merging section in order to solve congestion problem. All the ideas and strategies later will use towards increasing the level of comfort among highway users on time saving and reduce fuel cost especially for commuters of the Federal Highway Route 2.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The construction of highway in Malaysia begins after Singapore separated from Malaysia. It is an upgrade of the existing road system in Malaysia at that time. With the introduction of the highway system, social activities among the population become more efficient. Highway network in Malaysia can be considered as the best highway networks in Southeast Asia and third in Asia after Japan and China (Mohamad & A. Rahim, 2008).

Federal Highway Route 2 is one of the successes of the road system in Malaysia. History of it began with only a road network that links between Kuala Lumpur and Klang. Growth of economic and local development, force the ordinary road system to upgrade and become a four-lane highway. Rapid economic growth and to meet the driving comfort among road users, the highway is upgraded once again to provide a six-lane expressways and federal highway has become first expressway in Malaysia (Mohamad & A. Rahim, 2008). It serves as a major east-west corridor for local, regional and inter-province travel.

Congestion is a global problem not only happens in major cities in the world, but also occurs in major districts in Malaysia Federal Highway Route 2 also facing the same problem. Action should be taken to solve the problem before it become worst. Based on experience and observation, current condition of the congestion happens in Malaysia can be considered under control. The congestion happens at peak hours which at approximately at 7.30 am until 9.00 am in the morning and 4.30 pm until 6.00 pm in the evening. However the trend is different during weekends, public holidays and festive seasons. Instead of agencies and road users' cooperation, many aspects should be considered to solve congestion problem in Malaysia.

2.2 Malaysia Road Classification

According to *Arahan Teknik (Jalan) 8/86*, A guide on Geometric Design of Road, each road has its function according to its role either in the National Network, Regional Network, State Network or City/Town Network (JKR, 1986). The most basic function of a road is transportation. This can be further divided into two sub-functions; namely mobility and accessibility. However, these two sub-functions are in trade-off. To enhance one, the other must be limited. In rural areas, roads are divided into five categories, namely, Expressway, Highway, Primary Road, Secondary Road and Minor Road and in urban areas, roads are divided into four categories, namely, Expressway, Arterial, Collector and Local Street. Table 2.1 shows the classification of roads according to *Arahan Teknik (Jalan) 8/86*, A Guide on Geometric Design of Road. They are in ascending order of accessibility and thus in descending order of mobility.

Table 2.1: Classification of Road (JKR, 1986)

Road Classification	
Rural	Urban
Expressway	Expressway
Highway	Arterial
Primary Roads	Collector
Secondary Roads	Local Street
Minor Roads	

2.2.1 Expressway

An Expressway is a divided highway for through traffic with full control of access and always with grade separations at all intersections (JKR, 1986). In rural areas, they apply to the interstate highways for through traffic and make the basic framework of National road transportation for fast travelling. They serve long trips and provide higher speed of travelling and comfort. To maintain this, they are fully access-controlled and are designed to the highest standards. In urban areas, they form the basic framework of road transportation system in urbanized area for through traffic. They also serve relatively long trips and smooth traffic flow and with full access control and complements the Rural Expressway.

2.2.2 Highways

Highways constitute the interstate national network and complement the expressway network. It is usually link up directly or indirectly the Federal Capitals, State capitals and points of entry/exit to the country. Speed service is not as important as in an Expressway but relatively high to medium speed is necessary. Smooth traffic is provided with partial access control.

2.2.3 Primary Roads

Primary roads constitute the major roads forming the basic network of the road transportation system within a state. It serves intermediate trip lengths and medium travelling speeds. Smooth traffic is provided with partial access control. They usually link up the State Capitals and District Capitals or other Major Towns.

2.2.4 Secondary Roads

Secondary roads constitute the major roads forming the basic network of the road transportation system within a District or Regional Development Areas. It serves intermediate trip lengths with partial access control. They usually link up the major towns within the District or Regional Development Areas.

2.2.5 Minor Roads

Minor roads apply to all roads other than those described above in the rural areas. It forms the basic road network within a Land Scheme or other inhabited areas in a rural area. It also includes roads with special functions such as holiday resort roads, security roads or access roads to microwave stations. Minor roads serve mainly local traffic with short trip lengths and are usually with partial or no access control.

2.2.6 Arterials

An arterial is a continuous road with partial access control for through traffic within urban areas. Basically it conveys traffic from residential areas to the vicinity of the central business district or from one part of a city to another which does not intend to penetrate the city centre. Arterials do not penetrate identifiable neighborhoods. Smooth traffic flow is essential since it carries large traffic volume.

2.2.7 Collectors

A collector road is a road with partial access control designed to serve as a collector or distributor of traffic between the arterial and the local road systems. Collectors are the major roads which penetrate and serve identifiable neighborhoods, commercial areas and industrial areas.

2.2.8 Local Streets

The local street system is the basic road network within a neighborhood and serves primarily to offer direct access to abutting land. They are links to the collector road and thus serve short trip lengths. Through traffic should be discouraged.

2.3 Traffic Engineering Principle

According to *Arahan Teknik (Jalan) 8/86*, A guide on Geometric Design of Road there are some basic traffic parameters need to be understand which is speed, volume, capacity and etc (JKR, 1986). Speed is a primary factor in all modes of transportation, and is an important factor in the geometric design of roads. The speed of vehicles on a road depends, in addition to capabilities of the drivers and their vehicles, upon general conditions such as the physical characteristics of the highway, the weather, the presence of other vehicles and the legal speed limitations.

The term highway capacity pertains to the ability of a roadway to accommodate traffic and is defined as the maximum number of vehicles that can pass over a given section of a lane or a roadway during a given time period under prevailing roadway and traffic conditions (Jones, G. M., 2010). Capacity considered here is only applicable to uninterrupted flow or open roadway conditions. Capacity for interrupted flow as at inter sections will be dealt with separately. Capacity is also usually stated in terms of passenger car units (p.c.u.). Table 2.2 gives the conversion factors to be used in converting the various classes of vehicles to passenger car units.

Table 2.2: Passenger Car Equivalent (JKR, 1986)

Type of Vehicle	Equivalent Value in p.c.u's			
	Rural Standards	Urban Standards	Roundabout Design	Traffic Signal Design
Passenger Cars	1.00	1.00	1.00	1.00
Motorcycle	1.00	0.75	0.75	0.33
Light Vans	2.00	2.00	2.00	2.00
Medium Lorries	2.50	2.50	2.80	1.75
Heavy Lorries	3.00	3.00	2.80	2.25
Busses	3.00	3.00	2.80	2.25

2.4 Traffic Congestion

Congestion is a global problem not only happens in major cities in the world, but also occurs in major districts in Malaysia. Congestion usually relates to an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower and sometimes much slower than normal or free flow speeds. Congestion often means stopped or stop-and-go traffic (CSI, 2005). Congestion problems need to be taken seriously and it is the responsibility of the parties involved to ensure the provision of good design and control strategies to counter this problem. Geometric design standards and the appropriate control system at the point of conflict can help overcome this congestion. Standards used in Malaysia are as follows:

- i. *Arahan Teknik (Jalan) 8/86, A Guide on Geometric Design of Roads.*
- ii. *Arahan Teknik (Jalan) 11/87, A Guide to the Design of At-Grade Intersections.*

For better understanding of traffic congestion, it is important to understand the theory of traffic flow. Traffic parameters are defined as:

- i. Traffic flow (Q): Equivalent hourly rate at which vehicles pass a point on a highway during a time period less than 1 hour (veh/h)
- ii. Speed (v): Distance traveled by a vehicle during a unit of time (km/h)
- iii. Density (k): Number of vehicles traveling over a unit length of highway at an instant time (veh/km)

2.5 Causes of Congestion

According to Cambridge Systematics, Inc. (2005), there are seven causes of traffic congestion which is traffic incidents, work zones, weather, fluctuations in normal traffic, special events, traffic control devices and physical bottlenecks. All causes can be group into three categories. The categories are traffic-influencing events, traffic demand and road conditions itself.

2.5.1 Category 1 – Traffic-Influencing Events

2.5.1.1 Traffic Incidents

Traffic incidents are events that disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents. In addition to blocking travel lanes physically, events that occur on the shoulder or roadside can also influence traffic flow by distracting drivers, leading to changes in driver behavior and ultimately degrading the quality of traffic flow. Even incidents off of the roadway (a fire in a building next to a highway) can be considered traffic incidents if they affect travel in the travel lanes.

2.5.1.2 Work Zones

Work zones refer to the construction activities on the roadway that result in physical changes to the highway environment. These changes may include a reduction in the number or width of travel lanes, lane “shifts”, lane diversions, reduction, or elimination of shoulders, and even temporary roadway closures. Delays caused by work zones have been cited by travelers as one of the most frustrating conditions they encounter on trips.

2.5.1.3 Weather

Environmental conditions can lead to changes in driver behavior that affect traffic flow. Due to reduced visibility, drivers will usually lower their speeds and increase their headways when precipitation, bright sunlight on the horizon, fog, or smoke are present. Wet, snowy, or icy roadway surface conditions will also lead to the same effect even after precipitation has ended.

2.5.2 Category 2 – Traffic Demand

2.5.2.1 Fluctuations in Normal Traffic

Day-to-day variability in demand leads to some days with higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity also results in variable (i.e., unreliable) travel times, even without any Category 1 events occurring.

2.5.2.2 Special Events

Special events are a special case of demand fluctuations where traffic flow in the vicinity of the event will be radically different from “typical” patterns. Special events occasionally cause “surges” in traffic demand that overwhelm the system.

2.5.3 Category 3 – Physical Highway Features

2.5.3.1 Traffic Control Devices

Intermittent disruption of traffic flow by control devices such as railroad grade crossings and poorly timed signals also contribute to congestion and travel time variability.

2.5.3.2 Physical Bottlenecks

Transportation engineers have long study and addressed the physical capacity of roadways – the maximum amount of traffic capable of being handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves). Toll booths may also be thought of as a special case of bottlenecks because they restrict the physical flow of traffic. There is also a wild card in the mix of what determines capacity – driver behavior. Research has shown that drivers familiar with routinely congested roadways space themselves closer together than drivers on less congested roadways. This leads to an increase in the amount of traffic that can be handled.

2.6 Speed, Flow and Density Relationships

Basically the relationship of speed (v), flow (Q), and density (k) can be expressed as follow:

$$Q = kv \quad (2.1)$$

Where Q = traffic flow (veh/hr/ln)
 v = speed (km/h)
 k = density (veh/km/ln)

2.6.1 Speed (v) – Density (k) Relationship

A linear relationship exists between the speed of traffic on an uninterrupted traffic lane and the traffic density. Figure 2.1 shows the relationship of speed-density. At point A when traffic density is zero ($k = 0$), speed is in free flow condition which denoted as v_f . At this point vehicles will flow through the stream with their desire speed. However at point B it shows that there is no movement of the vehicles in traffic stream, the traffic speed is zero ($v = 0$) while the traffic density become jam density and denoted as k_j .

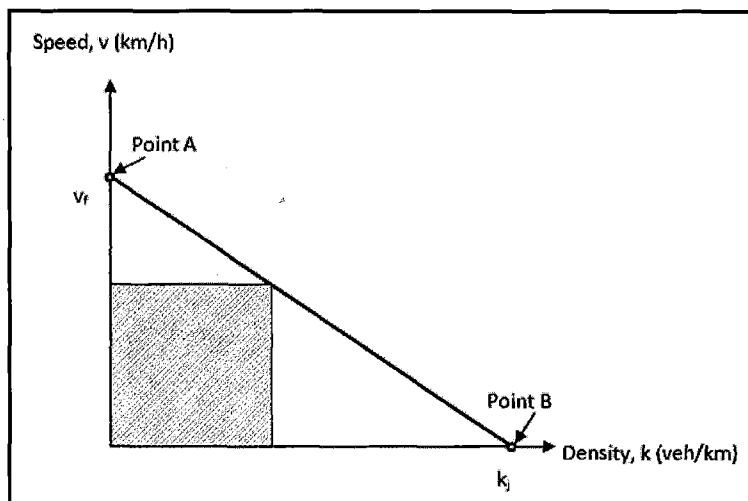


Figure 2.1: Speed (v) – Density (k) Relationship

2.6.2 Flow (Q) – Density (k) Relationship

Figure 2.2 shows the relationship of flow-density.

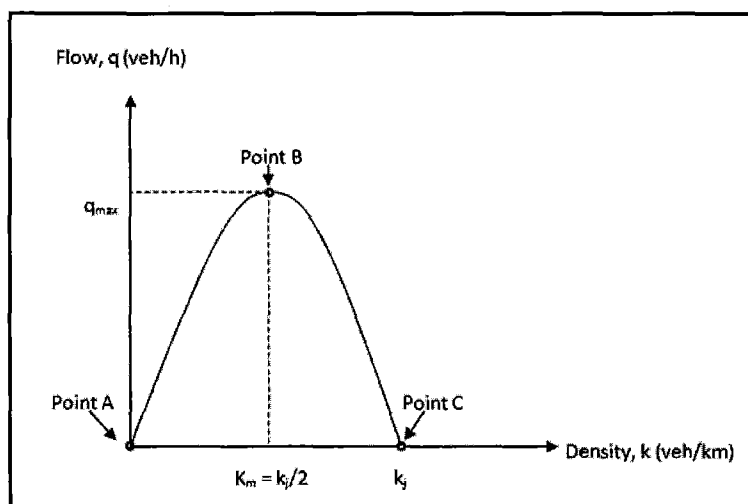


Figure 2.2: Flow (Q) – Density (k) Relationship

At point A, the traffic flow and density is zero ($Q = 0$ and $k = 0$) or in other word there is no vehicle in the traffic stream. Then, the traffic stream for both traffic

flow and traffic density will increase until reach at maximum point which is at point B. Here, the maximum flow (q_{max}) at point B occurs when the traffic density reach its optimum density and denoted as k_m . After the traffic flow reaches its maximum point, it will start decrease while the traffic density is still increasing. This is happening because of the others vehicle was keep entering the traffic stream. Point C shows that the traffic stream is already reach its jam density where the traffic flow becomes zero and the traffic density reaches its maximum point.

From the relationship curve (figure 2.2), the area before the k_m dash line (left side of the dash line) is uncongested and stable flow. The other side of the line considered as congested and unstable flow.

2.6 3 Speed (v) – Flow (Q) Relationship

The relationship between the speed and flow can be postulated as shown in Figure 2.3.

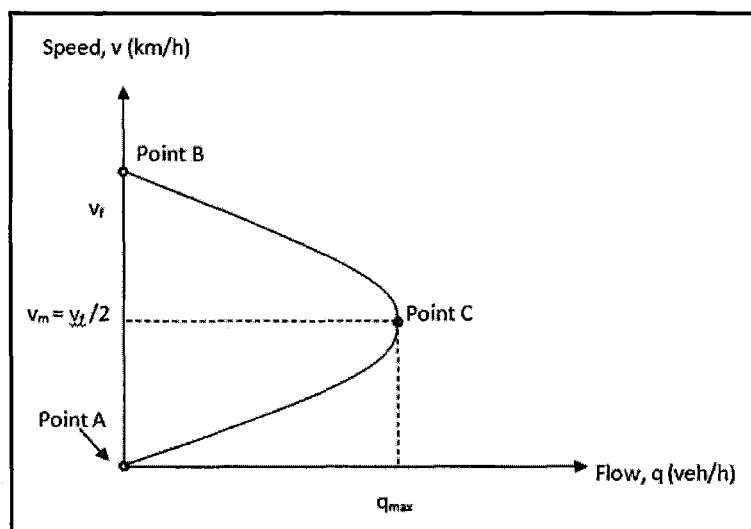


Figure 2.3: Speed (v) – Flow (Q) Relationship

The flow is zero either because there are no vehicles or there are too many vehicles so that they cannot move. This zero flow condition occurs at point A and point B of the curve. At maximum flow denoted as q_{\max} occur at point C, the speed will be in between zero and free flow speed (v_f). Speed at q_{\max} , considered as optimum speed and denoted as v_m .

Speed –flow relationship also indicates two types of flow which is uncongested stable flow and congested unstable flow. As the optimum speed (v_m) line as the separator of both traffic condition. Traffic stream considered uncongested stable flow when there are plenty of gaps available for merging traffic. This traffic condition shows that the traffic density is low and the traffic speed is high. In contrast to the condition of congested stable flow, it indicates high density and low speed. There are no available gaps for the vehicles to enter the stream in such condition. Any vehicle that does enter the stream will cause a disturbance and make it worst to the traffic condition which is not easy to recover.

2.7 Greenshields Model

Greenshields Model is one of the traffic flow models. The theory of traffic flow study has started since last seven decades. Greenshields in 1934 have done his studies in free flow regime of rural roads (highway 2 lanes, 2 ways) in Ohio. Free flow regime is the one that the number of vehicles is few and no traffic jams occur so that the driver can drive the speed desired by him and frequently during non-peak hours. The study by using photographic methods has been observing the relationship between speed and density (Greenshields 1935). He found that the relationship between speed and density is linear.

2.8 Breakdown

Lorenz and Elefteriadou (2000) define breakdown as transition from an uncongested state to a congested state. Definition of breakdown later introduced by Brilon et al. (2005) as the transition between proper operation and non-acceptable flow conditions. From the definition, the transition stated which can lead to the breakdown may take place at the bottleneck due to construction activities at basic segment or midblock, bottleneck due to the accident occur on the road and might also happen nearby on-ramp or at merging section. 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 breakdown event occurred may associated with decreasing of vehicle speed and increasing of capacity in a traffic flow. Wu (2004) find that breakdown also can be explained by the duality of capacity on an expressway. The duality features refer to the capacity before and after the breakdown event happen on expressway. The capacity before a breakdown is higher than the capacity after the breakdown. Figure 2.4 shows the duality of the capacity on a freeway.

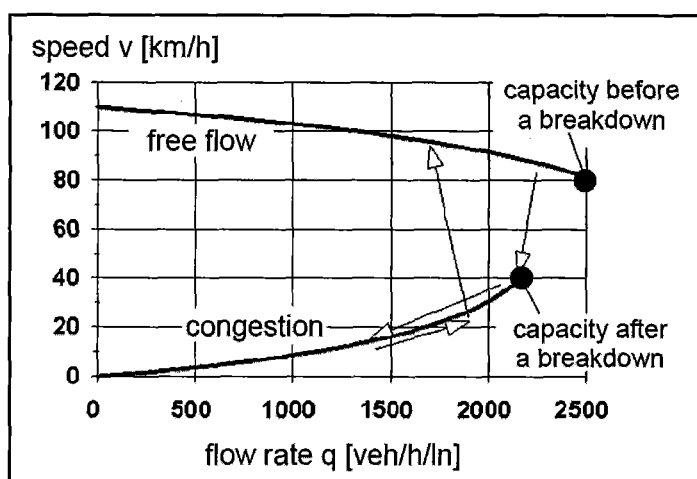


Figure 2.4: Duality of the capacity on a freeway

The severity level of the breakdown event is different between one country to another. The factor contributes to the breakdown is related to many factors. Brilon et al (2005) finds that general driving culture is one of the factors that make the

suddenness breakdown event differ among the countries. Previous studies (Elefteriadou et al., 1995 and Lorenz and Elefteriadou, 2000) 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 (2007), breakdown probability function can best be used to investigate factors that may affect the breakdown phenomenon.

In Malaysia, the traffic condition on roads is mixed or heterogeneous. It is different compared to the other developed countries like Japan, United States and Germany. Furthermore, the possibility of breakdown event will occur at merging section because of poor geometric design and control strategies applied.

2.9 Factors Affecting Breakdown Probability

Shawky and Nakamura (2007) in their study investigate two factors that may affect the probability distributions. Their study on breakdown phenomenon on urban expressway in Japan at six merging sections and find that geometric design impact and merging flow impact are those factors affecting breakdown probability distributions.

2.9.1 Geometric Design Impact

Based on Shawky and Nakamura (2007) study, all investigated sections are in straight two-lane main line segments and one-lane on-ramp with parallel acceleration lane type. The differences in breakdown probabilities are attributed to acceleration lane length and ramp side. They find that by increasing acceleration lane length, the

breakdown probability decreased at the same value of outflow rates. Their findings may slightly different compare to the geometric design of Federal Highway Route 2 since it's providing three-lane for main stream and two-lane on-ramp stream.

2.9.2 Merging Flow Impact

Shawky and Nakamura (2007) used the highest number of breakdown observations where is at Shibakoen and Hakozaki merging sections to investigate the impact of on-ramp flow rate on the breakdown probability. On-ramp flow ratio r_m is calculated as a relative percentage of on-ramp flow rates to outflow rates. The observed values of r_m range from 1.5% to 30% in the Shibakoen section and from 2.0% to 44% in the Hakozaki section. The observed breakdown and nonbreakdown outflow rates are classified on the basis of the 10% interval length of r_m . Then the breakdown probability at a given value of outflow rate is calculated at each class of r_m . They find that ramp flow rates significantly affected the breakdown probability at the same value of outflow rates. By increasing ramp flow ratio, the breakdown probability increases.

2.10 Ramps

Garber, N. J., Hoel, L. A., & Sarkar,. (2010) describes ramp are usually part of grade-separated intersections, where they serve as interconnecting roadways for traffic streams at different levels. Ramps are also sometimes constructed between two parallel highways to allow vehicles to change from one highway to the other. It can be divided into two groups which is entrance ramps and exit ramps. Entrance ramp allow the merging of vehicles into the freeway or main stream while exit ramps allow vehicles to leave the freeway or main stream.

Ramp control can be used as a tool to limit the number of vehicles entering or leaving an expressway at an off- or on-ramp. Good planning and design team needed in using ramp control or otherwise it may result in longer congestion or breakdown phenomenon on both expressway and local streets.

2.10.1 Entrance Ramp Control

The main objective in controlling entrance ramps to regulate the number of vehicles entering the freeway so that the volume is kept lower than the capacity of the freeway. It is essential to the efficient operation of freeways, particularly when volumes are high. (Garber and Hoel, 2002). This is to ensure that main stream will moves at optimum speed and also allow better level of service and safe condition for both users at main stream and on-ramp stream.

2.10.2 Exit Ramp Control

Garber and Hoel, (2002) state that control of exit ramps can be used to reduce the flow of traffic from the freeway to congested local streets, to reduce weaving when the distance between an entrance ramp and an exit-ramp is short, and to reduce the volume of traffic on the freeway beyond the point of lane-drop by encouraging more traffic more traffic to leave the freeway before the lane-drop.

2.11 Ramp Management

According to the Ramp Management and Control Handbook (2006), ramp management is the application of control devices, such as traffic signals, signing and gates to regulate the number of vehicles entering or leaving a freeway, in order to

achieve operational objectives. Most ramp management strategies are employed to balance freeway demand and capacity, maintain optimum freeway operation, improve safety on the freeway or adjacent arterial streets, or give special treatment to a specific class of vehicles. Ramp management strategies and the equipment/systems that support them are often implemented in conjunction with other freeway management programs to create operational efficiencies and to assist in the delivery of overall transportation management goals and objectives.

Ramp Management can offset congestion and safety problems that affect efficient and safe operation of traffic on ramps and or the facilities to which they connect. In doing so ramp management helps achieve greater return on transportation infrastructure investment and contributes to the realization of predetermined goals and objectives. Ramp management also serves as an effective medium through which different agencies can collaborate to address needs more effectively. Since ramps often join facilities that are operated by different agencies, ramp management can break down barriers that exist between agencies, allowing these agencies to work together to more effectively address issues. For instance, a state agency may operate a freeway including adjacent ramps, whereas a local agency may be responsible for operating the street or arterial that runs parallel to and connects with the freeway. Using ramp management strategies and techniques, the state and local agency can work together to address traffic problems near the ramp, while remaining cognizant of each other's concerns.

2.12 General Classification of Ramp Management Strategies

There are four general classifications of ramp management strategies consist of (Gedeon, 2006):

- i. Ramp metering.
- ii. Ramp closure.
- iii. Special use treatments.
- iii. Ramp terminal treatments.

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