# DEVELOPMENT OF EXPRESSWAY ON- AND OFF-RAMP CAPACITY MODELS BASED ON MALAYSIAN EXPRESSWAY CONDITION

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In my humble opinion, the FRGS grant is a beneficial funding in helping new researchers in expanding and enriching the fundamental knowledge in many niche areas. Traffic engineering is one of niche areas which are well known with many empirical models that continuously being studied by most fundamental researchers. Therefore, this report will hopefully assist future investigators and researchers in the related topic.

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Sincerely,
Mohd Erwan Sanik
Project Leader

# ABSTRACT

According to the U.S. HCM 2000, a ramp is described as a length of roadways providing an exclusive connection between two roadways facility. a ramp may be connected to facilities such as freeways, two-lane highways, multilane highways, urban and suburban roads. Three geometric elements which refer to a ramp are ramp-freeway junction, ramp-roadway, and ramp-street junction (TRB, 2000). Later in this introduction, the term "expressway" is used as freeway in Malaysia. In this study, the interest is on the ramp-expressway junctions which consist of on- and off-ramps. Other interests in this study are type of ramp-expressway: isolated; adjacent upstream on- and off-ramp; and adjacent downstream on- and off-ramp. In order to determine level of service of a road facility, analysis of capacity has to be done to the facility. The U.S. HCM 2000 uses density as the measure of effectiveness to determine level of service at ramp-expressway. To date, there is no certain method or guideline used in Malaysia to analyse on- or off-ramp junctions especially in expressway. Study of this facility has been done by various researchers in the field of traffic engineering such as Roess (1994), Eleftriadou et al. (1995), Albanese et al. (2003), and Akram (2006). In Malaysia, there is nearly no study done on ramps for expressway except one study by Akram (2006) who develop on-ramp-expressway models with respect to local condition. However, the study was limited to several expressways in Selangor. Akram (2006) has proved that his models are giving better prediction than the U.S. HCM 2000 on-ramp models and confirmed with respect to the actual field density. In this study, capacity models which consist of flow rate and density models for ramp-expressway are developed based on Malaysian expressway condition.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Expressway signifies an important component of modern roadway system at urban and rural areas in developing countries. It serves through movement of high speed traffic, therefore, it has limited access for incoming vehicles. Prediction of capacity and operational quality of an expressway is imperative to traffic engineers for planning, designing and maintaining the facility. Current and projected traffic demands with regard to the estimated capacity of this facility are decisive inputs to the future planning. Moreover, the understanding of capacity analysis may assist road designers and engineers to justify any practical alternative to be implemented. Traffic engineers normally utilize capacity prediction to foresee congestion and potential breakdown event at critical areas and by this approach, appropriate countermeasures and traffic management strategies to solve the congestion on the expressway may be imposed.

To date, the level of service (LOS) concept given in the U.S. Highway Capacity Manual (U.S. HCM) has been used as a qualitative measure representing highway operational conditions by local practitioners. Although the methodology has been published in the Arahan Teknik Jalan (ATJ), which is the guideline for Malaysian road designers, the values included were originally from United States of America. The application of the U.S. HCM to the analysis of Malaysian traffic condition need to be justified due to the fundamentally differences in driving habits, traffic composition and design configuration (Ibrahim et al., 2002: Men et al., 2003). Proper application of the design procedure is essential in order to ensure that safe, efficient and economical designs of expressways can be obtained by tackling the issue of under-design or over-design of this facility. Therefore, this research modifies the equation and model of the U.S. HCM 2000 method for entrance ramp merging and diverging analysis.

## 1.2 Problem statement

An entrance ramp-expressway junction is generally designed to permit high speed merging movements to take place with a minimum disruption to the adjacent expressway traffic systems and provide a maximum safety to the drivers. The high speed merging is due to the different in design speed for a ramp and the design speed of the expressway mainstream. Normally, the difference is about 30 to 50 km/hr (Hunter et al., 2001). The entrance ramp junction often leads to breakdown in operation thus, reducing mobility drastically. Accordingly, entrance ramp junctions have been the subjects of interest to many traffic engineers (Roess, 1980; Eleftriadou, 1994; Jinchuanet al., 2000: Carlsson and Cedersund. 2000; Lorenz and Elefteriadou, 2000; Al-Kaisy. 1999; Hidas, 2005; Bloomberg. 2006; Dowling and Halkias, 2006). Traffic engineers need to evaluate operational quality and design features of ramp-expressway junctions. A precise analysis or design of the junction is a very important task to them because undesirable operation at any one junction can aggravate the operation for the entire expressway corridor. Assessment of operational quality in such junctions is most often needed.

To date there is no firm guideline, based on local empirical studies and research so far by researchers for Malaysian expressway condition. It is therefore necessary to establish an empirical study that evaluates the impact of the length of the acceleration lane on the operation of ramp junctions. The study also compensates for the gap of knowledge toward a more realistic merging model in reflective of Malaysian expressway condition. The model can be used to determine the LOS that was used as an MOE for entrance ramp expressway junction.

Entrance ramp area is one of the major highway facilities that have long been investigated by researchers. Even though the HCM 2000 presents capacity estimates of entrance ramp areas, they were calibrated based on US expressway and traffic condition. This research is an attempt to develop models for entrance ramp expressway at Malaysian urban expressway junction using multiple linear regressions. The HCM 2000 merging density models are compared to the newly developed models from this research study. In addition, the methodology adopted in Arahan Teknik (Jalan) 8/87: Interchange Design (JKR, 1987) were based on the US HCM 1985 which were almost two decades old and need to be updated.

## 1.3 Objectives of the study

This study embarks on the following objectives.

1) To develop predictive models for on- and off-ramp junctions based on Malaysian expressway condition.
2) To determine the capacity of expressway in Malaysia.
3) To determine the parameters that significant to the models and develop it with respect to Malaysian expressway condition.
4) To evaluate the parameters for measure of effectiveness of ramp-expressway.

## 1.4 Scope and Limitation of the study

This research considers isolated entrance ramp at an urban expressway facilities and investigates its effect on the operational quality of the junction. Its primary concern resides in manifesting the role of acceleration lanes in operation of merge junction area. The scope of the study is limited to the cases where an isolated taper type single-acceleration lane entrance ramp urban expressway with exclusive motorcycle lane merges with six-lane expressway facilities on a level ground profile. In this study; considerable efforts were devoted to data collection and reduction process. Traffic data were collected by videotaping methods from a high vantage point from 40m to 70m heights from ground level that is placed on top of building roof. A high-resolution video camcorder was set up. Condition in which demand exceeds capacity or in an unstable flow regime were not included because these condition induced very different style of driver behaviours such as forced merging into 'stop-and-go' expressway flow and were not the issues and intention of this study.

## 1.5 Organization of the Report

This report is structured as follows. First, the introduction chapter gives an overview of the problem statement, research conceptual framework, research objectives and principle contributions. A background review of related research in, this field is summarized in the second chapter that starts with a review of the HCM 2000 entrance ramp methodology and is followed by discussion of the relevant research findings in the field. In the third chapter, the research methodology is described. The research methodology includes data collection and reduction techniques and methodology for modelling the entrance ramp models. The field data collection was designed to capture flow rates data. Chapter four and five discuss the results of data analysis and model calibration for on-ramp and off-ramp, respectively. Several multiple linear regression models were developed for prediction of flow rates $V_{12}$ and merging density models $D_R$ that are needed in determining the Level of Service at entrance ramp expressway junction. The last chapter summarizes the major conclusions of this report together with future research recommendations.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter provides review of design guides and available literature associated with the objectives of this research.

## 2.2 Review of Design Guidelines

The principal reference for highway capacity analysis for over 40 years has been the United States Highway Capacity Manual (U.S. HCM). The version of the U.S. HCM has been updated from time to time started from the first version published in 1965 to the latest version published in the year 2010. The manual presents techniques and methodologies for evaluating the capacity of different types of highway facilities and for analyzing their operating characteristics under various flow levels. Since the time that this manual appeared in the field of traffic engineering study, the procedures and techniques have been extensively exposed to actual applications. The relevant issues regarding this study are discussed in this section.

### 2.2.1 Expressway System: An Overview

Expressway represents an important and integral component of Malaysian highway network. These facilities are intended to provide mobility and uninterrupted traffic flow for both urban and rural areas. In Malaysia, expressway facilities started to be constructed in 1980's to accommodate the growth in vehicle ownership and accompanied the growth in Malaysian economy. Therefore, there was a need to provide highway facilities that could handle large traffic volumes at relatively high speeds through full control of access and with minimal vehicular conflicts and interactions.

As defined in AASHTO (2004), expressways or freeways are highways with full control of access. They are intended to provide movement of large volume of traffic at high speeds with high level of safety and efficiency. Urban expressways usually carry higher traffic volumes with four to sixteen through-traffic lanes in both directions (Al- Kaisy, 1999). However, their design is sometimes constrained due to limited space in urban area. In addition, design of alignment and cross section elements of rural expressway are more generous due to availability of the sufficient right-of-way at lower cost and usually associated with higher design speeds.

### 2.2.2 Overview of the U.S. HCM 2000

An expressway or a freeway is defined as a divided highway facility with full control of access and two or more lanes for exclusive use of traffic in each direction (TRB, 2000). In general, almost all expressway system is made up of the following types of components sections: basic segment, merge, diverge and weaving sections as shown in Figure 2.1.

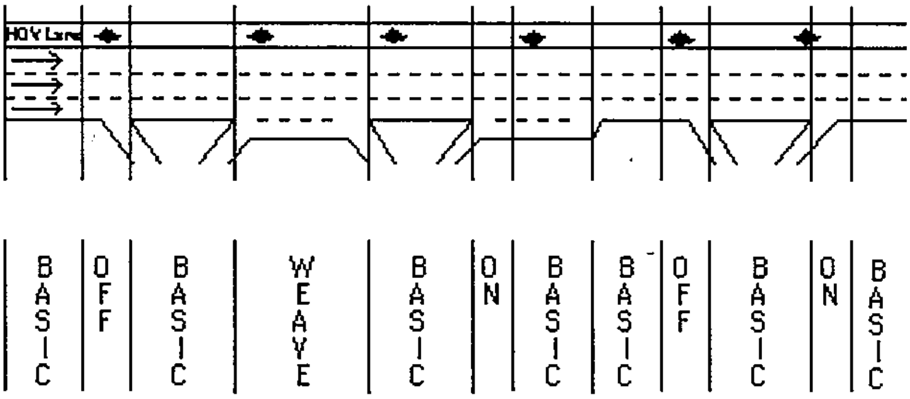


Figure 2.1: Freeway Facility Segments (TRB, 2000)

Basic expressway sections are expressway segments that are located outside the influence area of merge, diverge or weaving sections and therefore they are not affected by turbulence due to intensive merge, diverge or weaving activities. In order to provide access to and exit from expressway system, entrance ramp as shown in Figure 2.2 and exit ramp as shown in Figure 2.3 are provided to the expressway facilities.

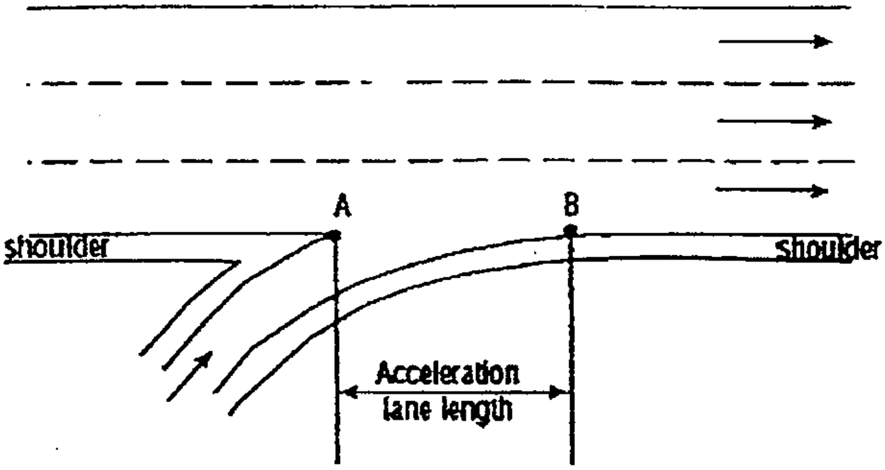


Figure 2.2: Entrance Ramp Diagram (TRB, 2000)

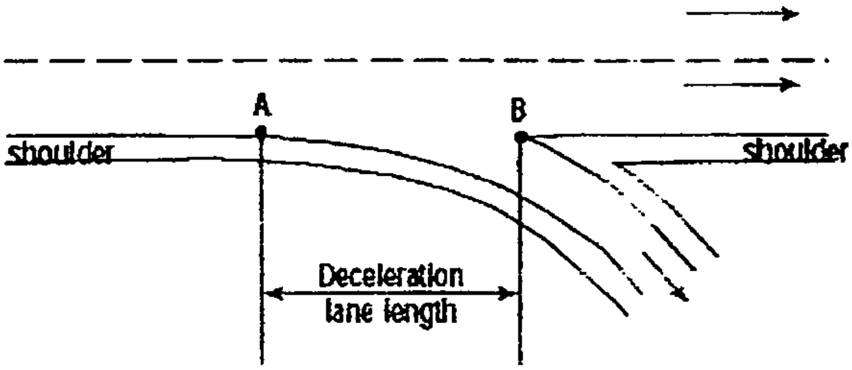


Figure 2.3: Exit Ramp Diagram (TRB, 2000)

These sections are characterized by merging and diverging traffic movements and are usually associated with a considerable amount of disturbance to the traffic stream on the mainline expressway. When a merge facility involves an entrance ramp or diverge involves exit ramp, the section is referred to as ramp-expressway junction'. This type of merge and diverge sections is the most common on expressway systems and is normally associated with higher impacts on the expressway mainline traffic. Another section in expressway facilities is a weaving section as shown in Figure 2.4. When a merge section is closely followed by a diverge section and connected with auxiliary lane, a crossing movements of merging and diverging vehicle take place, thus creating "weave motion" of traffic as shown in Figure 2.4

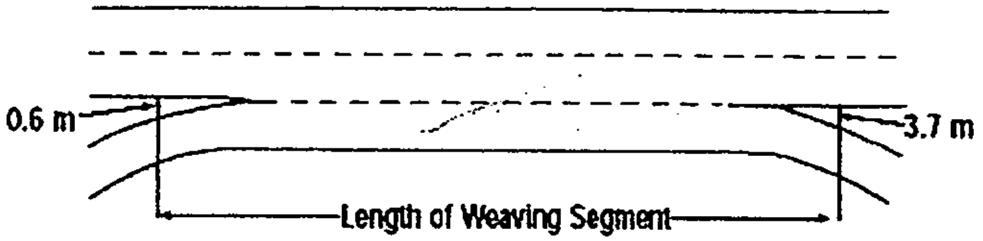


Figure 2.4: Weaving Segment (TRB, 2000)

The U.S. HCM 2000 is the first HCM to provide a technique for estimating the capacity and determining the LOS of transportation facilities, including not only intersections and roadways but also transit, bicycles and pedestrians (TRB, 2000). Each LOS is associated with a range of operating conditions and is assumed to represent traveller perceptions of various conditions (TRB, 2009). Table 2.1 shows the service measures recommended for use to determine the LOS of various system elements.

Table 2.1: Service Measures for various System Elements in the U.S. HCM 2000

| Element | | Service Measure |
|---|---|---|
| Uninterrupted Flow | Two-lane highway | Speed, percent time-spent-following |
| | Multilane highway | Density |
| | Freeway: Basic Segment | Density |
| | Freeway: Ramp Merge | Density |
| | Freeway: Ramp Diverge | Density |
| | Freeway: Weaving | Density |
| Interrupted Flow | Urban Street | Delay |
| | Signalized intersection | Delay |
| | Two-way stop interaction | Delay |
| | All way stop intersection | Delay |
| | Roundabout | n/a |
| | Interchange ramp terminal | Delay |

In term of MOE used for basic expressway sections and ramps junction, density has been used as the service measure in defining LOS in the U.S. HCM 2000. Density is defined as the number of vehicles occupying a given length of a lane or roadway at a particular instant (Garber and Hoel, 2002).

Entrance ramp expressway junctions are generally designed to permit high speed merging movements to take place with a minimum of disruption to the adjacent expressway traffic stream (TRB, 2000). Areas around entrance ramps experience more turbulence and conflicts compared to basic expressway segments. Therefore acceleration lanes are designed to allow vehicles to merge smoothly and without causing interference to expressway traffic streams. A well-designed acceleration lane should permit ramp drivers to perform a safe merge within the effective acceleration lane length. As such, the proper design and placement of ramps on high demand expressway is crucial for fast, efficient and safe operation. Determination of expressway capacity at ramp-expressway merge junction is important for several practical reasons (Al-Kaisy, 1999):

- The development of appropriate design for expressway merge facilities depends largely on expressway capacity and ramp capacity.
- Most expressway management and ramp control strategies are developed based on the estimated capacity values of expressway components and ramp junctions.
- The quality of service and operational breakdown are directly associated with expressway capacity and represent the important part of any operational analysis.

Due to the dynamic nature of expressway merge situation, in-depth study and research needs to be carried out in order to understand the impact of merging on the traffic operation at entrance ramp junction. Next section discusses in detail the idea and philosophies related to analysis of ramp merge influence areas and a 'step by step' process of the whole methodology structure for entrance ramp capacity analysis based on the U.S. HCM 2000.

### 2.2.3 Characteristics of Traffic Operation in Merge Influence Area

Merging occurs when two separate traffic streams join to form a single stream as illustrated in Figure 2.5. The ramp vehicle merging process is a complex pattern of driver behaviour. A driver performs several different tasks during the merging process such as (Gettman, 1998);

- lane changes of ramp vehicles into the expressway mainstreams,

- lane changes of mainline traffic to other lane to reduce the merging ramp impact and turbulence,
- Acceleration and deceleration behaviours due to intensive conflicts and turbulence such as searching for available gaps to make any movements.

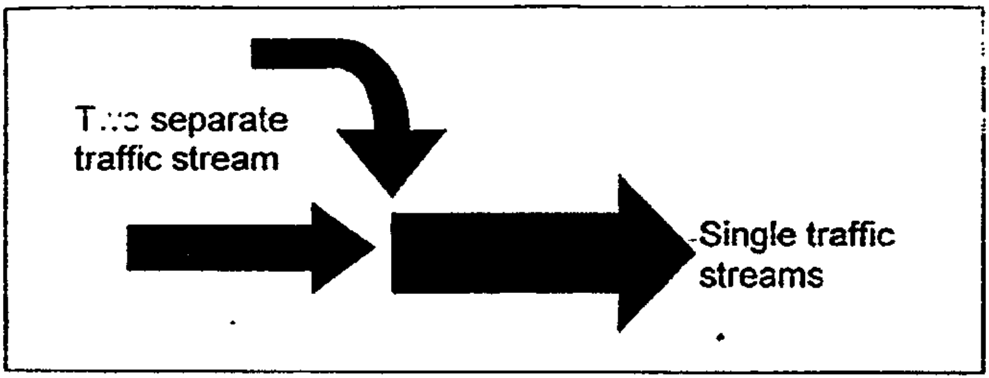


Figure 2.5: Illustration of merging traffic phenomenon

Various mathematical models have been developed to describe the relationships between flow, speed and density on expressway for any given instance (Fazio and Rouphail, 1986; Shin, 1993; Theophilopoulus, 1986; Choocharukul, 2003 and TRB, 2000). The most relevant one regarding the estimation and prediction of traffic operating condition is from the U.S HCM that is the core methodology adopted in this report.

Theoretically, capacity of the entrance ramp is mainly a function of the ability of the merge section to accommodate mainline traffic and ramp demand. The ability to accommodate mainline traffic is primarily governed by mainline geometric characteristics such as number of lanes, lane width, lateral clearance and etc. Apart from that, the ability of merge section to accommodate entrance ramp traffic is also influence by the availability of gaps on the adjacent expressway lane and gap acceptance process. However, this research is concerned with analysis of operational performance at ramp expressway merge sections which deals with macroscopic traffic parameters such as flow rate, density and speed.

### 2.2.4 Analysis of Capacity at Entrance Ramp Expressway Junction using the U.S. HCM Procedure

The 1985 U.S. HCM uses traffic flow rate in merge influence area as the MOE whereas the HCM 2000 uses density in merge influence area as MOE. Figure 2.6illustrates the methodology for determining the operational analysis of the entrance ramp junction using HCM 2000. Based on the HCM 2000, taper type acceleration lane and parallel type acceleration lane is treated as the same in the analysis procedure. Figure 2.6 illustrates the measurement of the length of acceleration lanes, $L_{A}$, for taper and parallel types.

The methodology for estimating and predicting the merge influence area level of service has three major steps. The first step is to calculate the flow entering lanes 1 and 2 ($V_{12}$ pc/hr) immediately upstream of the merge influence area. The second step is to determine capacity values and to compare the capacity values with existing or forecast demand flows to determine the likelihood of congestion. In this process, several capacity values are evaluated:

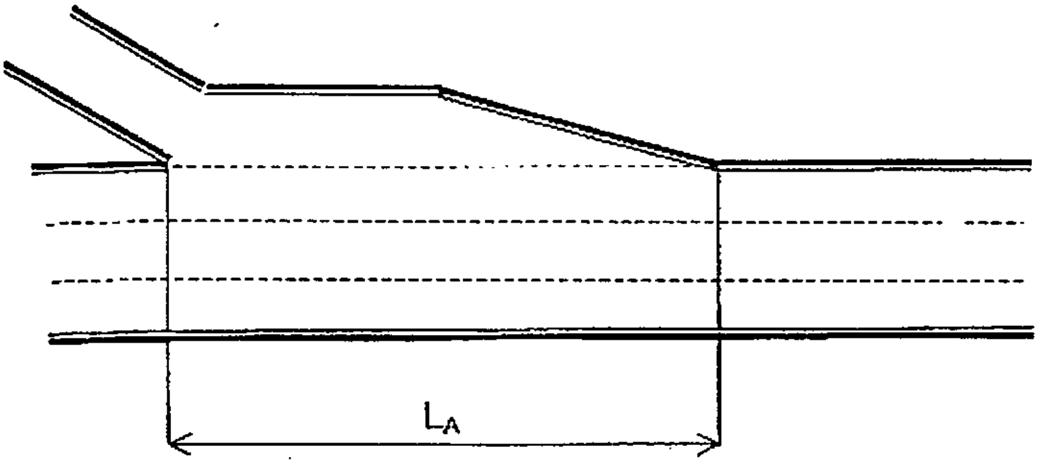
- Maximum total flow approaching a major merge area on the expressway ($V_F$),
- Maximum total flow departing from a merge area on the expressway ($V_{FO}$),
- Maximum total flow entering the ramp influence area $V_{R12}$ for merges areas and maximum flow on a ramp ($V_R$),

The capacity of a merge area is always controlled by the capacity of its entering roadways, that is, the expressway segments upstream and downstream of the ramps, or by the capacity of the ramp itself. Table 2.2 shows the Capacity of Ramp Roadways based on the HCM 2000 procedure. The density of flow within the ramp influence area ($D_R$) and the LOS are determined.

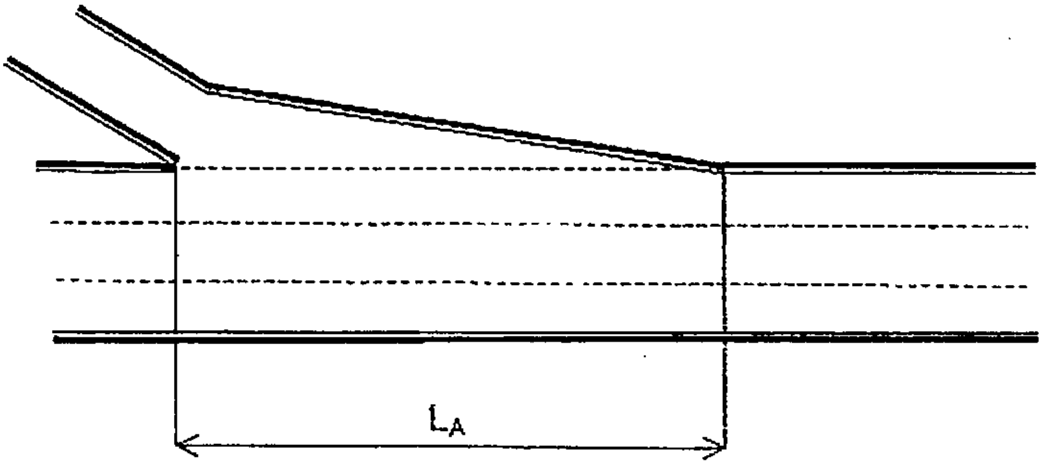
Although speed is a major concern of drivers as related to service quality, freedom to manoeuvre within the traffic stream and proximity to other vehicles are equally noticeable concerns. These qualities are related to the density of the traffic stream. Unlike speed, density increases as flow increases up to capacity, resulting in a measure of effectiveness that is sensitive to a broad range of flows (TRB, 2000).

Table 2.2: Approximate Capacity of Ramp Roadways (TRB, 2000)

| Free-Flow of Ramp ( km/h ) | Capacity (pc/h) | |
|---|---|---|
| | Single lane ramps | Two lane ramps |
| > 80 | 2200 | 4400 |
| >65-80 | 2100 | 4100 |
| >50-65 | 2000 | 3800 |
| ≥30-50 | 1900 | 3500 |
| <30 | 1800 | 3200 |



a. Parallel Type Acceleration Lane



b. Taper Type Acceleration Lane

Figure 2.6: Measuring the length of acceleration lanes (Modified from Roess et al., 2004)

Based on the U.S. HCM 2000, the free-flow speed of the ramp is best observed in the field but may be estimated as the design speed of the most restrictive element of the ramp. Figure 2.8 shows the ramp influence areas and key variables and their relationship to each other. A critical geometric parameter influencing operations at merge area is the length of the acceleration lane ($L_A$). The length of the acceleration lane is measured from the point at which the left edge of the ramp lane or of the expressway lanes converges to the end of the taper segment connecting the ramp to the expressway. The point of convergence can be defined by painted markings or physical barriers or by some combination of the two. To be noted here that both taper acceleration lane and parallel acceleration lane are analyzed in the same way (TRB, 2000).

All aspects of the model and LOS criteria are expressed in terms of equivalent maximum flow rates in passenger cars per hour (pc/h) under base conditions during the peak 15 min of the hour of interest (TRB, 2000). Therefore, before any of these procedures are applied, all relevant expressway and ramp flows must be converted to equivalent pc/h under base conditions during the peak 15 min of the hour, using Equation 2.1.

$$V_i = \frac{V_i}{PHF * f_{HV} * f_p} \qquad (2.1)$$

Where

$v_i$ = flow rate for movement i under base conditions during peak 15 min of hour (pc/h),
$V_i$= hourly volume for movement i (veh/h),
PHF = peak-hour factor,
$f_{HV}$ = adjustment factor for heavy vehicles, and
$f_p$ = adjustment factor for driver population.

A ramp-expressway junction is an area of competing traffic demands for space. Upstream expressway traffic competes for space with entering entrance ramp vehicles in merge areas. In a merge area, individual entrance ramp vehicles attempt to find gaps in the adjacent expressway lane traffic stream. Because most ramps are on the left side of the expressway in Malaysian roadway, the expressway lane in which entrance ramp vehicles seek gaps is designated as Lane 1 that is the closest lane to the ramp. By convention, expressway lanes are numbered from 1 to N, from the left shoulder to the median for Malaysian expressway condition. The action of individual merging vehicles entering the Lane 1 traffic stream creates turbulence in the vicinity of the ramp. Approaching expressway vehicles move toward the right to avoid this turbulence. The HCM 2000 stated that the operational effect of merging vehicles is heaviest in Lanes 1 and 2 and the acceleration lane for a distance extending from the physical merge point to 450 n downstream. Figure 2.7 shows this influence area for entrance ramp junctions and lane convention numbering based on Malaysian scenario.

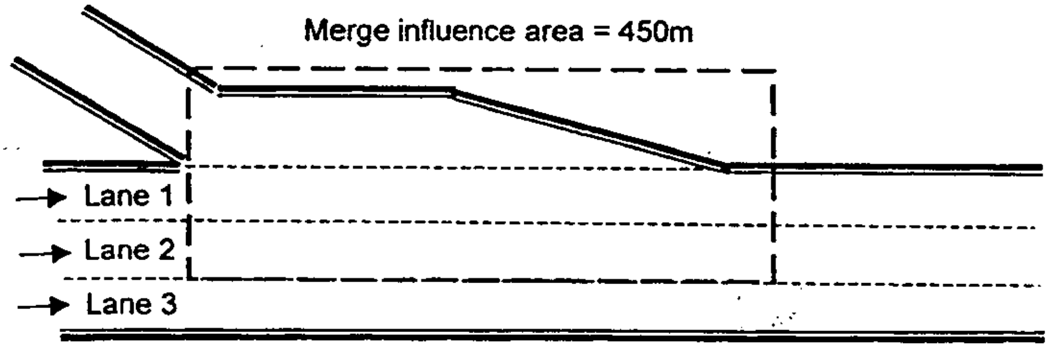


Figure 2.7: Merge influence Area and Lane Numbering (Modified from TRB 2000)

The starting point for the analysis of the entrance ramp operational performance is the estimation of demand flow rates in lane 1 and 2, $V_{12}$ (pc/hr). This is done using a series of regression-based modelling developed as part of a nationwide study of ramp freeway junctions in the U.S. (Roess et al., 1998). For merge areas, the flow rate remaining in lane 1 and 2 immediately upstream of the junction is simply as proportion of total expressway flow.

Table 2.3 summarised models for estimating proportion of approaching expressway flow remaining in Lanes 1 and 2 immediately upstream of merge, $P_{FM}$ for determining which model should be used for various analysis scenarios under 4 lane expressway, 6 lane expressway and 8 lane expressway

Table 2.3: Models for predicting $V_{12}$ at entrance ramps (TRB, 2000)

| $V_{12} = V_F * P_{FM}$ | |
|---|---|
| For 4-lane Expressway (2 lanes each direction) | $P_{FM} = 1.000$ |
| For 6-lane Expressway (3 lanes each direction) | $P_{FM\,=\,0.5775} + 0.000029L_A$<br>$P_{FM} = 0.7289 - 0.0000135\ (V_{F\,+}V_R\ ) - 0.002048S_{FR} + 0.0002L_{up}$<br>$P_{FM} = 0.5487 + 0.0801V_D/L_{down}$ |
| For 8-lane expressway (4 lanes each direction) | $P_{FM} = 0.2178 - 0.000125V_{R\,+}0.05887L_A/S_{FR}$ |

Where,

$V_{12}$ = flow rate in Lanes 1 and 2 of expressway immediately upstream of merge (pc/h)

$V_F$ = expressway demand flow rate immediately upstream of merge (pc/h)

$V_R$ = entrance ramp demand flow rate (pc/h)

$P_{FM}$= proportion of approaching expressway flow remaining in Lanes 1 and 2 immediately upstream of merge

$L_A$ = length of acceleration lane (m)

$S_{FR}$ = free-flow speed of ramp (km/h)

$L_{up}$ = distance to adjacent upstream ramp (m),.and

$L_{down}$ = distance to adjacent downstream ramp m)

For four-lane facilities (two lanes each direction), the value is equal to 1, as the entire flow is in lane 1 and 2. For six and eight lane expressway, the values are determined using the relevance model as shown in Table 2.4. For six-lane expressway, the analysis is based on configuration of adjacent ramps. Table 2.4 lists the various sequences of ramps that may occur on six-lane expressway and the appropriate equation that should be applied in each case. For example. Equation 2.3 in Table 2.4 is considered as an isolated ramp where there is no influence with the upstream and downstream adjacent ramp (Roess et al., 1998).

Table 2.4: Selecting Equations for $P_{FM}$ for Six-Lane Expressway (TRB, 2000)

| Adjacent Upstream Ramp | Subject Ramp | Adjacent downstream Ramp | Equation Used |
|---|---|---|---|
| None | On | None | Equation 2.3 |
| None | On | On | Equation 2.3 |
| None | On | Off | Equation 2.5 or 2.3 |
| Off | On | None | Equation 2.3 |
| Off | On | None | Equation 2.4 or 2.3 |
| Off | On | On | Equation 2.3 |
| Off | On | Off | Equation 2.5 or 2.3 |
| Off | On | On | Equation 2.4 or 2.3 |
| Off | On | Off | Equation 2.5, 2.4 or 2.3 |

The analysis procedure for merge area is computed just for LOS A, B, C, D and E. If the level of service of the ramp merge area is F, no further analysis is needed since it is considered as demand exceeding capacity of the ramp area. Capacity is checked as illustrated in Figure 2.8 and the capacity values for merge area are given in Table 2.5.

Table 2.5: Capacity Values for Merge Areas (TRB, 2000)

| Expressway Free-flow Speed(km/h) | Maximum Downstream Expressway Flow, V (pc/h) | | | | Max. Desirable influence area, $V_{R12}$ (pc/h) |
|---|---|---|---|---|---|
| | Number of lanes in one direction | | | | |
| | 2 | 3 | 4 | >4 | |
| 120 | 4800 | 7200 | 9600 | 2400/ln | 4600 |
| 110 | 4700 | 7050 | 9400 | 2350/ln | 4600 |
| 100 | 4600 | 6900 | 9200 | 2300/ln | 4600 |
| 90 | 4500 | 6750 | 9000 | 2250/ln | 4600 |

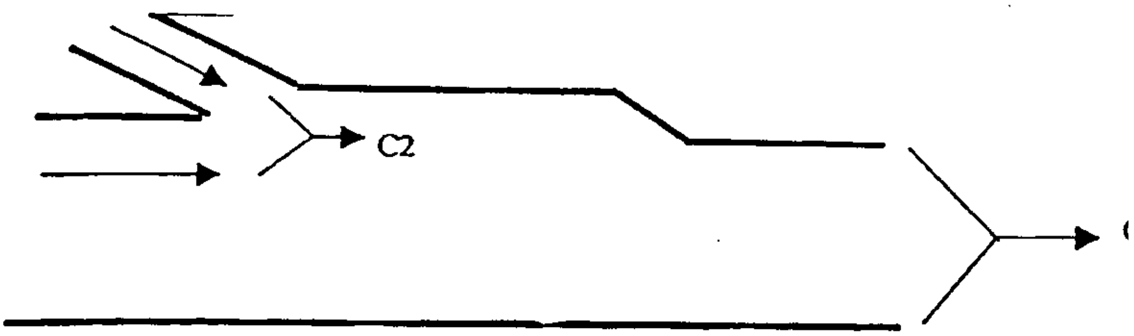


Figure 2.8: Capacity of Merge Areas (Modified from TRB, 2000)

Where, C1 = capacity of merge area, controlled by capacity of the downstream basic expressway segment

C2 = maximum flow into merge influence area

Studies have also shown that there is a practical limit to the total flow rate that can enter the ramp influence area. For an entrance ramp, the flow entering the ramp area includes $V_{12}$ and $V_R$. Thus, the total flow entering the ramp influence area is given according to equation 2.7.

$$V_{R12}=V_{12}+V_R \qquad (2.7)$$

The specific checkpoints that should be compared to the capacity criteria can be summarized as follows;

1. For merge areas, the maximum facility flow occurs downstream of the merge. Thus, the facility capacity is compared with the downstream facility flow using equation 2.8.

   $$V_{FO} = V_F + V_R. \qquad (2.8)$$

2. In cases where lanes are added or dropped at a merge, both upstream $V_F$ and downstream $V_{FO}$ facility flows must be compared to capacity criteria

3. For merge areas, the flow entering the ramp influence area is determined by equation 2.7. This sum is compared to the maximum desirable flow as indicated in Table 2.5.

4. All ramp flows, $V_R$ must be checked against the ramp capacities.

Service volumes for ramps are difficult to describe because of the number of variables that affect operations. Table 2.6 gives example of service volumes of a single lane entrance ramp under a set of condition. Service volumes for LOS A through D are based on conditions producing the limiting densities for these LOS. Service volumes for LOS E are based on the minimum of three limiting criteria: the capacity of the freeway, the maximum volume that can enter the ramp influence area and the capacity of the ram. In some cases, capacity constraints are more severe than density constraints. In such cases, some levels of service may not exist in practical terms for combinations of ramp and expressway volumes (Roess et al., 2004).

Table 2.6: Example Service Volumes for single Lane on Ramps (TRB, 2000)

| **Mainline Number of lanes** | **Service Volumes (veh/h) for LOS** | | | | |
|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **E** |
| Entrance Ramp | | | | | |
| 2 | N/A | 290 | 1250 | 1760 | 1760 |
| 3 | 500 | 1660 | 1760 | 1760 | 1760 |
| 4 | 650 | 1760 | 1760 | 1760 | 1760 |

Note:
Conditions for service volumes for this case are:

- Free Flow Speed mainline = 120 km/hr
- Mainline volume = 2000 veh/h/ln
- Free Flow Speed ramp = 55 km/hr
- Acceleration lane = 300 m
- 5 % truck

According to the U.S. HCM 2000, if all the capacity checks showed that the flow is in stable condition, the density in the ramp influence area may be calculated using Equation 2.9.

$$D_R = 3.402 + 0.00456V_R + 0.0048V_{12} - 0.01278L_A \qquad (2.9)$$

Where, $D_R$ = density of merge influence area (pc/km/ln),
$V_R$ = Entrance ramp peak 15-min flow rate (pc/h),
$V_{12}$= flow rate entering ramp influence area (pc/h), and
$L_A$= length of acceleration lane (m)

The density computed by equation 2.9 is directly compared to the threshold values in Table 2.7 to determine the expected level of service for entrance ramp merge area.

Table 2.7: Level of Service for On-ramp Merge Area (TRB, 2000)

| **LOS** | **Density (pc/km/ln)** |
|---|---|
| A | <= 6 |
| B | >6-12 |
| C | >12-17 |
| D | >17-22 |
| E | >22 |
| F | DEMAND EXCEED CAPACITY |

The LOS is defined to represent reasonable ranges in the three macroscopic traffic parameter variables namely speed, density and flow rate. For entrance ramp-expressway segment, the MOE used to define level of service is density in merge influence area, denoted as $D_R$ (pc/km/ln). The use of density, rather than speed is based primarily on the shape of the speed-flow relationships for basic expressway segment. Because average speed remains constant through most of the range of flow and the total different between free-flow speed and the speed at capacity is relatively small, therefore defining five level of service boundaries based on speed parameter would be very difficult (Roess et al., 2004). If flow rates vary write speed is relatively stable, then density must be varying throughout the range of flows (Roess et al., 2004). Apart from that, density describes the proximity of vehicles to each other, which is the principle influence on freedom to manoeuvre in merge influence area. Thus, it is an appropriate indicator of service quality (TRB, 2000). For uninterrupted flow facilities in merge influence area, the density boundary between LOS E and F is defined as the density at which capacity occurs.

The general operating condition for these LOS can be described as follows:

- Level of service A is intended to describe free-flow operations. At these low densities such as low ramp demand and expressway mainline demand; the operation of each vehicle is not greatly influenced by the presence of other vehicles. Speeds are not affected by flow in LOS A. Lane changing and merging manoeuvre are easily accomplished, as many large gaps in lane flow especially in lane 1 expressway will create opportunity for ramp vehicle to accelerate in order to enter mainline expressway.
- At LOS B, drivers begin to respond to the existence of other vehicles in the traffic stream, although operation is still at free flow speed. Manoeuvring of ramp vehicle to enter lane 1 expressway is still relatively easy and the traffic stream still, has sufficient gaps.
- At LOS C, the presence of other vehicles begins to restrict manoeuvrability and ramp drivers need to search for gaps in order to enter smoothly into lane 1 expressway. Operation remains at the free-flow speed, but ramp drivers now need to adjust their speed to find gaps.
- At LOS D, is the range in which average speeds begin to decline with increasing flows. Manoeuvring within the traffic stream is now becomes difficult, and ramp drivers often have to search for gaps for some time before successfully merge into lane 1 mainline expressway.
- At LOS E, represents operation approaching the capacity in merge influence area. In this situation, the gaps available for ramp vehicle are minimal. Even the smallest lane interruption may cause extensive queuing. Merging manoeuvring of ramp vehicle to enter the mainline traffic stream is now very

difficult.

- LOS F describes operation within the queue that forms upstream of the breakdown point. Such breakdown may occur where the ramp demand exceeds the capacity of the acceleration lane and mainline expressway. Forced merging can happen in this situation and the downstream expressway mainline will tend deteriorate drastically.

Based on the U.S. HCM 2000, the speed is not the measure of effectiveness for ramp expressway junction and is excluded from the methodology to determine the LOS. However, it is often convenient to have an average speed as an additional measure or as input to the system analysis (Roess et al., 2004). In the U.S. HCM 2000, there are three models to estimate speed as shown in Table 2.8.

1. Estimation model for average speed within the ramp influence area.
2. Estimation model for average speed in outer lanes within 450m boundaries of the ramp influence area.
3. Model for combining the above into an average space mean speed across all lanes within the 450m boundaries of the ramp influence area.

Table 2.8: Average Speeds in Vicinity of Expressway-Ramp Terminal (TRB, 2000)

| | |
|---|---|
| Merge areas | Average Speed in Ramp Influence Area (km/h) |
| | $S_R = S_{FF} - (S_{FF} - 67)M_S$ (2.10)<br>$M_S = 0.321 + 0.0039e^{(\frac{VR12}{1000})} - 0.006\left(\frac{L_A S_{FR}}{1000}\right)$ (2.11) |
| | Average Speed in Outer Lanes of Ramp Influence Area (km/h) |
| | $S_0 = S_{FF}$; Where $V_{OA} < 500pc/h$ (2.12)<br>$S_0 = S_{FF} - 0.0058(V_{OA} - 500)$: Where $V_{OA} = 500\ to\ 2300\ pc/h$ (2.13)<br>$S_0 = S_{FF} - 10.52 - 0.01\ (V_{OA} - 2300)$: Where $V_{OA} > 2300pc/h$ (2.14) |

Where,

$S_R$ = space mean speed of vehicles within ramp influence area (km/h); for merge areas, this includes all vehicles in $V_{R12}$

$S_0$ = space mean speed of vehicles travelling in outer lanes (Lanes 3 and 4, where they exist) within 450m length range of ramp influence area (km/h)

$S_{FF}$ = Free-flow speed of freeway approaching merge or diverge area (km/h)

$V_{R12}$ = sum of flow rates for ramp ($V_R$) and vehicles entering ramp influence area in

Lanes 1 and 2 ($V_{12}$) at a merge area (pc/h)

$V_{OA}$ = average per-lane flow rate in outer lanes (Lanes 3 and 4, where they exist) at the beginning of ramp influence area (pc/h/ln)

$M_S$ = intermediate speed determination variable for merge area

$S_{FR}$ = free-flow speed of ramp (km/h)

$L_A$ = length of acceleration lane (m)

$V_R$ = flow rate on ramp (pc/h)

### 2.2.5 Analysis of Capacity at Exit Ramp Expressway Junction using the U.S. HCM Procedure

There are three limit values should be checked for the exit ramp. It is the total flow out of the edge, beyond the capacity of freeway lane or edge and the maximum flow that can cross the threshould lane 1 and lane 2 with priority to the decelaration lane.

Capacity of each exit ramp must be checked by comparing the estimated flow. Capacity values can be obtained based on Table 2.9 to determine the appropriate number of lanes. For the exit lane, the capacity can be found on Table 2.10.

Table 2.9: Capacity value for Off-Ramp

| Freeway Free-FlowSpeed (km/h) | Maximum upstream, $v_{FI}$ or Downstream Freeway Flow, v (pc/h) | | | | Max Flow Entering Influence Area, $v_{12}$ (pc/h) |
|---|---|---|---|---|---|
| | Number lane in one direction | | | | |
| Speed (km/h) | 2 | 3 | 4 | >4 | Area, $v_{R12}$ (pc/h) |
| 120 | 4800 | 7200 | 9600 | 2400/ln | 4400 |
| 110 | 4700 | 7050 | 9400 | 2350/ln | 4400 |
| 100 | 4600 | 6900 | 9200 | 2300/ln | 4400 |
| 90 | 4500 | 6750 | 9000 | 2250/ln | 4400 |

Table 2.10: Approximate capacity of Ramp roadways (TRB, 2000)

| Free-Flow Speed of Ramp, $S_{FR}$ (km/h) | Capacity | |
|---|---|---|
| | Single-Lane Ramps | Two-Lane Ramps |
| >80 | 2200 | 4400 |
| >65-80 | 2100 | 4100 |
| >50-65 | 2000 | 3800 |
| ≥30-50 | 1900 | 3500 |
| <30 | 1800 | 3200 |

$v_{12}$ is the flow of traffic past the decelaration lane, and is guided by the Table 2.11 which is the flow of the exit lane.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This chapter describes techniques employed to obtain empirical data using video equipment. Large amounts of data were collected for model calibration. Observations were carefully reduced and verified to ensure that the database met an acceptable level of accuracy. The study methodology is as shown in Figure 3.1 and each of the flow chart process is elaborated in the coming sections. To ensure that the proposed model has broad application, calibration data reflect a wide range of stable flow operational conditions. This chapter also documents the geometric characteristics for sites selected.

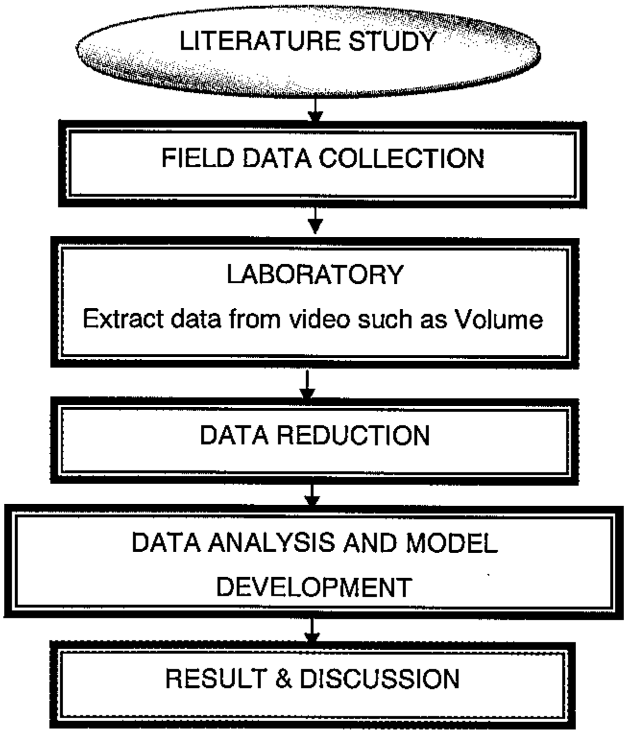


Figure 3.1: Outline of Study Methodology

## 3.2 Overview of the Methodology

One of the major tasks of this research is the collection and reduction of the field data used in calibrating entrance ramp merging and exit ramp diverging models. These data include traffic and flow rate. Obtaining accurate data is an important aspect of this research. The primary data reduced were traffic flow rates for acceleration and deceleration lanes and 3 lanes of expressway mainstreams. A video recording covers 8 to 10 hours for each of the sites, in stable flow condition where there is no 'stop' and 'go' traffic flow movements. The video recorded for all sites are excluded from the unstable flow of traffic movements or demands exceed the capacity of the entrance ramp junction. With regards to an affordable effort, this research focused on expressway entrance ramp with limited set of geometry and operational condition as mention in Chapter 1. Several expressway ramps along PLUS Expressway along NKVE corridor were selected to collect raw video data through the use of Video Recording system. These sites photos are as summarized in Figure 3.2.

Figure 3.2: Photo of Study Locations

## 3.3 Data Collection

In this research traffic data were collected using video recording method. An important advantage of the video recording method is that videotaping provides a permanent record of the data that can be later analyzed at various levels of detail or can be re-checked during data reduction as necessary. In order to perform videotaping, the selected sites must have a nearby vantage-point from which the operation of the entire merging area can be videotaped. The data characteristic of this research requires that the video camera should be positioned in such a way that the vehicle movements along the longitudinal direction can be clearly tracked. Experience gained from preliminary video recording at some sites indicated that overpass bridge immediately upstream or downstream of entrance ramp do not fulfil this necessary condition. These overpass bridge normally cannot provide vantage point from which the longitudinal movements along the acceleration lane can clearly viewed and tracked. Considerable time and effort were expended in finding a suitable site. High vantage-points from a nearby building roof were the best location to place the video camera. A 5-minute analysis period was chosen because of its steadiness and stability in terms of variation in count. Normally, the longer analysis period, such as a 15-minute period, has often turned out to be inadequate to be used because, within that time period, several dissimilar operations have been frequently observed (Shin, 1993; Cassidy, 1990 and Roess et al., 2004). The 15-minute periods often contain dramatic changes in speeds and relatively big fluctuations in counts. They need to be stratified into the shorter periods so that traffic flow can clearly be differentiated under various regimes, because averages over the 15-minute periods usually distort or dilute the transition flow process (Roess et al., 2004).

## 3.4 Data Reduction

Considerable efforts are required to reduce data from the videotapes manually. The data observed until sufficient amount of data required for data analysis. Observation data is carried out from the morning between 9.00 am to 11.00 am. While the observations from the afternoon between 2.30 pm to 4.30 pm. Each video recording is capable to record over 360 minutes of 6 hours. This period was chosen because the flow of vehicles is smooth where there is no ‘stop’ and ‘go’ traffic flow movements and

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