# Developing behavioral models for driver gap acceptance at priority intersections.

**Abdel-Malek Ibrahim Mohammad. Abu Sheikh**

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## Abstract

Priority intersections form a major element in road networks since significant portions of traffic accidents and delays occur at them. Nevertheless, there is lack in studies directed to evaluate the performance of these junctions and to understand driver behavior at them. Previous research has acknowledged that priority junctions can be studied within the context of driver gap acceptance behavior and has raised the importance of incorporating driver, vehicle, and trip attributes in gap acceptance studies related to these junctions. However, limited effort has been directed to this subject. The quantitative effects of driver, vehicle, and trip attributes were not evaluated and the reported results in literature about the effects of other typical traffic attributes aer inconsistent.

In this study Binomial Logit Behavioral Models are developed for diver gap acceptance at priority intersections. The study has investigated the effect of the main driver, vehicle, trip, gap, and traffic attributes on driver gap acceptance behavior at T-intersections. Left turns form major road and right and left turns from minor road are considered. Data needed to calibrate the models were collected using field administered questionnaires and video cameras. More than thirty models are reported and discussed in the study. Along with the basic traffic and delay attributes such as the gap size, the speed of the approaching vehicle, the total delay imposed on the driver at minor road, and the traffic volume at minor road the driver, trip and vehicle attributes such as driver age, sex and accident experience, trip duration, and vehicle occupancy were found to be significant factors in explaining driver gap acceptance behavior. The study has also concluded that binary choice models other than the binomial Logit could provide an adequate framework for modeling driver gap acceptance process.

The results of gap acceptance analysis are applicable to different traffic engineering fields. As an example, the study has demonstrated the applicability of the calibrated models to identify sight distance requirements at priority intersections.

# Developing Behavioral Models for Driver Gap Acceptance at Priority Intersections

BY

**Abdel-Malek Ibrahim Mohammad Abu Sheikh**

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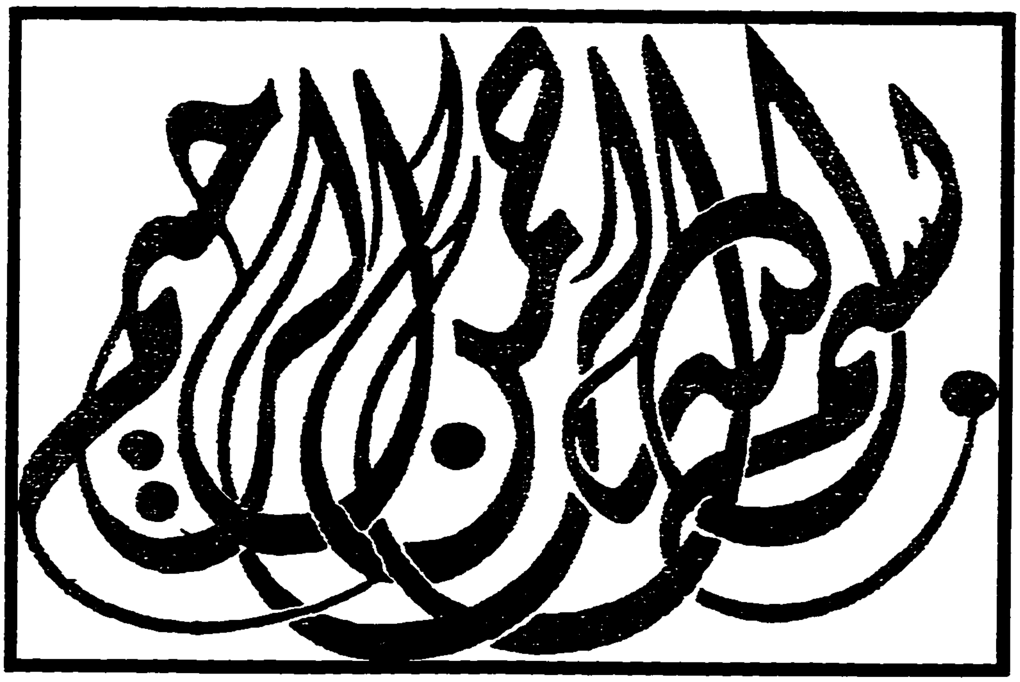
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بسم الله الرحمن الرحيم

# إهداء

أهدي هذا العمل المتواضع إلى:

والدي ووالدتي أطال الله في عمرهما .......

وإخوتي وأخواتي وفقهم الله .......

وزوجتي رعاها الله .......

وأبنائي أنس وأحمد حماهما الله .......

وزملائي وكل من ساعدني في إنجاز هذا العمل .......

سائلا المولى سبحانه وتعالى السداد والتوفيق.......

عبد المالك أبو الشيخ

# Dedication

**This work is dedicated to:**

**My Parents May Allah Extend Their Ages .......**

**My Brothers and Sisters.......**

**My Wife and My Sons Anas and Ahmad.......**

**My Friends Who Helped in Accomplishing This Work .......**

**Abdelmalek Abu Sheikh**

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**This dissertation, written by ABDELMALEK IBRAHIM MOHAMMAD ABU SHEIKH under the direction of his Dissertation Advisor and approved by his Dissertation Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements of the degree of DOCTOR OF PHILOSOPHY in CIVIL ENGINEERING.**

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**ALL PRAISE AND GRATITUDE TO ALLAH (سبحانه وتعالى)**

Praise and Glory be to the Almighty **ALLAH** for bestowing me with the health, spirit, strength and pertinacity to complete this work.

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## DISSERTATION ABSTRACT

| | |
|---|---|
| NAME | : ABDELMALEK IBRAHIM MOHAMMAD ABU SHEIKH |
| TITLE OF STUDY | : DEVELOPING BEHAVIORAL MODELS FOR DRIVER GAP ACCEPTANCE AT PRIORITY INTERSECTIONS |
| MAJOR FIELD | : CIVIL ENGINEERING |
| DATE OF DEGREE | : JUNE, 1997 |

Priority intersections form a major element in road networks since significant portions of traffic accidents and delays occur at them. Nevertheless, there is lack in studies directed to evaluate the performance of these junctions and to understand driver behavior at them. Previous research has acknowledged that priority junctions can be studied within the context of driver gap acceptance behavior and has raised the importance of incorporating driver, vehicle, and trip attributes in gap acceptance studies related to these junctions. However, limited effort has been directed to this subject. The quantitative effects of driver, vehicle, and trip attributes were not evaluated and the reported results in literature about the effects of other typical traffic attributes are inconsistent.

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**DOCTOR OF PHILOSOPHY DEGREE**
**KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS**
**DHAHRAN, SAUDI ARABIA**
**JUNE, 1997**

# خلاصة الرسالة

**اسم الطالب الكامل**: عبدالملك إبراهيم محمد أبو الشيخ

**عنوان الدراسة** : تطوير نماذج وصفية لعملية قبول السائقين للفجوات الزمنية على التقاطعات غير المحكومة بإشارات ضوئية.

**التخصص** : هندسة مدنية .

**تاريخ الشهادة** : يونيو ١٩٩٧م .

تشكل التقاطعات غير المحكومة بإشارات ضوئية عنصرا مهما في شبكات الطرق. حيث أن نسبة كبيرة من الحوادث والتأخير يحدث على هذه التقاطعات. وبالرغم من ذلك فهناك نقص في الدراسات اللازمة لتقييم وتحسين أداء هذه التقاطعات، وفهم سلوك (طريقة تصرف) السائقين عندها.

لقد تمت في الدراسات السابقة الإشارة بأنه يمكن دراسة وتحليل هذه التقاطعات ضمن إطار "خصائص قبول السائقين للفجوات الزمنية (Gap Acceptance) التي تحدث في اتجاه الحركة الرئيسي. وتمت الإشارة أيضا إلى أهمية أن تؤخذ خصائص السائقين، والمركبات، والرحلات بالإضافة إلي خصائص الحركة المرورية، وخصائص التقاطع نفسه بعين الاعتبار في هذه الدراسات. إلا انه لم يتم قبل هذه الدراسة إجراء أية دراسات تحليليه بهذا الشأن، ولم يتم تحديد أثر أي من خصائص السائقين والمركبات والرحلات على طريقة تصرف السائقين حيال قبول الفجوات الزمنية المتاحة لهم على التقاطعات غير المحكومة بإشارات ضوئية، كما أن النتائج الموجودة في الدراسات المحدودة السابقة حول آثار بعض العوامل المرورية التي تم دراستها مختلفة إلى حد التناقض.

ومن هنا يأتي دور هذه الدراسة لتغطية هذه الناحية، حيث تم من خلالها جمع معلومات دقيقة وشاملة عن طريق المقابلات الميدانية مع السائقين والتي تجرى لأول مرة في مثل هذه الدراسات، وكذلك باستعمال أجهزة التصوير (كاميرات الفيديو). وقد تم في الدراسة أخذ ما لا يقل عن أربعين عاملا تصف خصائص السائقين والمركبات والرحلات والحركة المروية و الفجوات الزمنية بعين الاعتبار. وتم دراسة الحركات الثلاثة المتعلقة بالتقاطعات ذات الشكل المشابه للحرف T . وقد تم من خلال الدراسة تطوير ومناقشة اكثر من ثلاثين نموذجا رياضيا وصفيا من نوع ( Binomial Logit) .

وقد توصلت الدراسة إلى نتائج هامة وجديدة في هذا المجال منها أن خصائص السائقين (مثل العمر والجنس وعدد الحوادث المرورية التي وقعت للسائق وخبرته في القيادة)، والمركبات (مثل عدد الركاب)، والرحلات (مثل زمن الرحلة) والتي لم تدرس من قبل تعتبر عوامل هامة في تفسير تصرف السائقين فيما يتعلق بقبول الفجوات الزمنية على التقاطعات غير المحكومة بإشارات ضوئية، كما بينت الدراسة أن هناك نماذج رياضية أخرى مثل (Binary Probit and Maximum Score ) يمكن تطبيقها على الظاهرة المدروسة، كما أن هناك تطبيقات عملية كثيرة لنتائج الدراسة في مجال هندسة المرور وتصميم الطرق، وقد تم توضيح بعض هذه التطبيقات.

درجة الدكتوراه في الفلسفة
جامعة الملك فهد للبترول و المعادن
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يونيو ١٩٩٦م

# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

The scarcity of space in urban areas and the high costs associated with the extension of the available urban transportation systems make it important to study the system users' behavior in order to optimize the utilization of these systems to the highest possible extent. In this regard, it is important to understand and be able to predict human behavior in many situations including travel choice, car following, gap acceptance and other driving behavior situations.

In the field of traffic engineering, much concern was devoted to the optimization of operational conditions at signalized intersections as they form a major element in any transportation system. Less effort has been directed to priority intersections

(intersections working under priority rules, yield and/or stop signs or flashers) although they form the most predominant type of intersections with considerable percentages of traffic accidents and delays occurring at them [Golias and Canellaidis (1990)].

Research on priority intersections aims to study driver behavior at these intersections and to build models that can describe this behavior. These models can be used to predict and evaluate traffic operations at this important type of intersections. It was revealed earlier that gap acceptance concept is an appropriate framework for analyzing gap acceptance at priority intersections [Kimber (1989), Kimber et al. (1986) and Troutbeck (1984 and 1993)].

Pant and Balakrishnan (1994) have stated that the simplest form of gap acceptance concept was originally explained by Adams (1936) and Raff and Tanner (1951). Hughes (1989) stated that the Tanner's study (1962) was considered as a pioneering work in applying gap acceptance principles in traffic engineering. After this study, many gap acceptance studies have been conducted. The main aim of these studies was to demonstrate the ability of different statistical distributions to fit accepted gaps and to build gap acceptance models (functions which describe driver gap acceptance behavior).

During the last few decades, many gap acceptance models have been developed for the purpose of studying delay, capacity and accident risk at priority intersections [Darzentas (1989)]. Consistent driver and probabilistic gap acceptance behaviors were the predominant assumptions in these models, [Darzentas (1989) and Golias (1990)], although step gap acceptance functions (acceptance probability is either zero or one) were used in old models.

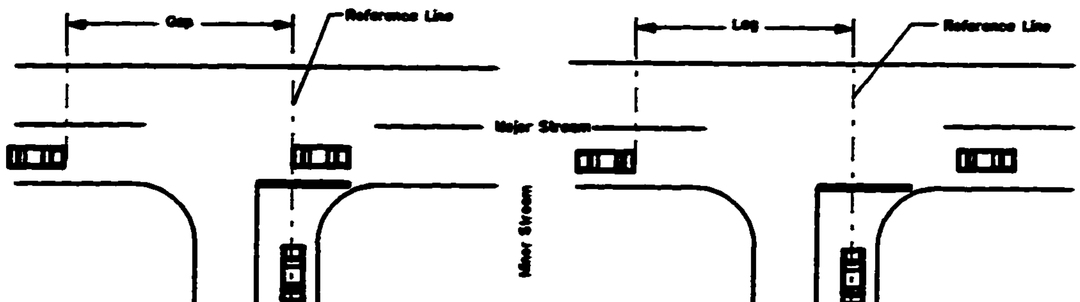


Figure 1.1 Definition of gap & lag

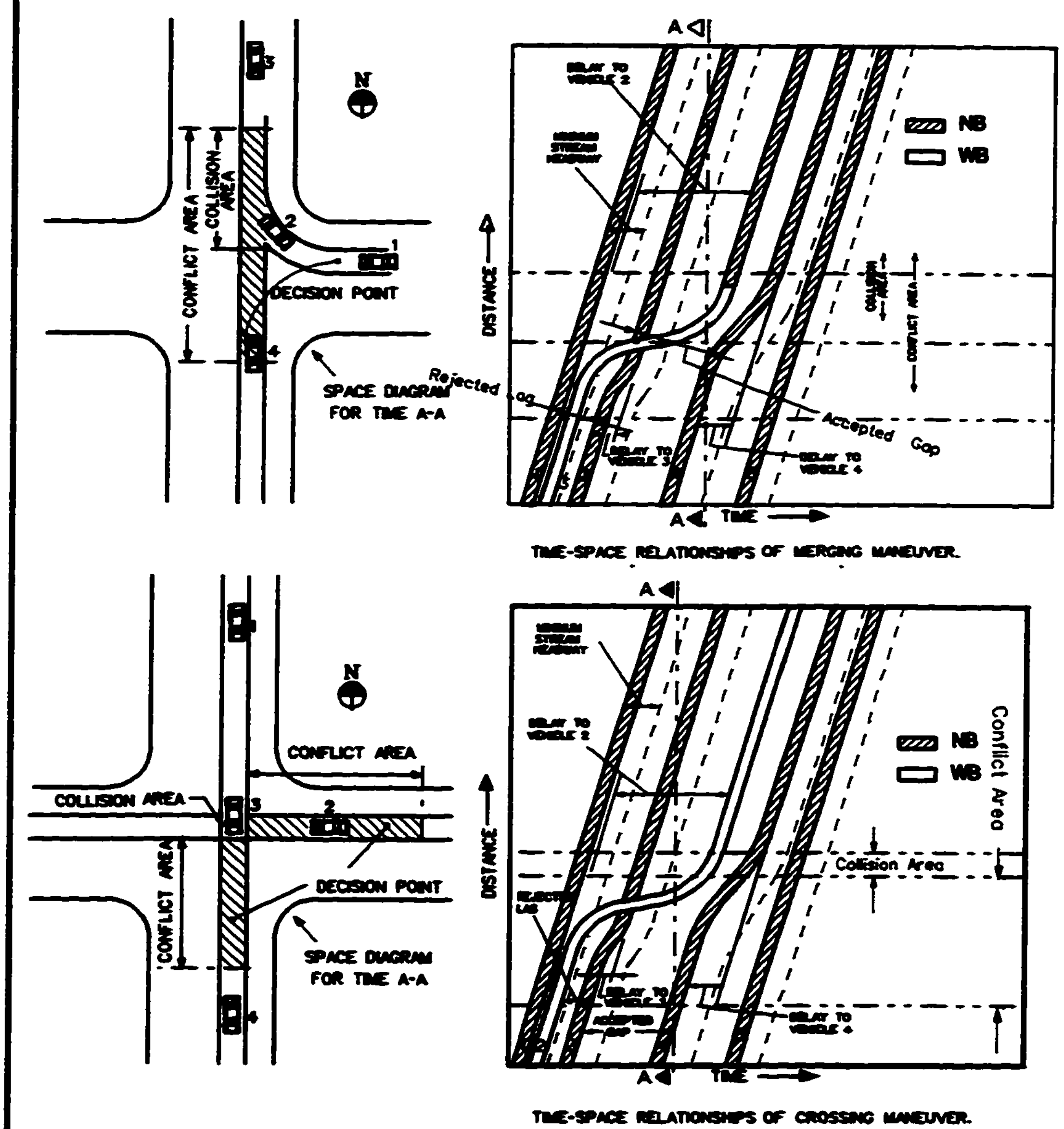


Figure 1.2 ILLUSTRATION OF GAP ACCEPTANCE PHENOMENON

Figure 1.2 SOURCE: (Malaco et al.,1985)

## 1.2 DESCRIPTION OF GAP ACCEPTANCE PROCESS

Driver behavior at priority intersections is a decision making process. The primary concern of the analyst is to understand how drivers make their decisions on accepting or rejecting a given gap and which factors significantly affect and explain these decisions. When a minor road driver arrives at a priority intersection he will, at first, face a lag (time interval between his arrival at the intersection, and the arrival of the first major stream vehicle) and he has to decide whether to accept or reject this lag. If he accepts this lag, his decision making process will end at this point. If he rejects this lag, he will wait and start observing and evaluating gaps occurring in the major stream, one by one, till he accepts a gap that he believes is long enough for him to execute his maneuver safely. Figures 1.1 and 1.2 illustrate the time space relationships and the basic terminology that describes the gap acceptance phenomenon.

Obviously, gap acceptance behavior is affected by a wide variety of characteristics and factors. These factors include driver, gap, traffic, vehicle, road, trip, driver inter-influence (influence of the decisions taken by one driver on the decisions taken by another driver), and even environmental characteristics and attributes. Hence, the process is expected to be difficult because driver does not know the number and size of gaps that will be offered to him *a priori*, variables affecting the decision may be hard to identify, utilities and probabilities for different options may be hard to assess [Edwards (1987)]. Uncertainty and accident risk involved in the process add more difficulty that indicates the importance of studying this phenomenon.

## 1.3 STATEMENT OF THE PROBLEM

One of the most important traffic engineering concerns occurs when vehicles either cross or enter (merge) a stream of traffic at priority intersections. These intersections are still by far the most common type of intersections in both urban and rural areas [Bottom and Ashworth (1977 and 1978), Cheng and Allam (1992), Golias (1990), Tracs (1987), and Troutbeck (1990)]. They are also the scene of considerable traffic delays and numerous accidents [Golias and Kanellaidis (1990)]. Considerable effort and interest were given to highway crossing problem at priority intersections. However, most of this interest was centered mainly on the prediction of delay rather than the behavior of drivers [Ashworth and Bottom (1977)].

Literature refers to driver decision of whether or not to enter the path of an oncoming vehicle in a priority stream as *"gap acceptance behavior"*. This behavior depends on numerous factors such as length of gap, type of intersection, speed and type of oncoming vehicle, surrounding environment, time of day, and mostly on the driver cognition of the situation [Darzentas (1989)]. Crucial factors affecting the operation of priority intersections include the availability and duration of gaps in the major stream and the acceptance of these gaps by minor stream drivers [May (1990) and Pant and Balakrishnan (1994)]. Therefore, understanding driver gap acceptance behavior at priority intersections is an essential element in estimating the operational measures of these intersections like capacity and delay [Adebisi and Sama (1989)]. Studies of such behavior have so far been in one of two general forms:

a. Queue acceptance studies that relate the number of minor stream vehicles entering a gap to the length of that gap;

b. Gap acceptance studies that assess the probability of accepting a gap by a minor road driver basically as function of gap length. In some cases, other characteristics and attributes which affect driver behavior were also incorporated [Adebisi and Sama (1989)].

Several studies of the second type have been conducted. The basic differences among these studies were the underlying assumptions about driver behavior (consistent or inconsistent), the mathematical distributions fitted to accepted gaps and the type of the developed gap acceptance model (deterministic or probabilistic). Three basic driver behavioral models have formed the basis for previous studies [Adebisi and Sama (1989), Darzentas (1989), and Golias and Kanellaidis (1990)]:

a. "Fixed critical" gap concept which implies that there is a minimum critical lag or gap, 't', which is identical for all drivers in a population. A driver will accept a lag or gap in the major stream only if it is equal to or greater than the critical gap, 't'. In this case, gap acceptance function is a "step function";

b. "Consistent driver" concept which implies that each individual driver, i, has his own constant critical lag or gap, '$g_i$', which is fixed for the driver but distributed over the population. This pattern of behavior implies absolute consistency for each individual driver although individuals may vary from each other;

c. "Inconsistent driver" concept which implies that variability in gap acceptance behavior exists within and between individuals as well.

A number of studies have been conducted to compare these models and to examine their implications on predicting intersection operational measures like delay and capacity. It was found that the resulting differences are significant and cannot be easily ignored [Darzentas (1989)]. The "inconsistent driver" approach better represents the actual driver behavior [Adebisi and Sama (1989), Chung et al. (1992), Hewitt (1983), Hughes (1989), and Pant and Balakrishnan (1994)]. However, studies showed that the "between driver" variances are much higher than the "within driver" variances [Darzentas (1989)]. This can be the main reason for adopting the "consistent driver" model by most of the studies specially those directed to capacity estimation [Darzentas (1989), Golias and Kanellaidis (1990), and Hewitt (1985)].

Most of the previous gap acceptance studies were mainly concerned about establishing proper statistical distributions that will fit the accepted gaps. Functions developed to explain the variation in driver gap acceptance behavior were limited to the use of few quantitative variables which include gap length, driver delay, and traffic volume. Many of the models developed so far relate the probability that a randomly chosen driver will accept a certain gap to the characteristics of this gap, particularly its length, [Mahmassani and Sheffi (1981)]. The effects of many other important factors are either completely neglected or only qualitatively described. Few studies have incorporated some of the variables other than gap length. Efforts in this field were limited to works done by Adebisi and Sama (1989), Ashworth and Bottom (1977),

Bottom and Ashworth (1978), Daganzo (1981), Darzentas, et al. (1980), and Madanat et al. (1994). It is important to stress that the above mentioned works were lap oriented and limited in scope. Therefore, they do not represent actual driving situations.

Ashworth and Bottom (1977) and Bottom and Ashworth (1978) have conducted one of the most comprehensive studies regarding traffic and human factors that affect driver gap acceptance behavior. They have studied "in between" driver variability by video recording driver behavior at a given location for a prescribed time. They judged driver sex and age and vehicle type based on video images only. Thirty experimental drivers were also used to study human factors that affect gap acceptance behavior. They found that driving behavior under real life situations is significantly different than driving behavior under simulated conditions even for the same set of drivers who participated in simulated and actual experiments. They also stated that "*... investigations into between subject differences were restricted by incomplete data which resulted from factors such as the inability to interview observed drivers and the difficulty in relating driving behavior to indices of driving experience*". They added, *"the results were not conclusive"* [Bottom and Ashworth (1978), pages 721 and 731].

Darzentas et al. (1980) have studied the effects of age, sex, and speed on gap acceptance behavior and on conflict involvement using experimental subjects located standing at road-side and asked to assess the minimum gap that they would accept to cross the main stream. Other researchers have studied the effects of variables that can be extracted from videotapes like traffic speed and volume at major stream and driver

delay at minor stream. Other variables that can significantly affect driver gap acceptance behavior were not studied at all. For example, Akcelik (1994) reported that *"... further research is recommended on the effects of heavy vehicles on arrival headway distributions and on gap acceptance parameters"*, [Akcelik (1994), page 506].

Moreover, effects of the few investigated variables (speed and volume at major stream and delay and queue size at minor stream) as reported in previous research are inconsistent and widely variant. Some researchers [Adebisi and Sama (1989), Ashton (1971), and Hewitt (1983)] have concluded that gap acceptance behavior is significantly affected by such variables. Other researchers like Pant and Balakrishnan (1994) and Neudorff (1985) have concluded that such variables have no significant impact on driver gap acceptance decision.

Therefore, it can be stated that understanding driver gap acceptance behavior is essential for predicting and evaluating traffic operations at priority intersections. Previous research has revealed that driver gap acceptance behavior is affected by numerous driver, gap, traffic, road, vehicle, and environmental factors. However, there is an apparent lack of the investigation of the effects of many of these factors. Adebisi and Sama (1989), have reported that *"It is worthwhile to note that driver variables such as age, sex, and driving experience can influence driving behavior and, hence gap acceptance characteristics. Apparently, the cited characteristics of drivers have seldom been included in the analysis of gap acceptance data"*. The same researchers added that *"incorporating such variables in gap acceptance models will result in less unexplained variability"* [Adebisi and Sama (1994), page 314].

Reasons mentioned for neglecting such variables in previous studies include the difficulty added to data collection procedures and the complexity introduced to the development of capacity and delay models.

In summary it can be stated that previous research has failed in directions which include:

a. Not considering some of the effects of many important driver factors (like driving experience, education, and familiarity with site), vehicle characteristics (like age, engine capacity and occupancy), trip attributes, and driver inter-influence factors;

b. Failure to study the effect of driver factors under real life driving environment;

c. Inconsistency and wide variance of the reported effects of the few variables (mainly volume and speed at major stream and delay and queue length at minor stream) studied in previous research.

This research is initiated to investigate the effects of the main driver, gap, vehicle, traffic, trip, and driver inter-influence factors and characteristics on driver gap acceptance behavior at priority intersections. The research will be a pioneering work that will investigate the effects of these variables under real life driving situation. Data will be collected based on the simultaneous use of both of video recording and field administrated interviews.

## 1.4 RESEARCH HYPOTHESIS

It is believed that driver characteristics (age, sex, driving experience, education level, familiarity with the area, and ability to estimate speed of the oncoming vehicle), traffic characteristics (volumes at major and minor streams, speed of oncoming vehicle, maneuver type, delay, and queue size at minor stream), vehicle characteristic (type, age, engine capacity, and vehicle occupancy), gap characteristics (type and size), trip characteristics (purpose and duration), and driver inter-influence factors (size of gap accepted by the driver ahead, size of queue behind driver at the queue head, number of gaps rejected by ahead driver, and number of vehicles entering ahead in the gap he accepted) will affect driver gap acceptance behavior at priority intersections. Other variables (excluded in this research for reasons to be explained later) like intersection geometric factors (intersection type, number of lanes, ...), type of control (stop, yield, priority rules), sight distance and visibility, road surface conditions and even environmental (weather and light conditions) factors can also affect driver gap acceptance behavior. However, the effect of these excluded factors will be kept common for all entities since similar sites will be studied. It should be stressed again that this research does not intend to study the effect of intersection type and geometry variables. The above stated hypothesis is formed based on literature review and an understanding of the nature of the studied phenomenon.

## 1.5 GOALS AND OBJECTIVES

This research is initiated for two main goals:

I. Building behavioral models that will be used to investigate and analyze the possible effects of the main driver, gap, traffic, vehicle, trip, and driver inter-influence factors on driver gap acceptance behavior at priority intersections. To achieve this main goal, the following objectives were considered:

a. Define and understand gap acceptance phenomenon at priority intersections, select an applicable modeling framework, formulate the problem within this framework and specify the main driver, traffic, gap, vehicle, trip, and driver inter-influence factors and characteristics that are believed to affect driver gap acceptance behavior at priority intersections;

b. Collect data required for calibrating behavioral driver gap acceptance models;

c. Calibrate and validate behavioral gap acceptance models.

II. Demonstrating the applicability of the developed gap acceptance models and the derived results in Traffic Engineering and Highway Geometric Design fields. This is (though important) is, however, a secondary goal of the study.

## 1.6 SIGNIFICANCE AND EXPECTED CONTRIBUTIONS OF THE STUDY

The main contributions of this research included the following:

a. Addressing and investigating the quantitative effects of factors which were not studied yet and which are expected to have significant influence on driver gap acceptance behavior such as driver inter-influence factors, vehicle occupancy, trip attributes and other variables believed to be studied for the first time;

b. Evaluating the effects of the main driver characteristics (age, driving experience, education level, ...) on gap acceptance behavior under complete real life driving situation;

c. Establishing a better understanding of the effect of the previously studied variables on driver gap acceptance behavior;

d. Investigating the applicability of binary logit modeling framework to the phenomenon of driver gap acceptance behavior at priority junctions.

## 1.7 SCOPE OF THE STUDY

The scope of the study was limited as discussed below:

a. The effect of factors related to intersection geometry were not explored. This was decided to keep equipment, personnel and data management requirements within manageable limits;

b. Capacity and delay predictions using the developed behavioral gap acceptance models were not demonstrated. The main aim of the research is to investigate

the significance of the different modeled variables on driver gap acceptance behavior and to demonstrate some other potential applications of the developed models in traffic engineering discipline.

## 1.8 DISSERTATION LAYOUT

A summary of the subjects discussed in each chapter is given below:

**Chapter 1: Introduction:** This chapter includes a general description of gap acceptance phenomenon, statement of the problem, research hypothesis and goals and objectives of the study.

**Chapter 2: Literature Review:** This chapter presents the necessary definitions and summarizes the basic findings of the extant literature regarding factors and attributes that affect driver gap acceptance behavior along with their reported effects, data collection methods, models applicable to gap acceptance phenomenon, and applications of gap acceptance concepts

**Chapter 3: Research Methodology:** This chapter explains the main research phases, steps, and tasks which were carried out in the research including problem formulation, model selection, model variables, general considerations related to logit model specification, calibration and validation, and the used statistical.

**Chapter 4: Data Collection:** This chapter covers data collection issues including selection study sites, sample size, data collection arrangements and methodology, questionnaire design, and data coding procedures and forms.

**Chapter 5: Preliminary Analysis of Gap Acceptance Data:** This chapter presents general descriptions and frequency analyses of the collected data including preliminary statistical, average, and critical gap analyses.

**Chapter 6: Model Validation and Calibration:** This chapter forms the main body of this research. It presents the behavioral gap acceptance models developed in the research and the results of the statistical tests carried out to test and validate these models along with the sensitivity analyses for the effects of the different modeled variables on driver gap acceptance behavior at priority junctions.

**Chapter 7: Applications of Gap Acceptance Analysis:** This chapter demonstrates some of the potential applications of the developed models and the derived gap acceptance results in traffic engineering and highway geometric design fields.

**Chapter 8: Summary, Conclusions and Recommendations:** This chapter summarizes the main conclusions derived from the study and the basic recommendation for further study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter presents the needed definitions and summarizes the basic findings of the conducted literature review regarding factors and attributes that affect driver gap acceptance behavior along with their reported effects, data collection procedures, models applicable to gap acceptance phenomenon, and applications of gap acceptance concepts and models.

## 2.2 DEFINITIONS

For the clarity of the following presentation, the basic relevant definitions are given bellow:

**Gap:** The elapsed time interval between arrivals of two successive vehicles in the major stream [Adebisi (1982a), Adebisi (1982b), Cheng and Allam (1992), Golias and Kanellaidis (1990), Neudorff (1985), Pant and Balakrishnan (1994), and Polus (1983)]. This definition applies regardless of the direction of travel or the lane each major stream vehicle occupies, [Neudroff (1985)]. Akcelik (1996), Chin (1985) and Robertson (1994) defined gap more specifically as "time elapsed between the rear bumper of one vehicle and the front bumper of the following vehicle passing a given point".

**Lag**: Time interval between the arrival of a driver in the minor stream reaching first to a stop line and ready to move into the intersection and the arrival of the front bumper of the first vehicle in the main road [Adebisi (1982a), Adebisi (1982b), Cheng and Allam (1992), Golias and Kanellaidis (1990), Hewitt (1983), Hughes (1989), Pant and Balakrishnan (1994), Polus (1983), and Robertson (1994)]. In other words, lag is the portion of the last gap in the major stream remaining when a vehicle at minor road reaches the intersection point from which it is ready to execute the desired maneuver. In this context lag is always a fraction of some gap [Adebisi (1982a)].

**Critical Gap**: There is no single identical definition of the term "critical gap", [Madanat et al. (1994)]. Literature includes two main types of definitions; "time

interval between two successive main road vehicles which the waiting driver at minor road considers to be just adequate to allow him to execute his desired maneuver safely", [Hewitt (1983), Hewitt (1985) and Pant and Balakrishnan (1994)] and "the gap size for which the number of drivers who accepted equals the number of drivers who rejected" [Ashton (1971), Darzentas (1989), Madanat et al. (1994), and Polus (1983)]. The second definition was originally used by Raff (1950) [Madanat et al. (1994)]. The first definition is slightly modified in some references as "the minimum gap into which a vehicle will enter" [Hughes (1989) and Robertson (1994)], Raff (1950) had defined critical gap as "the gap that the number of accepted gaps shorter than it equals the number of rejected gaps larger than it. The Highway Capacity Manual [HCM (1994)] defines critical gap as "the minimum time interval between vehicles in a major traffic stream that permits side-street vehicle at a stopped controlled approach to inter the intersection under prevailing traffic and roadway conditions in seconds".

**Accepted/Rejected Gap or Lag**: Gap or lag that a minor stream driver uses (accepts) to move into the major stream while rejected gap or lag is one which the minor stream driver does not use [Robertson (1994)].

**Gap Acceptance Behavior**: The decision making process of whether or not to enter the path of an oncoming vehicle [Darzentas (1989)].

**Gap Acceptance Function**: The function that defines the probability of accepting a randomly selected gap by certain driver [Golias (1990)].

**Gap Acceptance Theory**: The theory that deals with driver gap acceptance behavior and it has two elements [Troutbeck (1993)]:

a. Measurement of the usefulness of a gap of (t) seconds long to an entering driver measured by gap acceptance parameters (critical gap, move-up time);

b. Estimation of the frequency of acceptable gaps of duration, t, in the opposing traffic stream.

**Theory of Choice**: A collection of procedures which define decision maker, available alternatives, alternative attributes and characteristics, and the decision rule (mechanism used by decision maker to process available information and decide at a unique choice) [Ben-Akiva and Lerman (1985)].

**Queue Acceptance**: Acceptance of large gaps in major stream by two or more drivers waiting on minor road in a queue [Cooper and Wennell (1978) and Neudorff (1985)].

**Minor Road Capacity**: In gap acceptance context, minor road capacity can be defined as the steady-state expected rate at which minor road vehicles would enter priority intersection given that queue at minor road is infinite [Cheng and Allam (1992)].

**Move-up time**: Time that the next vehicle on minor road takes to move up and replace the ahead vehicle that has departed the minor road [Golias (1990) and Makigami and Matsuo (1990)]. This parameter is important in determining the number of minor road vehicles that can enter in a given gap and in predicting delay and capacity at priority intersection.

## 2.3 FACTORS AFFECTING DRIVER GAP ACCEPTANCE BEHAVIOR

The size of the gap a driver will accept is dependent on his characteristics and driving behavior. This gap is also affected by geometric features, type and speed of the trailing vehicle forming the gap, size of the gap itself, driver ability to correctly estimate the speed of trailing vehicle, driver frustration caused by delay, driver age and sex, driving experience, car age and power, purpose and length of the trip, vehicle occupancy, maneuver type, traffic flow rate at major stream, weather and pavement surface conditions, and pedestrian activity at the intersection.

Many of the above mentioned factors are cited in literature as factors that can affect driver gap acceptance behavior at priority intersections. However, literature has failed to address the specific effects of the majority of these factors. Moreover, there is considerable variance in the results reported on the effects of the few previously studied variables (specifically speed, volume and delay). Main studies conducted in the past to analyze factors which influence driver gap acceptance behavior include, Adebisi and Sama (1989), Ashworth and Bottom (1977 and 1978), Daganzo (1981), Daganzo (1987), Darzentas et al. (1980), Gibs (1968) and Herman and Weiss (1961) (as stated by Ashworth and Bottom (1987)), Madanat et al. (1994), and Pant and Balakrishnan (1994).

Conducted literature review showed that many factors affect driver gap acceptance behavior at priority intersections. These factors can be categorized as follows:

### 2.3.1 Driver Characteristics

Driver factors which affect gap acceptance behavior include driver age and sex. [Adebisi and Sama (1989), Daganzo (1987), Darzentas et al. (1980), Darzentas and Mcdowell (1981)]. Old and female drivers need longer gaps [Daganzo (1987), Darzentas et al. (1980), and Darzentas and Mcdowell (1981)]. Figure 2.1 shows the relationship developed by Darzentas, et al. (1980) between critical gap in seconds and speed of oncoming vehicle (ft/sec.) for old (61-70 years) and young (16-40 years) drivers. Adebisi and Sama (1989) and Bottom and Ashworth (1978) have mentioned driver experience, "previous year mileage", as a possible factor which can affect driver gap acceptance behavior.

### 2.3.2 Traffic Characteristics

Literature has mentioned and discussed many traffic factors that can affect driver gap acceptance behavior. Flow rate at main road is one main factor, [Adebisi (1982a), Adebisi (1982b), Adebisi and Sama (1989), Ashton (1971), Chung et al. (1992), Hewitt (1983), Kimber (1989), and Troutbeck (1993)]. Ignoring the influence of traffic

volume at main road may lead to more than 100 % errors in the estimated values of critical gaps [Adebisi (1982a)]. Relationship between circulating flow at a roundabout and the critical gap and follow-up headway at the entrance as found in a study conducted by Edward Chung et al. (1992) is shown in Table 2.1. Figure 2.2 shows the relationship developed by Adebisi (1982a) between critical gaps and flow rate (vph) at major stream for right turns merging in two-lane two-way major stream from one lane one-way minor stream. However, results about the effect of major stream volume are not in full agreement. Wohl and Martin (1967) showed that no significant difference in gap acceptance behavior was observed for two average main stream volumes of 470 and 620 (vph).

Another traffic factor that affects driver gap acceptance behavior is delay or waiting time at minor road. Driver critical gap will probably decrease as the amount of time waited increases, [Adebisi and Sama (1989), Ashworth and Bottom (1977), Daganzo (1983), Hewitt (1983), Pant and Balakrishnan (1994), Troutbeck (1984), and Velan and Aerde (1996)]. However, Pant and Balakrishnan (1994) have stated that Ashworth (1971), and Maze (1981), have found that driver decision is not affected by queuing delay. Similar result was reported by Darzentas and Mcdowell (1981) and Neudorff (1985). Researchers have incorporated delay factor in different ways. Mahmassani and Sheffi (1981) have used the number of gaps previously rejected by the driver. They stated that this factor represents driver behavior better than delay. Madanat, et al. (1994) and many other researchers have used delay as directly measured in seconds. Madanat et al. stated that number of previously rejected gaps is merely another measure of delay. They also stated that the latter represents the situation

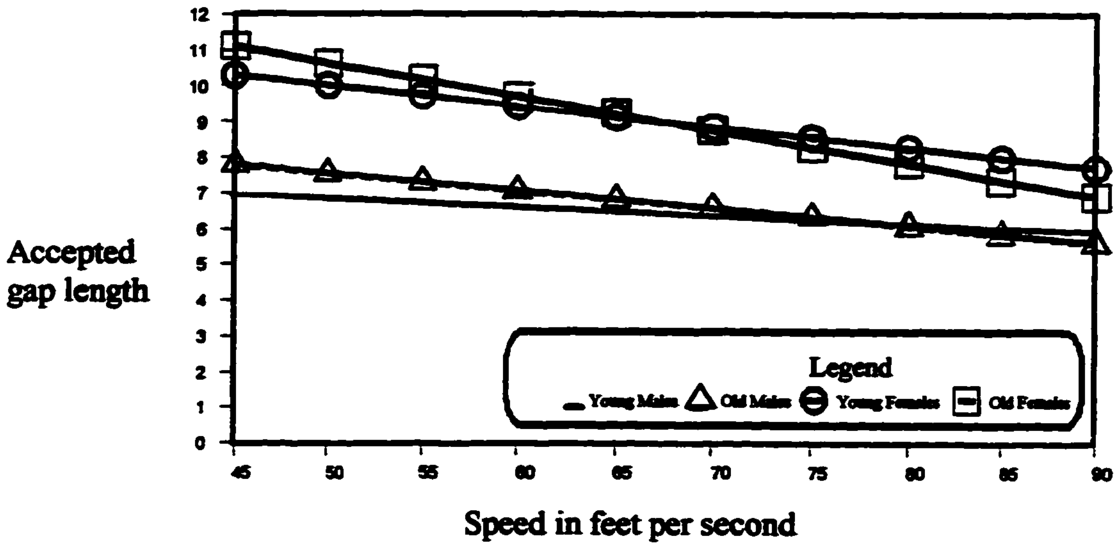


**Figure 2.1: Relationships between Accepted Gaps, speed and driver age**

Source: [Darzentas et al. (1980)]

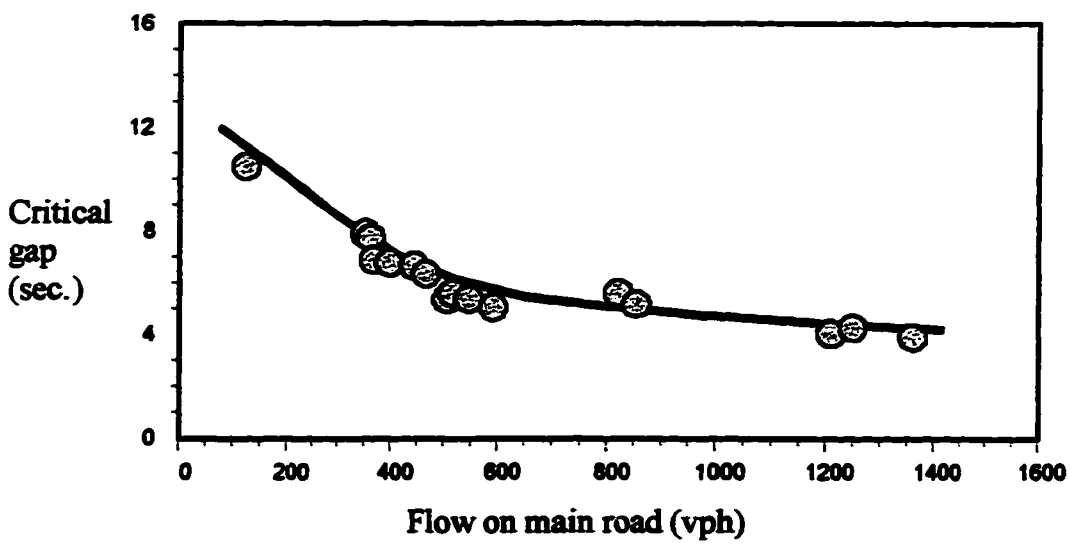


**Figure 2.2: Relationship between critical gap length and flow rate on the main road**

Source: [Adebisi (1982a)]

better. Furthermore, Madanat, et al. have modeled stop bar and queue delays separately but they found that it is better to combine both in one variable termed "total delay".

Another traffic factor that affect driver gap acceptance behavior is the speed of the oncoming vehicle [Adebisi and Sama (1989), Ashton (1971), Bates (1979), Darzentas et al. (1980), Darzentas and Mcdowell (1981), Fitzpatrick (1991), Hughes (1989), Pant and Balakrishnan (1994), Polus (1983), Tracz (1987), and Wohl and Martin (1967)]. Again, reported effects of this factor are controversial. Some studies indicated that critical gap length would increase as speed increases. Other studies revealed a negative effect of speed on gap acceptance [Pant and Balakrishnan (1994)]. Some researchers indicated that it is the ability of minor stream driver to guess the correct speed of the major stream vehicle that affects his behavior [Troutbeck (1984)]. In general, researchers [Ashworth and Bottom (1977), Bottom and Ashworth (1978), and Darzentas et al. (1980)] have found that the minimum acceptable gap "critical gap" decreases as oncoming vehicle speed increases. Figure 2.3 shows the relationship between accepted gaps (time and distance gaps) and speed of the oncoming vehicles as found by Bottom and Ashworth (1978). The relationship as found by Darzentas, et al. (1980) was previously presented in Figure 2.1.

Maneuver type, queue size at minor road, arrival time of minor stream vehicle, and pedestrian activity at priority intersections are other factors that affect driver gap acceptance behavior. Higher critical gaps are to be expected for left turns compared to right turns [Adebisi and Sama (1989), Daganzo (1987), Neudorff (1985), and Tracz

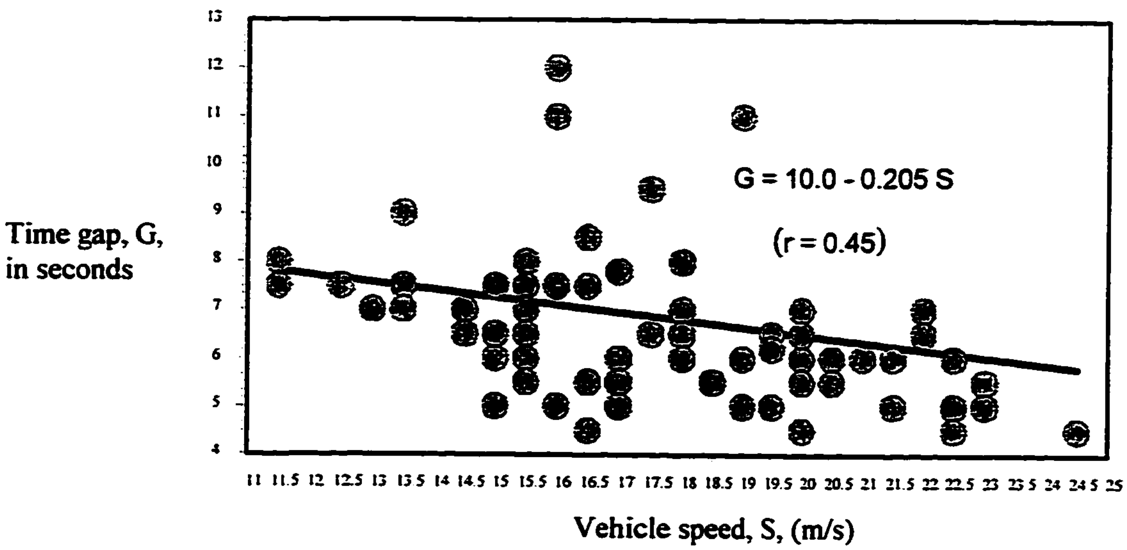


Figure 2.3, (a): Relationship between time gap, G, (sec.) and speed of approaching vehicle

Source: [Bottom and Ashworth (1978)]

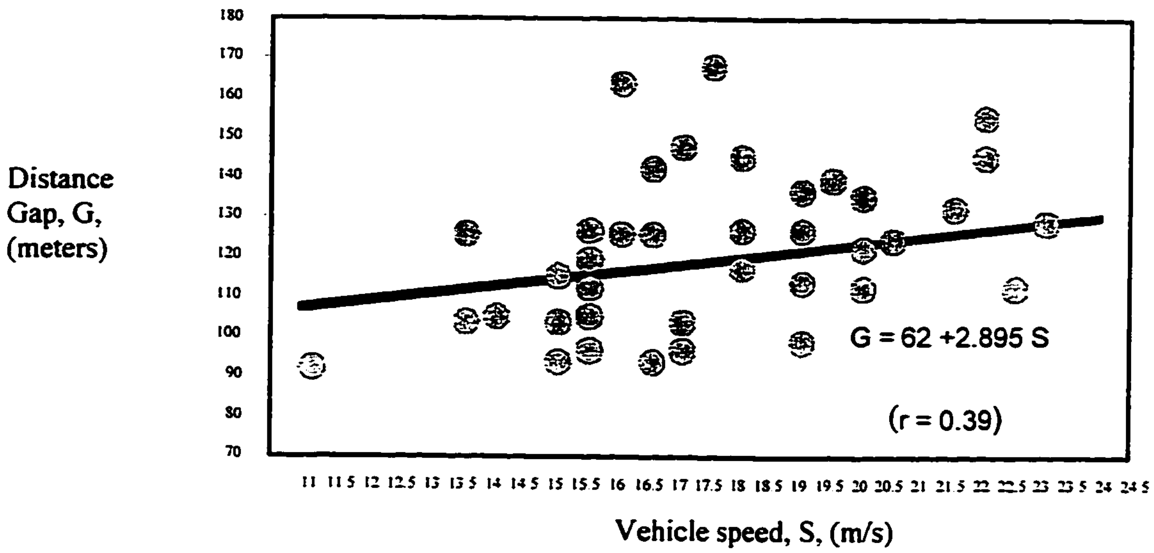


Figure 2.3 (b): Relationship between distance gap and speed of approaching vehicle

Source: [Bottom and Ashworth (1978)]

(1987)]. Pant and Balakrishnan (1994) stated that the queue size at minor stream affects driver decision to accept or reject a gap. However, Maze (1981) found that queue size at minor road is not a significant factor in gap acceptance decision. Results obtained by Maze are shown in Table 2.2. Cooper and Wennell (1978) also stated that the gap acceptance behavior of a turning vehicle does not depend on the presence of vehicles waiting behind it.

Arrival time of the minor stream vehicles was found to affect gap acceptance behavior where drivers are reluctant to accept lags [Troutbeck (1984)]. In addition, drivers accept shorter gaps during peak times compared to off-peak times [Neudorff (1985)]. Level of pedestrian activity at priority intersection is another factor that affects gap acceptance with long gaps accepted at higher pedestrian levels [Polus (1983)].

### 2.3.3 Gap Characteristics

Availability and duration (size) of gaps occurring in major stream are the main factors that affect driver gap acceptance behavior [Ashton (1971), Daganzo (1987), May (1990), Neudorff (1985), Pant and Balakrishnan (1994)]. Almost all gap acceptance models developed so far express the probability that a randomly selected driver would accept a given gap as function of the characteristics of this gap particularly its length [Mahmassani and Sheffi (1981)].

**Table 2.1: Relationship between circulating flow, critical gap and follow-up time at a roundabout.**

| Circulating flow (vph) | Critical gap (sec) | Follow-up time (sec). |
|---|---|---|
| 450 | 3.96 | 2.64 |
| 900 | 3.35 | 2.46 |
| 1350 | 2.78 | 2.29 |

Source: [Chung et al. 992)]

**Table 2.2: Relationship between queue size at minor road and median of acceptance gaps.**

| Queue length (cars) | Median accepted gap length (sec.) |
|---|---|
| 1-5 | 5.50 |
| 6-10 | 5.55 |
| 11-15 | 5.50 |
| 16-20 | 5.60 |
| ≥ 21 | 5.58 |

Source: [Maze (1981)].

### 2.3.4 Vehicle Characteristics

Vehicle characteristics which affect gap acceptance include; vehicle type [Bottom and Ashworth (1978) and Daganzo (1987)], vehicle occupancy [Daganzo (1987)], and engine capacity [Ashton (1971) and Bottom and Ashworth (1978)]. Vehicle type (truck or passenger car, PC) also affects gap acceptance significantly [Fitzpatrick (1991)]. Bottom and Ashworth (1978) indicated that stronger vehicles accept shorter gaps and that accepted gaps are longer where oncoming vehicle is commercial vehicle even when the effect of speed is removed. In another study, Ashworth and Bottom (1977) found that the within driver behavior of gap acceptance is ***not*** affected by the type of oncoming vehicle (commercial or PC) or by the size of the gap subsequent to the one which the driver had accepted.

### 2.3.5 Intersection Characteristics

Literature has cited many intersection characteristics that can affect driver gap acceptance behavior at priority intersections. These characteristics include site distance and visibility [Adebisi and Sama (1989), Daganzo (1987), and Neudorff (1985)], pavement condition [Ashton (1971) and Daganzo (1987)], road geometry [May (1990), Pant and Balakrishnan (1994) and Tracz (1987)], and type of control [Daganzo (1987), Pant and Balakrishnan (1994) and Polus (1983)]. Polus (1983) stated that type of control can not, by itself, explain the differences in accepted gaps. Neudorff (1985) stated that shorter gaps are accepted at intersections with restricted sight distance.

### 2.3.6 Trip Characteristics

Troutbeck (1993) mentioned that some trip attributes might affect driver gap acceptance behavior. He stated that drivers who are traveling short distances might be more apprehensive about entering the intersection.

### 2.3.7 Driver Inter-influence Factors

It is expected that driver behavior can (to some extent) be affected by the behavior of other drivers at the scene. Not much concern was devoted to identifying and studying the effects of driver inter-influence factors on gap acceptance behavior. One of such factors which has received some attention is the queue length behind the driver ahead. However, results reported on the effect of this factor are inconsistent as discussed in Section 2.2.2.

## 2.4 COLLECTION AND MEASUREMENT OF GAP ACCEPTANCE DATA

### 2.4.1 Data Collection Methods

Gap data can be collected using certain types of automatic vehicle detectors, laptop computers, audio tapes in combination with microcomputers, video tapes, or stop watches [Robertson (1994)]. Over a number of years, interest in the use of time

lapse cine films for the measurement of speed, headway, and delays has given way to the use of video recordings [Dickinson and Waterfall (1984)]. Pant and Balakrishnan (1994) used cameras to collect data on gap acceptance for 16 intersections. They collected data for 5230 observations (vehicles). Seventy six percent of the collected data was used for model building. The remaining 24 % was used for testing purposes. Other researchers who used video cameras with zoom lens and built in digital clock include Bottom and Ashworth (1977 and 1978), Madanat et al (1994) and Polus (1983 and 1985). The later has recorded intersection operation for 30 minutes and collected data on 217 gaps to build a binary logit model for right merging maneuver at a T priority intersection. Fitzpatrick (1991) has also used a video camera placed along the minor road as shown in Figure 2.4 to maximize the length of the road that can be filmed without jeopardizing the resolution of vehicles on the video tape.

### 2.4.2 Measurement of Critical Gap

By its nature, the critical gap of an individual driver is impossible to measure directly, [Fitzpatrick (1991), Golias and Kanellaidis (1990), and Hewitt (1983 and 1985)]. Observations at a junction will show only the range within which the critical gap of each driver must lie, between the length of the largest gap he rejected and the length of the gap he eventually accepted, [Hewitt (1983 and 1985) and Fitzpatrick (1991)].

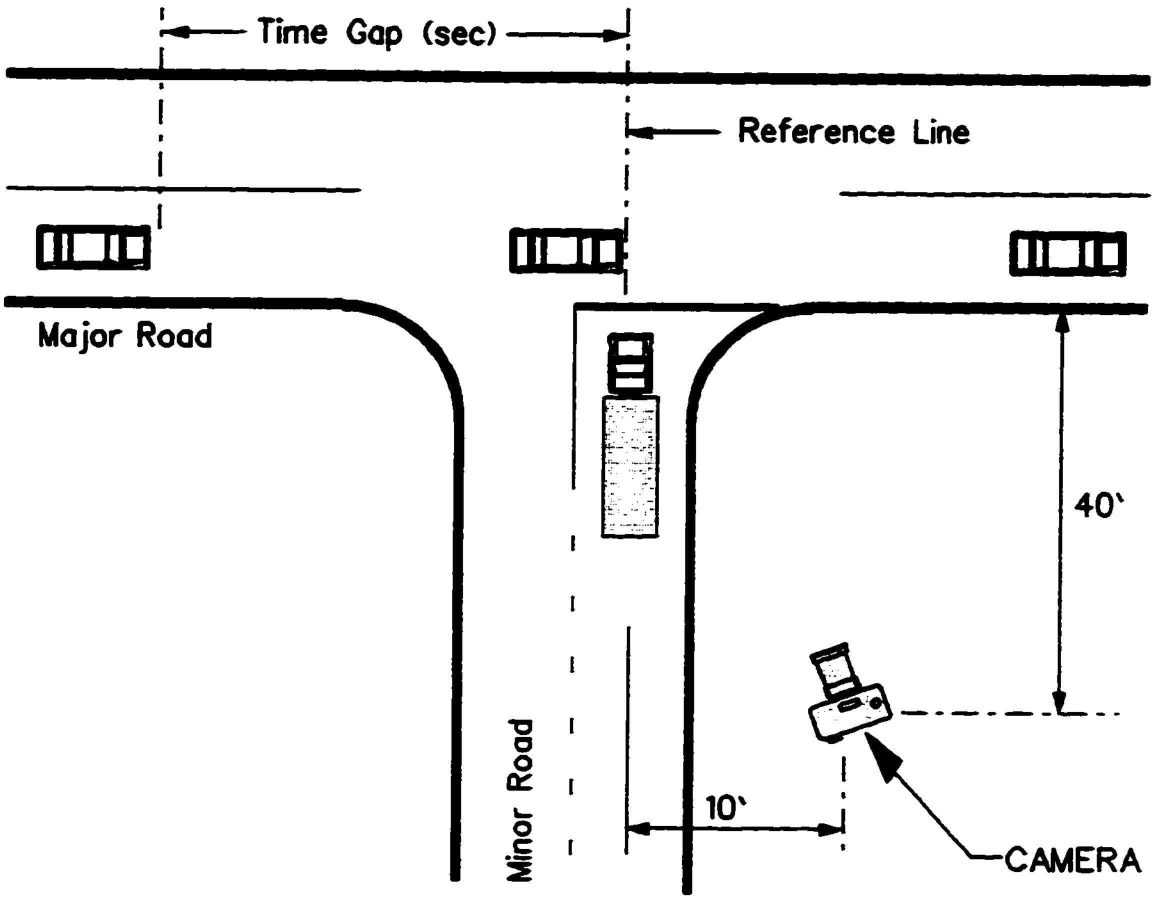


**Figure 2.4 Setup for Data Collection Followed by Fitzpatrick**

**Source: [ Fitzpatrick, 1991 ]**

### 2.4.3 Typical Values of Critical Gaps

Previous gap acceptance studies mostly deal with single minor and major traffic streams. Tables 2.3 through 2.5 present the results of some of those studies regarding critical gap values observed at priority intersections other than roundabouts. Table 2.6 presents gap acceptance parameter values obtained for roundabout intersections by different researchers. Table 2.7 shows gap values given in the 1985 and 1994 USA Highway Capacity Manuals and in the 1977 Swedish Capacity Manual. Note that these values are functions of the speed of vehicles on major stream.

### 2.4.4 Difficulties in Estimating Critical Gap

Difficulties in measuring and estimating critical gaps include:

a. Critical gap (by its nature) can not be measured exactly, [Hewitt (1983 and 1985) and Golias and Kanellaidis (1990)]. Its value for a given driver is somewhere between the longest gap he rejects and the gap he eventually accepts, [Hewitt (1983 and 1985)].

b. Driver reaction to lags is different than his reaction to gaps, [Hewitt (1983 and 1985) and Golias and Kanellaidis (1990)].

**Table 2.3: Some typical values for critical gaps in seconds.**

| Type of Maneuver at Minor Road | | | Reference |
|---|---|---|---|
| **Right turn** | **Straight through** | **Left turn** | |
| 3.0 - 4.0 | - | - | Troutbeck (1984) |
| 4.47 | 4.70 | 9.56 | Ashworth (1971) (normal time) |
| 4.05 | 4.22 | 6.04 | Ashworth (1971) (Rush hour) |
| 3.5 - 4.5 | 4.0 - 5.0 | 5.0 - 6.0 | NAASRA (1974) |
| 5.5 | 5.8 | 6.6 | May A. (1990) |
| - | 4.5 - 8 | — | Wohl and Martin (1967) |

Source: As given in the last column

**Table 2.4: Typical critical gap values obtained in different studies**

| Study (Analysis Method) | Measured | Gap | |
|---|---|---|---|
| Greensheild (1947) (Greensheild Method) | Crossing | Average minimum acceptable time gap = 6.1 sec. | |
| Raff (1950), (Raff Method) | Crossing | Critical lag = 5.9 sec.<br>Critical gap = 6.1 sec. | |
| Bessell (1960), 2 intersections, (Bessell Method) | Crossing | Critical gap = 5.8 sec. | |
| | | Gap accepted by 50 percent of drivers | |
| Radwan et al. (1980), multilane divided highways, 6 intersections, (Logit Method) | Right turn<br>Through, one maneuver<br>Through, two maneuvers<br>Left turn, one maneuver<br>Left turn, two maneuvers<br>Trucks, all maneuvers | 6.73 sec.<br>7.90 sec.<br>7.20 sec.<br>6.32 sec.<br>6.60 sec.<br>8.40 sec. | |
| | | Critical Gap | Critical Lag |
| Polus (1983), 2 intersections in Israel, (Raff Method) | Right turn from minor to major, Yield<br>Right turn from minor to major, Stop | 5.20 sec.<br>7.47 sec. | 5.10 sec.<br>7.55 sec. |

| Study (Analysis Method) | Duration Stop Delay (sec.) | Mean Delay for Group | Number of Samples | Mean Critical Gap (sec.) |
|---|---|---|---|---|
| Adebisi and Sama in (1989), 2 intersections Nigeria, Africa, left turns, (CHOMP computer program) | < 5.0 | 3.23 | 91 | 20.99 |
| | 5.1 - 10.0 | 7.46 | 209 | 18.77 |
| | 10.1 - 15.0 | 12.01 | 91 | 17.58 |
| | 15.1 - 20.0 | 16.52 | 61 | 16.31 |
| | 20.1 - 25.0 | 21.65 | 104 | 9.87 |
| | 25.1 - 30.0 | 27.53 | 66 | 10.46 |
| | 30.1 - 35.0 | 32.74 | 76 | 8.62 |
| | 35.1 - 40.0 | 37.78 | 48 | 8.29 |
| | 40.1 - 60.0 | 46.66 | 42 | 6.78 |
| | > 60.0 | 75.85 | 16 | 5.32 |

Source: Fitzpatrick (1991)

**Table 2.5: Median accepted gap values from major gap acceptance studies using probit analysis**

| Study | Measured | Median Accepted Gap (sec.) |
|---|---|---|
| Solberg and Oppenlander (1966), 4 intersections | Right Turn<br>Left Turn<br>Through | 7.36<br>7.82<br>7.18 |
| Cooper and McDowell (1977) Effects of police presence and police activity (warning signs or police motorcycle parked in view) at 3 intersections | Right Turn (UK) from minor road and merging with major road | 4.6 without police<br>5.7 with police<br>5.3 without police activity<br>5.9 with police activity |
| Cooper, Smith, Broadie (1976),<br><br>1 intersection | Left Turn (UK) from minor side<br>road and merging with the near<br><br>stream | Approach speed (mi/h) · Median accepted Gap (sec.) · (ft)<br>17.5 · 6.86 · 150<br>22.5 · 6.69 · 221<br>27.4 · 5.95 · 240<br>32.5 · 6.34 · 302<br>37.4 · 5.35 · 294<br>D= 38 + 5V where D is in ft and V is in ft/sec. |
| Darzentas, Holmes, Mcdowell (1980), 1 intersection, 10 evenings | Left Turn (UK) | 6.58 sec. daylight<br>6.32 sec. twilight<br>5.62 sec. darkness |
| Wennell and Cooper (1981), 4 intersections | Left Turn (UK) | Site · Cars (sec) · Goods (sec)<br>1 · 3.91 · 4.63<br>2 · 3.66 · 5.33<br>3 · 4.31 · 4.99<br>4 · 4.41 · 4.91 |

Source: [Fitzpatrick (1991)

**Table 2.6: Gap acceptance parameter values obtained in different studies**

| Reference | T | $T_o$ | Δ | Notes |
|---|---|---|---|---|
| Grant (1969) | 3.8 | 2.7 | 1.8 | 1 |
| Armitage and McDonald (1974) | 3.4 | 2.3 | 1.2 | 1 |
| Armitage and McDonald (1974) | 3.6 | 2.3 | 1.2 | 1, 2 |
| Ashworth and Field (1973) | 3.3 | 3.3 | 0.0 | 1, 3 |
| Ashworth and Laurence (1978) | 3.2 | 3.2 | 0.0 | 1, 3 |
| McDonald And Armitage (1978) | 3.8 | 2.4 | 0.0 | 1 |
| Horman and Turnbull (1974) | 4.0 | 2.0 | 0.0 | 1 |
| Horman and Turnbull (1974) | 4.0 | 2.0 | 1.5 | |
| Avent and Taylor (1979) | 3.5 | 2.1 | 2.2 | |
| Avent and Taylor (1979) | 3.5 | 2.1 | 1.1 | 1 |
| NAASRA (1982) | 4.0 | 2.0 | 2.0 | |
| NAASRA (1982) | 4.0 | 2.0 | 0.0 | 1 |

Notes:

1. two lane entries
2. Calculated from entry capacity and circulation flow data
3. Modified Tanner's (1962) equation used

Definition of parameters:

T: Critical gap in major stream

$T_o$: minimum possible headway in minor stream (move-up time)

Δ: minimum possible headway in major stream (follow-up time)

Source: [Troutbeck (1984)]

**Table 2.7: Critical gap values used in USA and in Swedish Highway Capacity Manuals**

| Manual | Gap (sec) | | | | |
|---|---|---|---|---|---|
| | Secondary Approach Stream | | | | |
| | Speed (mph) | Sign | Right turn | Straight | Left turn |
| **Swedish Capacity Manual (1977), based on 18 intersections** | 31 | Yield | 4.8 | 5.2 | 5.3 |
| | | Stop | 5.5 | 5.8 | 6.0 |
| | 43 | Yield | 6.0 | 6.0 | 6.2 |
| | | Stop | 6.5 | 6.5 | 6.8 |
| | 56 | Stop | 7.2 | 7.0 | 7.5 |
| **USA Highway Capacity Manual (1985)** | | **Average running speed, major road (mph)** | | | |
| | | **30** | | **55** | |
| | | Number of lanes on major road | | | |
| | | 2 | 4 | 2 | 4 |
| | Right - Stop (sec) | 5.5 | 5.5 | 6.5 | 6.5 |
| | Right - Yield (sec) | 5.0 | 5.0 | 5.5 | 5.5 |
| | Left - Stop (sec) | 6.5 | 7.0 | 8.0 | 8.5 |
| | Left -Yield (sec) | 6.0 | 6.5 | 7.0 | 7.7 |
| | Cross - Stop (sec) | 6.0 | 6.5 | 7.5 | 8.0 |
| | Cross - Yield (sec) | 5.5 | 6.0 | 6.5 | 7.0 |

Adjustments and modifications to critical gap (sec):

Right from minor street: curb radius > 50 ft or turn angle < 60 degree = -0.5 sec

Right from minor street: acceleration lane provided = -1.0 sec

All movements: population > 250,000 = -0.5 sec

Restricted sight distance = up to +1.0 sec

**Source: [Fitzpatrick (1991)]**

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**Critical gaps and follow-up times used in the USA 1994 Highway Capacity Manual for Two-Way Stop-Controlled intersections**

| Vehicle Maneuver | Critical Gap ($t_g$) in seconds | | Follow-up time , $t_f$ (Sec.) |
|---|---|---|---|
| | Two-Lane major road | Four-Lane major road | |
| Left turn, major street | 5.0 | 5.5 | 2.1 |
| Right turn, minor street | 5.5 | 5.5 | 2.6 |
| Through traffic, minor street | 6.0 | 6.5 | 3.3 |
| Left turn, minor street | 6.5 | 7.0 | 3.4 |

Note: Values in the above table apply to major street approach speeds of 30 mph in average. The values can still be used in other cases if no better data are available.

**Source: [USA 1994 Highway Capacity Manual]**

c. Drivers with multiple rejections will be over represented in the sample. Each driver who rejects a number of gaps will be presented by as much times as the number of gaps he rejected. While a driver who accepts the first gap/lag will be presented in the sample only once [Hewitt (1985)].

### 2.4.5 Methods of Finding Critical Gap

Critical gap can be found using graphical methods [Adebisi (1982), Drew (1968), Madanat, et al. (1994) and Salter (1976)] or analytical and empirical methods. In graphical methods, critical gap is associated to the point of intersection of the two curves representing number of rejected gaps greater than (t) and number of accepted gaps less than (t) where (t) extends over the possible time length of the observed gaps [Ashton (1971), Darzentas (1989), and Polus (1983)]. Graphical method is illustrated in Figure 2.5. Despite of the simplicity of the graphical method, its findings show high correlation with findings based on other analytical methods [Adebisi (1982a)].

Due to difficulties embedded in measuring the critical gaps, (see Section 2.3.4) many analytical methods were developed to estimate this important parameter. Detailed comparisons and comments on the main available critical gap estimation methods are discussed by Hewitt (1985). A summary of these methods and the resulted mean errors and standard deviations using each method are shown in Table (2.8). Hewitt (1985) concluded that the maximum likelihood method gives the most accurate mean

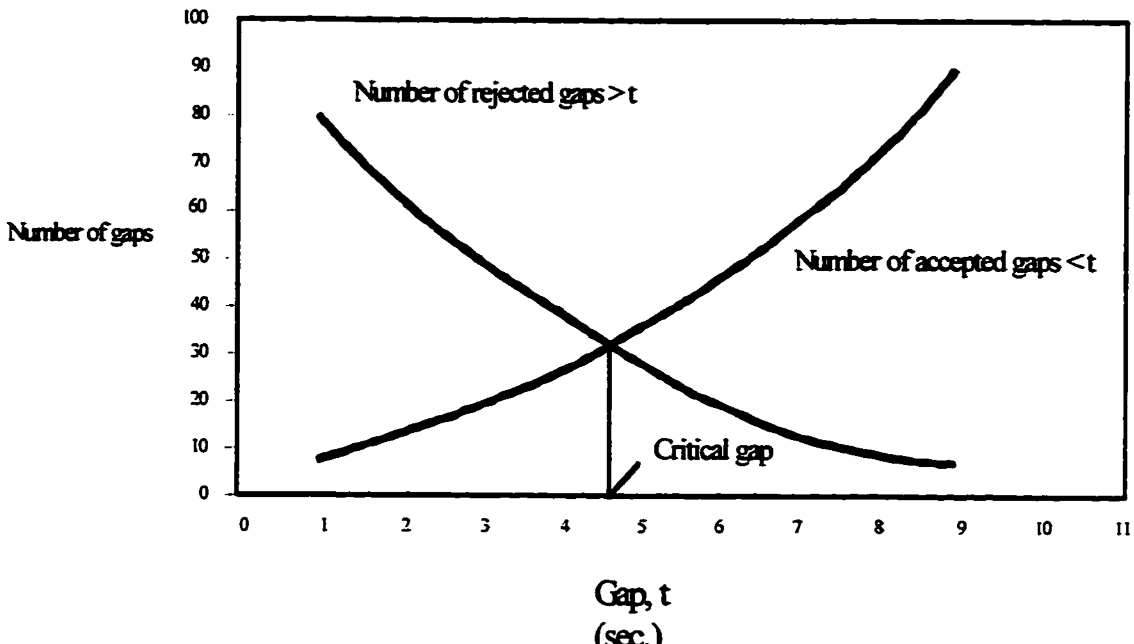



Figure 2.5: Graphical determination of critical gap

Source: [Adebisi (1982a)]

and standard deviation but it is comparatively complicated. Although Ramsy-Roultledge method is the simplest, it shows a comparable precision to other methods.

### 2.4.6 Classification of Observed Gaps

In gap acceptance studies, each data point (gap or lag) can be categorized as an accepted gap/lag, a rejected gap/lag, or an untested gap (no minor stream vehicle exists) [Robertson (1994)].

## 2.5 MODELING OF GAP ACCEPTANCE BEHAVIOR

### 2.5.1 Driver Reaction to Lags and Gaps

Response of minor road drivers to lags and gaps has been a controversial issue in previous gap acceptance studies. Darzentas and Mcdowell (1981) and Pant and Blakrishnan (1994) have cited that there is no significant difference in driver reaction to lags and gaps. However, many other researchers like Golias and Kanellaidis (1990), Hewitt (1983), and Hewitt (1985) have reported that drivers react differently to gaps and lags and that these two values cannot be assumed to be equal. Researchers like Daganzo (1981) and Polus (1983) have reported that **the mean critical gap is significantly smaller** than the mean critical lag. This result can be related either to the fact that drivers first tend to familiarize themselves with the situation and do not, usually, take advantage of their lags though they are of appropriate length [Daganzo

(1981)], or to the impatience effect of driver delay after he rejects his lag [Ashworth and Bottom (1977)].

Golias and Kanellaidis (1990) reported that the above mentioned result is due to the incorrect assumption that gap and lag acceptance distributions are identical. The assumption of having different critical gap and critical lag acceptance functions is closer to actual driver behavior. A model that assigns to each driver ( $i$ ) a critical lag ($L_i$) equals to a constant (A) times the critical gap ($G_i$), i.e. ($L_i = A \times G_i$) can be a reasonable representation of reality. The assumption that (A) takes a constant value for all drivers is made for reasons of mathematical simplicity and it is believed that it will preserve a satisfactory accuracy in highway analysis [Golias and Kanellaidis (1990)]. Value of (A) depends on critical lag and gap acceptance distributions and on the distribution of headways in major stream. Golias has given the following formula to find (A) when critical gaps and lags are assumed to follow gamma distributions of the form:

$$\alpha_L(X) = \frac{b^\alpha}{\Gamma(\alpha)} e^{(-bx)} X^{\alpha-1} \qquad \text{Where,}$$

$\alpha_L$ (X): Probability function that describes the distribution of accepted lags;

$\alpha$ , b : Parameters of gamma function;

$\Gamma$ ($\alpha$) : Gamma function;

and when headways in the major stream are assumed to follow a negative exponential distribution of the form:

$$f(t) = qe^{-qt}$$

Where,

f(t) : Distribution of gaps in major stream;

q : Major stream flow in vehicles per second.

Values of (A) found by Golias and Kanellaidis under these assumptions and for different levels of major stream flow (q) are given in Table 2.9.

In majority of the cases, researchers used lags and gaps combined because after treating them separately they found that the estimated parameters and probabilities of acceptance were similar for both of the lags and gaps [Darzentas (1989)]. Pant and Balakrishnan (1994) have reported that critical gap values obtained by using gaps alone were overestimated while the use of lag data alone has resulted in information loss. Hewitt (1985) has reported that the advantage of methods based on all gaps over those based on lags only is clear. He stated that "*There appears to be no merit in using any method based on lags alone*".

### 2.5.2 Critical Gap Distributions

Assumption about the proper statistical distribution that can best fit accepted gaps is one of the basic assumptions in gap acceptance studies. Many researchers indicated that critical gap should be treated as a random variable and several probability distributions were suggested [Madanat et al. (1994)]. These distributions included;

**Table 2.8: Mean errors and Standard deviations of 100 estimates of mean critical gap and its standard deviation**

| Method | Time Type of the used gap (Gap/Lag) | Whether the Distrib-ution is free or not | Statistics for the Estimated Mean | | Statistics for the Estimated Standard Deviation | |
|---|---|---|---|---|---|---|
| | | | Average error | Standard deviation | Average error | Standard deviation |
| Raff | Lags | Yes | -0.211 | 0.321 | -- | -- |
| Probit | Lags | No | 0.029 | 0.308 | 0.04 | 0.40 |
| Blunden | Lags | Yes | -0.138 | 0.287 | -0.44 | 0.24 |
| Mcneil | Lags | Yes | -0.019 | 0.332 | -0.04 | 0.60 |
| Hewitt | Lags | Yes | -0.079 | 0.306 | -0.42 | 0.35 |
| Drew | Max. gap | Yes | 2.720 | 0.638 | 2.66 | 0.84 |
| Dawson | Max. gap | Yes | 1.413 | 0.315 | 1.65 | 0.34 |
| Ashworth | All gaps | No | -0.023 | 0.197 | 0.06 | 0.19 |
| Miller | All gaps | Yes | -0.544 | 0.168 | -0.16 | 0.20 |
| Maximum likelihood | All gaps | No | -0.011 | 0.173 | -0.01 | 0.16 |
| Hewitt | All gaps | Yes | 0.081 | 0.230 | -0.09 | 0.20 |
| Ramsey-Routledge | Gaps Accepted | Yes | -0.015 | 0.222 | -0.02 | 0.20 |

Source: [Hewitt (1985)]

**Table 2.9: Values of (A) for different major stream flow rates**

| $q$ (veh./sec.) | 0.15 | 0.18 | 0.19 | 0.20 |
|---|---|---|---|---|
| (A) | 0.73 | 0.96 | 0.83 | 0.83 |

simple negative exponential [Hughes (1989)], truncated normal and truncated Weibul [Darzentas (1989)], Log and log normal [Cheng and Allam (1992), Chin (1985), Bottom and Ashworth (1978)], normal [Bottom and Ashworth (1978), Daganzo (1981) and Madanat et al. (1994)], and gamma distribution, [Ashton (1971)]. Some critical gap estimation methods, like Ramsy-Routledge method mentioned in Table 2.8, have the advantage of being distribution free and they make no assumptions about the form of the accepted gaps distribution [Hewitt (1985)].

### 2.5.3 Gap Acceptance Models

Studies of gap acceptance behavior have so far been in one of two model forms [Adebisi and Sama (1989)]:

a. Queue acceptance models which relate the length of each accepted gap in the major stream to the number of minor stream vehicles that accept (enter into) the gap;

b. Gap acceptance models that relate the length of gaps in main stream to the probability of accepting those gaps by minor stream drivers.

Based on the three driver behavioral concepts discussed in Section 1.3, several methods including empirical analyses and theoretical logit and probit models have been used to develop gap acceptance functions at priority intersections [Pant and Balakrishnan (1994)]. However, the majority of these methods have adopted the

consistent driver concept, which shows to produce only minor errors in capacity and delay estimates [Golias and Kanellaidis (1990) and Hewitt (1985)]. The earliest and simplest form of gap acceptance was originally explained by a step function of the form expressed below, [Pant and Balakrishnan (1994)]. Similar step function was used by Tanner (1962).

$$f(g) = H(g - c)$$
$$f(g) = \begin{cases} 0, \text{for } g < c \\ 1, \text{for } g \geq c \end{cases}$$

Where,

g: any gap in seconds;

c: critical gap in second;

f(g): probability of accepting a gap of length (g).

Discrete-Choice modeling techniques for predicting gap acceptance probabilities were proposed and demonstrated by several researchers [Madanat et al. (1994)]. As cited by Pant and Balakrishnan (1994), Solberg and Oppenlander (1962) have used probit analysis for the statistical treatment of gap acceptance phenomenon. The probit of the expected proportion accepting a gap (g) was expressed as [Pant and Balakrishnan (1994)]:

$$y = 5.0 + \frac{1}{\sigma}(X - \mu)$$

Where,

$y$: probit of proportion accepting gap (g);

$X$: logarithm of gap (g); ($X = \log(g)$);

$\mu$: mean;

$\sigma$: standard deviation.

Probit modeling approach has been used by other researchers like Daganzo (1981) and Mahmassani and Sheffi (1981). Maze (1981) has modeled gap acceptance behavior using a binary logit model of the form:

$$P = \frac{1}{1 + e^{F(X)}}$$

where,

$P$: cumulative probability of accepting a gap;

$X$: variables affecting gap acceptance;

$F(X)$: linear function in the attributes and factors that affect driver gap acceptance behavior.

Binary logit models were also developed by Fitzpatrick (1991) and Madanat, et al. (1994). Many researchers as stated by Madanat et al. (1994) have indicated that parameter estimates generated by logit models would not differ significantly from those generated by probit models. Probit and logit models differ only in scale, [Matsos (1985)].

## 2.6 DISCRETE CHOICE MODELING

### 2.6.1 Theoretical Background

The increasing use of disaggregate analysis in general and logit models in particular has led to a better use of the data, and indeed, to an improvement in the statistical basis of model building in general [Bates (1979), and Daganzo (1979)].

Discrete choice models are used to analyze situations in which a decision maker is faced with a finite and exhaustive set of mutually exclusive discrete choices. These models operate at the level of individual decision maker and provide the researcher with the probability with which any particular individual will take a given action [Genc (1994)]. Various forms of probabilistic choice functions have been proposed and used in different contexts. However, logit and probit functions have received greater attention [Daganzo (1987)]. Specifically, logit model in its various forms has been used for most individual discrete choice situations [Dickinson and Waterfall (1984) and Hewitt (1983)].

Probabilistic choice models are used to estimate the probability, ($P_{ai}$), that alternative (a) is selected by decision maker (i) where, ($P_{ai}$) is function of all factors that influence the choice process [Fischer and Nijkamp (1987)]. Desirability of choosing an alternative is usually based on the utility offered by that alternative. This utility is commonly expressed as a linear additive function that takes the form [Borgers

and Timmermans (1987), Fischer and Nijkamp (1987), Gerken (1991), Horowitz (1981), Horowitz (1991) and Wintraud (1991)]:

$$U_{ai} = v_{ai} + \varepsilon_{ai}, v_{ai} = \sum_{k} \beta_k X_{aki}$$

where,

$U_{ai}$ : utility of alternative (a) to individual (i);

$v_{ai}$ : systematic (deterministic or representative) component of utility;

$\beta_k$ : weight of the $K^{th}$ attribute;

$X_{aki}$ :value of the $K^{th}$ attribute which affects the choice of alternative (a) by individual (i);

$\varepsilon_{ai}$ : random component of utility which constitutes to unobserved attributes, imperfect information, and taste variations.

The model given above is the general form of the Logit Model. There are, however, two main approaches or assumptions in specifying Choice Model or in formulating the Utility Function for each alternative [Ben Akiva and Lerman (1985) and Manheim (1979)]. These assumptions are discussed in the following paragraphs based, basically, on Manheim (1979).

*i. Choice or Alternative Independent Utilities:*

In this case, the Utility Function is specified as "Choice Independent" in terms that the Function will be identical for all choices and independent of the choice. In this case the utility function takes the following form:

$$U_a = \sum_i \beta X_i$$

where, (a) stands for choice or alternative and $X_i$ stands for the $i^{th}$ attribute which is defined common for all choices. This means that none of the attributes is defined specific to any of the available choices or alternatives. Instead, each alternative is characterized by the same attributes and the same Utility Function although, the values of attributes and consequently the values of Utilities will be different for each alternative. The idea is that every attribute is given the same weight in the two Utility Functions. An example is a binary mode choice model (Bus and Air modes say) with travel time used as an attribute for both of the modes. Using the above specification for this example implies that the unit time (say an hour) has the same marginal effect on the utility whether it is incurred on the Bus mode or on the Air mode since the coefficient of the Utility Function of that attribute will be the same for both modes.

This Hypothesis is usually referred to as "Choice Abstract", and can be invalid for any of several reasons which include, [Manheim, (1979)]:

**a.** Some attributes are important and cannot be specified common for all of the choices. For example, the availability of an auto is an attribute which is specific to auto mode only in a Binary Choice Model for auto and transit;

**b.** It doesn't allow for different weights to be given by the choice maker to an attribute. For example the choice maker may give time incurred on air higher weight than time incurred on bus.

The Choice-Independent or "Choice Abstract" Model, however, has some advantages which include the less number of coefficients (parameters) to be estimated and the more efficient use of data in case if new similar alternatives (choices) may be introduced in future. However, the last point does not apply for the gap acceptance case since no more choices can develop. The only possible two choices are either to accept or to reject the offered gap.

*ii. Choice or Alternative dependent Utilities:*

In this case the Utility Functions for different choices are different in terms that attributes which are particular to a specific alternative or Choice are included in the Utility Function of that choice only and not in the Utility Function of the other. The Utility Function in this case takes the form:

$$U_{ai} = \sum_{i} \beta_{ai} X_{ai}$$

where, a stands for choice or alternative and i for the attribute.

If all attributes are specified as alternative dependent, the model will be completely choice dependent and, if some are specified as alternative dependent and some as alternative independent, the model will be partially choice-dependent.

Socioeconomic variables like age and sex basically reflect the differences in preferences for the available alternatives as function of these variables, [Ben Akiva and Lerman, (1985)]. For any given individual (a driver in this case) these variables are

constants in effect and, it would make no sense to define these variables in both alternatives because all that matters is their effect on the relative utility.

The choice of including these variables as alternative specific to either of the choices is wholly arbitrary [Ben Akiva & Lerman (1985)]. Only the sign of the corresponding coefficient will change by changing the choice to which they are specified. The differences in utilities and consequently the choice probabilities will remain unaltered. It should be noted that the above discussion applies for the typical discrete choice cases (like mode choice example) in which each individual has a priori known set of choices to select among them. For model calibration in these cases, data for each individual are organized in C rows where C is the number of the available choices or alternatives. In each data row the dependent variable is presented by the observed choice while the independent variables are presented by a vector of attributes which affect the choice.

Another approach which is more applicable for cases in which the decision maker is faced by one choice at a time and he decides either to accept or reject that choice is considered more appropriate to the studied gap acceptance phenomenon. The adopted methodology of organizing data for the purpose of calibrating gap acceptance models in this study is different in that each observation (the process of evaluating a gap and rejecting or accepting that gap) is coded as an individual row of data. This implies that different gaps evaluated by the same driver are treated as independent observations. However, previous studies indicated that gap acceptance increases as delay increases, [Adebisi (1989) and Madanat et al. (1995)]. Therefore different delay factors (delay in

queue, delay at queue head, and the total delay) are included in this study. More details about the gap acceptance phenomenon and the adopted methodology to organize the data for the purpose of calibrating binary logit models for the phenomenon are given in Chapter 4, Section 4.3.6.

As mentioned above, the utility derived from an alternative is used to measure the desirability of decision maker to select that alternative. When the mentioned utility is considered random, the model is termed "*random utility model*". In such a model, it is assumed that decision makers associate random utility values to alternatives and then choose, as stated by utility theory, so as to maximize utility. As shown above, utility is decomposed into a deterministic part ($v_{ai}$) and a random part ($\varepsilon_{ai}$) [Ben-Akiva and Lerman (1985) and Wintraud (1991)]. The utility function is not known *a priori* and it has to be specified and calibrated. The specification step consists of determining the form of utility function which is usually a linear function including unknown parameter vector $\beta$. The calibration step consists of finding the estimated values in vector $\beta$, i.e., finding the vector $\hat{\beta}$ using estimation methods like least squares and maximum likelihood [Ben-Akiva and Lerman (1985) and Daganzo (1987)].

To predict the probability of choosing an alternative (a) by individual (i), the utility of this alternative should be transferred into a probability. This can be attained using probabilistic choice logit models which transform utility into probability in the following manner [Daganzo (1987), Southworth (1981), and Wintraud (1991)]:

$$P_{ai} = \frac{e^{\upsilon_{ai}}}{\sum_{j=1}^{C} e^{\upsilon_{aj}}}$$

where,

$P_{ai}$ : probability of choosing alternative (a) by individual (i);

e : natural logarithm base (constant value);

$\upsilon_{ai}$ : the systematic component of the utility of alternative (a) to individual (i);

j : the $j^{th}$ alternative;

C : choice set (set of alternatives available for individual (i));

$\upsilon_{ji}$ : the systematic component of the utility of alternative (j) to individual i (j = 1, ...., C).

The probability of choosing an alternative (a) by individual (i), $P_{ai}$, is equivalent to the probability that the utility of this alternative to individual (i) will exceed the utility of each and every other alternative (j), ($j \neq i$), in the choice set (C) available for individual (i), [Ben-Akiva and Lerman (1985), Borgers and Timmermans (1987), Fischer and Nijkamp (1987), Horowitz (1991)], i.e.:

$$P_{ai} = \text{Prob.} ( U_{ai} > U_{ji} ), \ \forall\, i \neq j , i = 1, 2, \ldots\ldots, C)$$

$$P_{ai} = \text{Prob.} (\nu_{ai} + \varepsilon_{ai} > \nu_{ji} + \varepsilon_{ji}) , \ \forall\, i \neq j , i = 1, 2, \ldots\ldots, C)$$

$$P_{ai} = \text{Prob.} (\nu_{ai} - \nu_{ji} > \varepsilon_{ji} - \varepsilon_{ai}), \ \forall\, i \neq j , i = 1, 2, \ldots\ldots, C)$$

The dependent variable for the above stated choice model is the observed choice from a set of available alternatives. The probabilities of choice are, however, ***not***

observed and, only the actual choices are observed. Hence the observed dependent variable takes a value of either zero (concerned alternative is not chosen) or one (concerned alternative is chosen) [Southworth (1981)].

One main difference between various random utility choice models is the assumption underlying the probability distribution of the random component of the utility function [Horowitz (1991)]. The simplest and most widely used logit model assumes that random component is identically independently distributed as weibull distribution [Ben-Akiva and Lerman (1985), Fischer and Nijkamp (1987), Horowitz (1981), and Horowitz (1991)] while probit model assumes that it is multivariate normal distribution.

### 2.6.2 Use of Discrete Choice Models in Gap Acceptance Studies

Several researchers have previously proposed and demonstrated the applicability of discrete choice modeling techniques to model driver gap acceptance behavior [Madanat et al. (1994)]. The choice of whether or not to accept a gap is often modeled by using either logit or probit analysis [Maze (1981)]. Many researchers including Daganzo (1981), Mahmassani and Sheffi (1981), Miller (1972) and Solberg and Oppenlander (1966) have developed probit gap acceptance models. Other researchers including Madanat et al. (1994), Maze (1981), Fitzpatrick (1991), and Pant and Balakrishnan (1994) have developed binary logit gap acceptance models of the form:

$$P_{gd} = \frac{1}{1+e^{-\upsilon_{gd}}}$$

where,

$P_{gd}$ : Probability that a gap (g) will be accepted by an individual driver (d);

$\upsilon_{gd}$ : The deterministic (systematic) part of the utility of gap (g) to driver (d).

Variables used in utility functions of these models are summarized in Table 2.10.

Maze (1981) has noted that the cumulative probability distribution of the accepted gaps is skewed to the right. He accounted for this skewness by using the following transformation of accepted gaps ($g_i$) instead of using accepted gaps ($g_i$) themselves:

$$X_i = (\ \overline{G}/g_i) - 1$$

where,

$X_i$ : Transformation of the $i^{th}$ gap length;

$\overline{G}$ : Mean time length of accepted gaps ($\overline{G} = \sum_{i=1}^{n} \frac{g_i}{n}$);

$g_i$ : The time length of the $i^{th}$ accepted gap.

Drew (1961) (as stated by Maze (1981)) has used a transformation of the form:

$$X_i = \text{Log}\ (g_i)$$

where, all terms are as defined earlier.

**Table 2.10: Variables included in models developed by Maze (1981), Madanat et al. (1994) and Pant and Balakrishnan (1994)**

| Model Author | Modeled Variables |
|---|---|
| Maze (1981) | Major stream: Gap length and traffic volume<br>Minor stream: Queue length |
| Madanat et al. (1994) | Major stream: Gap length (all models).<br>Minor stream: Delay at queue front (Model 2); Delay at queue front and delay in queue (Model 3); Total delay (Model 4); Number of gaps being rejected (Model 5). |
| Pant and Balakrishnan (1994) | Major stream: Gap length, speed and movement type (left, through, right).<br>Minor stream: Stopline delay, presence of vehicle on opposite approach (yes, no), stopping condition (complete, rolling), movement type (left, through, right), presence of queue (yes, no) and control type (stop, stop plus beacon) |

Madanat, et al. (1994) developed five binary logit models of the form discussed above to describe gap acceptance behavior. The first of those models includes gap length as the only independent variable. Each of the remaining four models incorporates gap length plus some other variable(s). The five models developed by Madanat et al. along with the variables included in each model and the basic statistics obtained are shown in Table 2.11.

Pant and Balakrishnan (1994) have developed a neural network model (NNM) for gap acceptance. For comparison purposes they have also developed a binary logit model of the form developed by Madanat et al. (1994) and Maze (1981). For sites they studied and for variables included in their model (Table 2.10), Pant and Balakrishnan found that their NNM performs better than the binary logit model at all the considered levels of significance as shown in Table 2.12. Data set used to check the prediction ability of both of the models consists of 1230 vehicles which form 24% of the whole sample size (5230 vehicles) collected at 16 intersections [Pant and Balakrishnan (1994)].

### 2.6.3 Assumptions Underlying Discrete Choice Models

The major assumptions underlying discrete choice models include:

a. Each individual decision maker (i) in the population faces a set (C) of mutually exclusive choice options or alternatives (a), (a = 1,.....,C) [Fischer and Nijkamp (1987)];

**Table 2.11: Binary logit gap acceptance models developed by Madanat et al.**

**Model 1:** $\text{Prob (accept)} = \dfrac{1}{1+e^{5.212-089934t}}$

| Independent Variable | Estimated Coefficient | t - Statistic |
|---|---|---|
| ONE (Constant) | -5.21200 | -7.65608 |
| t (Gap Length) | 0.89934 | 7.01240 |
| **Auxiliary Statistics** | **At convergence** | **Initial** |
| Log likelihood | -67.129 | -150.41 |
| Number of observations | 217 | |
| Adjusted Rho-Square | 0.547 | |

**Model 2:** $\text{Prob (accept)} = \dfrac{1}{1+e^{6.304-1.020t-0.060DF}}$

| Independent Variable | Estimated Coefficient | t - Statistic |
|---|---|---|
| ONE (Constant) | -6.30360 | -7.15757 |
| t (Gap Length) | 1.02016 | 6.94325 |
| DF (Delay Front of Queue) | 6.02741e-002 | 2.49629 |
| **Auxiliary Statistics** | **At convergence** | **Initial** |
| Log likelihood | -63.897 | -150.41 |
| Number of observations | 217 | |
| Adjusted Rho-Square | 0.565 | |

**Model 3:** $\text{Prob (accept)} = \dfrac{1}{1+e^{8.053-1.158t-0.039DQ-0.078DF}}$

| Independent Variable | Estimated Coefficient | t - Statistic |
|---|---|---|
| ONE (Constant) | -8.05251 | -6.48341 |
| t (Gap Length) | 1.15822 | 6.54410 |
| DQ (Delay in Queue) | 3.87872e-002 | 2.86514 |
| DF (Delay Front of Queue) | 7.82490e-002 | 2.99416 |
| **Auxiliary Statistics** | **At convergence** | **Initial** |
| Log likelihood | -59.178 | -150.41 |
| Number of observations | 217 | |
| Adjusted Rho-Square | 0.593 | |

Source: [Madanat et al., (1994)]

**Table 2.11 "Continued": Binary logit gap acceptance models**

**Developed by Madanat et al.**

**Model 4: Prob (accept) =** $\frac{1}{1+e^{7.492-1.082t-0.043TD}}$

| Independent Variable | Estimated Coefficient | t - Statistic |
|---|---|---|
| ONE (Constant) | -7.49178 | -6.58427 |
| t (Gap Length) | 1.08159 | 6.64134 |
| TD (Total Delay) | 4.32609e-002 | 3.31965 |
| **Auxiliary Statistics** | **At convergence** | **Initial** |
| Log likelihood | -60.421 | -150.41 |
| Number of observations | 217 | |
| Adjusted Rho-Square | 0.588 | |

**Model 5: Prob (accept) =** $\frac{1}{1+e^{5.970-0.984t-.126NUMF}}$

| Independent Variable | Estimated Coefficient | t - Statistic |
|---|---|---|
| ONE (Constant) | -5.96955 | -7.24281 |
| t (Gap Length) | 0.98422 | 6.97793 |
| NUMF (# of Rejected Gaps) | 0.12581 | 2.02307 |
| **Auxiliary Statistics** | **At convergence** | **Initial** |
| Log likelihood | -65.058 | -150.41 |
| Number of observations | 217 | |
| Adjusted Rho-Square | 0.557 | |

Source: [Madanat et al., (1994)]

**Table (2.12): Comparison of percentages of success for (NNM) and (BLM)**

| Error difference | Neural network model (NNM) | Binary logit model (BLM) | Difference in performance (NNM - BLM) |
|---|---|---|---|
| 0.05 | 77 | 57.7 | 19.3 |
| 0.10 | 81.3 | 68.1 | 13.2 |
| 0.15 | 83.7 | 73.6 | 10.1 |
| 0.20 | 84.9 | 77.2 | 7.64 |
| 0.25 | 87.5 | 79.3 | 8.2 |

b. The population of decision makers is partitioned into population segments (s = 1,.....,S) based on the involved attributes [Fischer and Nijkamp (1987)];

c. The decision maker, $i \in s$, assigns to each alternative (a) a utility value ($U_{ai}$) and chooses the alternative which yields the maximum utility; ($U_{ai} > U_{ji}$, $\forall$ $a \neq j$, a = 1, ... , C) as discussed in Section (2.5.1) [Fischer and Nijkamp (1987)];

d. Random utility is assumed to represent variations among decision makers within the same segment. All decision makers have completely deterministic preferences but these preferences cannot be fully observed by the analyst because certain choice relevant attributes are unobserved and because valuation of observed attributes may vary form one decision maker to another [Fischer and Nijkamp (1987)];

e. Random utility models are based on the assumption that an individual's preferences among the available alternatives can be described by utility function. The utility of an alternative depends on attributes of the alternative and characteristics of the individual, [Horowitz (1991)];

f. With only very few exceptions, choice models based on random utility assume that random utility functions are linear in the parameters and additive in the variables, [Fischer and Nijkamp (1987) and Southworth (1981)];

g. The assumptions about the distribution of the random component of utility define the form of choice probability function. In logit models, it is assumed that error

terms are independently and identically Gumble (or type I extreme value) distributed, [Ben-Akiva and Lerman (1985) pp 71 and 104, Fischer and Nijkamp (1987) and Horowitz (1991)];

h. Logit models have the independence of irrelevant alternative property (IIA). This property is discussed in Section 2.6.4.2.

### 2.6.4 Criticisms of Discrete Choice Models

#### 2.6.4.1 General Criticisms

One main criticism for probabilistic choice models is that they are highly sensitive to a large number of specification errors such as miss-specification of the choice set, C, incorrect specification and improper assumptions about the probability distribution of the random component and incorrect functional form of the deterministic component of the utility function [Horowitz (1981)].

Probabilistic choice models with specification errors can cause large errors in the predicted choice probability [Fischer and Nijkamp (1987)]. Some of the important sources for specification errors in logit models which are the most widely used probabilistic choice models include [Horowitz (1981)]:

a. Inclusion of irrelevant explanatory variables in the utility function;

b. Non independently and identically distributed (IID) random component of utility;

c. Random taste variations where utility function parameters may not be identical to all individuals due to not including important explanatory variables that can account for taste variations between individuals;

d. Informal procedures where the examination of utility function parameter signs, ratios, t-statistics of the estimated coefficient, and computation of $\rho^2$ goodness of fit statistic can provide only rough indication of the quality of the model;

e. Neglecting the possible substitution effects between alternatives.

#### 2.6.4.2 Logit Models Criticism

The main criticisms of the widely used probabilistic logit models include:

a. Predicted choice probabilities are independent of the size and the composition of the choice set. Consequently substitution effects as well as the interrelation among alternatives in the choice set available to the decision maker are not incorporated [Borgers and Timmermans (1987), Horowitz (1981) and Wintraud (1991)]. Adjusted forms of logit models which account for this drawback have been developed. An example of such models was developed by Cooper and Nakanishi (1983) as stated by Borgers and Timmermans (1987). A scaled attribute called Zeta-Squared transformation was used with an ordinary logit model. This transformation takes the form:

$$Z_{ak}^2 = \begin{cases} \left(1 + Z_{ak}^2\right), \text{ for } Z \geq 0 \\ \left(1 + Z_{ak}^2\right)^{-1}, \text{ for } Z \leq 0 \end{cases}$$

$$Z_{ak} = (X_{ak} - \bar{X}_k)/[(1/C)(X_{jk} - \bar{X}_k)^2]^{1/2}$$

Where,

$X_{ak}$ : Value of the $k^{th}$ attribute for alternative (a);

$\bar{X}_k$ : The mean score for attribute k;

C : Size of choice set.

Zeta squared transformation is appropriate when choice behavior is affected by extreme substitution effects [Borgers and Timmermans (1987)].

Borgers and Timmermans (1987) have developed other adjusted models. They also mentioned that other models were developed by other researchers like Bustell (81) and Meyer and Eagle (1981 and 1982). These models (as stated by Borgers and Timmermans (1987)) always yield similar choice probabilities for alternatives with similar deterministic utility components and measures. Probit model performs better whenever substitution effects are present in the observed data. However, not very much may be gained (in terms of prediction ability) by using this complex model instead of the conventional logit model or an adjusted form of it [Borgers and Timmermans (1987)].

b. Multinomial logit model has the property of independence of irrelevant alternatives (IIA). This property implies that the relative odds between any two

alternatives (a, b) depends exclusively on their systematic utility components, ($V_{ai}$, $V_{bi}$), and independent of the availability or attributes of any other alternatives [Fischer and Nijkamp (1987) and Kanafani (1983)]. In mathematical terms:

$$\frac{P_{ai}}{P_{bi}} = \frac{e^{\upsilon_{ai}}}{e^{\upsilon_{bi}}}$$

The (IIA) property can lead to erroneous predictions when alternatives are close substitutes for each other [Fischer and Nijkamp (1987)].

c. Multinomial logit, MNL, model is not applicable where alternatives have common unobserved attributes that influence choice because disturbances will be correlated across alternatives.

### 2.6.5 Sample Size Requirements

Main advantages of using disaggregate analysis include the better use of data and the improvement of the statistical basis of model building. Samples of 500-1000 are normally sufficient for most of the disaggregate analyses [Bates (1979)]. Daganzo (1979) reported that it is possible to use just few hundred data points in order to obtain accurate estimates of the parameter vector $\beta$. Much less sample sizes were recommended and used by many other researchers. Inaba and Wallence (1989), developed a joint model/destination MNL choice model using a total sample of 183

individuals. Daganzo (1981) has developed a probit gap acceptance model using 203 driver observations. Madanat, et al. (1994) developed a binary logit gap choice models using 217 observations (gaps). Richards and Ben-Akiva (1975) reported that a sample of 200 to 500 per mode is reasonable for mode-choice model calibration using MNL models. In the same reference it is, however, stated that samples as small as 50 to 70 per mode produce reasonable results. Fitzpatrick (1991) considered a sample size of 50 data points as target size but he used samples as small as 16 data points to build gap acceptance logit models for trucks and passenger cars.

A formula which can be used to determine the required sample size (n) based on the desired level of confidence (1-$\alpha$), allowable error (E), normal distribution score (Z), and the standard deviation ($\sigma$) is given by:

$$n = [Z^2_{(1-\alpha/2)}\ \sigma^2] / E^2 \qquad \text{where,}$$

n: Minimum sample size;

Z: Random variable;

$\alpha$ : level of significance;

$\sigma$ : Standard deviation;

E : Allowable error.

However, this formula can be used only if the statistical information about the input variables are available. An estimation of such variables can be obtained from a pilot survey results or based on values reported in literature. For $\alpha = 5\%$ and assuming that accepted gaps follow a normal distribution, the value of $Z_{(1-\alpha/2)}$ will be 1.96. The standard deviation of average gap lengths given in Table 2.6 is 0.296. Based on this

result and reviewing values of standard deviation given in Table 2.8, the standard deviation, $\sigma$, can be assumed as 0.3. Taking the allowable error as 0.1 seconds and using the above mentioned values of $Z_{(1-\alpha/2)}$ and $\sigma$, the minimum sample size computed using the given equation will be: $n = [(1.96)^2 (0.3)^2] / (0.1)^2 = 35$

If the value of $\sigma$ is increased to 0.4 with all other inputs kept the same, the minimum required sample size will become 60.

### 2.6.6 Statistical Tests

The question of "how good is the calibrated model" can be answered based on statistical tests and validation tests using a part of data reserved for validation and check purpose. The standard tests of goodness of fit for logit models are weak. A stronger and to some extent complimentary test is to compare the log-likelihood value given by the model to the value obtained for the "full" or "standard" model [Bates (1979)]. In addition to the goodness of fit tests, there are specification tests which include [Fischer and Nijkamp (1987)]:

a. Informal specification tests for the utility function such as examination of signs, t-statistics and ratios of the estimated parameters. These tests, however, lack power because models with specification errors can have parameters with right signs and satisfactory statistics and parameter ratios;

b. Formal statistical comparison of models with different specifications and the inclusion of likelihood ratio tests, Lagrangian multiplier tests, and other tests;

c. Testing the statistical significance of the differences between prediction and observations.

# CHAPTER 3

## RESEARCH METHODOLOGY

### 3.1 INTRODUCTION

This chapter explains the main research phases and steps and it covers technical gap acceptance modeling issues and considerations which include problem formulation and model selection, model specification, calibration and validation, model dependent and independent variables, and model testing.

### 3.2 MAIN RESEARCH PHASES

This research consists of the phases summarized in Figure 3.1 and discussed below:

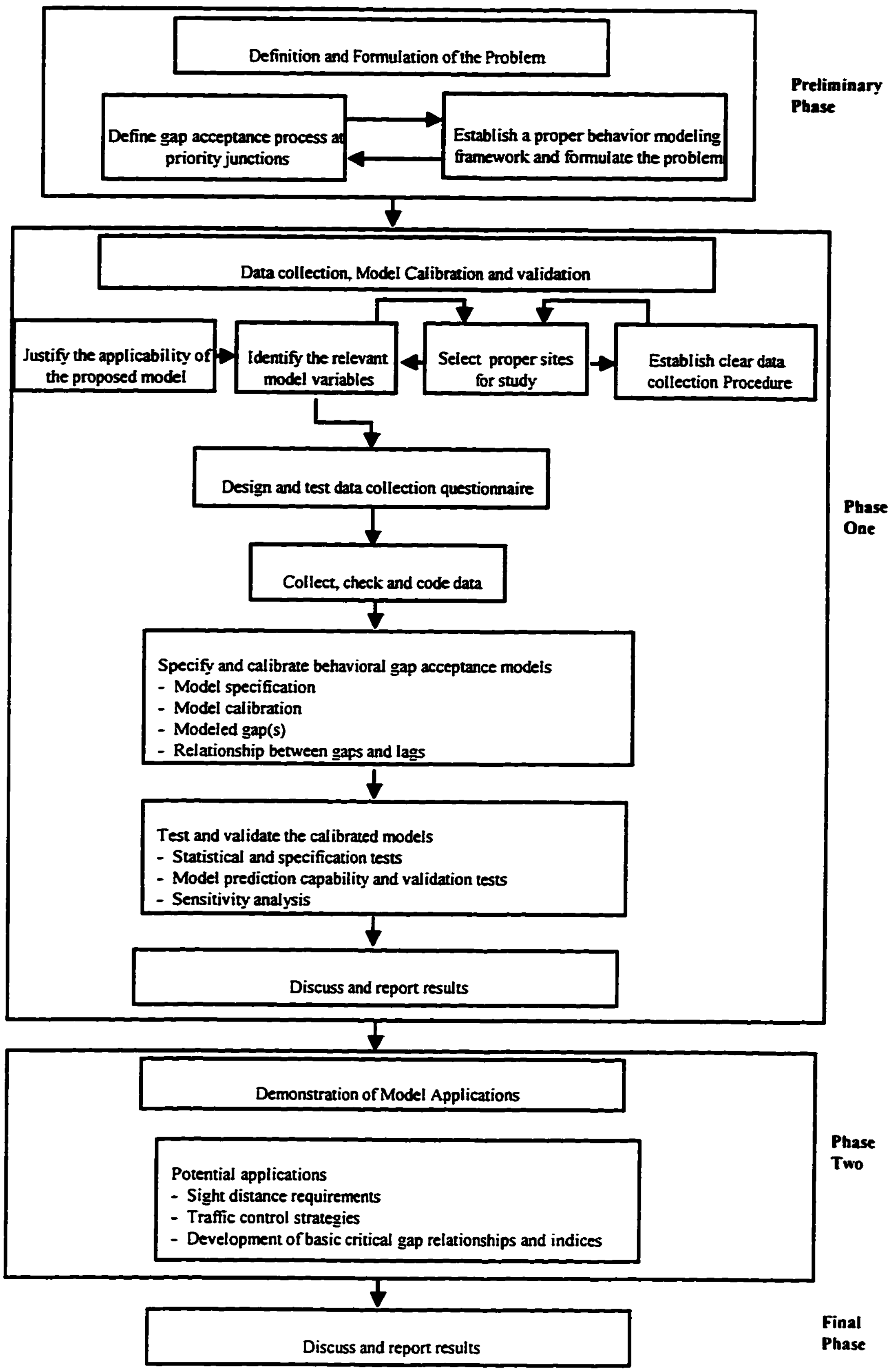



**Figure (3.1) : Basic Research Phases and Steps**

a. **Preliminary phase:** This phase is concerned about defining driver gap acceptance phenomenon at priority intersections, formulating this phenomenon and selecting a proper behavioral modeling framework to investigate it;

b. **Data collection phase:** This phase covers selection of study sites, identification of model variables, designing and checking data collection questionnaire, and collecting and coding data needed for model calibration;

c. **Model specification, calibration, and validation phase:** This phase forms the main body of this research. It is concerned about the specification, calibration and validation of behavioral driver gap acceptance models at priority intersections. Many sub stages are included in this phase such as deciding a proper modeling technique and justifying its applicability to the studied phenomenon, investigating the implications of developing separate and joint models for gaps and lags, calibrating behavioral models, and, finally, testing and validating the calibrated models;

d. **Demonstration of model applicability phase:** This phase is concerned with demonstrating some of the potential traffic engineering applications of gap acceptance concept in general and the developed models in particular. These applications included the establishment of sight distance requirements, and the development of traffic control strategies. Other demonstrations included the study the variability of gap acceptance within different driver age groups, vehicle types and other traffic characteristics like speed, volume, and delay. The establishment of the basic gap acceptance relationships and indices that can

be used in improving the analysis of traffic operations at priority intersections were also discussed.

## 3.3 MODEL DEVELOPMENT

### 3.3.1 Formulation of the Problem

A driver arriving at a priority intersection from a minor stream will observe and evaluate one single lag and probably a number of gaps occurring in the major stream. These gaps will occur sequentially one at a time. Consequently, the driver will evaluate them one by one. For each one he has to decide whether to accept it or not. Numerous driver, traffic, gap, vehicle, trip, road, and environmental factors affect this decision process. Hence, driver gap acceptance behavior can be considered as a highly random process that can ***not*** be determined with full certainty. This uncertainty stems from many factors that include driver taste variations and driver inconsistency. Therefore, the best that can be done in this situation is to predict the probability that certain driver will accept a given gap. Predicting this probability should take in consideration the effect of the most important measurable factors that can influence driver decision.

With this understanding of driver gap acceptance behavior at priority intersections and knowledge of the basic probabilistic discrete choice modeling concepts presented in Section 2.5.1, it can be seen that this behavior can be formulated and modeled as binary choice process using a binary logit model in which the probability of accepting a gap by

a given driver is determined based on the utility offered to the driver by that gap. The specific form of the proposed model is discussed in Section 3.2.2. However, the use of logit models to describe driver gap acceptance behavior at priority intersections was previously proposed and demonstrated by some researchers like Fitzpatrick (1991), Madanat, et al. (1994), Maze (1981) and Pant and Balakrishnan (1994). Fitzpatrick (1991) has stated that "the logit model is appropriate for a situation in which subjects (drivers) have a series of opportunities (gaps) in which one of two discrete choices (acceptance or rejection) is made" [Fitzpatrick (1991), page 110].

### 3.3.2 Proposed Model

Discussion in Section 3.2.1 has led to the conclusion that driver gap acceptance behavior at priority intersections can be modeled using a probabilistic binary logit model (BLM) in which the probability of accepting a gap is predicted based on the utility of that gap.

### 3.3.3 Model Specification

Driver gap acceptance behavior at priority intersections will be modeled as a discrete probabilistic choice process using a binary logit model and random utility functions of the following general form:

$$P_{gd} = \frac{1}{1+e^{-v_{gd}}}$$

where,

$P_{gd}$: probability that a gap of length (g) will be accepted by driver (d);

$v_{gd}$ : the deterministic (systematic) part of the utility function which can be expressed as:

$$U_{gd} = v_{gd} + \varepsilon_{gd}, v_{gd} = \sum_{k} \beta_k X_{gk}$$

where,

$U_{gd}$ : Utility of gap (g) to driver (d);

$v_{gd}$ : The deterministic part of $U_{gd}$;

$\varepsilon_{gd}$ : An error term which represents the effects of unobserved attributes and factors, unobserved taste variations, measurement errors and imperfect information.

k: the $k^{th}$ attribute or factor that influence driver gap acceptance decision;

$\beta_k$ : weight of the $k^{th}$ attribute;

$X_{gk}$ : value or score of the $k^{th}$ attribute which affects the acceptance of gap (g).

The utility function specified above is not known *a priori* and it has to be calibrated (estimated). The calibration process means finding an approximation of the vector β using methods like maximum likelihood and least squares techniques [Daganzo (1987)]. As utility function is calibrated, the above stated binary logit model can be used to transform the utility of each gap to a probability of acceptance for that gap.

## 3. 4 MODEL VARIABLES

Literature has addressed numerous factors and variables that can affect driver gap acceptance behavior at priority intersections. Those variables include a wide variety of driver, traffic, gap, vehicle, road, and even environmental characteristics and attributes. However, the quantitative effects of few of these variables (mainly gap size, major stream volume and speed, and minor stream delay) were evaluated. In addition, widely variant results are reported on the effects of the few evaluated variables.

As stated earlier, this research will investigate the effects of the main driver, traffic, vehicle, gap, trip, and driver inter-influence factors on driver gap acceptance behavior at priority intersections. Variables that will be modeled and studied in this research are discussed in the following paragraphs.

### 3.4.1 Dependent Variable

Dependent variable in the above specified model is an indicator variable (either acceptance or rejection of a gap) [Fitzpatrick (1991)]. The probabilities of choice ($P_{gd}$) themselves are not observed. Only the actual choices are observed and hence, the observed dependent variable takes a value of either zero or one [Southworth (1981)]. The "zero" value will be assigned when lag/gap is rejected and the "one value" when lag/gap is accepted.

### 3.4.2 Independent Variables

Independent variables that will be modeled and studied in this research include the following:

#### 3.4.2.1 Driver Characteristics and Attributes

There are several driver characteristics that can affect driver gap acceptance behavior. Based on literature survey, driving experience, and engineering common sense, the following driver factors seems to be relevant to the phenomenon being studied:

***a. Age and sex***

Bottom and Ashworth (1978) have indicated that younger drivers accept shorter gaps. It is also hypothesized here that younger drivers will accept shorter gaps. Darzentas (1990) has found that the critical gap length for female drivers was longer than male drivers as discussed in Chapter 2 (refer to Figure 2.1).

***b. Driving Experience***

Bottom and Ashworth (1978) have mentioned two possible measures of driving experience, number of years of driving experience, and mileage covered in the previous year. However, they did not evaluate the effect of this variable. In this research number of years of driving experience will be used since it is easier to get this information from the driver. It is expected that experienced drivers will accept shorter gaps.

*c. Level of Education*

Driver gap acceptance behavior is expected to be affected by his level of education. Drivers with different levels of education may differently assess the risk level involved in accepting a given gap and hence they will accept different gaps. As level of education increases, accepted gap is expected to increase.

*d. Familiarity with the Site*

It is expected that driver gap acceptance behavior at a given site is affected by his familiarity to that site. Drivers familiar with the site may accept shorter gaps. Familiarity can be measured by the number of times the driver passes the site weekly or monthly, or simply by asking the driver whether the site is familiar to him or not.

*e. Ability to Estimate the Speed and distance of the Oncoming Vehicle*

Troutbeck (1984) has indicated that it is the ability of the minor road driver to correctly estimate the oncoming vehicle speed rather than the speed itself that affects his behavior. This factor can be measured by the difference between actual (A) and estimated (E) speeds, (A-E). If the difference is positive ($A - E > 0$), the driver will be classified as "speed under estimator" and he is expected to accept shorter gaps compared to "speed over estimator" drivers ($A-E < 0$). The ability of the driver to estimate the distance gap will also have a similar effect.

### *f. Accident and traffic violation records*

It is expected that driver gap acceptance behavior is affected by his accident and traffic violation records. Drivers with higher accident and traffic violation rates are expected to accept shorter gaps. Information on driver accident and traffic violation experiences will be collected directly from the interviewed drivers.

### *g. Nationality*

Driver nationality by itself is *not* expected to affect his gap acceptance behavior. However, different driving roles, enforcement levels, and driving learning procedures implemented in different countries may cause some variation in driving gap acceptance behavior.

## 3.4.2.2 Traffic Characteristics and Attributes

### *a. Major Stream Volume*

Many researchers like Adebisi (1982a), Adebisi (1982b), Adebisi and Sama (1989), Ashton (1971), Chung et al. (1992), Hewitt (1983), Kimber (1989) and Troutbeck (1993) indicated that driver gap acceptance is affected by traffic flow at major stream. However, the cited results about the effect of flow rate are, somehow, controversial. Adebisi (1982a) reported that ignoring the influence of traffic volume at main road may lead to more than 100% errors in the estimated values of critical gaps. On the other hand, Wohl and Martin (1967) reported that no significant differences in

gap acceptance behavior were observed for two average main stream flows of 470 and 620 vphpl. Neudorff (1985) also cited that major stream flow has no impact on gap acceptance decision. Studying this variable here will help in establishing a clearer cut about its effect. It is expected that minor stream driver will accept shorter gaps at higher major stream volumes.

***b. Speed of the Oncoming Vehicle***

Many researchers like Adebisi and Sama (1989), Darzentas et al. (1980), Darzentas and Mcdowell (1981), Hughes (1989), Pant and Balakrishnan (1994), Polus (1983), Tracz (1987), Troutbeck (1984) and Wohl and Martin (1967) have addressed the effect of the speed of oncoming (trailing) vehicle on driver gap acceptance behavior. Troutbeck (1984) indicated that it is the ability of the minor stream driver to estimate the oncoming vehicle speed not the speed itself that affects his gap acceptance behavior. Some studies (as cited by Pant and Balakrishnan (1994)) revealed a negative effect of speed on gap acceptance behavior. Ashworth and Bottom (1977) and Darzentas et al. (1980) found that the mean accepted gap decreases as oncoming vehicle speed increases. Bottom and Ashworth (1979) found that accepted "distance gap" increases as the speed of the oncoming vehicle increases while accepted "time gap" decreases as speed increases. Neudorff (1985) stated that speed of oncoming vehicle has no significant effect on gap acceptance decision. This indicates that the effect of this important factor need to be studied more. Here it is expected that as speed of oncoming vehicle increases, accepted gap will decrease. Because it is believed that

drivers, usually, base their gap acceptance decision on evaluating a combination of distance and time gaps rather than time gaps only. This may lead to accepting shorter gaps at higher speeds since distance gaps in such cases appear to be long enough. This research will also check which of the (distance and time gaps) can better describe driver gap acceptance behavior.

### *c. Minor Stream Delay*

Driver delay at minor stream is one of the few factors that received considerable attention in previous gap acceptance research. Nevertheless, results reported about the effect of this factor are not conclusive. Many researchers like Adebisi and Sama (1989), Daganzo et al. (1987), Hewitt (1983), and Pant and Balakrishnan (1994) reported that delay has a pronounced effect on driver gap acceptance behavior. Accepted gaps tend to decrease as delay increases [Ashworth and Bottom (1977), Hewitt (1983), Pant and Balakrishnan (1994) and Troutbeck (1984)]. However, other researchers like Ashton (1971) and Maze (1981) (as discussed by Pant and Balakrishnan (1994)) and Neudorff (1985) cited that delay has no significant effect on driver gap acceptance decision.

This research hypothesizes that delay has an effect on driver gap acceptance behavior and that accepted gaps will decrease as delay increases due to driver impatience and frustration caused by delay.

Researchers have suggested different measures for delay. Some have separated delay into stop bar delay and queue delay. Others have found that it is better to combine both into one variable termed "total delay". Mahmassani and Sheffi (1981) reported that the number of gaps previously rejected by driver can represent driver behavior better than delay. In this research, it is hypothesized that the influence of stop bar delay on driver can be different than the influence of queue delay. Drivers are expected to be more sensitive to stop bar delay. Therefore each of the stop bar and queue delays will be modeled separately to check this assumption.

*d. Maneuver Type*

Many researchers like Darzentas and Mcdowell (1981), Neudorff (1985), Pant and Balakrishnan (1994) and Tracz (1987), and Valen and Aerde (1996) have addressed the effect of maneuver type (merging, crossing through, turning left) on driver gap acceptance behavior. Usually merging maneuvers have the lowest critical gaps and left turns have the highest [Adebisi and Sama (1989), Daganzo (1987), May (1990) and NAASRA (1974)]. In this sense the effect of maneuver type on the accepted gap size is well established. However, the significance of the influence of different factors that affect driver gap acceptance behavior may differ from one maneuver type to another. This assumption will be tested in this research. Since the studied site is a (T) intersection, then three types of maneuvers will be studied; right turn and left turn from minor stream into major stream and left turn from major stream into minor stream. Separate models will be developed for each of the studied maneuvers.

### *c. Queue Size*

Maze (1981) has indicated that driver gap acceptance is not affected by the size of queue waiting behind him. Pant and Balakrishnan (1994) have indicated that queue size can affect driver gap acceptance behavior. In this research it is hypothesized that number of vehicles waiting behind the driver at the front of the queue can affect his gap acceptance behavior. Driver is expected to accept shorter gaps when the queue of vehicles waiting behind him is long because he will be under some kind of psychological pressure and under the feeling that he is delaying the people in the queue behind him.

### *f. Minor Stream Volume*

It is expected that critical gaps will be shorter at higher minor stream volumes due to the possible increase in delay and queue size.

### *g. Minor Stream speed*

Vehicles approaching the intersection at higher speeds are expected to accept shorter gaps.

#### 3.4.2.3 Vehicle Characteristics and Attributes

The main vehicle characteristics that can influence driver gap acceptance behavior include:

*a. Type of Oncoming Vehicle*

Drivers are expected to be more reluctant to accept gaps when the oncoming vehicle is a large one. Bottom and Ashworth (1978) reported that drivers have allowed longer critical gaps for commercial vehicles than for passenger cars even when the effects of vehicle speed were removed. Fitzpatrick (1991) reported similar results.

*b. Vehicle Age*

Driving newer vehicles may make drivers more confident about the ability of their vehicles and hence they may accept shorter gaps. On the other hand, being afraid to expose his new vehicle to any accident risk, driver may desire to accept a longer gap. However, the first scenario is believed to be more probable.

*c. Engine Capacity*

Drivers riding powerful vehicles are expected to accept shorter gaps. Information on engine capacity in litters and number of combustion cylinders in the engine will be collected and will be used as indicators for vehicle strength. Other measures like vehicle acceleration capability can be a more accurate measure for this variable. However, getting correct acceleration information for different vehicles in different ages is very difficult. The used indicators (engine capacity and number of cylinders) are considered to be satisfactory for the purpose of this research.

*d. Minor Road Vehicle Occupancy*

Daganzo (1987) stated that occupancy of the minor road vehicle can affect driver gap acceptance behavior significantly. It is expected that as vehicle occupancy increases, the accepted gap will increase specially if occupants are members of one family or a group of relatives/friends.

*e. Minor Road Vehicle Type*

Drivers of large vehicles (trucks) are expected to accept longer gaps due to the different characteristics of these vehicles (slower acceleration and longer vehicles) [Fitzpatrick (1991)], while drivers of public transport vehicles (taxis) are expected to accept shorter gaps compared to drivers of private cars.

*f. Type of Transmission*

Drivers in cars with full automatic transmission may accept shorter gaps compared to drivers in cars with manual transmission especially when starting from complete stop because, automatic cars need less preparation effort to start movement in such conditions.

### 3.4.2.4 Gap Characteristics and Attributes

*a. Type of Gap (Gap or Lag)*

Some researchers like Darzentas and Mcdowell (1981) and Pant and Balakrishnan (1994) stated that drivers respond indifferently to lags and gaps. Other researchers like Golias and Kanellaidis (1990) , Hewitt (1983) and Hewitt (1985) reported that driver response to lags is different than his response to gaps. The mean accepted lags were found to be higher than the mean accepted gaps [Ashworth and Bottom (1977), Daganzo (1981), Polus (1983), and Polus et al. (1985)]. This result is due to the incorrect assumption that gap acceptance distribution is identical to lag acceptance distribution. Polus (1983) reported that the mean lag is longer than the mean gap but the difference is not significant at 5 % confidence level. The general practice is to use both lags and gaps in model building rather than using either lags or gaps [Pant and Balakrishnan (1994)]. Golias and Kanellaidis (1990) reported that a model that assigns to each driver a critical lag (CL) which equals to a constant (A) times the critical gap (CG), i.e. (CL = A×CG), can be a reasonable representation of reality. The

assumption that the value (A) is constant for all drivers is believed to preserve a satisfactory accuracy in highway analysis [Golias and Kanellaidis (1990)]. Method of finding the constant (A) as described by Golias and Kanellaidis is discussed in section (2.4.1). In this research, separate models will be developed for lags and gaps to check whether the response of drivers for them is different. Appropriate likelihood ratio tests and t-tests will be performed on these models to find out whether they are significantly different.

***b. Gap Size***

Gap size is one of the crucial factors that determine driver gap acceptance behavior [May (1990) and Pant and Balakrishnan (1994)]. Of course, as gap size increases, acceptance probability will increase.

***c. Size of Gaps preceding and succeeding the Accepted Gap***

The decision of a driver observing gaps occurring in the major stream is expected to be affected by the length of the gaps preceding and following the gap he accepted. If the next gap is apparently long, driver may reject the current gap even if it is long enough for him to execute his desired maneuver. If the next gap is very short, driver may accept the current gap even if it is hardly enough for executing his maneuver. On the other hand, if the preceding rejected gap is long enough, driver may try to

compensate for loosing such a gap and he may try to accept the current gap even if it is dangerously short.

### *d. Type of Gap for Minor Stream Left Turners.*

Drivers executing left turns from minor stream are expected to respond differently to gaps solely created by the near side stream, gaps created solely by the far side stream, and gaps evaluated under the effect of both near and far side streams simultaneously. When lag or gap is solely generated by either near or far side stream, driver decision process will be easier. In this case, the driver is expected to accept shorter gaps compared to the case in which he has to simultaneously evaluate two gaps created in the near and far streams at the same time.

### *e. Type of Gap Acceptance*

Drivers' behavior in queue acceptance situations (two or more vehicles accepting a gap) is different than their behavior in single acceptance cases [Cooper and Wennell (1978) and Neudorff (1985)].

*f. Number of Rejected Gaps*

As discussed in Section 3.2.3.2, the number of gaps previously rejected by driver can be considered as another measure of delay. Hence, delay and number of previously rejected gaps are expected to be correlated. Results of the preliminary analysis will indicate which of these two variables will be included in the models. The effect of the two variables on driver gap acceptance behavior is expected to be similar where driver is expected to accept shorter gaps as any of the two variables increases.

**3.4.2.5 Trip Characteristic and Attributes**

*a. Trip Purpose*

It is hypothesized that trip purpose can affect driver sensitivity and response to gaps. A driver making an emergency trip to a hospital or even a work trip is expected to be more sensitive to gaps and, consequently, he may accept shorter gaps compared to a driver making, say, a recreational trip.

*b. Trip Length*

Troutbeck (1993) indicated that travel distance might affect gap acceptance behavior. He reported that drivers who may be traveling short distances may be more apprehensive about entering the intersection and may prefer to accept large critical gaps. This research will test the effect of trip purpose and length on driver gap acceptance behavior.

*c. Trip Time*

Trip time in terms of peak and off-peak periods is a factor that affects driver gap acceptance behavior [Ashton (1971), Cooper and Wennell (1978) and Neudorff (1985)]. During peak periods, drivers are expected to accept shorter gaps [Neudorff (1985)]. However, it is believed that the effect of this factor will be implicitly accounted for through using other variables that mainly include traffic volume, delay, and trip purpose.

**3.4.2.6 Driver Inter-influence Factors**

It is believed that driver is, to some extent, influenced by the behavior of other drivers at the scene. The following driver inter-influence factors (as named by researcher) can affect driver gap acceptance behavior:

*a. Gap Size Accepted by the Driver Ahead*

It is expected that a driver's gap acceptance decision can be affected by the decision of the driver ahead. If the driver ahead accepted short gap and managed to execute his maneuver safely (risk free), the following driver would be encouraged to accept a shorter gap. On the other hand he may prefer to wait for a long enough gap if he notes any risk involved in the decision of the previous driver. In summary, driver gap acceptance behavior may be guided "positively or negatively" by the action of the

driver ahead due, may be, to the competitive/imitative nature inherent in human beings. For a given driver, the size of gap accepted by the driver ahead will be observed from video record.

*b. Number of Gaps Rejected by the Driver Ahead*

This factor may affect driver behavior in a manner similar to factor (a) above. For example, if the ahead driver rejected many gaps including long enough ones, the following driver would, most probably, become frustrated and may accept shorter gaps. This factor is a measure of one of the delay components. If factors discussed in (a) and (b) show to be highly correlated, the one that can better represent driver gap acceptance behavior will be included in the model.

*c. Queue Size*

This factor can be considered a traffic as well as a driver inter-influence factor as discussed in Section (3.2.3.2)

*d. Number of Vehicles Entering Ahead*

It is expected that driver gap acceptance decision be affected by the number of vehicles that entered the intersection ahead of the driver during the same gap he

accepted. This expected behavior could be associated to "flow continuation" or "flux" effect. When one or more of the vehicles accept a gap ahead of the concerned driver, the driver will move to occupy the queue head and hence he will be deciding whether or not to accept the remaining part of the gap (lag) while he is in motion. This may encourage the driver to continue the flow of vehicles into the offered gap and to accept a shorter gap.

#### 3.4.2.7 Geometric Characteristic and Attributes

Intersection type (T,Y,+), sight distance and visibility, road surface condition, type of control, and driver angle of sight are the main factors that can affect driver gap acceptance behavior. Studying the effects of those factors, necessitate investigating a representative number of each type of intersections. Such a case will require more data that is beyond the scope and financial resources of this research. Therefore, data will be collected at *two* geometrically and physically similar T-junctions.

Independent variables discussed above along with their recommended units and methods of measurement are summarized in Table 3.1. These variables will be collected using data collection procedures discussed in Chapter 4. Whether to model a given continuous variable in its normal form or in a transformed form will depend on the type of relationship with the dependent variable, skewness of the distribution of that variable, etc. Previous researchers showed that distribution of accepted gaps is,

**Table 3.1: Studied Variables with Their Recommended Units and Methods of Measurement**

| Variable Group | Variable Identification | Recommended Unit and Method of Measurement | Source * |
|---|---|---|---|
| Driver Charac. And Attributes | Age | Actual driver age in years. | Ques. |
| | Sex | Driver sex (Male or Female) | Ques. |
| | Driving experience | Number of years of practicing driving | Ques. |
| | Education | Categories | Ques. |
| | Familiarity with Site | Number of times a driver passes the site monthly | Ques. |
| | Gap acceptance criteria | Criteria on which driver bases his gap acceptance behavior (Speed and/or distance of oncoming vehicle) | Ques. |
| | Ability to estimate oncoming veh. speed and distance | Difference between actual and estimated speeds and distances | Actual: Vid.<br>Est.: Ques. |
| | Consistency in gap acceptance | Difference between accepted and maximum rejected gaps | Video Record |
| | Gap acceptance criteria | Criteria on which the driver bases his gap acceptance decision (distance, speed or distance and speed of the oncoming vehicle | |
| | Accident and traffic violation records | Number of accidents in the last 2 years.<br>Number of traffic violations in the last year. | Ques. |
| | Nationality | nationality of the interviewed driver at the minor road | Ques. |
| Traffic Charac. And Attributes | Major stream volume | Volume in 30-second intervals (veh./30-sec.) | Video Record |
| | Speed of oncoming vehicle | Actual speed in meters per seconds (Mt./sec.) | Video Record |
| | Minor Stream Delay (Queue, Queue Head) | Actual queue and queue head delay in seconds | Video Record |
| | Maneuver Type | Categories (right turn, left turn from minor stream and left turn from major stream) | Video Record |
| | Queue Size | Actual number of vehicles in queue at gap acceptance time | Video Record |
| | Minor stream volume | Volume in 1-minute intervals (veh./min.) | Video Record |
| | Minor stream speed | Actual speed of minor stream vehicle (Mt./sec.) | Video Record |

* Ques.: Questionnaire

Vid. : Video Record

**Table 3.1: "continued": Studied Variables With Their Recommended Units and Methods of Measurement**

| Variable Group | Variable Identification | Recommended Unit and Method of Measurement | Source |
|---|---|---|---|
| Vehicle Charac. and Attributes | Type of oncoming Vehicle | Categories (Truck, PCs) | Video Record |
| | Vehicle Age | Actual age of minor stream vehicle in years | Ques. |
| | Engine Capacity | Engine capacity (cc) or number of engine cylinders of minor stream vehicle | Ques. |
| | Vehicle Occupancy | Number of persons inside minor stream vehicle including driver | Ques. |
| | Type of Minor stream Vehicle | Categories (PC, Taxi, Truck) | Ques. |
| | Type of Movement Transmission | Automatic/ Manual | Ques. |
| Gap Charac. and Attributes | Lag - gap | Categories (Lags, gaps) | Video Rec. |
| | Gap size (time, distance) | Actual gap size in seconds/meters | Video Rec. |
| | Size of Preceding and Succeeding gaps | Actual size in seconds | Video Record |
| | Type of gap for left turns from minor stream | Categories ( near side gap, far side gap, and dual gaps) | Video Record |
| | Number of rejected gaps | Actual number of gaps rejected by the driver before he accepts a gap | Video Record |
| Trip Charac. & attributes | Trip purpose | Categories | Ques. |
| | Trip length | Driver perceived trip time in minutes | Ques. |
| Driver Inter-Influence Factors | Gap accepted by the ahead driver | Actual gap length in seconds | Video Record |
| | Gaps rejected by the ahead driver | Number of gaps rejected by the ahead driver | Video Record |
| | Number of ahead entries | Actual number of vehicles entering ahead the driver in his accepted gap. This indirectly shows the type of gap acceptance in terms of queue or single acceptance. | Video Record |

Ques.: Questionnaire

Rec. : Record

usually, skewed to the right [Maze (1981)]. Some of the transformations suggested to deal with such a situation have already been discussed in Section 2.5.2.

### 3.4.3 Variable Correlation

Correlation matrix for studied variables will be developed and analyzed. If two or more of the independent variables are highly correlated with correlation coefficients in the vicinity of 0.5, the variable with higher correlation to the dependent variable will be retained in the model to avoid collinearity problems. Detailed correlation analyses of the modeled variables will be discussed in Chapter 5.

## 3.5 MODEL CALIBRATION

Calibration of the model specified in Section 3.2.7.1 means estimating the individual values of the coefficient vector $\beta$. This can be done using one of the many available logit model estimation packages like LIMDEP, BLOGIT, SLOGIT, and ULOGIT. Two of these packages; LIMDEP and BLOGIT were available to the researcher. LIMDEP [Greene (1995)] was selected because it is a very recent and more powerful package.

One problem related to the estimation of gap acceptance model parameters is the over representation of the drivers who reject several gaps. This may lead to biased estimates of the parameters. Researchers have tried to solve this problem through

building gap models in which each driver will be presented once. Some of the suggested approaches include (see Table 2.6 in Section 2.3.3.):

a. Using lags only (each driver faces and evaluates only one lag);

b. Using accepted gaps only (each driver accepts only one gap);

c. Using only the first gap offered to each of the observed drivers;

d. Using only the maximum gap rejected by each of the observed drivers.

However, most of the researchers agree that excluding any gaps or lags will lead to significant loss of information [Pant and Balakrishnan (1994)]. Consequently, many researchers have recommended the use of all gaps and lags. Furthermore, it was shown that this approach (using all gaps and lags in model building) produces ***unbiased*** estimates for the mean and standard deviation of the critical gap distribution [Hewitt (1983)]. In addition, using all gaps and lags will allow for the effect of the within driver variation (which is an important factor in gap acceptance analysis) to be reflected in the calibrated model [Ashworth and Bottom (1977) and Bottom and Ashworth (1978)]. Darzentas has reported that "in majority of the cases researchers have used lags and gaps combined because after treating them separately they found that the estimated parameters and probabilities of acceptance were similar for both lags and gaps". [Darzentas (1989), page 182]. Hewitt has reported that "the advantage of methods based on all gaps over those based on lags is clear. There appears to be no merit in using any method based on lags alone" [Hewitt (1985), page 17].

Based on the above discussion, both lags and gaps will be combined to calibrate models for driver gap acceptance behavior at priority intersection. However, the difference in driver response to gaps and lags will be considered in the way discussed in Section 3.2.3.4. As discussed earlier, separate models will be developed for gaps and lags and will be compared to models developed for gaps and lags altogether.

## 3.6 MODEL TESTING

The computer package (LIMDEP) used to calibrate driver gap acceptance models in this study gives the individual parameter estimates along with various statistics needed to perform different statistical tests. These tests include the likelihood ratio tests, t-tests and the goodness of fit tests using $\rho^2$ values and the percent of correctly predicted observations. Other informal tests of the signs and relative values of the model coefficients will also be performed.

After reviewing the relevant literature (mainly Ben-Akiva and Lerman (1984) and Stopher (1979)), the main tests which could be applicable to the models to be developed in this study are summarized below;

*a. T-tests*

T-tests can be used to:

i. Test the null hypothesis that the value of each of the estimated model parameters is not significantly different from zero, i. e.:

$$H_0 : \beta_i = 0 \quad , i = 1, 2, ..., k$$

where, $\beta_i$ is the coefficient of the $i^{th}$ variable in utility function. The calculated t-value of the concerned model coefficient will be compared to the table t-value at 5% level of significance. If the calculated t-value is larger than table value, the null hypothesis will be rejected.

ii. Test the linear relationship among parameters, i.e., to test whether the values of two parameters are significantly different from each other.

$$H_0: \beta_1 = \beta_2 \text{ or } \beta_1 - \beta_2 = 0$$

the t-statistic for this test is calculated as:

$$t_{cal.} = (\beta_1 - \beta_2)/ \sqrt{Var (\beta_1 - \beta_2)}, \text{ Where}$$

$$Var (\beta_1 - \beta_2) = Var (\beta_1) + Var (\beta_2) - 2 \, Cov (\beta_1 , \beta_2)$$

Coefficient covariances can be obtained from the coefficient's covariance matrix that is an output of the used LIMDEP package. The calculated t-value will be compared with table value as discussed in (i) above.

iii. Test the corresponding pairs of coefficients in models developed for different market segments. In this case the statistic for the t-test of equality of individual coefficients between two market segments (segments 1 and 2 say) is, [Ben-Akiva and Lerman (1985)]:

$$t_{cal} = \frac{\beta_k^1 - \beta_k^2}{\sqrt{Var(\beta_k^1) + Var(\beta_k^2)}}$$

where 1 and 2 refer to segments 1 and 2, respectively and k refers to the concerned $k^{th}$ attribute coefficient in the models calibrated for the two segments.

iv. Test whether the means of two populations $(\mu_1, \mu_2)$ are significantly different from each other. If the average values $(\overline{Y}_1, \overline{Y}_2)$ computed from representative samples of sizes $(n_1, n_2)$, respectively are used as estimates for $(\mu_1, \mu_2)$ and if the unknown standard deviations of the two populations are assumed to be not equal, the statistic to test the null hypothesis $(H_0: \mu_1 = \mu_2)$ is computed as;

$$t_{cal} = \frac{\overline{Y}_1 - \overline{Y}_2}{\sqrt{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)}}$$

where, $S_1^2, S_2^2$ are the variances of the two samples and other terms are as defined above. According to Montgomery (1991), this statistic is *not* exactly distributed as t and, however, can be approximated by t-distribution if the degrees of freedom (v) are computed as;

$$v = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\left(\frac{\left(S_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(S_2^2/n_2\right)^2}{n_2 - 1}\right)}$$

This case is referred to as Behrins-Fisher problem, [Hines and Montgomery, (1990)]. This test will be used to check whether the average accepted gap lengths computed at different levels of the studied variables (say the average accepted gap lengths for different driver age groups) are significantly different.

### *b. Likelihood Ratio Test (LRT)*

This test is similar to F-test in regression models and it is used to test a set of restrictions imposed on model parameters estimated by maximum likelihood method [Ben-Akiva and Lerman (1985)]. The likelihood ratio test, LRT, can be used to:

i. Test the null hypothesis that all the estimated model parameters are not significantly different from each other and from zero, i.e.:

$$H_0: \beta_1 = \beta_2 = \ldots\ldots = \beta_k = 0$$

The likelihood ratio test statistic (LRTS) used to test the above null hypothesis is:

LRTS = -2 [L(0) - L(β)], Where,

L(0): Log likelihood value of the model when all parameters equal to zero. In binary choice models L(0) represents the log likelihood of the most naive possible model in which the choice probabilities are 0.5 for each of the two alternatives, [Ben-Akiva and Lerman (1985)]. This model is called the "equal-shares" model, [Stopher (1979)].

L(β): Log likelihood value of the model at its maximum.

The computed LRTS will be compared to table $\chi^2$ value at 5% level of significance (α) and k degrees of freedom where k equals the number of estimated coefficients including the constant. If LRTS is larger than the table value of $\chi^2_{(\alpha,k)}$, the null hypothesis will be rejected.

Ben-Akiva and Lerman (1985) reported that it is not useful to use the above statistic as almost always the null hypothesis can be rejected at a very low level of significance. Stopher (1979) also mentioned that the $\chi^2$ test applied in this way is a poor statistical test.

**ii.** Test the null hypothesis that all the coefficients except for the alternative-specific constants are zero, i. e.:

$$H_0 : \beta_2 = \beta_3 = \beta_4 = \ldots\ldots = \beta_k = 0$$

According to Ben-Akiva and Lerman, (1985, pp 165) this test is more informative than the test described above. The likelihood ratio test statistic (LRTS) for testing the above hypothesis is computed as:

$$LRTS = -2[L(c) - L(\beta)], \text{ where}$$

$L(\beta)$ : Log Likelihood of the model at maximum;

$L(c)$: Log Likelihood of the model with (j-1) alternative specific constants where j is the number of the available choices or alternatives. This value corresponds to a naive model in which choice probability for each alternative simply equals the fraction of sample choosing the alternative, [Ben-Akiva and Lerman (1985)]. This model is called the "market-shares" model, [Stopher, (1979)]. The value of L(c) is a default output in the used package (LIMDEP). This value is, however, computed as following:

$$L(c) = \sum_{i=1}^{j} N_i \ln(N_i/N)$$

where,

$N_i$ : Number of observations in which alternative i is selected;

N : Total sample size;

j : Number of available alternatives.

The calculated value of LRTS will be compared to the table $\chi^2$ value at 5% level of significance and (K-J+1) degrees of freedom where J is the number of alternatives and k is the number of coefficients including the constant. In the case of binary choice models the degrees of freedom for this test are simply (k-1) since j in this case equals 2. If LRTS value is greater than $\chi^2_{(\alpha,\ k-j+1)}$ at the desired $\alpha$ level of significance, the null hypothesis will be rejected.

This test is necessarily more stringent and informative than the test described in (i) above [Ben-Akiva and Lerman (1085) and Stopher (1979)]. To be noted in this regard that the restricted log likelihood value which is a default output of the used LIMDEP package is the L(c) value described above as stated in the users manual of the package [Greene, (1995)]. Hence, the printed $\chi^2$ value, degrees of freedom, and level of significance for $\chi^2$ test apply for the null hypothesis that all the coefficients except the constant are zeros.

iii. Test the null hypothesis that the coefficients obtained from the validation data are the same as the coefficients obtained from the calibration data i.e., there exists no significant difference between the observed and the predicted behavior of the model:

$H_0$: There exists no difference between the observed and the predicted behavior

The LRTS value to test the above hypothesis is obtained from the following relationship:

$LRTS = -2[L_R(\beta) - L_U(\beta)]$, where

$L_R(\beta)$: Log likelihood value of the model at its maximum when the coefficients are restricted to the values obtained from the model built for the "calibration data";

$L_U(\beta)$: Log likelihood value of the model at its maximum when the coefficients are unrestricted.

The LRTS obtained as described above will be compared with the table $\chi^2$ value at 5% significance level and degrees of freedom equal to $(K_U - K_R)$ where, $K_U$ and $K_R$ are the number of ***estimated*** coefficients in the unrestricted and restricted models respectively. Note that if all coefficients in the restricted model are restricted, the degrees of freedom will equal $K_U$ since the number of the estimated parameters in the restricted model will be zero, i.e., $K_R = 0$.

If the LRTS is greater than $\chi^2_{(\alpha, K_U - K_R)}$ for the desired $\alpha$ level, the null hypothesis will be rejected.

**iv.** Test market segmentation models. The aim of market segmentation is to search for systematic variations among population subgroups, [Ben-Akiva and Lerman (1985, pp 194)]. The likelihood ratio test statistic (LRTS) for this test is computed as, [Ben-Akiva and Lerman (1985) and Stopher, (1979)];

$$LRTS = -2\left(L_p - \sum_{g=1}^{G} L_g\right) \quad \text{Where,}$$

$L_p$ = log likelihood value at maximum for the pooled model;

$L_g$ = log likelihood value at maximum for the model of segment g;

The statistic of this test is $\chi^2$ distributed with $\left(\sum_{g=1}^{G} K_g\right) - K$ degrees of freedom where $K_g$ is the number of coefficients in the $g^{th}$ market segment model and K is the number of coefficients in the pooled model. To be noted is that the sum of the observations in all segmented models should equal the sum of observations in the pooled model, i.e., $\sum_{g=1}^{G} N_g = N_p$ where $N_g$ is the sample size in the $g^{th}$ segment and $N_p$ is the sample size in the pooled model. If this condition does not apply, an adjustment should be introduced as follows, [Stopher, (1979)]:

$$\mathrm{Adj}\left(\sum_{g=1}^{G} L_g\right) = \left(\frac{N_p}{\sum_{g=1}^{G} N_g}\right)\sum_{g=1}^{G} L_g$$

The null hypothesis of equality of coefficients across the market segments is [Ben-Akiva and Lerman (1985)]:

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \ldots\ldots = \beta_G$$

where $\beta_g$ is the vector of coefficients of the $g^{th}$ segment model. A rejection of the above hypothesis raise the need for further investigation of the reasons for the statistically significant differences in the market segments models and to explore which coefficients are significantly different. A t-test applicable for

pairwise testing of the corresponding coefficients of the models developed for different market segments is discussed in point (a-iii) above. As quoted from Ben-Akiva and Lerman (1985);

> " .... *it is possible that all the t-tests will be insignificant (i.e., individual coefficients are not significantly different) despite the fact that the joint likelihood ratio test is significant (i.e., the null hypothesis of equality of coefficients across the market segments is rejected). It is also possible that the joint likelihood ratio test will not reject the null hypothesis though a few individual coefficients are significantly different. The market segmentation log likelihood ratio tests for joint hypotheses and the individual t-tests can be used to test models developed using samples from different locations or from different points in time....* " [Ben-Akiva and Lerman, (1985, page 202)].

This indicates that these tests can be used in this study to check whether the gap acceptance models developed for the same maneuver using data samples collected at different sites are significantly different.

**vi.** Test differently specified models that are calibrated using the same data set. The LRTS for this test is, [Stopher, (1979)]:

$$LRTS = -2 (L_J - L_M)$$

Where $L_J$ and $L_M$ are the log likelihoods at maximum for the models with J and M variables, respectively. The above test can be applied if the following conditions are satisfied, [Stopher, (1979)];

a. The M and J variables used in the two models should belong to the same data set;

b. J is a subset of M, i.e. $J \in M$, and;

c. The same number of observations is used in the two models. If this condition does not apply, the following adjustment should be introduced, [Stopher, (1979)]:

$$\text{Adj.}(L_J) = \left( N_M / N_J \right) L_J$$

where $N_M$ and $N_J$ are the number of observations in the models with M and J variables, respectively.

The LRTS for this test is $\chi^2$ distributed with (M - J) degrees of freedom and the null hypothesis of the test is;

$H_0$: The model with M variables is not different of the model with J variables

The null hypothesis will be rejected if the calculated statistic exceeds the table value at the desired level of confidence.

### c. *Goodness of fit tests*

#### *i- $\rho^2$ test*

The $\rho^2$ test is similar to $R^2$ test in regression analysis and is considered as the standard test of goodness of fit for logit models. The $\rho^2$ parameter measures the fraction of an initial log likelihood value explained by the model. $\rho^2$ is computed as:

$$\rho^2 = 1 - (L(\beta)/L(0))$$

where L (β) and L (0) are the log likelihoods for the fitted model at maximum and at the equal-share case, respectively. As per Stopher (1979), the log likelihood of the market-share model, L(c), can replace the log likelihood of the equal-share model, L(0), in computing $\rho^2$ .

A shortcoming of this test is that $\rho^2$ will increase or at least stay the same whenever new variables are added to the utility function. For this reason the adjusted likelihood ratio index $\bar{\rho}^2$ is used. This index is computed as:

$$\bar{\rho}^2 = 1 - [(L(\beta) - (K))/L(0)]$$

The term [L(β) - (K)] is known as the Akaike information criteria where K is the number of parameters estimated in the model. When L(c) is used instead of

L(0) in the computations, K should be substituted by (K-1). Ben-Akiva and Lerman, (1985) mentioned that there are no general guidelines for when a $\rho^2$ value is sufficiently high.

### *ii. Predictions Success Table*

The prediction success table is a table that presents the number of correct and erroneous cases predicted by the model as compared to the actually observed choices. This table is one of the outputs given by the used LIMDEP package. The "percent right" as termed by Ben-Akiva and Lerman, (1985) or the "percent correctly predicted" as termed by Stopher, (1979) is a measure of the goodness of fit. This measure is computed as:

$$PCP = \left(100/N\right)\sum_{n=1}^{N} \hat{Y}_n \quad \text{where,}$$

PCP = percent of the correctly predicted cases;

N = total number of observations;

$\hat{Y}_n$ = 1 if the highest predicted probability for the $n^{th}$ observation corresponds to the observed choice (i.e., if the predicted and observed choices coincide) and zero otherwise.

Another approach to find the PCP is to use the calculated choice probabilities rather than the predicted choices themselves. In this approach the PCP is calculated as, [Stopher, (1979)]:

$$PCP = \left(100/_{N}\right)\sum_{c=1}^{C} N_{cc} \quad , \qquad N_{cc} = \sum_{n=1}^{N} S_{cn} P_{cn} \quad \text{Where,}$$

N = the total number of observations in the model;

$N_{cc}$ = number of observations correctly predicted to select choice (c). In our case the choice is either accept or reject a gap, i.e., C=2;

$S_{cn}$ = 1 if choice (c) is selected in the $n^{th}$ observation and zero otherwise;

$P_{cn}$ = the calculated probability of selecting choice (c) in the $n^{th}$ observation.

*d. **Informal tests***

In addition to the above discussed tests, other informal tests including the check for signs and relative values of model coefficients will be carried out for the calibrated gap acceptance models.

## 3.7 MODEL VALIDATION

Developed models will be validated using a prescribed part (25%) of the collected data other than the part (75%) used to calibrate the model. Likelihood ratio test (LRT) discussed in paragraph 3.6, point b-iii will be used to test whether there are statistically significant differences between model parameters for models built for "validation data" and "calibration data". The null hypothesis to be tested is formulated as follows:

$H_0$ : Model coefficients obtained from calibration and validation data are the same, i.e., $\beta_c = \beta_v$ where $\beta_c$ and $\beta_v$ refer to

parameter vectors obtained from models built for calibration and validation data sets, respectively.

Alternatively the null hypothesis can be stated as, [Ben-Akiva and Lerman,(1985)];

$H_0$ : The imposed restrictions are true

The likelihood ratio test statistic (LRTS) used to test this hypothesis is computed as discussed in point (b-iii) earlier. "Validation data" will be used to get log likelihood values needed to compute LRTS. Log likelihood value for the restricted model is found by restricting the parameters of the model of "validation data" to the values obtained from the "calibration data". This is done by imposing the set of constraints $\beta_c = \beta_v$. The log likelihood value for the unrestricted model is found by calibrating an unrestricted model for the validation data. The mentioned LRTS is Chi-square distributed with (K) degrees of freedom where K is the total number of the estimated coefficients in the unrestricted model (please refer to section 3.6, point b-iii for further details on this test). If the calculated Chi-square value is greater than the table value at the desired level of significance, the null hypothesis will be rejected.

# CHAPTER 4

# DATA COLLECTION AND CODING

## 4.1 INTRODUCTION

This chapter explains the followed procedure and setup to collect gap acceptance data used in this study. Site selection procedure, questionnaire design, and data coding forms and procedures are also covered in this chapter.

## 4.2 STUDY SITES

Data needed to build behavioral models for driver gap acceptance in this study is collected from two T-junctions at dual lane single carriageway roads. Geometrically similar junctions are selected to keep the effect of geometric factors common for the drivers since the study of these factors is beyond the scope of this research. Such a practice is common in literature. For example, each of Maze (1981) and Madanat et al.

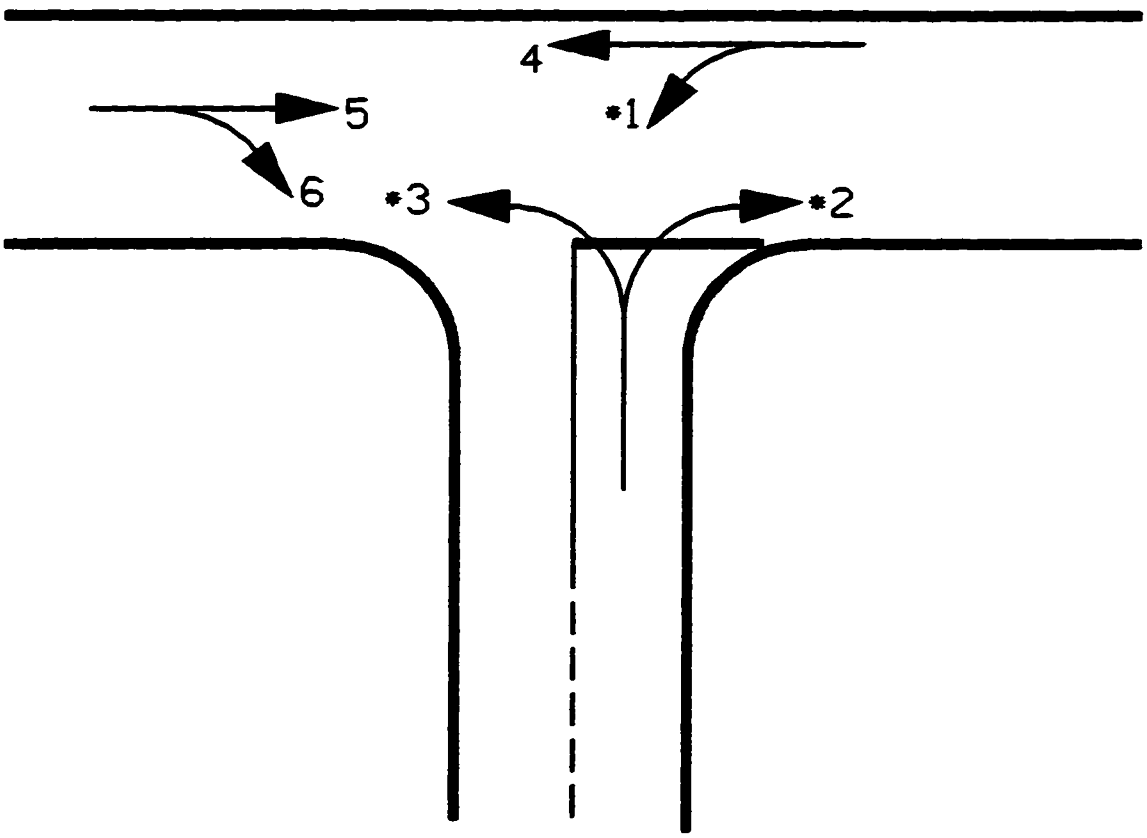
(1994) has developed behavioral gap acceptance models of the binomial logit type using data collected at one individual T-junction. In this research, two right angle (T) intersections of the type shown in Figure 4.1 are used to collect the needed data. Selecting more than one site will help in providing more variations in the collected data regarding driver, vehicle and traffic characteristics. Study sites with standard geometric features including lane width, turning radii, and proper sight distances at all approaches are selected. Site selection criteria are detailed in Section 4.2.1 of this chapter.

### 4.2.1 Site Selection Procedure and Criteria

Site selection process has involved preliminary field investigations and reconnaissance surveys for around 30 potential sites (intersections). A key site plan for junctions investigated at this stage is given in Figure 4.2. Criteria considered while investigating potential study sites include the following:

a. **Surrounding Land Use:** Higher preference is given to intersections surrounded by mixed land uses;

b. **Traffic Characteristics:** Preferable traffic characteristics include an acceptable volume sufficient to obtain the needed sample size, an acceptable variation of traffic volume to enable observing both peak and off-peak characteristics, and an acceptable vehicle type mix to enable observing gap acceptance characteristics for different vehicle types (basically large and small vehicles);




* Maneuvers considered in this Study

**Figure 4.1 Type of intersections Considered in the Study**

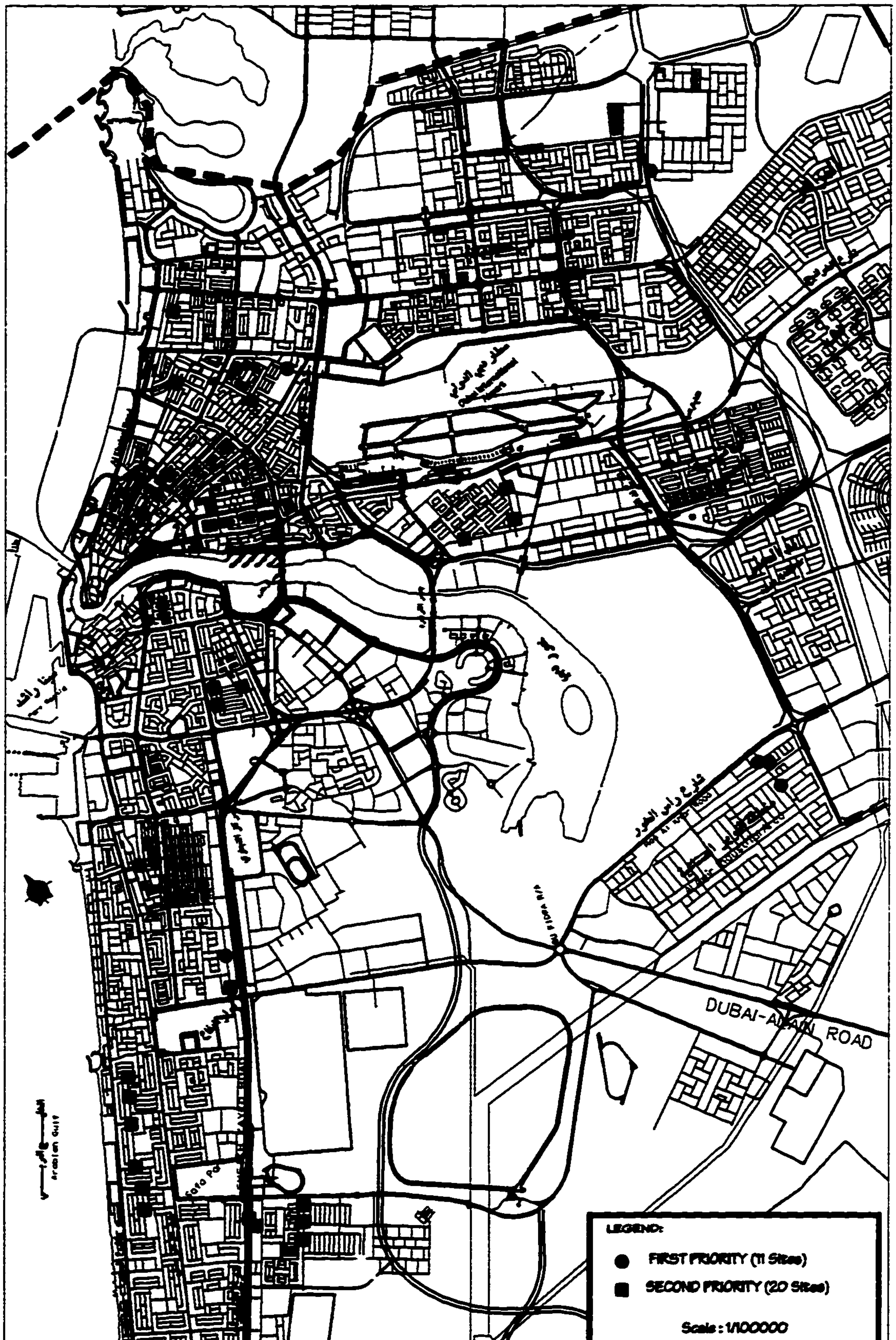



Figure (4.2): Site Plan for The Preliminary Investigated Locations During The Process of Site Selection.

c. **Geometric Characteristics:** All of the investigated sites are T-junctions located at two lanes single carriageways with standard lane width and proper visibility;

d. **Proximity of Other Junctions:** It is preferred that no other junctions exist in the vicinity of any of the studied junctions. A proper separation of not less than 250 meters is considered;

e. **Availability of Space for Conducting Roadside Interviews:** Enough space to conduct road side interviews for drivers should be available at all approaches. Junctions with no proper space for conducting roadside interviews were excluded;

f. **Availability of Proper Location for Camera:** Preference is given to junctions where proper location (like a nearby building) to mount the video camera to achieve proper coverage of the junction is available.

### 4.2.2 Selected Study Sites

Considering the above discussed criteria, investigated sites (around 30) were screened into two groups; the first group included around ten sites which, in general, meet the desirable criteria. The second group includes the remaining sites that count for around 20 sites and lack some of the desirable criteria. Further screening and field investigations were made for sites in the first group to select two appropriate sites (based on the above discussed criteria). The result of this step was the selection of the two sites shown in Figure 4.3. In the site selection process, the main problem was to find sites that satisfy

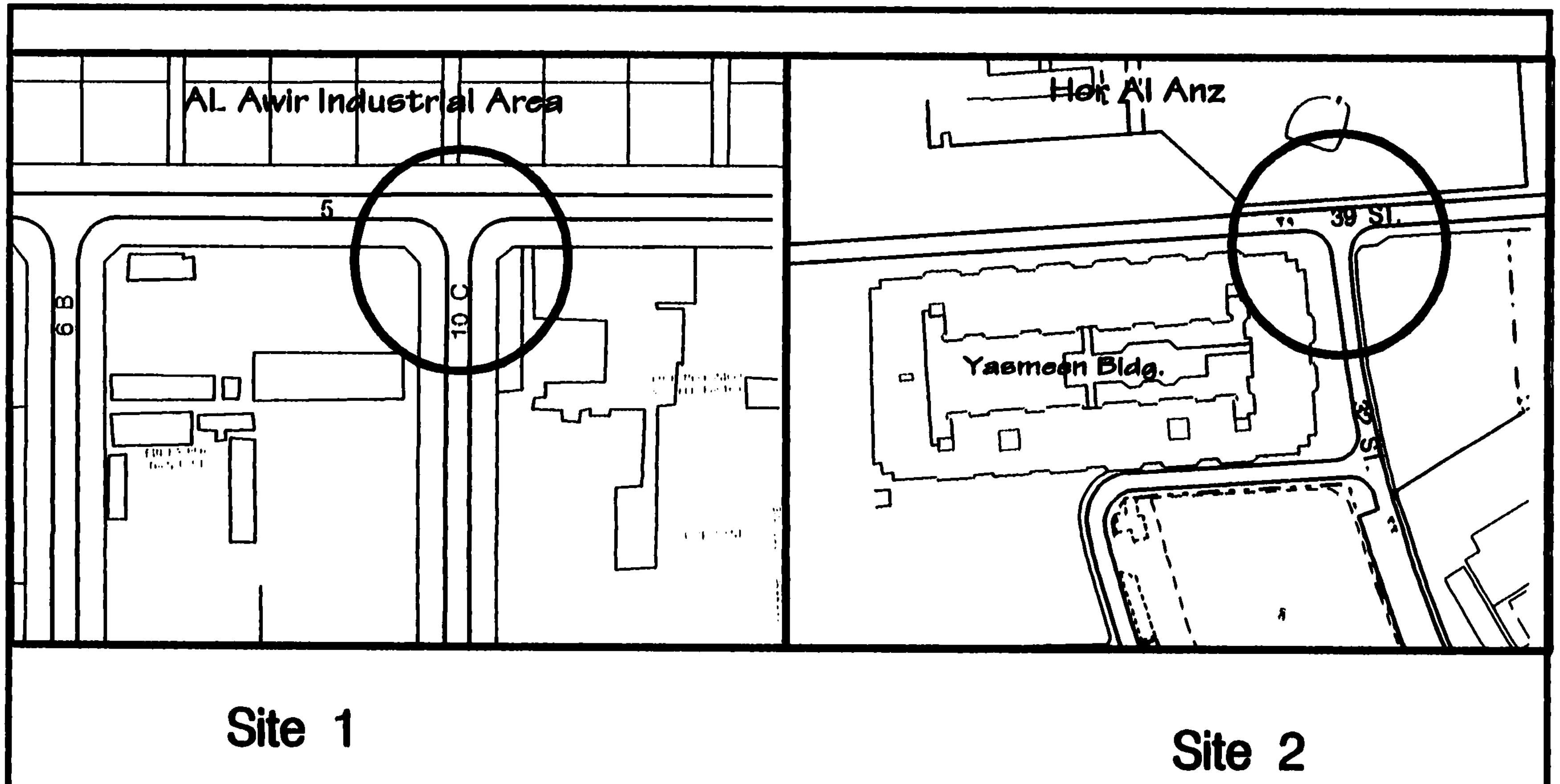



Figure (4.3): Site Plan for the Studied Junctions

Scale: 1 = 2500

criteria b, e, and f simultaneously. At many locations that have good traffic characteristics, either a proper place to mount the video camera or nearby space needed to stop drivers to conduct the roadside interviews safely was not available. However, the two selected sites met all the criteria to an acceptable level and are considered the most appropriate ones among all the investigated sites. In fact it was concluded that only four sites of the whole investigated group were appropriate and satisfy the required criteria to an acceptable level. Data needed to develop behavioral models for driver gap acceptance at priority intersections was collected from these two sites. Traffic counts were also conducted at these sites prior to the collection of driver gap acceptance data. The results of analyzing these counts along with the experience gained from the pilot data collection surveys were used to decide the needed number of interviewers, the proper sampling procedure, and the survey time needed to collect a sample with appropriate size.

## 4.3 DATA COLLECTION

### 4.3.1 Observation Unit

Literature review shows that there are two possible ways of defining the observation in gap acceptance studies:

**a.** Each ***gap*** can be treated as an observation in an independent sequential binary choice process. This approach was followed by many researchers including Fitzpatric (1991), Madanat, et al. (1994), Mahmassani and Sheffi (1981), Maze

(1981) and Pant and Blakrishnan (1994). In this approach, probability can be expressed in terms of the probability of accepting a gap by a given driver or the probability that a driver accepts a given gap. Both statements are equivalent under the assumption of independence of gap acceptance decision across and within drivers [Madanat et al. (1994)];

b. Each driver with his group of gaps (gaps he observed) is considered as one observation. This approach was followed by some researchers like Ashton (1971) and Daganzo (1981) who used multi choice models specially multinomial probit model which assumes that a driver selects one specific gap out of several possible options (gaps) through a single comparison of all of the available gaps. This might be an unrealistic representation of the gap acceptance process [Madanat et al. (1994)], since gaps offered to a driver are not known to him *a priori*.

Based on this last comment and discussion presented in Chapter 3 (Section 3.2.1), the first approach will be adopted in this research.

### 4.3.2 Classification of Observations

#### *4.3.2.1 Driver Response-Based Classification*

Based on driver response each observation (lag or gap) can be classified into one of the following three categories [Robertson (1994)]:

a. ***Accepted Gap/lag***: A gap/lag which is accepted (used) by a minor stream driver aiming to execute a given maneuver;

b. ***Rejected Gap/lag***: A gap/lag which is rejected (not used) by a minor stream driver aiming to execute a given maneuver;

c. ***Untested Gap:*** A gap occurred while no minor stream driver exists at the intersection. This type of gaps can not, by its nature, be included in the model.

#### *4.3.2.2 Gap Type-Based Classification*

Based on gap type each observation (gap/lag) can be classified into one of the following categories;

a. ***Gap***: Which is the time interval between two successive vehicles passing a given point;

b. ***Lag***: Which is the remaining part of the gap during which the minor road driver reaches the junction;

c. ***Nearside Gap/lag***: Which is a gap/lag created by a major stream vehicle coming from the *left hand side* of the driver waiting at the minor road, i.e., the major stream vehicle will be moving on the *near lane* with respect to the driver waiting at the minor road;

d. ***Farside Gap/lag***: Which is a gap/lag created by a major stream vehicle coming from the *right hand side* of the driver waiting at the minor road, i.e., the major stream vehicle will be moving on the *far lane* with respect to the driver waiting at the minor road.

See Chapter 2 for more detailed definitions of the above discussed terms and Section 4.3.3, Figure 4.4 in this chapter for graphical illustrations of the terms.

For the binary logit choice model developed in this study, the response-based classification represents the binary qualitative response of the driver, i.e., the dependent variable which takes the value of one when the driver accepts a gap/lag and the value of zero when he rejects a gap/lag. The last two classes of gaps/lags (nearside and farside gaps/lags) apply only for maneuver 3 (the left turn from minor road into major road).

### 4.3.3 Data Collection Methodology

Data for this research is collected based on the simultaneous use of video camera and field administered questionnaires. Video camera is used to record traffic operations at study sites. Video tapes are later viewed to extract data items discussed in Chapter 3 (Table 3.1). These items include gap size, oncoming vehicle type and speed, delay at minor stream, traffic volume, maneuver type, queue size at minor stream, number of vehicles accepting a given gap, speed and type of minor stream vehicle, and driver decision in terms of accepting or rejecting a given gap.

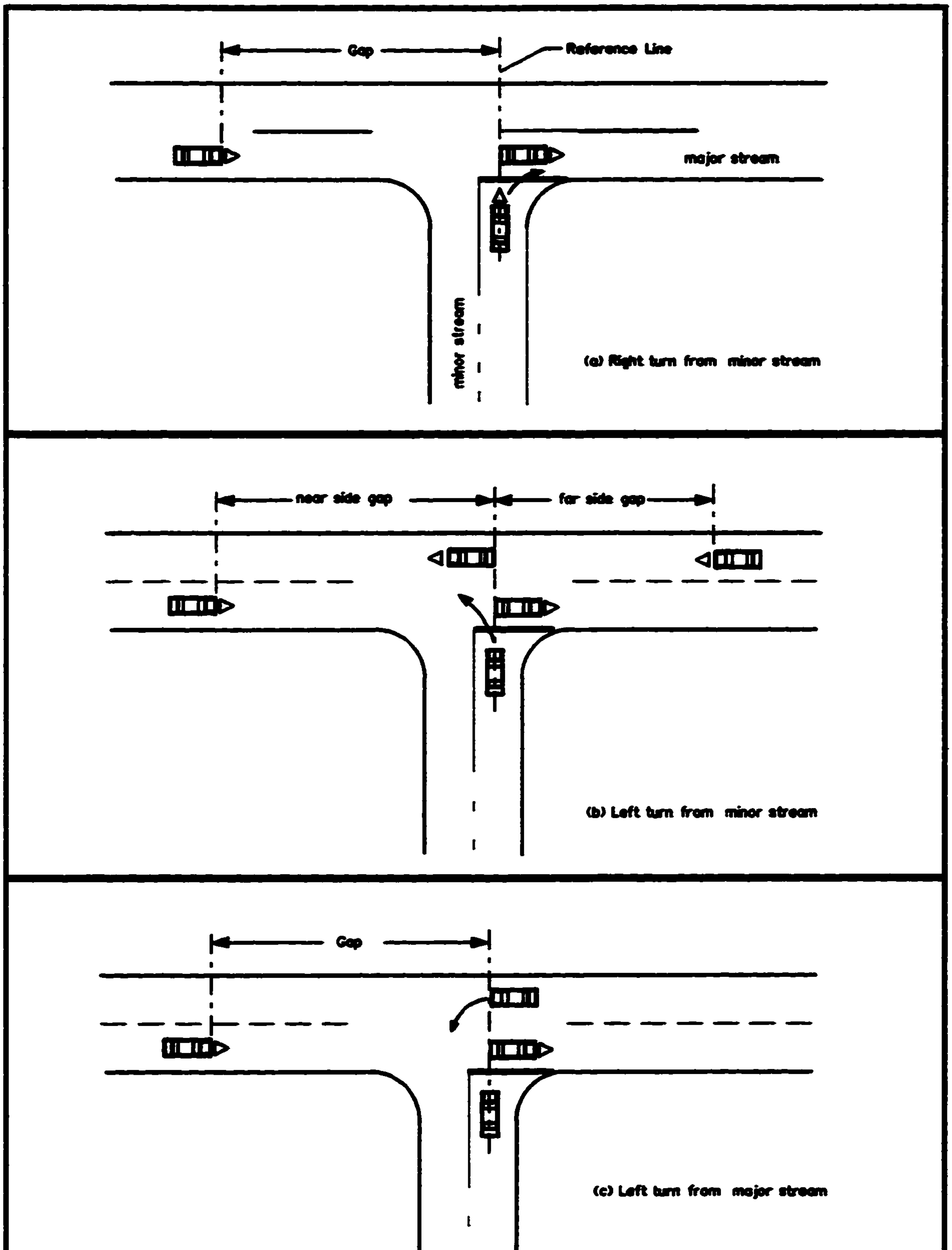



Figure 4.4 Illustration of manuver types to be studied along with their relevant Gaps

A field administered questionnaire is used to collect other data items which can not be extracted from video tape. These items include driver characteristics (age, driving experience, education, ...), vehicle characteristics (age, engine capacity, occupancy, ...), and trip characteristics (trip purpose and duration). The questionnaire used to collect data in the field and the forms utilized in coding the collected and extracted data from video tapes are included in Appendix A. Road side interviews to collect data from minor street drivers executing the concerned maneuver should be made down stream at far enough distance (150 - 200 meters) from the intersection in order to:

a. Minimize traffic operation interruption and keep the intersection working under normal traffic conditions as possible;

b. Minimize the possible alteration in drivers gap acceptance behavior by ***not*** attracting their attention and awareness.

Roadside interviews are conducted only for drivers executing the concerned maneuvers. The questionnaire used in these interviews is given in Appendix (A). The following three types of T-junction maneuvers are studied:

***a. Right turns from minor stream;***

***b. Left turns from minor stream;***

***c. Left turns from major stream.***

These maneuvers along with the gaps relevant to each of them are illustrated in Figure 4.4. Driver gap acceptance behavior is modeled for each of the above discussed

maneuvers. Conducting roadside interviews and other manual data collections for the three maneuvers simultaneously is difficult and requires a large team including at least three traffic police patrols with their crews and around twenty other persons (observers and interviewers). Therefore, data for each maneuver was collected at a separate normal weekday but during common periods (7:00-10:30 A.M. and 12:00 - 3:30 P.M.) for the three maneuvers. Data collection periods for each maneuver were selected like this for capturing variations in traffic operations and gap acceptance characteristics in peak and off-peak times (morning and evening). As mentioned above, this approach provides a common base for comparing results obtained for different maneuvers. It should also be mentioned that collecting data for each maneuver at a separate day offers the advantage of causing less interruption to the traffic at the junction and significantly reduces the size of the required data collection team and hence makes the process more controllable.

To be able to cover a wide enough intersection area (50-100 meters at each approach), which is needed to determine the speed of the approaching vehicles at major and minor roads and queue size at minor road, video camera should be placed far enough from the intersection. In such a case, plate numbers of minor stream vehicles (which are needed for matching video tape data to questionnaire data) can not be extracted from video tapes.

This problem was solved by assigning an observer to record the plate numbers of each and every minor stream vehicle executing the concerned maneuver in the very strict order in which these vehicles have executed the maneuver. Figure 4.5 illustrates the basic set-up for data collection.

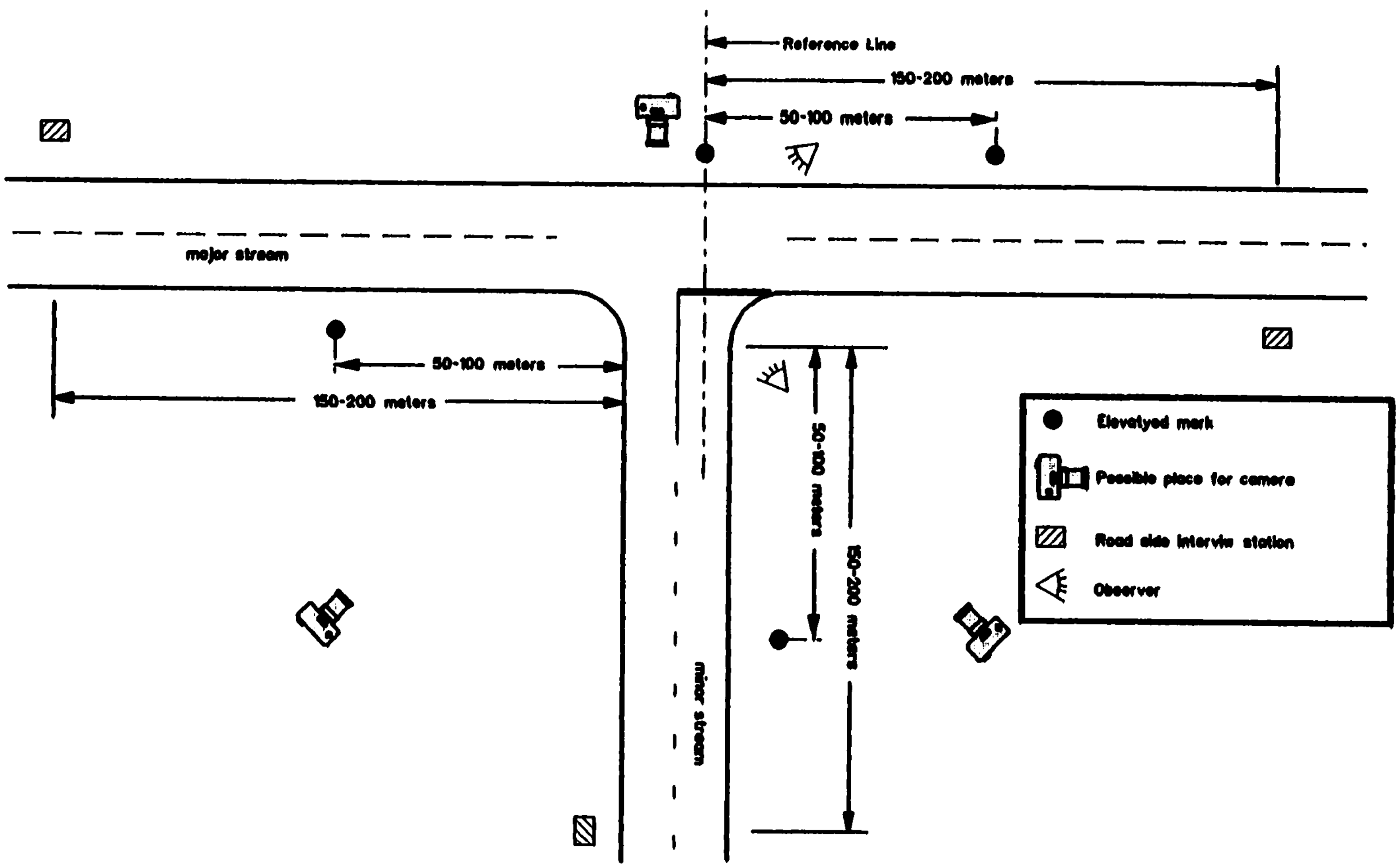



Figure 4.5 Basic arrangements for data collection

### 4.3.4 Data Collection Team

A total of eleven persons were employed for collecting the required data. These comprised of a supervisor to transport the team to the sites and to supervise its performance during the survey period, a policeman to assist in stopping drivers to be interviewed, a camera operator to operate and supervise the operation of the video camera, a plate number observer to note down the plate numbers of the studied minor stream vehicles in the exact order by which they execute the maneuvers, and a team of 7 roadside interviewers. The data collection team (especially the vehicle plate number observer and the interviewers) was fully trained to get accurate information. Interviewers were adequately trained prior to the survey. In order to ensure that the data is collected accurately, two types of training were given to the team. Initially office training was conducted in order that the team members understand the questions included in the questionnaire and be able to communicate with drivers in a smooth and easy way. Later a field pilot survey was carried out on one of the sites for three full hours. This pilot survey was very useful in checking out the practical difficulties posed during the survey and the average time needed to conduct the surveys and adequacy of the staff deployed for the survey.

It was revealed from the pilot survey that some of the drivers find difficulty in answering some of the questions especially the one in which the driver is asked to estimate the speed and distance of the oncoming vehicle. Therefore interviewers were

further trained to explain the questions in a simple way with the help of illustrative sketches whenever required. Pilot survey also revealed the importance of recording the color and brand of the interviewed vehicle. This helped in data matching process later. It was also found that each interview takes (in average) around 5 minutes and that using seven interviewers will result in collecting an adequate number of interviews at the selected sites.

### 4.3.5 Data Coding and Processing

Data processing in this study has included the following three main phases and tasks:

i. ***Checking and coding data collected from Roadside interviews:*** The filled in questionnaires were checked and data items included in these questionnaires (refer to Table 3.1) were coded using the form given in Appendix A. The used questionnaire itself is also given in Appendix A.

ii. ***Extracting data from video tapes:*** One of the main and time consuming tasks in the study was the extraction of data from video tapes recorded during the survey.

Data items needed from video tapes (Refer to Table 3.1) were extracted in two steps using a team of four observers:

a. Direct observation and manual coding to extract the following data sets, one set per each observer:

- Queue size at the time of gap acceptance and number of ahead entries in the accepted gap if any;
- Driver response to each gap he evaluates (accept or reject) and the type of gap (gap or lag) and far or near ((apply to maneuver 3 only);
- Type (Small or large) and color of minor stream vehicle arranged in same order in which they execute the studied maneuver;
- Type of oncoming vehicle.

b. Direct observation and digital coding to extract information needed to derive gap length, speed of the oncoming vehicle and the studied vehicles as well, traffic volumes at major and minor streams, delay imposed on the studied vehicles (in queue and at queue head). Data items needed to derive these variables were collected using a simple program coded in FOXBASE. In this program, a set of computer keys were selected and defined such that the actual time (to the nearest of 0.01 seconds) is noted down automatically at the press of these keys. The sequential order of pressing these keys is kept. The resulted data is stored in a spread sheet format which can be later easily manipulated by other powerful and

user friendly software like MS-Excel. For example F1 and F5 keys were used by one of the observer to get the information needed to derive gap length and speed of the oncoming vehicle in the following manner. (refer to Figure 4.6 for illustration).

A point at known distance "D" upstream of the oncoming flow is defined and clearly marked for the observer. As the oncoming vehicle passes that point, the observer will press the F1 key and as it passes infront of the car waiting at the minor approach he will press the F5 key. The observer will repeat the same action for each of the oncoming vehicles if there is a car at the stop line of the minor approach. Speed of the $n^{th}$ oncoming vehicle and the size of the gap created by the $n^{th}$ oncoming vehicle and its succeeding vehicle (the $n+1^{th}$ vehicle) is computed as follows:

$$G_n = (F_5)_{n+1} - (F_5)_n$$

$$T_n = (F_5)_n - (F_1)_n$$

$$S_n = D / T_n$$ Where,

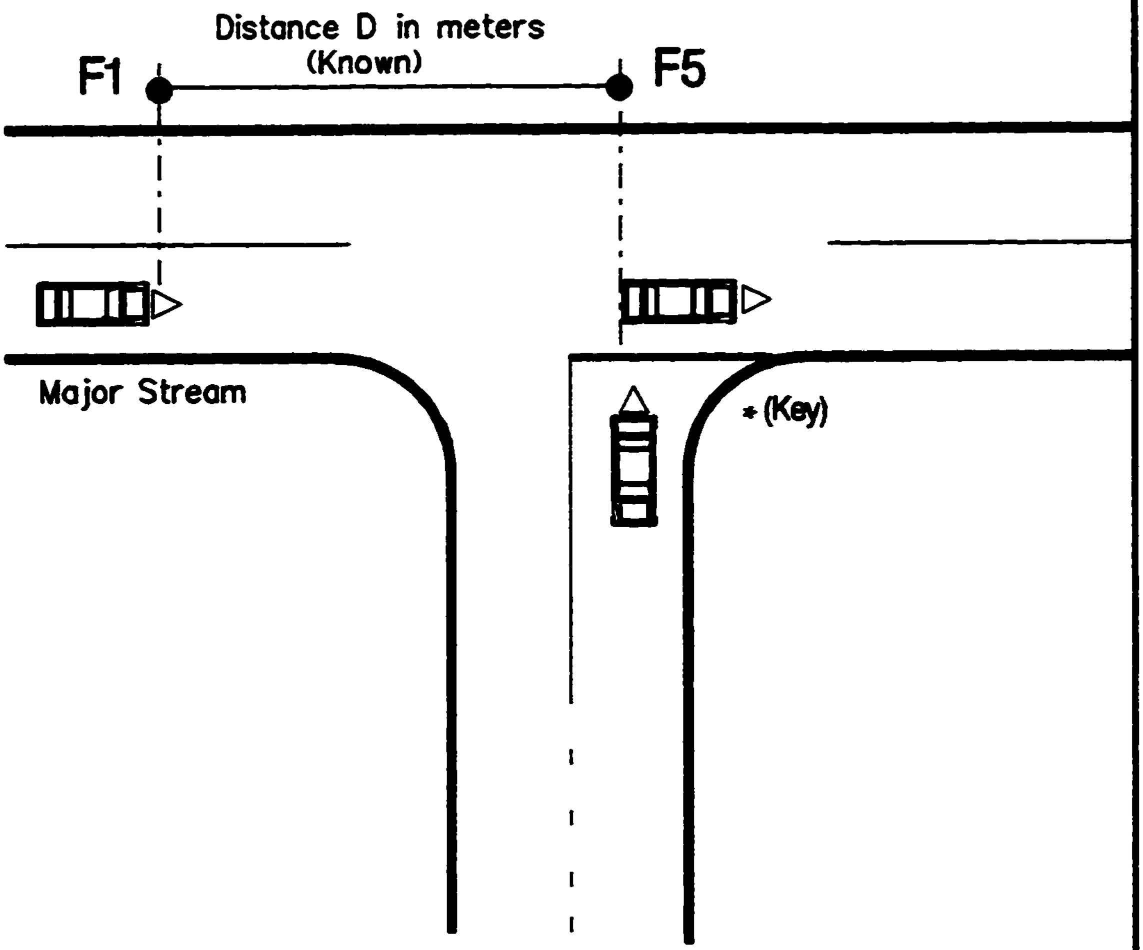
$G_n$ = gap created by the $n^{th}$ oncoming vehicle and the succeeding vehicle (i.e., the $n+1^{th}$ vehicle);

$(F_5)_n$ = time at which the $n^{th}$ vehicle passes infront of the vehicle waiting at minor approach;

$(F_5)_{n+1}$ = time at which the $n+1^{th}$ vehicle passes infront of the vehicle waiting at the approach;

$(F_1)_n$ = time at which the $n^{th}$ vehicle passes a point at "D" distance upstream (D is known from field measurements);

$T_n$ = time needed for the $n^{th}$ vehicle to pass over the distance D;




(Travel time for nth vehicle, Tn)=(F5)n-(F1)n

(Gap)n = (F5)n+1 -(F5)n

Speed of the nth oncoming vehcle, Sn=(*)n

Delay at queue head for nth vehicle

at minor steam=(*)n+1 -(*)n

**Figure 4.6 Illustrative Example of manipulating data extracted from video tapes.**

D = the distance over which the speed of the oncoming vehicle is measured.

Other keys are used in a similar way in order to get the information needed to derive the other variables mentioned above. It is to be noted here that the process of extracting data from video tapes was very slow, time consuming, and needs high concentration from the video observers. In order to ensure that the data extraction is accurate the observers were highly trained. Prior to extraction of data, pilot runs of the video tapes were made and the data was cross checked against each other to ensure that the observers are well trained and results are accurate. The forms used to extract data from video and the form used to summarize and code the extracted data are included in Appendix A.

*iii.* ***Data Matching:*** One basic and crucial step in the data processing phase is to accurately match data collected from Roadside interviews to data extracted from video tapes. The main controlling key in this process is the vehicle plate numbers. The matching process has been finalized through the following main steps;

**a.** The vehicle plate numbers recorded by the roadside interviewers are matched to the vehicle plate numbers noted down by the "vehicle plate number's observer" described in Section 4.3.3. This matching step has been accomplished making use of the capabilities of the MS-EXCEL package after coding the data in an EXCEL worksheet format. As discussed earlier, the basic job of the above mentioned observer is to note down the plate number of each of the minor stream vehicles executing the studied maneuver in the *exact order* by which they executed the

maneuver. Hence, the *serial numbers* given for the minor stream vehicles by the plate number's observer represent the *correct sequence* in which these vehicles had executed the studied maneuver. Therefore, the result of this step is the arrangement of the data collected in roadside interviews (one data set per driver/vehicle) in the same sequence by which the interviewed drivers had executed the studied maneuver;

**b.** Serial numbers of the minor stream vehicles which are recorded by the "vehicle plate number's observer" are matched to the data sets extracted from the video record. Note that there is one data set per driver/vehicle and that the number of observations in each set equals the number of gaps/lags which are offered to/evaluated by that driver. As discussed in step (a) above, the serial number recorded by the observer represent the correct order by which vehicles have executed the maneuver under consideration. One crucial issue in this regard is to match the first vehicle (the first serial number) in the observer's record to the same vehicle in the video record. To be able to define this vehicle correctly the following measures were taken:

- The "vehicle plate number's observer" was instructed to start noting down the plate numbers at the instant of receiving the start signal from the video camera operator;

- In addition to the plate numbers, the observer was instructed to note down the type (small or large) and color of the first ten vehicles executing the studied maneuver;

- Vehicle characteristics (type and color) noted down by the observer for the first ten vehicles were checked against the characteristics of the first few vehicles as observed in the video record to identify (in video record) the first vehicle recorded by the observer. The first vehicle as per the observer's record is given the serial number 1 and all the preceding vehicles (if any) in the video record are excluded from any further analysis.

The result of step (b) is the matching of data sets collected in roadside interviews to the data sets extracted from video record.

c. The accuracy of the results of the matching process is confirmed by cross checking the type (small or large) and the color of vehicles as recorded in roadside interviews against the type and color as observed in the video record and as recorded by the "vehicle plate number's observer" whc was instructed to note down the type and color for every tenth vehicle or so;

d. At the completion of the matching process, data sets are refined and finalized in terms of removing the cases (drivers/vehicles) for which roadside interviews were not conducted and removing the measures and characteristics like vehicle color and plate number which were needed to complete the matching process only.

After the above precautionary measures, it was totally ensured that the matching process is correct. The following example illustrates the above discussed steps using the first five vehicles observed at a site. The information available from the observer record, roadside interviews, and video record are given in Table 4.1. The result of applying step (a) of the matching process to the given information is presented in Table 4.2.

Matching the information available from the observer record to the information extracted from video record, it can be easily identified that vehicle number 1 in the observer record is itself the vehicle number 2 in the video record. Therefore the starting point in video record is vehicle number 2. The results of applying step (b) in the matching process to the information given in Table 4.2 are given in Table 4.3.

Checking the vehicle type and color information obtained from different sources (observer, roadside interviews, and video record) in Table 4.3 indicates that the characteristics from the different sources are identical which confirms the accuracy of the matching process. Hence, the measures used for the matching process and which are not further needed can be removed at this stage. The rows corresponding to the uninterviewed drivers/vehicles can also be removed. The refined data set for the illustrative example after removing the items not needed in further analyses is given in Table 4.4.

As discussed early, the data set for a roadside interview represents all of the data items collected during that interview while the data set extracted from the video record represents the data for all of the gaps/lags that were offered to and evaluated by the driver.

**Table 4.1: Given information for the illustrative example on data matching process**

| Information from the observer record | | | | Information from roadside interviews | | | | Information from video record | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sr. No. | Plate No. | Type | Color | Plate No. | Type | Color | Data Set | Sr. No. | Type | Color | Data Set |
| 1 | 5782 | Small | Black | 31721 | Large | Blue | Ques. 1 | 1 | Small | Green | Video 1 |
| 2 | 20904 | Small | White | 5782 | Small | Black | Not Int. | 2 | Small | Black | Video 2 |
| 3 | 31721 | Large | Blue | 20904 | Small | White | Ques. 2 | 3 | Small | White | Video 3 |
| 4 | 86223 | Small | Brown | 65432 | Small | White | Not Int. | 4 | Large | Blue | Video 4 |
| 5 | 65432 | Small | White | 86223 | Small | Brown | Ques. 3 | 5 | Small | Brown | Video 5 |

Note: Ques. n represents the $n^{th}$ roadside questionnaire filled for the given driver/vehicle and "Not int." represents a driver/vehicle which was not interviewed.

Table 4.2: Results of applying step (a) of the matching process to the illustrative example

| Sr. No. | Obs. No. | Obs. Type | Obs. Color | Int. No. | Int. Type | Int. Color | Int. Data |
|---|---|---|---|---|---|---|---|
| 1 | 5782 | Small | Black | Not Int. | Not Int. | Not Int. | Not Int. |
| 2 | 20904 | Small | White | 20904 | Small | White | Ques. 2 |
| 3 | 31721 | Large | Blue | 31721 | Large | Blue | Ques. 1 |
| 4 | 86223 | Small | Brown | 86223 | Small | Brown | Ques. 3 |
| 5 | 65432 | Small | White | Not Int. | Not Int. | Not. Int. | Not Int. |

Abbreviations in the table mean: Obs. No.: Plate number registered by the observer; Obs. Type and Obs. Color: Vehicle type and color as recorded by the interviewer; Int. No, Int. Type, and Int. Color: Vehicle plate number, Type, and Color as noted by the interviewer; Int. Data: Data set extracted from roadside interviews for the given vehicle; Ques. n: The $n^{th}$ field administered questionnaire.

**Table 4.3: Results of applying step (b) of the matching process to the illustrative example**

| Obs. Serial | Obs. No. | Obs. Type | Obs. Color | Int. No. | Int. Type | Int. Color | Int. Data | Vid. Serial | Vid. Type | Vid. Color | Vid. Data |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Not Obs. | Not Obs. | Not Obs. | Not Obs. | Not Int. | Not Int. | Not Int. | Not Int. | 1 | Small | Green | Video 1 |
| 1 | 5782 | Small | Black | Not Int. | Not Int. | Not Int. | Not Int. | 2 | Small | Black | Video 2 |
| 2 | 20904 | Small | White | 20904 | Small | White | Ques. 2 | 3 | Small | White | Video 3 |
| 3 | 31721 | Large | Blue | 31721 | Large | Blue | Ques. 1 | 4 | Large | Blue | Video 4 |
| 4 | 86223 | Small | Brown | 86223 | Small | Brown | Ques. 3 | 5 | Small | Brown | Video 5 |
| 5 | 65432 | Small | White | Not Int. | Not Int. | Not. Int. | Not Int. | 6 | Small | White | Video 6 |

Abbreviations in the table mean: Obs. No.: Plate number registered by the observer; Obs. Type and Obs. Color: Vehicle type and color as recorded by the interviewer; Int. No. Int. Type, and Int. Color: Vehicle plate number, Type, and Color as noted by the interviewer; Int. Data: Data set extracted from roadside interviews for the given vehicle; Ques. n: The $n^{th}$ field administered questionnaire; Vid. Serial, Vid. Type, Vid. Color, and Vid. Data: Serial number, Type, color, and data set extracted from video record, respectively: Video n: data set extracted from video record for the $n^{th}$ vehicle.

### 4.3.6 Data Organization

Models developed in this study are of the binary logit type described in Chapter 3. The dependent variable in these models is binary and takes the values of 0 (reject a gap) or 1 (accept a gap) only.

In the studied gap acceptance phenomenon, it is possible that some drivers may evaluate and reject several gaps before accepting a gap while other drivers will accept the first time intervals (the lags) offered to them. In this context, it could be inappropriate to model the phenomenon as a typical discrete choice one in which gaps are considered as "choice alternatives" since the driver does not know, a priori, neither the number nor the characteristics of the gaps that could be available for him. It could be also inappropriate to model the phenomenon as a typical binary discrete choice problem. In such a case, two choice alternatives (say auto and bus in the binary mode choice example) are available for each of the observed individuals unless the individual is captive to either of the choices. The decision process in the gap acceptance phenomenon is different in terms that there is only one available gap (call it decision subject) at a time and two possible outcomes of the process (reject or accept that gap). Hence, in gap acceptance case there is actually one available alternative (a gap) and the decision is whether to accept it or not while in the typical binary alternative case there are two available choice alternatives (auto and bus in the given example) and the decision is which one to select. Therefore the two examples are similar in terms that the outcome of the decision process in both is binary while they

are different in terms that only one alternative is available in the gap acceptance case while two alternatives are available in the binary mode choice example.

Bearing in mind the above discussion, and referring to similar decision making cases discussed by Greene (1995), gap acceptance data for this study were organized in the same manner followed in regression analysis in terms that each "decision making run" was coded as an observation and was represented by a row of data. This row of data consists of the outcome of the process (accept or reject) which represents the dependent variable and a vector of driver, gap, traffic, vehicle, and trip attributes which represent the independent variables. As mentioned above, this approach is followed in organizing data for similar decision processes presented in LIMDEP manual [Greene, (1995)]. This approach was also confirmed to be appropriate by Professor Frank Koppleman (Northwestern University) who was consulted directly in this regard. In his reply to some of our queries, Professor Koppleman has stated that in the case of using binary probit and logit models *"the data should be organized as if running linear regression (one row for each individual decision process)"*. Therefore data were organized in rows as illustrated in Table 4.5 where each row represents an individual "decision making run" in which a driver evaluates a gap/lag and either rejects or accepts it.

## 4.4 SAMPLE SIZE

Main advantages of using disaggregate modeling techniques include better use of data, less data requirements, and improved statistical bases of model building. [Bates

**Table 4.4: Summarized form of the matched data for the illustrative example**

| Serial Number of driver/Vehicle | Roadside interview data | Video record data |
|---|---|---|
| 1 | Ques. 2 | Video 3 |
| 2 | Ques. 1 | Video 4 |
| 3 | Ques. 3 | Video 5 |

Abbreviations in the table mean: Ques. n: The n$^{th}$ field administered questionnaire; Video n: data set extracted from video record for the n$^{th}$ vehicle.

**Table 4.5: Data organization for model calibration purposes**

| Observation | Dependent Variable | Dependent Variables |
|---|---|---|
| A driver evaluating a gap/lag | Driver response or decision in terms of accepting (1) or rejecting (0) the gap/lag | Vector of driver, gap, traffic, vehicle, and trip Attributes and characteristics |

(1979)]. Sample size requirements for such models were discussed in Chapter 2 (Section 2.5.5). Literature review revealed that as small samples as 50 data points could produce reasonable results [Richard and Ben-Akiva (1975)]. In some cases, researchers have used as small samples as only 16 data points [Fitzpatrick (1991)]. Based on these results, complete data will be collected for a sample in the range from 50 to 100 drivers at each site for each of the three studied maneuvers. Since each driver may be exposed to more than one gap if he does not accept the first one, the number of data points (number of lags and gaps) may exceed this value. In terms of time, data was collected over a period in the range of three to four hours for each maneuver. Based on field investigations and a priori conducted traffic counts, it was decided that the above specified survey period is long enough to observe a proper sample size. Actual sample sizes collected for each of the studied maneuvers are given in Chapter 5.

# CHAPTER 5

## PRELIMINARY ANALYSIS OF GAP ACCEPTANCE DATA

### 5.1 INTRODUCTION

This chapter gives a summary of the collected data, provides the general description and frequency analyses conducted for these data and discusses the critical gaps derived for different levels of the studied driver, vehicle, gap, traffic, and trip attributes. The chapter also outlines the procedure adopted to identify the group of the significant independent variables among the long list of the studied variables.

## 5.2 DESCRIPTION OF THE DATA

The data used in this study was collected in May 1996 from two priority T-junctions according to the procedure detailed in Chapter 4. Based on pre-conducted traffic counts at each of the studied junctions, a minimum of 3-hour survey was carried out to collect data for each of the studied maneuvers. This means that a total of 9-hour surveys were conducted for each of the studied junctions. This survey period was sufficient to get the target sample size for each maneuver. The percentage of the interviewed drivers ranged from more than 33% to around 46% as can be seen from Table 5.1 which presents a summary of the collected data. Other more detailed statistics and information about the collected data are discussed in Section 5.3.

### 5.2.1 Describing and Naming the Variables

Variables modeled in this research are discussed in Chapter 3 (refer to Table 3.1). in this section, studied variables will be coded and described briefly. The basic aim to define each variable at this stage is to use it as a reference during modeling description in the coming Chapters. The order of variable abbreviation list will follow the order of variables as mentioned in Table 3.1. Variables considered in this study along with their codes and definitions are given in Table 5.2.

**Table (5.1): Summary of the collected data**

| Item | Site 1 | | | Site 2 | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** |
| Total number of cars observed at the minor road | 416 | 565 | 260 | 391 | 509 | 263 | 807 | 1074 | 523 |
| Total number and percentage of the interviewed drivers | 185 (44.47) | 241 (42.65) | 120 (46.15) | 150 (33.25) | 180 (35.36) | 117 (44.49) | 335 (41.50) | 421 (39.20) | 237 (45.32) |
| Number and percentage of the complete/usable questionnaires | 147 (79.46) | 203 (84.23) | 105 (87.50) | 130 (86.67) | 163 (90.56) | 111 (94.49) | 277 (82.69) | 366 (86.94) | 216 (91.14) |
| Total number of gaps/lags evaluated by the interviewed drivers (sample size) | 176 | 216 | 265 | 161 | 180 | 359 | 337 | 396 | 624 |
| Number of observations reserved for validation purpose | 58 | 72 | 88 | 53 | 60 | 105 | 111 | 132 | 193 |
| **Total sample size** | **243** | **288** | **353** | **214** | **240** | **464** | **448** | **528** | **817** |
| Average number of gaps/lags per interviewed driver. | 1.59 | 1.42 | 3.36 | 1.64 | 1.47 | 4.18 | 1.62 | 1.44 | 3.78 |

***Note: Mn represents the $n^{th}$ maneuver***

**Table 5.2: Variable Coding and Definition**

| Serial No. | Variable Coding | Description of the Variable |
|---|---|---|
| | | ***DEPENDENT VARIABLE*** |
| *1.* | ***RESP*** | Driver Response (Accept, Reject). This is the dependent variable. |
| | | ***INDEPENDENT VARIABLE*** |
| | | ***A) DRIVER RELATED CHARACTERISTICS AND ATTRIBUTES*** |
| *2.* | ***DAGE*** | *Age of the minor stream driver in years* |
| *3.* | ***DEXP*** | *Driving experience of the minor stream driver in years* |
| *4.* | ***DEDU*** | *Driver education (Preliminary School or less, Secondary School, University Degree)* |
| *5.* | ***ACTN*** | *Gap acceptance criteria (Based on speed and/or distance of oncoming vehicle)* |
| *6.* | ***DFAM*** | *Driver familiarity to the studied site measured as the number of times he passes the site in a week* |
| *7.* | ***DSEX*** | *Sex of the minor stream driver (Male, Female)* |
| *8.* | ***NLTY*** | *Driver nationality* |
| *9.* | ***SDES*** | *Driver estimate of the speed of the oncoming vehicle that he entered in front* |
| *10.* | ***DTES*** | *Driver estimate of the distance of the oncoming vehicle that he entered in front (Distance gap that he accepted)* |
| *11.* | ***DEAS*** | *Difference between actual and estimated speed, DEAS = MJSD-SDES where MJSD is the actual speed of the oncoming vehicle in Km/Hr.* |
| *12.* | ***DEAD*** | *Difference between actual and estimated gap distance DEAD = GMET-DTES* |
| *13.* | ***GEAP*** | *Difference between actual and estimated time gap in seconds GSEC = 1/3.6(SDES/DTES)* |
| *14.* | ***DAMR*** | *Difference between accepted gap and maximum rejected gap* |
| *15.* | ***NREJ*** | *Number of gaps or lags rejected by the driver* |
| *16.* | ***ACDT*** | *Number of traffic accidents occurred to driver in the last two years* |
| *17.* | ***VLTN*** | *Number of traffic violations issued to the driver in the last year* |
| | | ***B) TRAFFIC CHARACTERISTICS AND ATTRIBUTES*** |
| *18.* | ***MJVL*** | *Major stream traffic volume conflicting with the studied maneuver expressed in vehicles/30 seconds* |
| *19.* | ***MJSD*** | *Speed of the major stream vehicle (Speed of the oncoming vehicle)* |
| *20.* | ***MNVL*** | *Minor stream volume in vehicles per 30 seconds* |
| *21.* | ***MNSD*** | *Speed of the minor stream vehicle in Km/Hr* |
| *22.* | ***QSIZ*** | *Queue size at minor stream at the time of accepting the gap* |
| *23.* | ***DLIQ*** | *Delay in queue for the minor stream vehicle* |
| *24.* | ***DLQH*** | *Delay at queue head for the minor stream vehicle* |
| *25.* | ***TLDL*** | *Total delay for the minor stream vehicle (TLDL = DLIQ+DLQH)* |

**Table 5.2 "continued": Variable Coding and Definition**

| Serial No. | Variable Coding | Description of the Variable |
|---|---|---|
| ***C. VEHICLE CHARACTERISTICS AND ATTRIBUTES*** | | |
| ***26.*** | ***VAGE*** | *Age of the minor stream vehicle in years* |
| ***27.*** | ***EGCA*** | *Engine capacity of the minor stream vehicle expressed in number of cylinders* |
| ***28.*** | ***OCUP*** | *Occupancy of the minor stream vehicle (number of passengers including driver)* |
| ***29.*** | ***TRAN*** | *Type of movement Transmission (Automatic, Manual)* |
| ***30.*** | ***MJTP*** | *Type of major stream vehicle* |
| ***31.*** | ***MNTP*** | *Type of minor stream vehicle* |
| ***D. GAP CHARACTERISTICS AND ATTRIBUTES*** | | |
| ***32.*** | ***TMGP*** | *Time Type of gap (Gap/Lag)* |
| ***33.*** | ***TRGP*** | *Traffic Type of gap (Near side/Far side) for maneuver 3 only* |
| ***34.*** | ***GSEC*** | *Gap size in seconds* |
| ***35.*** | ***GMET*** | *Gap size in meters GMET = (GSEC)(MJSD)* |
| ***36.*** | ***PSEC*** | *Size of the preceding gap in seconds in case the driver rejects the gap* |
| ***37.*** | ***PMET*** | *Size of the preceding gap in meters* |
| ***38.*** | ***SSEC*** | *Size of the succeeding gap in seconds* |
| ***39.*** | ***SMET*** | *Size of the succeeding gap in meters* |
| ***40.*** | ***TTGP*** | *Type of the gap for maneuver 3 i.e., left from minor (Far side or near side)* |
| ***E - TRIP CHARACTERISTICS AND ATTRIBUTES*** | | |
| ***41.*** | ***TRPS*** | *Trip purpose for the driver of the minor stream vehicle* |
| ***42.*** | ***TRDN*** | *Trip duration for the driver of the minor stream vehicle* |
| ***F - DRIVER INTER-INFLUENCE FACTORS*** | | |
| ***43.*** | ***ASEC*** | *Gap accepted by the ahead driver in seconds* |
| ***44.*** | ***AMET*** | *Gap accepted by the ahead driver in meters* |
| ***45.*** | ***AREJ*** | *Number of gaps rejected by the ahead driver* |
| ***45.*** | ***AENT*** | *Number of ahead entries in the same gap accepted by the driver* |

### 5.2.2 Categorical Variables

Some of the variables listed in Table 5.2 are discontinuous or categorical variables. These categorical variables will be coded as dummy variables. Separate Models will be calibrated for the two gap types (Gaps and Lags) and will be checked to investigate whether the type of the gap affects driver gap acceptance behavior offered to him. Separate models for other categorical variables will be tried only when the available sample size for each level (category) of the concerned variable is in the vicinity of 100 observations and only if the variable itself is significant in explaining the driver gap acceptance behavior. Separate models for non-significant categorical socioeconomic variables will be developed if significant differences in gap acceptance behavior at different levels of the variable are indicated from the critical gap analysis phase and if the available sample size for each level of the variable is appropriate.

In coding categorical variables as dummies an (n-1) dummy variables should be created for each categorical variable with (n) levels. Binary categorical variables (DSEX, TRAN, MJTP, TMGP, and TRGP) are coded as (0,1) dummies. For variables with n categories or more where n is greater than 2, (n-1) dummies should be used for each variable. For illustration purpose the driver education, DEDU, which is a 3 level categorical variable is considered. This variable would be coded as shown below if the three levels are to be studied in the model:

| Driver Education Category | Dummy Variables | |
|---|---|---|
| | DEDU2 | DEDU3 |
| 1) Preliminary | 0 | 0 |
| 2) Secondary | 1 | 0 |
| 3)University | 0 | 1 |

It should be noted that in binary choice models of the type specified in this study (where data is organized as described in Chapter 4, Section 4.3.6), there must be observations for which the dependent variable takes both of the values 0 and 1 for each of the created dummy variables. This means that (for the case of a binary dummy variable as an example) for dummy = 0 the dependent variable (which is also binary in this case) should have 0 and 1 values and for dummy = 1 the dependent variable should also have 0 and 1 values. To be mentioned here is that all categorical variables in this study are either coded as binary dummies or studied through calibrating separate models for the two defined levels of the variable.

### 5.2.3 Variables Relevant to Subsets of the Collected Data

It should be noted at this stage that some of the variables are only relevant and available to some cases and cannot be coded as Choice-Dependent variables due to the adopted methodology of organizing data in this study. These variables are discussed below.

a. The suggested driver consistency measure (DAMR) which represents the difference between the length of the accepted gap/lag and the length of the maximum rejected gap/lag is only applicable for the cases in which the driver has actually rejected a gap or more. The same applies for variables describing the effect of any preceding gaps that are available for the driver consideration (evaluation) before he accepted a gap. These variables are coded as PSEC and PMET;

b. Variables describing the effect of the behavior of the ahead driver on gap acceptance behavior of the concerned driver. These variables are only applicable for cases in which an ahead driver exists when the concerned driver arrives at the stop line i.e., when there is a possibility for the concerned driver to observe the behavior of the ahead driver. These variables are ASEC, AMET and AREJ;

c. Variables which measure the ability of the driver to estimate the gap he accepted and the speed of the oncoming vehicle which creates that gap are only applicable to the accepted gap/lag only. Since the driver is asked to estimate the speed and distance of the oncoming vehicle that creates the gap which he accepted. Since it is unreasonable to ask him to recall/remember and estimate the speed and distance for all the gaps he has rejected especially when he rejects a considerable number of these gaps. These variables are SDES, DTES, DEAS, DEAD, DEAG.

To investigate the effect of these variables separate models will be calibrated for each of the cases discussed above whenever the available sample is appropriate (in the vicinity of 100 observations) as follows:

**a.** Model for cases in which the driver rejects gaps to study the effect of DAMR, PSEC, and PMET on driver gap acceptance behavior;

**b.** Model for cases in which an ahead driver exists at the time that the concerned driver arrives to the junction. This model aims to study the effect of ASEC, AMET and AREJ on the driver gap acceptance behavior.

When the sample size is not enough, other graphical and preliminary analysis tools will be used to investigate the effect of these variables on driver gap acceptance behavior. It is to be noted that no Logit model of the type developed in this study can be calibrated to study the effect of variables which are relevant to the cases in which the independent variable (driver response to an offered gap) is always 1, i.e., the "accept" cases. Again, the effect of these variables will be studied using graphical and other preliminary analysis tools.

## 5.3 GENERAL STATISTICS FOR THE COLLECTED DATA

Table 5.3 details out the general statistics for each of the studied maneuvers using data collected from sites 1 and 2 combined.

Table 5.3: Basic Descriptive Satistics for the Collected Data

| Variable | Variable Level | Maneuver 1 | Maneuver2 | Maneuver 3 |
|---|---|---|---|---|
| Total Number of the Observed Gaps/ | | 448 | 528 | 817 |
| DSEX | Male | 93.53% | 88.89% | 91.31% |
| | Female | 6.47% | 11.11% | 8.69% |
| DAGE | Average(years) | 35.56 | 37.12 | 36 |
| | Minimum (yrs) | 20 | 20 | 21 |
| | Maximum (Yrs) | 57 | 65 | 70 |
| DEDU | Preliminary/secondary or l | 69.92% | 76.33% | 64.14% |
| | University | 30.08% | 23.67% | 35.86% |
| ACTN | Distance of the oncommin | 48.44% | 39.02% | 39.05% |
| | Speed of the oncomming | 51.56% | 60.98% | 60.95% |
| ACDT | Average/ driver | 0.38 | 0.24 | 0.34 |
| | Minimum | 0 | 0 | 0 |
| | Maximum | 5 | 4 | 5 |
| VLTN | Average/ driver | 0.6 | 0.47 | 0.6 |
| | Minimum | 0 | 0 | 0 |
| | Maximum | 8 | 6 | 6 |
| NTLY | Arabs | 11.16% | 10.61% | 18.97% |
| | Non Arabs | 88.84% | 89.39% | 81.03% |
| RESP | Accept | 61.38% | 69.32% | 27.27% |
| | Reject | 38.62% | 30.68% | 72.73% |
| MJTP | Passenger Cars | 91.74% | 96.21% | 96.45% |
| | Large Vehicles | 8.26% | 3.79% | 3.55% |
| MNTP | Passenger Cars | 85.50% | 89.77% | 86.78% |
| | Large Vehicles | 14.50% | 10.23% | 13.22% |
| MJVL | Average (Vehicles/30 sec) | 3.63 | 2.52 | 5.89 |
| | Minimum (Vehicles/30 sec | 0 | 0 | 0 |
| | Maximum (Vehicles/30 se | 10 | 12 | 11 |
| MNVL | Avarage(Vehicles/30 sec) | 2.23 | 3.51 | 1.7 |
| | Minimum (Vehicles/30 sec | 1 | 0 | 0 |
| | Maximum (Vehicles/30 se | 5 | 8 | 5 |
| QSIZ | Average (Cars) | 0.42 | 1.35 | 1.57 |
| | Minimum (Cars) | 0 | 0 | 0 |
| | Maximum (Cars) | 4 | 9 | 9 |
| MJSD | Average (kms/hr) | 38.93 | 33.72 | 42.66 |
| | Minimum ( kms/hrs) | 12.7 | 15.38 | 11.9 |
| | Maximum (kms/hrs) | 73.3 | 79.3 | 75.9 |
| MNSD | Average (kms/hr) | 10.76 | 14.78 | 3.7 |
| | Minimum (kms/hrs) | 0 | 0 | 0 |
| | Maximum (kms/hrs) | 51.6 | 46.2 | 52.1 |

Table 5.3 "Continued": Basic Descriptive Satistics for the Collected Data

| Variable | Variable Level | Maneuver 1 | Maneuver2 | Maneuver 3 |
|---|---|---|---|---|
| VAGE | Average (yrs) | 4.8 | 5.26 | 5.45 |
| | Minimum(yrs) | 0 | 0 | 0 |
| | Maximum(yrs) | 20 | 16 | 17 |
| T RAN | Manual | 77.90% | 74.24% | 75.89% |
| | Automatic | 22.10% | 25.76% | 24.11% |
| OCUP | Average (Passenger/Car) | 2.47 | 2.04 | 2.78 |
| | Minimum (Passenger/Car) | 1 | 1 | 1 |
| | Maximum (Passenger/Car | 33 | 25 | 72 |
| TMGP | Gap | 38.62% | 28.22% | 72.83% |
| | Lag | 61.38% | 71.78% | 27.17% |
| TRGP | Near Side | NA | NA | 51.65% |
| | Far Side | NA | NA | 48.35% |
| GSEC | Average accepted(sec) | 10.12 | 8.8 | 7.57 |
| | Minimum accepted(sec) | 3 | 3.2 | 3.9 |
| | Maximum accepted(sec) | 34.8 | 35.3 | 21.8 |
| | Average Rejected (sec) | 4.29 | 3.67 | 3.47 |
| | Minimum Rejected(sec) | 1.3 | 1.4 | 0.1 |
| | Maximum Rejected (sec) | 8.5 | 7.6 | 8.5 |
| GMET | Average accepted(mt) | 106.3 | 103.17 | 95.68 |
| | Minimum accepted(mt) | 19.06 | 3.2 | 22.73 |
| | Maximum accepted(mts) | 714.95 | 35.3 | 363.94 |
| | Average Rejected (mt) | 54.82 | 51.25 | 45.95 |
| | Minimum Rejected(mt) | 8.16 | 9.13 | 0.43 |
| | Maximum Rejected (mt) | 163.57 | 112.34 | 167.42 |
| NREJ | Average (gaps/lags per dri | 0.64 | 0.6 | 2.59 |
| | Minimum (gaps/laps per d | 0 | 0 | 0 |
| | Maximum (gaps/laps per d | 7 | 13 | 19 |
| DLIQ | Average (sec) | 2.67 | 8.31 | 8.34 |
| | Minimum(sec) | 0 | 0 | 0 |
| | Maximum(sec) | 23.4 | 62.1 | 81.5 |
| DLQH | Average (sec) | 2.73 | 2.08 | 9.13 |
| | Minimum (sec) | 0 | 0 | 0 |
| | Maximum (sec | 26.6 | 34.7 | 67.4 |
| TRPS | Work | 80.80% | 82.39% | 73.07% |
| | Non Work | 19.20% | 17.60% | 26.93% |
| TRDN | Average (min) | 16.19 | 22.14 | 18.23 |
| | Minimum (min) | 3 | 10 | 10 |
| | Maximum (min) | 55 | 120 | 60 |

The Basic Observations on Table 5.3 include:

a. Percentage of gaps/lags evaluated by female drivers in different maneuvers ranges from 6.5% to 11.1%;

b. The percentage of cases in which drivers have based their decision to accept gaps/lags on their estimation of the distance of the oncoming vehicle ranges from 39% to 48%. In the remaining cases, drivers have based their gap acceptance decisions on estimating the speed of the oncoming vehicles;

c. Arab drivers evaluated 11% to 19% of the studied gaps/lags;

d. The percentage of gaps/lags that were evaluated by large vehicles at minor roads ranges from 10.2% to 14.5% of the total gaps/lags. On the other hand, large vehicles at major roads created around 3.6 to 8.3% of gaps/lags;

e. Around 51.7% of the observed gaps/lags in Maneuver 3 are nearside gaps/lags;

f. Size of the average accepted gap/lag ranges from 7.6 to 10.1 seconds while the size of the average rejected gap/lag ranges for 3.5 to 4.3 seconds;

g. Drivers performing work trips evaluated 73% to 82.4% of the observed gaps/lags.

## 5.4 BASIC FREQUENCY TABLES AND HISTOGRAMS FOR THE COLLECTED DATA

The basic statistics for the studied variables are given in Table 5.3. Table 5.4 gives the basic frequency table converted to percentages of the accepted and the rejected gaps/lags based on different categorical variables. Average and critical gaps at different levels of the studied variable will be discussed in the next section. The basic comments on Table 5.4 include:

a. If the time type of gaps is considered, it can be noted that the percentage of the rejected lags is higher than the accepted lags regardless of the movement type. The contrary is observed for gaps. This indicates that drivers have higher tendency to reject lags while they have higher tendency to accept gaps;

b. Female drivers have higher tendency to accept gaps/lags. This is due to the fact that female trips are mostly done in the off-peak time during which the frequency of rejecting gaps/lags is less due to lower traffic volumes and longer available gaps/lags;

c. Drivers who base their gap acceptance decision on estimating the speed of the oncoming vehicle have lower tendency to accept gap/laps compared to drivers who base their decision on estimating the distance. This is due to the fact that

Table 5.4: Percentage of Accepted and Rejected Gaps/Lags for Different Driver, Traffic, and Trip Attributes.

| Variable | Variable Level | Accepted Gaps | | | Rejected Gaps | | |
|---|---|---|---|---|---|---|---|
| | | M1 | M2 | M3 | M1 | M2 | M3 |
| Total number of observed gaps/lags | | 275 | 366 | 594 | 173 | 162 | 223 |
| **TMGP** | Gap | 0,62 | 0,60 | 0,25 | 0,38 | 0,40 | 0,75 |
| | Lag | 0,72 | 0,63 | 0,34 | 0,28 | 0,37 | 0,66 |
| **DSEX** | Male | 0,69 | 0,61 | 0,27 | 0,31 | 0,39 | 0,73 |
| | Female | 0,72 | 0,69 | 0,28 | 0,28 | 0,31 | 0,72 |
| **DEDU** | Secondary school or less | 0,67 | 0,61 | 0,29 | 0,33 | 0,39 | 0,71 |
| | University | 0,78 | 0,63 | 0,25 | 0,22 | 0,37 | 0,75 |
| **NTLY** | Arabs | 0,86 | 0,54 | 0,26 | 0,14 | 0,46 | 0,74 |
| | Non Arabs | 0,67 | 0,62 | 0,27 | 0,33 | 0,38 | 0,73 |
| **ACTN** | Distance of oncoming vehicle | 0,75 | 0,66 | 0,29 | 0,25 | 0,34 | 0,71 |
| | Speed of oncoming vehicle | 0,66 | 0,56 | 0,26 | 0,34 | 0,44 | 0,74 |
| **MJTP** | Passenger Car | 0,70 | 0,61 | 0,27 | 0,30 | 0,38 | 0,73 |
| | Large Vehicle | 0,60 | 0,65 | 0,34 | 0,40 | 0,35 | 0,66 |
| **MNTP** | Passenger Car | 0,69 | 0,61 | 0,28 | 0,31 | 0,39 | 0,72 |
| | Large Vehicle | 0,76 | 0,62 | 0,26 | 0,24 | 0,38 | 0,74 |
| **TRPS** | Work | 0,69 | 0,62 | 0,22 | 0,31 | 0,42 | 0,72 |
| | Non work | 0,73 | 0,58 | 0,26 | 0,27 | 0,58 | 0,74 |

drivers overestimate the speed of oncoming vehicles as concluded from analysis that will follow;

d. In general, the tendency to reject gaps/lags in work trips is less compared to nonwork trips.

In addition to frequency tables, the capability of LIMDEP to produce histograms for the studied variable is used to analyze the general distribution of the studied variable in terms of the number of observations in each category (interval) of the variable. This analysis is used to provide guidance in deciding the adequate levels of each variable to be considered in the average and critical gap analysis. As an example, the histograms drawn for the number of rejected gaps and the total delay by drivers for Maneuver 2 were investigated. It was concluded that considering three levels of the number of rejected gaps (NREJ) and three levels of the total delay (TLDL) could be appropriate for the purpose of average and critical gap analysis which is discussed in the next section. The mentioned histograms for (NREJ) and (TLDL) are given in Figures 5.1 and 5.2. The levels of the two variables decided using these histogram are 0, 1, and greater than 1 for NREJ and 0, greater than zero and less than or equal 10, and greater than 10 for TLDL. Samples of other histograms produced and analyzed in this context are given in Appendix B.

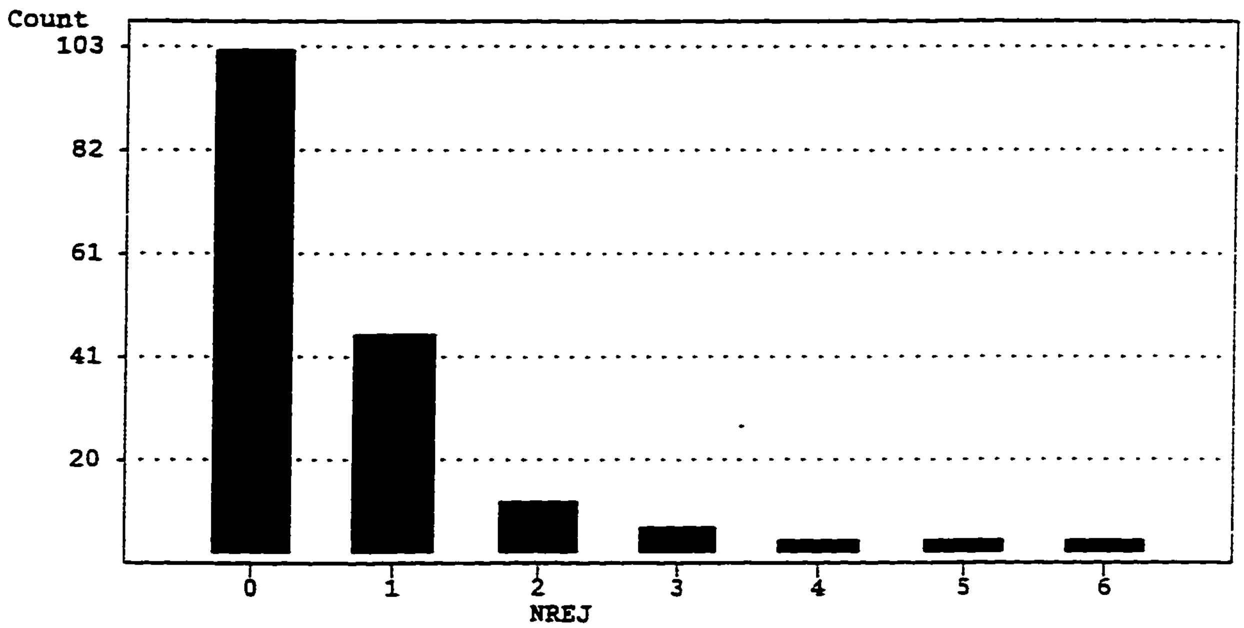



Figure 5.1: Histogram for the Number of Rejected Gaps/Lags per Driver for Maneuver 1.

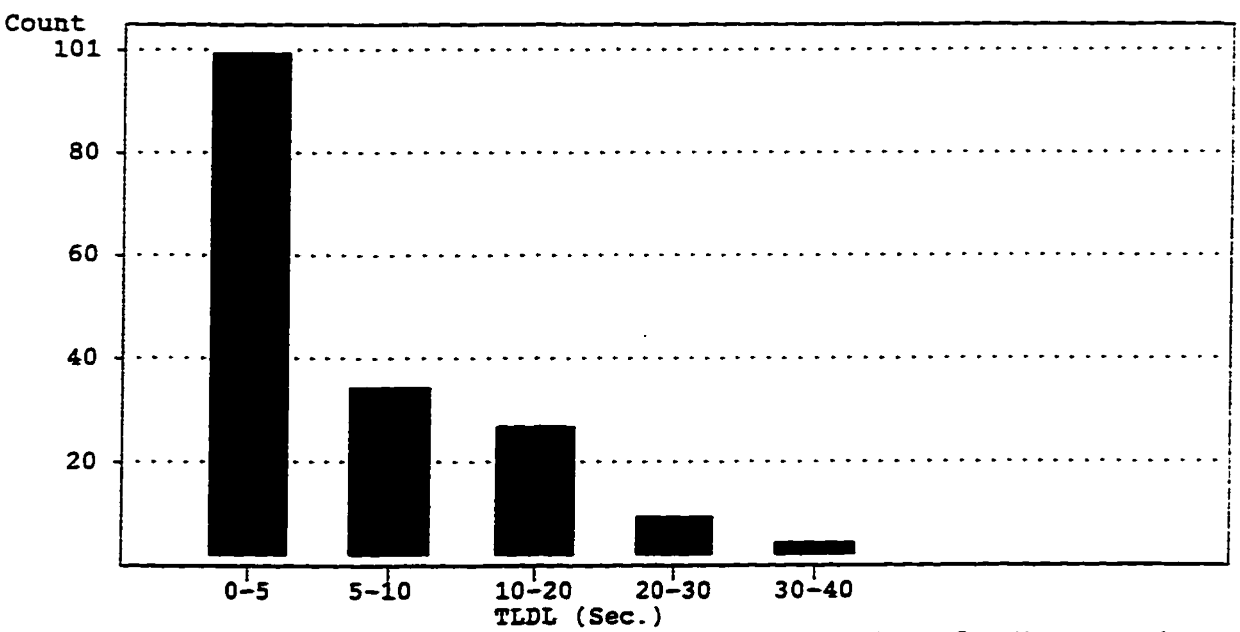



Figure 5.2: Histogram for the Total Delay per Driver for Maneuver 1

## 5.5 ANALYSIS OF THE AVERAGE AND CRITICAL GAPS

The material and results presented in this section constitutes a significant portion of gap acceptance analysis carried out in this study. Average and critical gaps are computed at different levels of the studied attributes and statistical tests are performed to check for the possible variations in driver gap acceptance behavior at these levels. Critical gaps are found using Raff's definition in which the critical gap/lag corresponds to the intersection points of the cumulative curves drawn for the number of rejected gaps longer than (GSEC) and the number of accepted gaps shorter than (GSEC), where GSEC is the length of gap/lag. In performing t-tests on critical gaps computed for the different levels of a given variable, it was assumed that the standard error of the critical gap for a given attribute level is equal to the standard error of the average gap for that level.

### 5.5.1 Analysis of the Average and Critical Gaps/Lags for Maneuver 1

#### *5.5.1.1 Average Accepted and Rejected Gaps/Lags for Maneuver 1*

The average accepted and rejected gaps calculated for different levels of the studied attributes using the data sample at Maneuver 1 are given in Table 5.5. The main comments on this table include:

Table 5.5: Average Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 1

| Variable Name and Levels | | Average Rejected Gap (Sec) | Average Accepted Gap (Sec) | Variable Name and Levels | | Average Rejected Gap (Sec) | Average Accepted Gap (Sec) |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 4.44 | 9.96 | TMGP | Gap | 3.56 | 7.11 |
| | GT 3 | 3.70 | 10.88 | | Lag | 4.79 | 11.91 |
| VAGE | LT 5 yr. | 4.37 | 9.89 | NREJ | 0 | 4.79 | 11.82 |
| | 5 to 10 yr. | 4.09 | 9.88 | | 1 | 3.69 | 7.69 |
| | GT 10 yr. | 4.74 | 11.74 | | GT 1 | 3.35 | 6.20 |
| EGCA | LE 4 Cls. | 4.22 | 10.09 | AREJ | 0 | 4.27 | 10.24 |
| | GT 4 Cls. | 4.38 | 10.20 | | GT 0 | 4.55 | 8.12 |
| TRAN | Manual | 4.22 | 9.99 | MJTP | PC | 4.25 | 9.46 |
| | Automatic | 4.59 | 10.50 | | LV | 4.78 | 16.93 |
| TRPS | Work | 4.35 | 9.86 | MNTP | PC | 4.13 | 10.07 |
| | Non Work | 4.05 | 11.24 | | LV | 5.26 | 10.38 |
| TRDN | LE 20 Mn. | 4.11 | 10.17 | MJSD | LE30 | 2.89 | 8.16 |
| | GT 20, LT 40 | 5.20 | 10.56 | | GT30, LE45 | 4.02 | 9.32 |
| | GE 40 | 4.51 | 6.87 | | GT 45 | 4.78 | 15.68 |
| DSEX | Male | 4.31 | 9.87 | MNSD | 0 | 3.82 | 7.33 |
| | Female | 3.86 | 13.19 | | GT 0, LE20 | 5.21 | 13.28 |
| DEXP | LT 2 yr. | 4.16 | 6.53 | | GT 20 | 4.86 | 13.00 |
| | 2 to 5 yr. | 4.80 | 7.47 | MJVL | LE 2 | 4.86 | 12.29 |
| | GT 5 yr. | 4.48 | 10.90 | | GE 3, LE 4 | 4.83 | 8.60 |
| DEDU | Secondary | 4.34 | 9.63 | | GT 4 | 3.87 | 6.96 |
| | University | 4.16 | 11.16 | MNVL | LE 1 | 3.83 | 14.94 |
| DFAM | LE 10 | 4.33 | 10.75 | | 2 | 4.37 | 9.99 |
| | GT10, LE20 | 4.12 | 10.16 | | GT 2 | 4.75 | 8.58 |
| | GT 20 | 4.36 | 9.34 | QSIZ | 0 | 4.39 | 10.94 |
| ACTN | Speed | 4.37 | 9.93 | | GT 0 | 3.95 | 6.11 |
| | Distance | 4.23 | 10.35 | TLDL | 0 | 5.03 | 13.17 |
| ACDT | 0 | 4.42 | 11.00 | | GT 0, LE10 | 3.86 | 7.86 |
| | 1 | 3.89 | 7.53 | | GT 10 | 3.79 | 6.69 |
| | GT 1 | 3.85 | 6.64 | DEAD | LE 0 | NA | 6.65 |
| VLTN | 0 | 4.64 | 10.54 | | GT 0 | NA | 10.52 |
| | 1 | 3.84 | 10.78 | DEAS | LE 0 | NA | 8.82 |
| | GT 1 | 3.96 | 6.91 | | GT 0 | NA | 12.61 |
| DAGE | LT 30 yr. | 4.10 | 8.79 | DEAG | LT 5 | NA | 4.77 |
| | 30 TO 45 yr. | 4.44 | 10.82 | | 5 to 10 | NA | 7.69 |
| | GT 45 yr. | 3.93 | 9.48 | | GT 10 | NA | 16.81 |
| NLTY | Non Arabs | 4.39 | 9.87 | DAMR | LE 0 | 3.95 | 11.28 |
| | Arabs | 3.63 | 12.41 | | GT 0 | 4.44 | 7.55 |
| Average accepted gap/lag for maneuver 1 = 10.12 seconds | | | | | | | |
| Average rejected gap/lag for maneuver 1 = 4.29 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than: LE = Less than or Equal to: GT = Greater Than: GE = Greater Than or Equal to:

PC = Passenger Car: HV = Heavy Vehicle: Cls. = Cylinders: NA = Not Applicable.

**I. Accepted Gaps:**

**a.** Average accepted gaps range from around 4.8 seconds to around 16.9 seconds. The average accepted gap takes the highest value when the oncoming vehicle on the major road is a large vehicle. The overall average of the accepted gap is 10.1 as given in Table 5.5;

**b.** Higher values of the average accepted gaps are observed for old vehicles, nonwork trips, female drivers, drivers with university education, drivers with low accident and violation records, Arab drivers, low delay cases, large vehicles on both minor and major roads, high speeds of oncoming vehicles, low traffic levels at both minor and major roads, and consistent drivers who have low values of the variable DMAR;

**c.** Visibly lower averages of the accepted gap/lags are observed for drivers with high accident and violation records, less experienced driver, high delay levels (higher TLDL, NREJ, QSIZ values), high volumes at major road, and inconstant drivers (higher volumes of DAMR);

**d.** There is a clear increase in the average accepted gaps as the ability of the driver to estimate the speed and the distance and time gap of the oncoming vehicle decreases as each of DEAD, DEAS, and DEAG increases. The same observation applies for Maneuvers 1, 2, and 3.

**II. Rejected Gaps:**

**a.** Average rejected gaps ranges from around 2.9 seconds to 5.3 seconds. The overall average of the rejected gaps is 4.3 seconds (Table 5.5) with the majority of the values concentrated around this value;

**b.** Visibly lower averages of the rejected gaps/lags are observed for drivers with high accident and violation records, higher levels of delay and higher levels of traffic volumes at major road;

**c.** Some variable levels like driver sex as an example have relatively high average of the accepted gap and at the same time low average of the rejected gaps. This appears as a conflicting result. This phenomenon, however, can be related to the presence of larger variations in gap acceptance behavior within the drivers in these levels. Where it was found that the standard deviations of the accepted and rejected gaps within these levels are relatively high compared to other levels. The same observation applies for drivers of highly occupied vehicles within whom Taxi drivers constitute a significant portion.

**III. T-Tests for Average Accepted and Rejected Gaps/Lags for Maneuver 1.**

To check whether the computed average accepted/rejected gaps/lag for a certain level of an attribute is significantly different from the average accepted rejected gap for other levels of the same attributes, the t-test detailed in Chapter 3, Section 3.6 is

applied. Tables 5.6 and 5.7 present the results of this test for average accepted and rejected gaps, respectively. The main comments on these tables include:

**A) Accepted Gaps**

The last column in Table 5.6 indicates that the difference in the average accepted gap is significant at 5% for the two defined vehicle occupancy (OCUP) levels, levels (1,3) and (2,3) of the trip duration attribute (TRDN), the levels (1,3) and (2,3) of driver experience (DEXP), levels (1,2) and (1,3) of ACDT, levels (1,3) and (2,3) of VLTN, levels (1,2) of DAGE, all combinations of the three levels of NREJ, the two levels of MJTP, level (1,2) and (1,3) of MNSD, all combinations of each of the MJSD, MJVL, QSIZ, TLDL, DEAD, DEAS, DEAG, and DAMR. The defined levels of different variables are given in Table 5.6 for convenience. The order of testing between levels is (1,2), (1,3) and (2,3), respectively as detailed in the footnote of Table 5.6 for further convenience.

In summary, it can be stated that vehicle occupancy, trip duration, driver experience, driver accident and violation records, delay measures (NREJ, TLDL, QSIZ), speed and traffic volume at major road, and driver ability to estimate the speed and distance of the oncoming vehicle are main factors with potential ability to explain variations in driver gap acceptance behavior. However, significantly different values of the accepted gap/lag within the levels of a given attributes does not necessarily mean that the attribute itself will be significant in gap acceptance models to be calibrated in

Table 5.6: Average Accepted Gaps and the Relevant t-tests. Maneuver 1

| Variable Name | Variable Level * | Av. Accepted Gap for Level i | Standard Deviation | Number of Observations | Av. Accepted Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated Value | Result of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2,GT3 | 9.96 | 5.34 | 218 | 10.88 | 1.14 | 27 | 191 | -2.175 | DS |
| VAGE | LT5 | 9.89 | 5.43 | 157 | 9.88 | 5.79 | 84 | 161 | 0.013 | DNS |
| | 5 TO 10 | 9.89 | 5.43 | 157 | 11.74 | 6.86 | 34 | 42 | -1.476 | DNS |
| | GT10 | 9.88 | 5.79 | 84 | 11.74 | 6.86 | 34 | 53 | -1.393 | DNS |
| EGCA | 4, GT4 | 10.09 | 5.63 | 220 | 10.20 | 6.22 | 55 | 78 | -0.119 | DNS |
| TRAN | MAN, AUT | 9.99 | 5.61 | 209 | 10.50 | 6.18 | 66 | 101 | -0.597 | DNS |
| TRPS | WRK, NW | 9.86 | 5.46 | 225 | 11.24 | 6.81 | 50 | 64 | -1.340 | DNS |
| TRDN | LE20 | 10.17 | 5.73 | 230 | 10.56 | 6.14 | 36 | 45 | -0.358 | DNS |
| | GT20, LT4 | 10.17 | 5.73 | 230 | 6.87 | 3.45 | 9 | 10 | 2.726 | DS |
| | GE40 | 10.56 | 6.14 | 36 | 6.87 | 3.45 | 9 | 22 | 2.397 | DS |
| DSEX | MALE, FE | 9.87 | 5.44 | 255 | 13.19 | 8.33 | 20 | 20 | -1.753 | DNS |
| DEXP | LT2 | 6.53 | 2.06 | 4 | 7.47 | 3.11 | 58 | 4 | -0.848 | DNS |
| | 2 TO 5 | 6.53 | 2.06 | 4 | 10.90 | 6.10 | 213 | 4 | -3.931 | DS |
| | GT5 | 7.47 | 3.11 | 58 | 10.90 | 6.10 | 213 | 185 | -5.870 | DS |
| DEDU | SEC, UNI | 9.63 | 5.23 | 188 | 11.16 | 6.63 | 87 | 137 | -1.897 | DNS |
| DFAM | LE10 | 10.75 | 5.87 | 111 | 10.16 | 5.98 | 69 | 142 | 0.648 | DNS |
| | GT10, LE2 | 10.75 | 5.87 | 111 | 9.34 | 5.38 | 95 | 203 | 1.798 | DNS |
| | GT20 | 10.16 | 5.98 | 69 | 9.34 | 5.38 | 95 | 137 | 0.904 | DNS |
| ACTN | SD, DIST | 9.93 | 5.57 | 153 | 10.35 | 5.96 | 122 | 251 | -0.598 | DNS |
| ACDT | 0 | 11.00 | 6.05 | 210 | 7.53 | 3.01 | 46 | 137 | 5.695 | DS |
| | 1 | 11.00 | 6.05 | 210 | 6.64 | 4.00 | 19 | 26 | 4.325 | DS |
| | GT1 | 7.53 | 3.01 | 46 | 6.64 | 4.00 | 19 | 27 | 0.873 | DNS |
| VLTN | 0 | 10.54 | 5.75 | 180 | 10.78 | 6.02 | 59 | 95 | -0.269 | DNS |
| | 1 | 10.54 | 5.75 | 180 | 6.91 | 4.14 | 36 | 65 | 4.469 | DS |
| | GT1 | 10.78 | 6.02 | 59 | 6.91 | 4.14 | 36 | 92 | 3.706 | DS |
| DAGE | LT30 | 8.79 | 4.70 | 70 | 10.82 | 6.16 | 166 | 168 | -2.752 | DS |
| | 30 TO 45 | 8.79 | 4.70 | 70 | 9.48 | 5.21 | 39 | 72 | -0.686 | DNS |
| | GT45 | 10.82 | 6.16 | 166 | 9.48 | 5.21 | 39 | 65 | 1.394 | DNS |
| NTLY | NAR, ARA | 9.87 | 5.52 | 248 | 12.41 | 7.19 | 27 | 29 | -1.779 | DNS |
| TMGP | LAG, GAP | 7.11 | 2.30 | 103 | 11.91 | 6.40 | 172 | 234 | -8.921 | DS |
| NREJ | 0 | 11.82 | 6.34 | 177 | 7.69 | 2.66 | 55 | 211 | 6.924 | DS |
| | 1 | 11.82 | 6.34 | 177 | 6.20 | 1.40 | 43 | 217 | 10.763 | DS |
| | GT1 | 7.69 | 2.66 | 55 | 6.20 | 1.40 | 43 | 85 | 3.570 | DS |
| AREJ | 0, GT0 | 10.24 | 5.63 | 26 | 8.12 | 4.21 | 28 | 46 | 1.558 | DNS |
| AENT | 0, GT0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| MJTP | PC, LV | 9.46 | 5.36 | 251 | 16.93 | 5.28 | 24 | 28 | -6.613 | DS |
| MNTP | PC, LV | 10.07 | 5.89 | 235 | 10.38 | 4.85 | 40 | 60 | -0.361 | DNS |
| MJSD | LE30 | 8.16 | 3.57 | 102 | 9.32 | 5.13 | 120 | 212 | -1.977 | DS |
| | GT30, LE4 | 8.16 | 3.57 | 102 | 15.68 | 6.96 | 53 | 67 | -7.378 | DS |
| | GT45 | 9.32 | 5.13 | 120 | 15.68 | 6.96 | 53 | 78 | -5.974 | DS |
| MNSD | 0 | 7.33 | 2.80 | 141 | 13.28 | 8.17 | 23 | 23 | -3.460 | DS |
| | GT0, LE20 | 7.33 | 2.80 | 141 | 13.00 | 6.19 | 111 | 145 | -8.956 | DS |
| | GT20 | 13.28 | 8.17 | 23 | 13.00 | 6.19 | 111 | 27 | 0.155 | DNS |
| MJVL | LE 2 | 12.29 | 6.73 | 138 | 8.60 | 3.51 | 81 | 215 | 5.324 | DS |
| | GE3, LE4 | 12.29 | 6.73 | 138 | 6.96 | 2.85 | 56 | 192 | 7.748 | DS |
| | GT4 | 8.60 | 3.51 | 81 | 6.96 | 2.85 | 56 | 131 | 3.009 | DS |
| MNVL | 1 | 14.94 | 9.20 | 35 | 9.99 | 4.75 | 141 | 39 | 3.083 | DS |
| | 2 | 14.94 | 9.20 | 35 | 8.58 | 4.47 | 99 | 40 | 3.929 | DS |
| | GT2 | 9.99 | 4.75 | 141 | 8.58 | 4.47 | 99 | 219 | 2.344 | DS |
| QSIZ | 0, GT0 | 10.94 | 5.94 | 228 | 6.11 | 1.57 | 47 | 260 | 10.611 | DS |
| TLDL | 0 | 13.17 | 6.60 | 127 | 7.86 | 3.01 | 101 | 185 | 8.072 | DS |
| | GT0, LE10 | 13.17 | 6.60 | 127 | 6.69 | 2.90 | 47 | 167 | 8.970 | DS |
| | GT10 | 7.86 | 3.01 | 101 | 6.69 | 2.90 | 47 | 93 | 2.257 | DS |
| DEAD | LE0, GT0 | 6.65 | 2.58 | 29 | 10.52 | 5.88 | 246 | 70 | -6.362 | DS |
| DEAS | LE0, GT0 | 8.82 | 4.39 | 181 | 12.61 | 7.09 | 94 | 131 | -4.733 | DS |
| DEAG | LT5 | 4.77 | 0.64 | 56 | 7.69 | 1.45 | 128 | 182 | -18.951 | DS |
| | 5 TO 10 | 4.77 | 0.64 | 56 | 16.81 | 5.08 | 91 | 95 | -22.323 | DS |
| | GT 10 | 7.69 | 1.45 | 128 | 16.81 | 5.08 | 91 | 100 | -16.650 | DS |
| DAMR | LE0, GT0 | 11.28 | 6.43 | 189 | 7.55 | 2.25 | 86 | 261 | 7.079 | DS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle; NAR = Nonarabs;DNS = Difference is not significant;
DS = Difference is significant.
* Note: t-Tests for different levels of a given variable are arranged as following;
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.
** The null hypothesis for this test is: Average accepted gap for level i equals average accepted gap for level j of the concerned variable

Table 5.7: Average Rejected Gaps and the Relevant t-tests for Maneuver 1

| Variable Name | Variable Level * | Av. Rej. Gap for Level i | Standard Deviation | Number of Observations | Av. Rej. Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated Value | Rsult of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2,GT3 | 4.44 | 1.45 | 120 | 3.70 | 1.14 | 27 | 47 | 2.888 | DS |
| VAGE | LT5 | 4.37 | 1.49 | 108 | 4.09 | 1.27 | 58 | 134 | 1.273 | DNS |
| | 5 TO 10 | 4.37 | 1.49 | 108 | 4.74 | 0.99 | 7 | 8 | -0.923 | DNS |
| | GT10 | 4.09 | 1.27 | 58 | 4.74 | 0.99 | 7 | 9 | -1.587 | DNS |
| EGCA | 4, GT4 | 4.27 | 1.42 | 144 | 4.38 | 1.37 | 29 | 41 | -0.392 | DNS |
| TRAN | MAN, AUT | 4.22 | 1.45 | 140 | 4.59 | 1.16 | 33 | 58 | -1.566 | DNS |
| TRPS | WRK, NW | 4.35 | 1.41 | 137 | 4.05 | 1.39 | 36 | 55 | 1.149 | DNS |
| TRDN | LE20 | 4.11 | 1.34 | 128 | 5.20 | 1.54 | 25 | 31 | -3.303 | DS |
| | GT20, LT4 | 4.11 | 1.34 | 128 | 4.51 | 1.44 | 20 | 24 | -1.169 | DNS |
| | GE40 | 5.20 | 1.54 | 25 | 4.51 | 1.44 | 20 | 42 | 1.549 | DNS |
| DSEX | MALE, FE | 4.31 | 1.41 | 164 | 3.86 | 1.37 | 9 | 9 | 0.958 | DNS |
| DEXP | LT2 | 4.16 | 0.93 | 10 | 4.80 | 1.28 | 62 | 15 | -1.905 | DNS |
| | 2 TO 5 | 4.16 | 0.93 | 10 | 4.48 | 1.49 | 101 | 14 | -0.972 | DNS |
| | GT5 | 4.80 | 1.28 | 62 | 4.48 | 1.49 | 101 | 144 | 1.454 | DNS |
| DEDU | SEC, UNI | 4.34 | 1.48 | 122 | 4.16 | 1.22 | 51 | 113 | 0.829 | DNS |
| DFAM | LE10 | 4.33 | 1.34 | 70 | 4.12 | 1.70 | 40 | 67 | 0.671 | DNS |
| | GT10, LE2 | 4.33 | 1.34 | 70 | 4.36 | 1.29 | 63 | 130 | -0.131 | DNS |
| | GT20 | 4.12 | 1.70 | 40 | 4.36 | 1.29 | 63 | 67 | -0.764 | DNS |
| ACTN | SD, DIST | 4.37 | 1.38 | 78 | 4.23 | 1.43 | 95 | 167 | 0.653 | DNS |
| ACDT | 0 | 4.42 | 1.36 | 132 | 3.89 | 1.37 | 24 | 32 | 1.745 | DNS |
| | 1 | 4.42 | 1.36 | 132 | 3.85 | 1.69 | 17 | 19 | 1.336 | DNS |
| | GT1 | 3.89 | 1.37 | 24 | 3.85 | 1.69 | 17 | 30 | 0.081 | DNS |
| VLTN | 0 | 4.64 | 1.46 | 93 | 3.84 | 1.31 | 54 | 121 | 3.421 | DS |
| | 1 | 4.64 | 1.46 | 93 | 3.96 | 1.05 | 26 | 55 | 2.661 | DS |
| | GT1 | 3.84 | 1.31 | 54 | 3.96 | 1.05 | 26 | 60 | -0.441 | DNS |
| DAGE | LT30 | 4.10 | 1.08 | 48 | 4.44 | 1.52 | 106 | 124 | -1.584 | DNS |
| | 30 TO 45 | 4.10 | 1.08 | 48 | 3.93 | 1.45 | 19 | 26 | 0.463 | DNS |
| | GT45 | 4.44 | 1.52 | 106 | 3.93 | 1.45 | 19 | 26 | 1.401 | DNS |
| NTLY | NAR, ARA | 4.39 | 1.41 | 150 | 3.63 | 1.19 | 23 | 32 | 2.778 | DS |
| TMGP | GAP, LAG | 3.56 | 1.15 | 70 | 4.79 | 1.35 | 103 | 162 | -6.430 | DS |
| NREJ | 0 | 4.79 | 1.35 | 103 | 3.69 | 1.21 | 44 | 90 | 4.872 | DS |
| | 1 | 4.79 | 1.35 | 103 | 3.35 | 1.03 | 26 | 49 | 5.954 | DS |
| | GT1 | 3.69 | 1.21 | 44 | 3.35 | 1.03 | 26 | 59 | 1.249 | DNS |
| AREJ | 0, GT0 | 4.27 | 1.66 | 7 | 4.55 | 1.15 | 26 | 8 | -0.420 | DNS |
| AENT | 0, GT0 | 4.28 | 1.41 | 171 | 5.40 | 0.00 | 2 | 170 | -10.387 | DS |
| MJTP | PC, LV | 4.25 | 1.44 | 160 | 4.78 | 0.88 | 13 | 18 | -1.968 | DNS |
| MNTP | PC, LV | 4.13 | 1.28 | 148 | 5.26 | 1.73 | 25 | 29 | -3.125 | DS |
| MJSD | LE30 | 2.89 | 1.47 | 15 | 4.02 | 1.49 | 75 | 20 | -2.712 | DS |
| | GT30, LE4 | 2.89 | 1.47 | 15 | 4.78 | 1.06 | 83 | 17 | -4.761 | DS |
| | GT45 | 4.02 | 1.49 | 75 | 4.77 | 1.06 | 83 | 132 | -3.611 | DS |
| MNSD | 0 | 3.82 | 1.21 | 105 | 5.21 | 0.93 | 30 | 60 | -6.721 | DS |
| | GT0, LE20 | 3.82 | 1.21 | 105 | 4.86 | 1.66 | 38 | 52 | -3.537 | DS |
| | GT20 | 5.21 | 0.93 | 30 | 4.86 | 1.66 | 38 | 60 | 1.099 | DNS |
| MJVL | LE 2 | 4.86 | 1.13 | 18 | 4.83 | 1.62 | 57 | 41 | 0.088 | DNS |
| | GE3, LE4 | 4.86 | 1.13 | 18 | 3.87 | 1.17 | 98 | 24 | 3.398 | DS |
| | GT4 | 4.83 | 1.62 | 57 | 3.87 | 1.17 | 98 | 90 | 3.919 | DS |
| MNVL | 1 | 3.83 | 1.28 | 44 | 4.37 | 1.45 | 102 | 92 | -2.245 | DS |
| | 2 | 3.83 | 1.28 | 44 | 4.75 | 1.28 | 27 | 55 | -2.940 | DS |
| | GT2 | 4.37 | 1.45 | 102 | 4.75 | 1.28 | 27 | 45 | -1.333 | DNS |
| QSIZ | 0, GT0 | 4.39 | 1.46 | 135 | 3.95 | 1.15 | 38 | 74 | 1.956 | DNS |
| TLDL | 0 | 5.03 | 1.41 | 66 | 3.86 | 1.27 | 70 | 131 | 5.074 | DS |
| | GT0, LE10 | 5.03 | 1.41 | 66 | 3.79 | 1.09 | 37 | 91 | 4.971 | DS |
| | GT10 | 3.86 | 1.27 | 70 | 3.79 | 1.09 | 37 | 84 | 0.298 | DNS |
| DAMR | LE0, GT0 | 3.95 | 1.25 | 53 | 4.44 | 1.45 | 120 | 115 | -2.261 | DS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle; NAR = Nonarabs;DNS = Difference is not significant;
DS = Difference is significant.
* Note: t-Tests for different levels of a given variable are arranged as following:
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.
** The null hypothesis for this test is: Average rejected gap for level i equals average rejected gap for level j of the concerned variable

Chapter 6. Another note of concern in Table 5.6 is that the average accepted gap is significantly different from the average accepted lag which indicates that driver response to lags could be different from their response to gaps. This issue is, however, further investigated in Chapter 6.

**B. Rejected Gaps:**

The last column in Table 5.7 indicates that the average rejected gaps are significantly different within defined levels of vehicle occupancy, driver violation record, driver nationality, delay measures (NREJ, TLDL), speed and volume at both major and minor roads, and driver gap acceptance consistency measure (DAMR).

Again, the difference between the average of the rejected gaps and lags is significantly different at 5% level. Some of the variables such as DEXP, TRDN and ACDT have significant differences between the average accepted gaps within their levels as shown in Table 5.6. The differences between the average rejected gaps/lags at the different levels of the same variables are, however, not significant..

*5.5.1.2 Critical Gaps/Lags for Maneuver 1*

The critical gaps/lags derived for different levels of the studied attributes using Raff's graphical method are summarized in Table 5.8. Raff's critical gap plots

Table 5.8 : Critical Gaps at Different Levels of the Studied Variables for Maneuver 1

| Variable Name and Levels | | Critical Gap (Sec.) | Variable Name and Level | | Critical Gap (Sec.) |
|---|---|---|---|---|---|
| OCUP | LE 2 | 5.6 | TMGP | GAP | 5.8 |
| | GT 3 | 5.3 | | LAG | 4.9 |
| VAGE | LT 5 yr. | 5.7 | NREJ | 0 | 5.8 |
| | 5 to10 yr. | 5.1 | | 1 | 5.3 |
| | GT10 yr. | 5.6 | | GT1 | 4.5 |
| EGCA | LE 4 Cls. | 5.4 | AREJ | 0 | 5.1 |
| | GT 4 Cls. | 5.6 | | GT0 | 5.5 |
| TRAN | Manual | 5.8 | MJTP | Passenger Car | 5.4 |
| | Automatic | 5.3 | | Heavy Vehicle | 6.3 |
| TRPS | Work | 5.4 | MNTP | Passenger Car | 5.3 |
| | Non Work | 5.6 | | Heavy Vehicle | 6.3 |
| TRDN | LE 20 Min. | 5.4 | MJSD | LE 30 Kph | 4.8 |
| | GT20, LT 40 | 5.3 | | GT30, LE45 | 5.3 |
| | GE 40 Min. | 5.5 | | GT 45 | 6.4 |
| DSEX | Male | 5.5 | MNSD | 0 | 4.9 |
| | Female | 6.1 | | GT 0, LE 20 | 6.0 |
| DEXP | LT 2 yr. | 4.9 | | GT 20 | 6.7 |
| | 2 to 5 yr. | 4.9 | MJVL | LE 2 | 6.0 |
| | GT 5 yr. | 5.8 | | GE 3, LE 4 | 5.9 |
| DEDU | Secondary | 5.6 | | GT4 | 4.9 |
| | University | 5.4 | MNVL | LE1 | 5.1 |
| DFAM | LE10 Visits/WK | 5.7 | | 2 | 5.7 |
| | GT 10, LE 20 | 5.4 | | GT2 | 5.7 |
| | GT 20 | 5.5 | QSIZ | 0 | 5.7 |
| ACDT | 0 | 5.7 | | GT 0 | 4.7 |
| | 1 | 5.0 | TLDL | 0 | 6.5 |
| | GT1 | 4.4 | | GT 0, LE 10 | 5.3 |
| VLTN | 0 | 6.0 | | GT 10 | 4.7 |
| | 1 | 5.1 | DAMR | LE 0 | 4.6 |
| | GT1 | 4.6 | | GT 0 | 5.7 |
| DAGE | LT 30 yr. | 5.1 | ACTN | Speed | 5.6 |
| | 30 to 45 yr. | 5.8 | | Distance | 5.5 |
| | GT 45 yr. | 5.3 | NLTY | Non Arabs | 4.7 |
| | | | | Arabs | 5.6 |
| Critical gap/lag for Maneuver 1 = 5.5 seconds | | | | | |
| $50^{th}$ percentile accepted gap/lag for Maneuver 1 = 8.1 seconds | | | | | |
| $85^{th}$ percentile accepted gap/lag for Maneuver 1 = 16.7 seconds | | | | | |

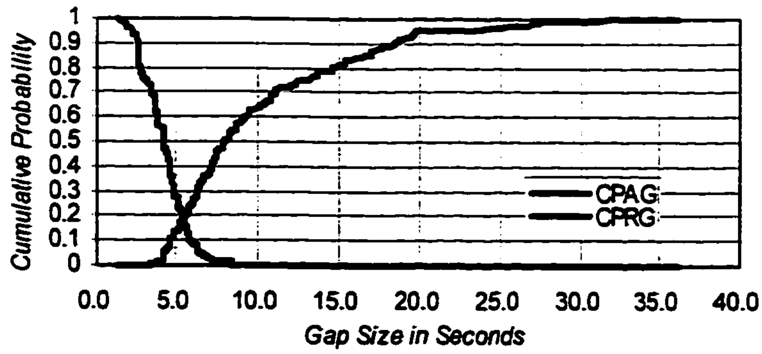
Abbreviations listed in the above table stands for the following:
LT = Less Than; LE = Less than or Equal to; GT = Greater Than; GE = GreaterThan or Equal to; NA = Not Applicable; Cls. = Cylinders

prepared using the whole data collected for Maneuvers 1, 2, and 3 are given in Figures 5.3 through 5.5. The main comments on Table 5.8 include:

a. Derived critical gaps changes over the range from 4.4 seconds to 6.7 seconds;

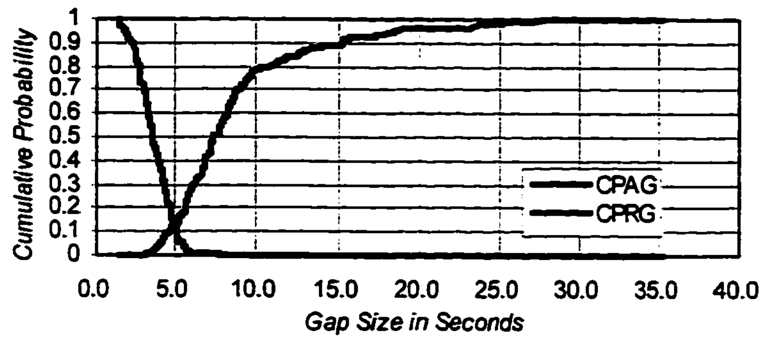
b. Some variables do not show a steady trend of change (increase/decrease) in the critical gap as their levels increase. Examples of these variables are; VAGE, TRDN, DEAM, and DAGE. This behavior provides some guidance about the way the data may be segmented;

c. With variables like ACDT, VLTN, delay measures (NREJ, TLDL), MJSD, and MJVL, the change in critical gap is steady in its direction and expected in its nature. As an example, the critical gap decreases continuously as each of the ACDT, VLTN, TLDL increases and decreases continuously as MJSD increases. Such variables could be potential candidates for gap acceptance models to be calibrated later in Chapter 6. In general, the expected driver behavior could be better described using critical gaps rather than the average gaps as discussed in the previous section. Taking DSEX as an example we find that the critical gap for females is visibly longer than males which agrees with the expected driver behavior. However, the average rejected gap for females in Table 5.5 is shorter than males which could be against expectation. It should be mentioned in this context that the driver gap acceptance indications derived based on the average accepted gaps and the critical gaps are not always similar. For some variables



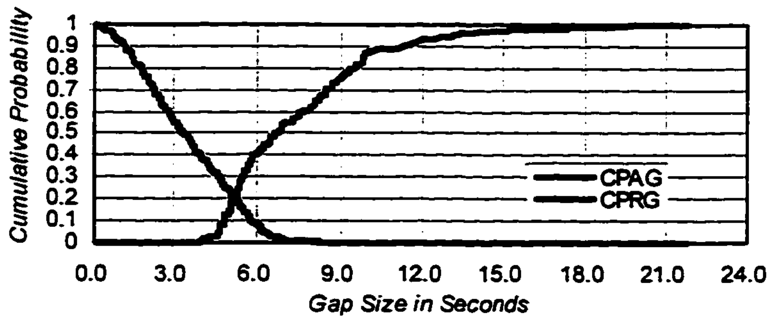

**Critical Gap = 5.5 Seconds**

**Figure 5.3: Critical Gap for Maneuver 1**




**Critical Gap = 4.6 Seconds**

**Figure 5.4: Critical Gap for Maneuver 2**




**Critical Gap = 5.2 Seconds**

**Figure 5.5: Critical Gap for Maneuver 3**

Key: CPAG = The cumulative probability of accepting a gap shorter than t
CPRG = The cumulative probability of rejecting a gap longer than t

such as TLDL, MJSD and MNVL the trend of change in both of the average accepted and the critical gaps at different levels of these variables is, however, similar and agrees with the expected driver behavior. Such variables could be strong candidates in gap acceptance models to be developed in Chapter 6.

To check whether the critical gaps found at different levels of an attribute are significantly different from each other, the t-test discussed in Section 5.5.1.1 was used. In this test it is assumed that the standard error of the critical gap of a certain level of an attribute is equal to the standard error of the average accepted gap of that level. Table 5.9 gives the results of the conducted t-tests. The last column in Table 5.9 shows that the critical gaps are significantly different for levels (2,3) of DEXP, levels (1,3), (2,3) of NREJ, levels (1,3) of MJSD and MNSD, levels (2,3) of MJVL, levels (1,2), (1,3) of TLDL and for the two defined levels of DAMR. All of the above mentioned levels of variables have also significantly different average accepted gaps as can be concluded by comparing the last columns in Tables 5.6 and 5.9. Some combinations of levels for DEXP, ACDT, VLTN, NREJ, MNTP, MJSD, MJVL, and TLDL have relatively high t-statistics.

A note of particular concern is that the critical lag is significantly different from the critical gap that again indicates that driver response to gaps and lags could be different.

Table 5.9: Critical Gaps/Lags and the Results of the Relevant t-tests for Maneuver 1

| Variable Name | Variable Level * | Critical Gap for Level i | Standard Deviation | Number of Observations | Critical Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated | Result of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2.GT3 | 5.60 | 5.34 | 338 | 5.30 | 1.14 | 110 | 413 | 0.967 | DNS |
| VAGE | LT5 | 5.70 | 5.43 | 265 | 5.10 | 5.79 | 142 | 273 | 1.018 | DNS |
| | 5 TO 10 | 5.70 | 5.43 | 265 | 5.60 | 6.86 | 41 | 48 | 0.089 | DNS |
| | GT10 | 5.10 | 5.79 | 142 | 5.60 | 6.86 | 41 | 57 | -0.425 | DNS |
| EGCA | 4. GT4 | 5.40 | 5.63 | 364 | 5.60 | 6.22 | 84 | 116 | -0.270 | DNS |
| TRAN | MAN. AUT | 5.30 | 5.61 | 349 | 5.80 | 6.18 | 99 | 147 | -0.725 | DNS |
| TRPS | WRK. NW | 5.40 | 5.46 | 362 | 5.60 | 6.81 | 86 | 112 | -0.254 | DNS |
| TRDN | LE20 | 5.40 | 5.73 | 358 | 5.30 | 6.14 | 71 | 96 | 0.127 | DNS |
| | GT20. LT4 | 5.40 | 5.73 | 358 | 5.50 | 3.45 | 19 | 24 | -0.118 | DNS |
| | GE40 | 5.30 | 6.14 | 71 | 5.50 | 3.45 | 19 | 52 | -0.186 | DNS |
| DSEX | MALE. FE | 5.50 | 5.44 | 419 | 6.10 | 8.33 | 29 | 30 | -0.382 | DNS |
| DEXP | LT2 | 4.90 | 2.06 | 14 | 4.90 | 3.11 | 120 | 21 | 0.000 | DNS |
| | 2 TO 5 | 4.90 | 2.06 | 14 | 5.80 | 6.10 | 314 | 25 | -1.386 | DNS |
| | GT5 | 4.90 | 3.11 | 120 | 5.80 | 6.10 | 314 | 399 | -2.017 | DS |
| DEDU | SEC. UNI | 5.60 | 5.23 | 310 | 5.40 | 6.63 | 138 | 216 | 0.314 | DNS |
| DFAM | LE10 | 5.70 | 5.87 | 181 | 5.40 | 5.98 | 109 | 224 | 0.417 | DNS |
| | GT10. LE2 | 5.70 | 5.87 | 181 | 5.50 | 5.38 | 158 | 336 | 0.327 | DNS |
| | GT20 | 5.40 | 5.98 | 109 | 5.50 | 5.38 | 158 | 216 | -0.140 | DNS |
| ACTN | SD. DIST | 5.60 | 5.57 | 231 | 5.50 | 5.96 | 217 | 439 | 0.183 | DNS |
| ACDT | 0 | 5.70 | 6.05 | 342 | 5.00 | 3.01 | 70 | 202 | 1.440 | DNS |
| | 1 | 5.70 | 6.05 | 342 | 4.43 | 4.00 | 36 | 54 | 1.710 | DNS |
| | GT1 | 5.00 | 3.01 | 70 | 4.43 | 4.00 | 36 | 56 | 0.752 | DNS |
| VLTN | 0 | 6.00 | 5.75 | 273 | 5.70 | 6.02 | 122 | 223 | 0.464 | DNS |
| | 1 | 6.00 | 5.75 | 273 | 4.80 | 4.14 | 62 | 121 | 1.903 | DNS |
| | GT1 | 5.70 | 6.02 | 122 | 4.80 | 4.14 | 62 | 166 | 1.188 | DNS |
| DAGE | LT30 | 5.10 | 4.70 | 118 | 5.80 | 6.16 | 272 | 287 | -1.225 | DNS |
| | 30 TO 45 | 5.10 | 4.70 | 118 | 5.30 | 5.21 | 58 | 104 | -0.247 | DNS |
| | GT45 | 5.80 | 6.16 | 272 | 5.30 | 5.21 | 58 | 94 | 0.641 | DNS |
| NTLY | NAR. ARA | 5.60 | 5.52 | 398 | 4.70 | 7.19 | 50 | 56 | 0.854 | DNS |
| TMGP | LAG. GAP | 4.90 | 2.30 | 173 | 5.80 | 6.40 | 275 | 373 | -2.124 | DS |
| NREJ | 0 | 5.80 | 6.34 | 280 | 5.30 | 2.66 | 99 | 367 | 1.078 | DNS |
| | 1 | 5.80 | 6.34 | 280 | 4.50 | 1.40 | 69 | 345 | 3.135 | DS |
| | GT1 | 5.30 | 2.66 | 99 | 4.50 | 1.40 | 69 | 156 | 2.531 | DS |
| MJTP | PC. LV | 5.40 | 5.36 | 411 | 6.30 | 5.28 | 37 | 43 | -0.992 | DNS |
| MNTP | PC. LV | 5.30 | 5.89 | 383 | 6.30 | 4.85 | 65 | 99 | -1.487 | DNS |
| MJSD | LE30 | 4.80 | 3.57 | 119 | 5.30 | 5.13 | 195 | 307 | -1.016 | DNS |
| | GT30. LE4 | 4.80 | 3.57 | 119 | 6.40 | 6.96 | 134 | 203 | -2.337 | DS |
| | GT45 | 5.30 | 5.13 | 195 | 6.40 | 6.96 | 134 | 229 | -1.561 | DNS |
| MNSD | 0 | 4.90 | 2.80 | 246 | 6.00 | 8.17 | 53 | 55 | -0.968 | DNS |
| | GT0. LE20 | 4.90 | 2.80 | 246 | 6.70 | 6.19 | 149 | 185 | -3.348 | DS |
| | GT20 | 6.00 | 8.17 | 53 | 6.70 | 6.19 | 149 | 74 | -0.568 | DNS |
| MJVL | LE 2 | 6.00 | 6.73 | 156 | 5.80 | 3.51 | 138 | 239 | 0.325 | DNS |
| | GE3. LE4 | 6.00 | 6.73 | 156 | 4.90 | 2.85 | 154 | 209 | 1.878 | DNS |
| | GT4 | 5.80 | 3.51 | 138 | 4.90 | 2.85 | 154 | 264 | 2.388 | DS |
| MNVL | 1 | 5.10 | 9.20 | 79 | 5.70 | 4.75 | 243 | 92 | -0.556 | DNS |
| | 2 | 5.10 | 9.20 | 79 | 5.70 | 4.47 | 126 | 101 | -0.541 | DNS |
| | GT2 | 5.70 | 4.75 | 243 | 5.70 | 4.47 | 126 | 267 | 0.000 | DNS |
| QSIZ | 0. GT0 | 5.70 | 5.94 | 363 | 5.70 | 1.57 | 85 | 441 | 0.000 | DNS |
| TLDL | 0 | 6.50 | 6.60 | 193 | 5.30 | 3.01 | 171 | 276 | 2.273 | DS |
| | GT0. LE10 | 6.50 | 6.60 | 193 | 4.70 | 2.90 | 84 | 275 | 3.153 | DS |
| | GT10 | 5.30 | 3.01 | 171 | 4.70 | 2.90 | 84 | 171 | 1.533 | DNS |
| DAMR | LE0. GT0 | 11.28 | 6.43 | 189 | 7.55 | 2.25 | 86 | 261 | 7.079 | DS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle;NAR = Nonarabs; DNS = Difference is not significant;
DS = Difference is significant.
* Note: t-Tests for different levels of a given variable are arranged as following;
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.
Null Hypothesis for this test is: Critical Gap for Level i is equal to the Critical Gap for Level j

### 5.5.2 Analysis of the Average and Critical Gaps for Maneuver 2.

#### *5.5.2.1 Average Accepted and Rejected Gaps/Lags for Maneuver 2.*

The average accepted and rejected gaps calculated at different levels of the studied variables are summarized in Table 5.10. A general comparison of Tables 5.10 and 5.5 reveals that the general trends in both of the tables are similar which means that the discussion given on Table 5.5 will mostly apply here. Some of the specific comments on Table 5.10 include:

**I. Accepted Gaps/Lags**

a. Values of the average accepted gaps/lags change over the range from 4.42 seconds to 18.25 seconds. Visibly high values observed for drivers with lower driving experience (DEXP), large oncoming vehicles on major road (MJTP), high speeds at major road (MJSD), low delay levels (TLDL), and higher difference between the actual and the estimated gap (DEAG) and speed of the oncoming vehicles (DEAS). These results agree with the expected driver behavior. The last observation indicates that drivers with less ability to estimate the distance and time gap of the oncoming vehicle tend to accept longer gaps as mentioned previously in Section 5.5.1.1;

Table 5.10: Average Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 2

| Variable Name and Level | | Average Rejected Gap (Sec) | Average Accepted Gap (Sec) | Variable Name and Levels | | Average Rejected Gap (Sec) | Average Accepted Gap (Sec) |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 3.84 | 8.58 | TMGP | Gap | 2.69 | 5.91 |
| | GT 3 | 3.40 | 9.79 | | Lag | 4.24 | 9.91 |
| VAGE | LT 5 yr. | 3.56 | 9.07 | NREJ | 0 | 4.24 | 9.91 |
| | 5 to 10 yr. | 3.73 | 8.56 | | 1 | 2.78 | 6.51 |
| | GT 10 yr. | 4.02 | 8.20 | | GT 1 | 2.61 | 4.42 |
| EGCA | LE 4 Cls. | 3.66 | 8.44 | AREJ | 0 | 3.80 | 5.99 |
| | GT 4 Cls. | 3.72 | 10.48 | | GT 0 | 3.65 | 6.42 |
| TRAN | Manual | 3.89 | 8.64 | MJTP | PC | 3.58 | 8.67 |
| | Automatic | 3.19 | 9.31 | | HV | 5.46 | 12.48 |
| TRPS | Work | 3.58 | 8.60 | MNTP | PC | 3.65 | 8.78 |
| | Non Work | 4.17 | 9.63 | | HV | 3.95 | 8.92 |
| TRDN | LE 20 Mn. | 3.43 | 8.94 | MJSD | LE30 | 2.14 | 5.08 |
| | GT 20, LT40 | 4.05 | 8.84 | | GT30, LE45 | 2.96 | 8.02 |
| | GE 40 | 4.00 | 7.89 | | GT 45 | 4.32 | 15.50 |
| DSEX | Male | 3.54 | 8.53 | MNSD | 0 | 3.16 | 5.99 |
| | Female | 4.36 | 10.62 | | GT 0, LE20 | 4.28 | 18.25 |
| DEXP | LT 2 yr. | 4.20 | 11.80 | | GT 20 | 4.34 | 10.51 |
| | 2 to 5 yr. | 3.33 | 8.64 | MJVL | LE 2 | 4.09 | 9.57 |
| | GT 5 yr. | 3.85 | 8.67 | | GE 3, LE 4 | 3.86 | 7.20 |
| DEDU | Secondary | 3.59 | 8.35 | | GT 4 | 3.35 | 5.15 |
| | University | 4.05 | 10.02 | MNVL | LE 2 | 3.52 | 10.91 |
| DFAM | LE 10 | 3.72 | 9.41 | | GT 2 | 3.70 | 8.48 |
| | GT10, LE20 | 4.07 | 9.89 | QSIZ | 0 | 3.85 | 10.33 |
| | GT 20 | 3.53 | 7.33 | | GT 0 | 3.38 | 5.97 |
| ACTN | Speed | 3.55 | 8.37 | TLDL | 0 | 4.43 | 11.97 |
| | Distant | 3.93 | 9.37 | | GT 0, LE10 | 3.49 | 6.77 |
| ACDT | 0 | 3.67 | 9.16 | | GT 10 | 3.15 | 6.13 |
| | 1 | 3.72 | 7.63 | DEAD (mt.) | LE 0 | NA | 8.15 |
| | GT 1 | 3.52 | 6.17 | | GT 0 | NA | 9.25 |
| VLTN | 0 | 3.67 | 9.45 | DEAS Kph | LE 0 | NA | 7.78 |
| | 1 | 3.71 | 7.58 | | GT 0 | NA | 12.60 |
| | GT 1 | 3.61 | 6.79 | DEAG (Sec.) | LT 5 | NA | 4.66 |
| DAGE | LT 30 yr. | 3.31 | 8.55 | | 5 to 10 | NA | 7.64 |
| | 30 TO 45 yr. | 3.84 | 9.26 | | GT 10 | NA | 16.46 |
| | GT 45 yr. | 3.92 | 7.62 | DAMR (Sec.) | LE 0 | 3.24 | 9.64 |
| NLTY | Non Arabs | 3.68 | 8.71 | | GT 0 | 3.84 | 6.25 |
| | Arabs | 3.49 | 9.38 | | | | |
| Average accepted gap/lag for Maneuver 2 = 8.80 seconds | | | | | | | |
| Average rejected gap/lag for Maneuver 2 = 3.67 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than; LE = Less Than or Equal to; GT = Greater Than; GE = Greater Than or Equal to:
PC = Passenger Car: HV = Heavy Vehicle; Cls. = Cylinders: NA = Not Applicable.

**b.** Values of the average accepted gaps and lags are visibly different. The accepted lags have higher average value. This indicates that drivers' tendency to reject lags (compared to gaps) is higher. This result is explainable since the delay imposed on the driver at the time of evaluating the single lag he faces at the moment he is ready to execute his maneuver is less. This result agrees with previous research findings [Ashworth and Bottom, 1977 and Daganzo, 1981];

**c.** For some variables such as TRPS and DSEX, the results in Table 5.10 better reflects the expected driver behavior compared to the results of Table 5.5.

**II. Rejected Gaps/Lags**

**a.** Values of the average rejected gaps for Maneuver 2 ranges from around 2.7 seconds to 5.5 seconds with lower values observed particularly at higher levels of delay (TLDL) and lower levels of the speed at major road (MJSD);

**b.** Average value of the rejected gaps is visibly shorter than the average value of the rejected lags, which indicates higher driver tendency to accept shorter gaps compared to lags.

## III. T-Tests for Average Accepted/Rejected Gaps/Lags for Maneuver 2.

### A. Accepted Gaps/Lags

Results of the t-tests performed on the average accepted gaps/lags for different levels of the studied attributes are presented in Table 5.11. Main comments on the table include:

a. Difference in the average accepted gaps/lags is significant for levels (1,2) of VAGE, the two defined levels for each of the ECGA, DSEX, DEDU, MNVL, levels (1,3), (2,3) of DFAM, levels (1,2), (1,3) of each of VLTN, NREJ and TLDL, levels (2,3) of DAGE, all levels of each of ACDT, MJSD, MJVL, MNVL, QSIZ, DEAD, DEAS, DEAG and DAMR. Common features within the results observed in Maneuver 1 include the significant difference between average accepted gaps/lags for particular attributes like ACDT, VLTN, NREJ, TLDL, MJSD and the measures of driver estimation ability (DEAD, DEAS, DEAG). This again indicates the ability of these variables in capturing variations in driver gap acceptance behavior;

b. The difference in the average accepted gaps is again significantly different from the average accepted lags which again indicates that drivers' reaction to lags could be different from their reaction to gaps;

Table (5.11): Average Accepted Gaps and the Relevant t-tests for Maneuver 2

| Variable Name | Variable Level * | Av. Accepted Gap for Level i | Standard Deviation | Number of Observations | Av. Accepted Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated Value | t-Table Value | Result of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2,GT3 | 8.58 | 4.33 | 303 | 9.79 | 6.21 | 23 | 24 | -0.918 | 2.064 | DNS |
| VAGE | LT5 | 9.07 | 5.00 | 206 | 3.73 | 1.05 | 35 | 231 | 13.658 | 1.960 | DS |
| | 5 TO 10 | 9.07 | 5.00 | 206 | 8.20 | 3.58 | 57 | 123 | 1.479 | 1.960 | DNS |
| | GT10 | 8.56 | 4.88 | 103 | 8.20 | 3.58 | 57 | 146 | 0.533 | 1.960 | DNS |
| EGCA | 4, GT4 | 8.44 | 4.52 | 303 | 10.48 | 5.56 | 63 | 80 | -2.731 | 1.991 | DS |
| TRAN | MAN, AUT | 8.64 | 4.54 | 282 | 9.31 | 5.47 | 84 | 119 | -1.023 | 1.980 | DNS |
| TRPS | WRK, NW | 8.60 | 4.77 | 248 | 9.63 | 4.75 | 68 | 107 | -1.583 | 1.991 | DNS |
| TRDN | LE20 | 8.94 | 4.93 | 245 | 8.84 | 4.95 | 77 | 127 | 0.155 | 1.960 | DNS |
| | GT20, LT4 | 8.94 | 4.93 | 245 | 7.89 | 3.36 | 44 | 81 | 1.760 | 1.991 | DNS |
| | GE40 | 8.84 | 4.95 | 77 | 7.89 | 3.36 | 44 | 115 | 1.253 | 1.986 | DNS |
| DSEX | MALE, FE | 8.53 | 4.64 | 320 | 10.62 | 5.32 | 46 | 55 | -2.530 | 2.010 | DS |
| DEXP | LT2 | 11.80 | 7.29 | 15 | 8.64 | 4.74 | 80 | 16 | 1.616 | 2.120 | DNS |
| | 2 TO 5 | 11.80 | 7.29 | 15 | 8.67 | 4.58 | 271 | 15 | 1.645 | 2.131 | DNS |
| | GT5 | 8.64 | 4.74 | 80 | 8.67 | 4.58 | 271 | 126 | -0.050 | 1.960 | DNS |
| DEDU | SEC, UNI | 8.35 | 4.28 | 268 | 10.02 | 5.77 | 98 | 138 | -2.614 | 1.960 | DS |
| DFAM | LE10 | 9.41 | 4.60 | 144 | 9.89 | 6.01 | 92 | 158 | -0.653 | 1.960 | DNS |
| | GT10, LE2 | 9.41 | 4.60 | 144 | 7.33 | 3.47 | 130 | 264 | 4.250 | 1.960 | DS |
| | GT20 | 9.89 | 6.01 | 92 | 7.33 | 3.47 | 130 | 134 | 3.675 | 1.960 | DS |
| ACTN | SD, DIST | 8.37 | 4.43 | 211 | 9.37 | 5.17 | 155 | 301 | -1.941 | 1.960 | DNS |
| ACDT | 0 | 9.16 | 5.07 | 292 | 7.63 | 3.14 | 61 | 135 | 3.062 | 1.960 | DS |
| | 1 | 9.16 | 5.07 | 292 | 6.17 | 1.29 | 13 | 34 | 6.433 | 2.036 | DS |
| | GT1 | 7.63 | 3.14 | 61 | 6.17 | 1.29 | 13 | 47 | 2.713 | 2.009 | DS |
| VLTN | 0 | 9.45 | 5.35 | 257 | 7.58 | 2.65 | 65 | 209 | 3.992 | 1.960 | DS |
| | 1 | 9.45 | 5.35 | 257 | 6.79 | 1.84 | 44 | 191 | 6.130 | 1.960 | DS |
| | GT1 | 7.58 | 2.65 | 65 | 6.79 | 1.84 | 44 | 107 | 1.837 | 1.987 | DNS |
| DAGE | LT30 | 8.55 | 4.83 | 86 | 9.26 | 5.07 | 214 | 164 | -1.135 | 1.960 | DNS |
| | 30 TO 45 | 8.55 | 4.83 | 86 | 7.62 | 3.33 | 66 | 148 | 1.403 | 1.960 | DNS |
| | GT45 | 9.26 | 5.07 | 214 | 7.62 | 3.33 | 66 | 165 | 3.055 | 1.960 | DS |
| NTLY | NAR, ARA | 8.71 | 4.71 | 318 | 9.38 | 5.18 | 48 | 59 | -0.845 | 2.003 | DNS |
| TMGP | LAG, GAP | 9.91 | 1.65 | 100 | 5.91 | 5.10 | 265 | 357 | 11.297 | 1.960 | DS |
| NREJ | 0 | 9.91 | 5.09 | 265 | 6.51 | 1.51 | 70 | 329 | 9.418 | 1.960 | DNS |
| | 1 | 9.91 | 5.09 | 265 | 4.42 | 0.86 | 31 | 268 | 15.742 | 1.960 | DS |
| | GT1 | 6.51 | 1.51 | 70 | 4.42 | 0.86 | 31 | 93 | 8.798 | 1.996 | DS |
| AREJ | 0, GT0 | 5.99 | 1.78 | 76 | 6.42 | 1.42 | 64 | 138 | -1.589 | 1.960 | DNS |
| AENT | 0, GT0 | 9.47 | 5.17 | 281 | NA | NA | NA | NA | NA | NA | DNS |
| MJTP | PC, LV | 8.67 | 4.66 | 354 | 12.48 | 6.55 | 12 | 11 | -1.998 | 2.201 | DNS |
| MNTP | PC, LV | 8.78 | 4.80 | 325 | 8.92 | 4.57 | 41 | 52 | -0.184 | 2.011 | DNS |
| MJSD | LE30 | 5.08 | 1.04 | 66 | 8.02 | 2.88 | 237 | 283 | -12.970 | 1.960 | DS |
| | GT30, LE4 | 5.08 | 1.04 | 66 | 15.50 | 6.08 | 62 | 64 | -13.313 | 1.996 | DS |
| | GT45 | 8.02 | 2.88 | 237 | 15.50 | 6.08 | 62 | 68 | -9.415 | 1.994 | DS |
| MNSD | 0 | 5.99 | 1.80 | 173 | 18.25 | 5.27 | 20 | 20 | -10.334 | 2.086 | DS |
| | GT0, LE20 | 5.99 | 1.80 | 173 | 10.51 | 4.56 | 173 | 224 | -12.127 | 1.960 | DS |
| | GT20 | 18.25 | 5.27 | 20 | 10.51 | 4.56 | 173 | 224 | 6.301 | 2.074 | DS |
| MJVL | LE 2 | 9.57 | 4.96 | 228 | 7.20 | 3.62 | 52 | 100 | 3.950 | 1.990 | DS |
| | GE3, LE4 | 9.57 | 4.96 | 228 | 5.15 | 1.35 | 36 | 202 | 11.101 | 1.960 | DS |
| | GT4 | 7.20 | 3.62 | 52 | 5.15 | 1.35 | 36 | 69 | 3.726 | 1.996 | DS |
| MNVL | LE 2, GT2 | 10.91 | 4.77 | 47 | 8.48 | 4.70 | 319 | 60 | 3.267 | 2.000 | DS |
| QSIZ | 0, GT0 | 10.33 | 5.17 | 237 | 5.97 | 1.78 | 129 | 322 | 11.765 | 1.960 | DS |
| TLDL | 0 | 11.97 | 5.41 | 160 | 6.77 | 2.13 | 64 | 222 | 10.322 | 1.960 | DS |
| | GT0, LE10 | 11.97 | 5.41 | 160 | 6.13 | 1.85 | 142 | 200 | 12.835 | 1.960 | DS |
| | GT10 | 6.77 | 5.41 | 160 | 6.13 | 1.85 | 142 | 200 | 1.407 | 1.960 | DNS |
| DEAD | LE0, GT0 | 8.15 | 5.19 | 153 | 9.25 | 4.44 | 213 | 295 | -2.122 | 1.960 | DS |
| DEAS | LE0, GT0 | 7.78 | 3.70 | 289 | 12.60 | 6.24 | 72 | 84 | -6.285 | 1.990 | DS |
| DEAG | LT5 | 4.66 | 0.75 | 77 | 7.64 | 1.27 | 215 | 227 | -24.490 | 1.960 | DS |
| | 5 TO 10 | 4.66 | 0.75 | 77 | 16.46 | 5.20 | 74 | 76 | -19.328 | 1.993 | DS |
| | GT 10 | 7.64 | 1.27 | 215 | 16.46 | 5.20 | 74 | 76 | -14.443 | 1.993 | DS |
| DAMR | LE0, GT0 | 9.64 | 5.14 | 225 | 6.25 | 1.82 | 91 | 310 | 8.644 | 1.960 | DS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle; NAR = Nonarabs;DNS = Difference is not significant;
DS = Difference is significant.

* Note: t-Tests for different levels of a given variable are arranged as following;
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.

** The null hypothesis for this test is: Average accepted gap for level i equals average accepted gap for level j of the concerned variable

c. Drivers with less ability to estimate the speed and distance of the oncoming vehicles have significantly higher average accepted gaps. The same applies for less consistent drivers who has higher values of the variable DAMR.

## B. Rejected Gaps/Lags

Results of the t-tests performed on the average rejected gaps for different levels of the attributes are given in Table 5.12. Main comments on the table include:

a. The results of this test are more or less similar to the results obtained for Maneuver 1. Major deviations are observed for driver's sex (DSEX) and driver's age (DAGE) variables. Differences in the accepted and rejected gaps/lags between the defined levels of these two variables show higher significance levels in the case of Maneuver 2 which indicates some potentiality for these variables to be significant in gap acceptance models for this maneuver;

b. The average value of rejected gaps is significantly different from the average value of the rejected lags;

c. Difference in the average rejected Gaps/Lags for the two defined levels of the driver gap acceptance consistency measure (DAMR) is not significant in this case.

Table (5.12): Average Rejected Gaps and the Relevant t-tests for Maneuver 2

| Variable Name | Variable Level * | Av. Rej. Gap for Level i | Standard Deviation | Number of Observations | Av. Rej. Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated Value | t-Table Value | Result of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2,GT3 | 3.84 | 1.13 | 114 | 3.40 | 1.05 | 26 | 39 | 1.900 | 2.020 | DNS |
| VAGE | LT5 | 3.56 | 1.11 | 101 | 3.73 | 1.05 | 35 | 62 | -0.813 | 1.998 | DNS |
| | 5 TO 10 | 3.56 | 1.11 | 101 | 4.02 | 1.31 | 26 | 35 | -1.645 | 2.020 | DNS |
| | GT10 | 3.73 | 1.05 | 35 | 4.02 | 1.31 | 26 | 47 | -0.929 | 2.016 | DNS |
| EGCA | 4, GT4 | 3.66 | 1.15 | 148 | 3.72 | 1.07 | 14 | 16 | -0.199 | 2.120 | DNS |
| TRAN | MAN, AUT | 3.89 | 1.19 | 110 | 3.19 | 0.85 | 52 | 135 | 4.278 | 1.960 | DS |
| TRPS | WRK, NW | 3.58 | 1.04 | 137 | 4.17 | 1.51 | 25 | 28 | -1.874 | 2.048 | DNS |
| TRDN | LE20 | 3.43 | 1.05 | 97 | 4.05 | 0.99 | 29 | 48 | -2.917 | 2.010 | DS |
| | GT20, LT4 | 3.43 | 1.05 | 97 | 4.00 | 1.32 | 36 | 52 | -2.332 | 2.090 | DS |
| | GE40 | 4.05 | 0.99 | 29 | 4.00 | 1.32 | 36 | 63 | 0.174 | 1.996 | DNS |
| DSEX | MALE, FE | 3.54 | 1.12 | 144 | 8.53 | 4.64 | 320 | 392 | -18.102 | 1.960 | DS |
| DEXP | LT2 | 4.20 | 0.71 | 2 | 3.33 | 1.06 | 58 | 1 | 1.670 | 12.706 | DNS |
| | 2 TO 5 | 4.20 | 0.71 | 2 | 3.85 | 1.15 | 102 | 1 | 0.680 | 12.706 | DNS |
| | GT5 | 3.33 | 1.06 | 58 | 3.85 | 1.15 | 102 | 127 | -2.892 | 1.960 | DS |
| DEDU | SEC, UNI | 3.59 | 1.12 | 135 | 4.05 | 1.18 | 27 | 36 | -1.865 | 2.031 | DNS |
| DFAM | LE10 | 3.72 | 1.38 | 48 | 4.07 | 1.05 | 26 | 64 | -1.222 | 1.996 | DNS |
| | GT10, LE2 | 3.72 | 1.38 | 48 | 3.55 | 1.15 | 129 | 73 | 0.761 | 1.991 | DNS |
| | GT20 | 4.07 | 1.05 | 26 | 3.53 | 0.99 | 88 | 39 | 2.334 | 2.020 | DS |
| ACTN | SD, DIST | 3.55 | 1.13 | 111 | 3.93 | 1.12 | 51 | 98 | -2.000 | 1.976 | DS |
| ACDT | 0 | 3.67 | 1.15 | 129 | 3.72 | 1.01 | 27 | 41 | -0.228 | 2.020 | DNS |
| | 1 | 3.67 | 1.15 | 129 | 3.52 | 1.56 | 6 | 5 | 0.233 | 2.571 | DNS |
| | GT1 | 3.72 | 1.01 | 27 | 3.67 | 1.19 | 125 | 43 | 0.226 | 2.019 | DNS |
| VLTN | 0 | 3.67 | 1.19 | 125 | 3.71 | 1.01 | 25 | 39 | -0.175 | 2.020 | DNS |
| | 1 | 3.67 | 1.19 | 125 | 3.61 | 0.93 | 12 | 15 | 0.208 | 2.131 | DNS |
| | GT1 | 3.71 | 1.01 | 25 | 3.61 | 0.93 | 12 | 24 | 0.298 | 2.064 | DNS |
| DAGE | LT30 | 3.31 | 1.06 | 57 | 3.84 | 1.09 | 94 | 121 | -2.947 | 1.960 | DS |
| | 30 TO 45 | 3.31 | 1.06 | 57 | 3.92 | 1.26 | 31 | 53 | -2.290 | 2.011 | DS |
| | GT45 | 3.84 | 1.09 | 94 | 3.92 | 1.26 | 31 | 46 | -0.317 | 2.016 | DNS |
| NTLY | NAR, ARA | 3.68 | 1.14 | 154 | 3.49 | 1.07 | 8 | 8 | 0.488 | 2.306 | DNS |
| TMGP | GAP, LAG | 2.69 | 0.80 | 58 | 4.24 | 0.90 | 102 | 130 | -11.252 | 1.960 | DS |
| NREJ | 0 | 4.24 | 0.90 | 102 | 2.78 | 0.90 | 32 | 52 | 8.006 | 2.011 | DS |
| | 1 | 4.24 | 0.90 | 102 | 2.61 | 0.69 | 28 | 55 | 10.320 | 2.009 | DS |
| | GT1 | 2.78 | 0.90 | 32 | 2.61 | 0.69 | 28 | 57 | 0.826 | 2.007 | DNS |
| AREJ | 0, GT0 | 3.80 | 0.96 | 30 | 3.65 | 1.15 | 37 | 65 | 0.582 | 1.997 | DNS |
| MJTP | PC, LV | 3.58 | 1.04 | 154 | 5.46 | 1.58 | 8 | 7 | -3.328 | 2.365 | DS |
| MNTP | PC, LV | 3.65 | 1.12 | 149 | 3.95 | 1.38 | 13 | 13 | -0.762 | 2.160 | DNS |
| MJSD | LE30 | 2.14 | 0.73 | 7 | 2.96 | 0.98 | 66 | 8 | -2.723 | 2.306 | DS |
| | GT30, LE4 | 2.14 | 0.73 | 7 | 4.32 | 0.79 | 89 | 7 | -7.560 | 2.365 | DS |
| | GT45 | 2.96 | 0.98 | 66 | 4.32 | 0.79 | 89 | 122 | -9.261 | 1.960 | DS |
| MNSD | 0 | 3.16 | 1.03 | 91 | 4.28 | 0.65 | 24 | 57 | -6.547 | 1.997 | DS |
| | GT0, LE20 | 3.16 | 1.03 | 91 | 4.34 | 1.04 | 47 | 92 | -6.337 | 1.986 | DS |
| | GT20 | 4.28 | 0.65 | 24 | 4.34 | 1.04 | 47 | 66 | -0.298 | 1.996 | DNS |
| MJVL | LE 2 | 4.09 | 1.05 | 37 | 3.86 | 1.10 | 47 | 79 | 0.976 | 1.983 | DS |
| | GE3, LE4 | 4.09 | 1.05 | 37 | 3.35 | 1.12 | 28 | 56 | 2.709 | 2.019 | DS |
| | GT4 | 3.86 | 1.10 | 47 | 3.35 | 1.12 | 28 | 56 | 1.920 | 2.019 | DNS |
| MNVL | LE 2 GT 2 | 3.52 | 1.37 | 29 | 3.70 | 1.08 | 133 | 36 | -0.664 | 2.031 | DNS |
| QSIZ | 0, GT0 | 3.85 | 1.12 | 101 | 3.38 | 1.12 | 61 | 127 | 2.588 | 1.960 | DS |
| TLDL | 0 | 4.43 | 0.85 | 52 | 3.49 | 1.19 | 51 | 90 | 4.605 | 1.986 | DS |
| | GT0, LE10 | 4.43 | 1.12 | 52 | 3.15 | 0.95 | 59 | 101 | 6.447 | 1.983 | DS |
| | GT10 | 3.49 | 1.19 | 51 | 3.15 | 0.95 | 59 | 95 | 1.638 | 1.986 | DNS |
| DAMR | 3.24 | 1.05 | 46.00 | 3.84 | 1.13 | 1.16 | 120 | 3 | -0.003 | 2.776 | DNS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle; NAR = Nonarabs; DNS = Difference is not significant;
DS = Difference is significant.

* Note: t-Tests for different levels of a given variable are arranged as following:
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.

** The null hypothesis for this test is: Average rejected gap for level i equals average rejected gap for level j of the concerned variable

*5.5.2.2 Critical Gaps/Lags for Maneuver 2*

**I. Values of the Critical Gaps/Lags for Maneuver 2**

Critical gaps found using Raff's graphical method are given in Table 5.13. Main comments and observations on this table include:

a. The values of critical gaps/lags for Maneuver 2 ranges from 3.2 to 6.1 seconds with much concentration in the range of 4 to 5 seconds. These values are comparable to the findings of previous studies as can be concluded by comparing values in Table 5.13 to values given in Chapter 2, Tables 2.3, 2.4, and 2.5;

b. The trend of increase/decrease in critical gaps agrees with the expected driver gap acceptance behavior for almost all of the variables in Table 5.13. The few exceptions are limited to DEXP and VLTN. In this context, the expected driver behavior is much better represented by the critical gap values compared to average accepted gap values. The reason of conflict between driver gap acceptance indications derived based on critical and average accepted gaps/lags could be contributed to the method in which each of the two measures is computed. In computing the average acceptance gap, the weight of each accepted gap/lag is solely defined by its value while in critical gap case both of the value (length) of the gap/lag and driver action towards this gap/lag (accept/reject) are considered simultaneously. Hence, it is reasonable to have driver gap acceptance

Table 5.13 : Critical Gaps at Different Levels of the Studied Variables for Maneuver 2

| Variable Name and Levels | | Critical Gap (Sec) | Variable Name and Levels | | Critical Gap (Sec) |
|---|---|---|---|---|---|
| OCUP | LE 2 | 5.1 | TMGP | GAP | 4.2 |
| | GT 3 | 4.5 | | LAG | 5.3 |
| VAGE | LT 5 yr. | 4.9 | NREJ | 0 | 5.3 |
| | 5 to10 yr. | 4.9 | | 1 | 4.2 |
| | GT10 yr. | 5.1 | | GT1 | 3.4 |
| EGCA | LE 4 Cls. | 4.9 | AREJ | 0 | 4.5 |
| | GT 4 Cls. | 4.7 | | GT0 | 5.1 |
| TRAN | Manual | 5.1 | MJTP | Passenger Car | 5.0 |
| | Automatic | 4.4 | | Heavy Vehicle | 5.2 |
| TRPS | Work | 4.9 | MNTP | Passenger Car | 4.9 |
| | Nonwork | 5.6 | | Heavy Vehicle | 5.7 |
| TRDN | LE 20 Min. | 4.8 | MJSD | LE 30 Kph | 3.2 |
| | GT20 LT 40 Min. | 5.1 | | GT30, LE45 | 4.5 |
| | GE 40 Min. | 5.2 | | GT 45 | 5.7 |
| DSEX | Male | 4.9 | MNSD | 0 | 4.3 |
| | Female | 5.1 | | GT 0, LE 20 | 5.7 |
| DEXP | LT 2 yr. | 5.0 | | GT 20 | 6.1 |
| | 2 to 5 yr. | 4.7 | MJVL | LE 2 | 5.1 |
| | GT 5 yr. | 5.1 | | GE 3, LE 4 | 4.7 |
| DEDU | Secon. or less | 4.9 | | GT4 | 3.8 |
| | University | 5.2 | MNVL | LE 2 | 5.1 |
| DFAM | LE10 Visits/Wk | 5.5 | | GT2 | 4.9 |
| | GT 10, LE 20 | 5.1 | QSIZ | 0 | 5.5 |
| | GT 20 | 4.7 | | GT 0 | 4.5 |
| ACDT | 0 | 5.1 | TLDL | 0 Sec. | 6.1 |
| | 1 | 5.0 | | GT0, LE10 Sec | 5.9 |
| | GT 1 | 4.8 | | GT 10 Sec. | 4.9 |
| VLTN | 0 | 4.9 | DAMR | LE 0 | 3.4 |
| | 1 | 5.1 | | GT 0 | 5.1 |
| | GT 1 | 4.3 | ACTN | Speed | 4.8 |
| DAGE | LT 30 yr. | 4.7 | | Distance | 5.2 |
| | 30 to 45 yr. | 5.1 | NLTY | Non Arabs | 4.6 |
| | GT 45 yr. | 5.1 | | Arabs | 5.1 |
| Critical gap/lag for maneuver 2 = 4.6 seconds | | | | | |
| $50^{th}$ percentile accepted gap/lag for Maneuver 2 = 7.4 seconds | | | | | |
| $85^{th}$ percentile accepted gap/lag for Maneuver 2 = 12.5 seconds | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than; LE = Less than or Equal to; GT = Greater Than;
GE = Greater Than or Equal to; Cls. = Cylinders.

behavior represented better by critical gap/lag compared to the average accepted gap/lag;

c. Critical lag is visibly shorter than critical gap that again indicates different driver action to gaps and lags.

**II. T-Tests for Critical Gaps/Lags of Maneuver 2**

The t-tests needed to check whether critical gaps/lags derived for different levels of an attribute are significantly different at 5% are given in Table 5.14. Main comments and observations on this Table include:

a. Differences in Critical Gaps/Lags are significantly different at 5% level for levels (1,3) of DFAM, levels (2,3) of VLTN, all of the levels of and levels (1,2), (1,3) of TLDL, all levels, MJSD, NREJ, AREJ, QSIZ, and DAMR;

b. Value of the critical gaps is significantly different from the value of the critical lags which again indicates different driver action to gaps and lags;

c. The significant difference in critical gaps derived for different levels of certain attributes along with the correct and steady trend in the change of critical gaps for these attributes indicate that such attributes have high potentiality to be significant

Table 5.14: Critical Gaps and the Relevant t-tests for Maneuver 2

| Variable Name | Variable Level * | Critical Gap for Level i | Standard Deviation | Number of Observations | Critical Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated | Result of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2,GT3 | 5.10 | 4.33 | 417 | 4.50 | 6.21 | 111 | 140 | 0.958 | DNS |
| | LT5 | 4.90 | 5.00 | 307 | 4.90 | 1.05 | 138 | 361 | 0.000 | DNS |
| VAGE | 5 TO 10 | 4.90 | 5.00 | 307 | 5.10 | 3.58 | 83 | 178 | -0.412 | DNS |
| | GT10 | 4.90 | 4.88 | 138 | 5.10 | 3.58 | 83 | 210 | -0.350 | DNS |
| EGCA | 4, GT4 | 4.90 | 4.52 | 451 | 4.70 | 5.56 | 77 | 94 | 0.299 | DNS |
| TRAN | MAN, AUT | 5.10 | 4.54 | 392 | 4.40 | 5.47 | 136 | 203 | 1.341 | DNS |
| TRPS | WRK, NW | 4.90 | 4.77 | 435 | 5.60 | 4.75 | 93 | 135 | -1.289 | DNS |
| | LE20 | 4.80 | 4.93 | 342 | 5.10 | 4.95 | 120 | 207 | -0.572 | DNS |
| TRDN | GT20, LT4 | 4.80 | 4.93 | 342 | 5.20 | 3.36 | 66 | 126 | -0.813 | DNS |
| | GE40 | 5.10 | 4.95 | 120 | 5.20 | 3.36 | 66 | 176 | -0.163 | DNS |
| DSEX | MALE, FE | 4.90 | 4.64 | 464 | 5.10 | 5.32 | 64 | 77 | -0.286 | DNS |
| | LT2 | 5.00 | 7.29 | 15 | 4.70 | 4.74 | 140 | 15 | 0.156 | DNS |
| DEXP | 2 TO 5 | 5.00 | 7.29 | 15 | 5.10 | 4.58 | 373 | 14 | -0.053 | DNS |
| | GT5 | 4.70 | 4.74 | 140 | 5.10 | 4.58 | 373 | 242 | -0.859 | DNS |
| DEDU | SEC, UNI | 4.90 | 4.28 | 403 | 5.20 | 5.77 | 125 | 168 | -0.537 | DNS |
| | LE10 | 5.50 | 4.60 | 192 | 5.10 | 6.01 | 118 | 200 | 0.620 | DNS |
| DFAM | GT10, LE2 | 5.50 | 4.60 | 192 | 4.70 | 3.47 | 218 | 352 | 1.967 | DS |
| | GT20 | 5.10 | 6.01 | 118 | 4.70 | 3.47 | 218 | 160 | 0.665 | DNS |
| ACTN | SD, DIST | 4.80 | 4.43 | 322 | 5.20 | 5.17 | 206 | 388 | -0.916 | DNS |
| | 0 | 5.10 | 5.07 | 421 | 5.00 | 3.14 | 88 | 196 | 0.240 | DNS |
| ACDT | 1 | 5.10 | 5.07 | 421 | 4.80 | 1.29 | 19 | 51 | 0.778 | DNS |
| | GT1 | 5.00 | 3.14 | 88 | 4.80 | 1.29 | 19 | 70 | 0.448 | DNS |
| | 0 | 4.90 | 5.35 | 382 | 5.10 | 2.65 | 90 | 281 | -0.511 | DNS |
| VLTN | 1 | 4.90 | 5.35 | 382 | 4.30 | 1.84 | 56 | 226 | 1.631 | DNS |
| | GT1 | 5.10 | 2.65 | 90 | 4.30 | 1.84 | 56 | 142 | 2.150 | DS |
| | LT30 | 4.70 | 4.83 | 143 | 5.10 | 5.07 | 288 | 296 | -0.796 | DNS |
| DAGE | 30 TO 45 | 4.70 | 4.83 | 143 | 5.10 | 3.33 | 97 | 238 | -0.759 | DNS |
| | GT45 | 5.10 | 5.07 | 288 | 5.10 | 3.33 | 97 | 253 | 0.000 | DNS |
| NTLY | NAR, ARA | 5.10 | 4.71 | 472 | 4.60 | 5.18 | 56 | 66 | 0.689 | DNS |
| TMGP | LAG, GAP | 4.20 | 1.65 | 161 | 5.30 | 5.10 | 367 | 497 | -3.713 | DS |
| | 0 | 5.30 | 5.09 | 367 | 4.20 | 1.51 | 102 | 465 | 3.608 | DS |
| NREJ | 1 | 5.30 | 5.09 | 367 | 3.40 | 0.86 | 59 | 423 | 6.590 | DS |
| | GT1 | 4.20 | 1.51 | 102 | 3.40 | 0.86 | 59 | 159 | 4.283 | DS |
| AREJ | 0, GT0 | 4.50 | 1.78 | 106 | 5.10 | 1.42 | 422 | 140 | -3.222 | DS |
| MJTP | PC, LV | 5.30 | 4.66 | 508 | 5.20 | 6.55 | 20 | 20 | 0.068 | DNS |
| MNTP | PC, LV | 4.90 | 4.80 | 474 | 5.70 | 4.57 | 54 | 67 | -1.212 | DNS |
| | LE30 | 3.20 | 1.04 | 73 | 4.50 | 2.88 | 304 | 322 | -6.336 | DS |
| MJSD | GT30, LE4 | 3.20 | 1.04 | 73 | 5.70 | 6.08 | 151 | 167 | -4.906 | DS |
| | GT45 | 4.50 | 2.88 | 304 | 5.70 | 6.08 | 151 | 184 | -2.300 | DS |
| | 0 | 4.30 | 1.80 | 264 | 5.70 | 5.27 | 44 | 45 | -1.745 | DNS |
| MNSD | GT0, LE20 | 4.30 | 1.80 | 264 | 6.10 | 4.56 | 220 | 276 | -5.508 | DS |
| | GT20 | 5.70 | 5.27 | 44 | 6.10 | 4.56 | 220 | 57 | -0.470 | DNS |
| | LE 2 | 5.10 | 4.96 | 315 | 4.70 | 3.62 | 99 | 223 | 0.872 | DS |
| MJVL | GE3, LE4 | 5.10 | 4.96 | 315 | 3.80 | 1.35 | 114 | 408 | 4.238 | DS |
| | GT4 | 4.70 | 3.62 | 99 | 3.80 | 1.35 | 114 | 122 | 2.337 | DS |
| MNVL | LE 2, GT2 | 10.91 | 4.77 | 47 | 8.48 | 4.70 | 319 | 60 | 3.267 | DS |
| QSIZ | 0, GT0 | 5.50 | 5.17 | 338 | 4.50 | 1.78 | 190 | 458 | 3.232 | DS |
| | 0 | 5.90 | 5.41 | 212 | 4.70 | 2.13 | 115 | 303 | 2.848 | DS |
| TLDL | GT0, LE10 | 5.90 | 5.41 | 212 | 4.20 | 1.85 | 201 | 262 | 4.317 | DS |
| | GT10 | 4.70 | 5.41 | 115 | 4.20 | 1.85 | 201 | 129 | 0.960 | DNS |
| DAMR | LE0, GT0 | 3.40 | 5.14 | 57 | 5.10 | 1.82 | 471 | 58 | -2.478 | DS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle; NAR = Nonarabs; DNS = Difference is not significant;
DS = Difference is significant.

* Note: t-Tests for different levels of a given variable are arranged as following:
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.
Null Hypothesis for this Test is as Follows: Critical Gap for Level i is Equal to the Critical Gap for Level j

in gap acceptance models. Examples of these attributes in Maneuver 2 include delay measures particularly the TLDL and volume at minor road.

### 5.5.3 Analysis of the Average and Critical Gaps/Lags for Maneuver 3.

#### *5.5.3.1: Average Accepted and Rejected Gaps/Lags for Maneuver 3*

The average accepted and rejected gaps/lags computed for Maneuver 3 at different levels of the studied attributes are given in Table 5.15. The main observations from this table include:

**I. Average Accepted Gaps/Lags for Maneuver 3**

**a.** Values of the average accepted gaps/lags range from around 5 to 13.9 seconds. The majority of the values is concentrated between 7.5 and 8 seconds which is comparable to findings in previous studies specially Solberg and Open-Lander who found that the median accepted gap for left turn is 7.82 seconds as given in Chapter 2, Table 2.5;

**b.** In general, the trend of change in the average accepted gaps/lags for different levels of attributes is according to the expected driver gap acceptance behavior. Exceptions in this regard include; TRDN, and DEXP. The trend of change for

Table 5.15: Average Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 3

| Variable Name and Levels | | Average Rejected Gap (Sec.) | Average Accepted Gap (Sec.) | Variable Name and Level | | Average Rejected Gap (Sec.) | Average Accepted Gap (Sec.) |
|---|---|---|---|---|---|---|---|
| OCUP | | 3.41 | 7.63 | TMGP | Gap | 3.40 | 7.00 |
| | GT 3 | 3.68 | 7.54 | | Lag | 4.47 | 8.69 |
| VAGE | LT 5 yr. | 3.56 | 7.63 | NREJ | 0 | 4.45 | 8.63 |
| | 5 to 10 yr. | 3.77 | 7.44 | | 1 | 3.38 | 8.94 |
| | GT 10 yr. | 3.25 | 7.65 | | GT 1 | 3.04 | 6.56 |
| EGCA | LE 4 Cls. | 3.46 | 7.52 | AREJ | 0 | 3.63 | 7.98 |
| | GT 4 Cls. | 3.49 | 7.76 | | GT 0 | 4.41 | 7.13 |
| TRAN | Manual | 3.54 | 7.63 | MJTP | PC | 3.42 | 7.55 |
| | Automatic | 3.24 | 7.39 | | HV | 4.81 | 8.10 |
| TRPS | Work | 3.50 | 7.51 | MNTP | PC | 3.47 | 7.58 |
| | Non Work | 3.39 | 7.75 | | HV | 3.45 | 7.86 |
| TRDN | LE 20 Min. | 3.56 | 7.55 | MJSD | LE30 | 1.60 | 6.15 |
| | GT 20 LT 40 | 3.21 | 7.81 | | GT30, LE45 | 2.83 | 6.19 |
| | GE 40 | 3.66 | 7.11 | | GT 45 | 5.08 | 9.40 |
| DSEX | Male | 3.47 | 7.57 | MNSD | 0 | 3.29 | 7.09 |
| | Female | 3.45 | 7.63 | | GT 0, LE20 | 5.32 | 11.18 |
| DEXP | LT 2 yr. | 3.11 | 7.64 | | GT 20 | 4.24 | 9.17 |
| | 2 to 5 yr. | 3.46 | 7.56 | MJVL | LE 2 | 4.47 | 8.80 |
| | GT 5 yr. | 3.48 | 7.57 | | GE 3, LE 4 | 3.94 | 7.88 |
| DEDU | Secondary | 3.49 | 7.36 | | GT 4 | 3.30 | 6.90 |
| | University | 3.43 | 8.03 | MNVL | LE 1 | 3.54 | 7.05 |
| DFAM | LE 10 | 3.44 | 7.92 | | 2 | 3.53 | 7.80 |
| | GT10, LE20 | 3.74 | 7.89 | | GT 2 | 2.79 | 7.49 |
| | GT 20 | 3.30 | 7.03 | QSIZ | 0 | 3.55 | 8.27 |
| ACTN | Speed | 3.37 | 7.54 | | GT 0 | 3.35 | 6.67 |
| | Distance | 3.62 | 7.61 | TLDL | 0 Sec. | 4.52 | 10.35 |
| ACDT | 0 | 3.56 | 7.25 | | GT 0, LE10 | 3.55 | 8.32 |
| | 1 | 3.21 | 7.58 | | GT 10 Sec. | 3.14 | 6.64 |
| | GT 1 | 2.97 | 5.95 | DEAD | LE 0 Mt. | NA | 6.45 |
| VLTN | 0 | 3.57 | 7.87 | | GT 0 Mt. | NA | 7.88 |
| | 1 | 3.42 | 7.46 | DEAS | LE 0 Kmph | NA | 6.89 |
| | GT 1 | 3.00 | 5.93 | | GT 0 Kmph | NA | 8.04 |
| DAGE | LT 30 yr. | 3.57 | 7.18 | DEAG | LT 5 Sec. | NA | 5.03 |
| | 30 TO 45 yr. | 3.39 | 7.61 | | 5 to 10 Sec. | NA | 7.49 |
| | GT 45 yr. | 3.55 | 7.93 | | GT 10 Sec. | NA | 13.86 |
| NLTY | Non Arabs | 3.41 | 7.50 | DAMR | LE 0 Sec. | 3.40 | 7.21 |
| | Arabs | 3.71 | 7.89 | | GT 0 Sec. | 3.56 | 8.01 |
| Average accepted gap/lag for Maneuver 3 = 7.57 seconds | | | | | | | |
| Average rejected gap/lag for Maneuver 3 = 3.47 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:
LT = Less Than; LE = Less than or Equal to; GT = Greater Than; GE = Greater Than or Equal to;
PC = Passenger Car; HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

these variables matches partially with the expected behavior, i.e., only for some levels of the attributes;

c. Value of the average accepted gaps exceeds the value of the average accepted lags;

d. Average accepted gaps/lags increase steadily with the decrease in the ability of the driver to correctly estimate the speed and distance of the oncoming vehicle.

**II. Average Rejected Gaps/Lags for Maneuver 3**

a. Average rejected gaps for Maneuver 3 range from 1.6 to 5.3 seconds with the majority of them concentrated around the value 3.5 seconds;

b. The average value of rejected lags (4.47 seconds) is visibly longer than the average value of the rejected gaps (3.40 seconds);

c. In general, the trend of change in the length of the average rejected gaps/lags is according to the expected driver gap acceptance behavior. The few exceptions include the variable TRPS in which the average rejected gap/lag for non-work trips is unexpectedly shorter than the average rejected gap/lags for work trips.

## III. T-Tests for the Average Accepted and Rejected Gaps/Lags for Maneuver 3.

### A) Accepted Gaps/Lags

Results of the t-tests conducted to check whether the average accepted gap/lag for a particular level of an attribute is significantly different from the average accepted gap/lag for the other levels of the same attribute are given in Table 5.16. The main observations from this table include:

a. Difference in the average accepted gaps/lags are significant at 5% for the two defined levels for each of the OCUP, DEDU, QSIZE, DEAD, DEAS, and DAMR. Differences are also significant for all levels of NREJ, MJVL, TLDL, DEAG, levels (1,3), of DEAM, levels (1,3), (2,3) of each of ACDT and VLTN, and levels (1,3), (2,3) of MJSD;

b. The difference between the average accepted lags and gaps is significantly different at 5%.

### B) Rejected Gaps/Lags

Results of the t-tests performed on average rejected gaps for Maneuver 3 are given in Table 5.17. Main observation on the table include:

Table 5.16: Average Accepted Gaps and the Results of the Relevant t-tests for Maneuver 3

| Variable Name | Variable Level * | Av. Accepted Gap for Level i | Standard Deviation | Number of Observations | Av. Accepted Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated | t-Table Value | Rsult of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2.GT3 | 7.63 | 3.05 | 183 | 4.54 | 3.04 | 20 | 23 | 4.315 | 2.069 | DS |
| VAGE | LT5 | 7.13 | 3.22 | 117 | 7.44 | 2.67 | 73 | 173 | -0.718 | 1.960 | DNS |
| | 5 TO 10 | 7.63 | 3.22 | 117 | 7.65 | 2.92 | 33 | 56 | -0.034 | 2.008 | DNS |
| | GT10 | 7.44 | 2.67 | 73 | 7.65 | 2.92 | 33 | 57 | -0.352 | 2.009 | DNS |
| EGCA | 4. GT4 | 7.52 | 2.97 | 175 | 7.76 | 3.12 | 48 | 72 | -0.477 | 1.996 | DNS |
| TRAN | MAN. AUT | 7.63 | 3.02 | 169 | 7.39 | 2.95 | 54 | 91 | 0.517 | 1.990 | DNS |
| TRPS | WRK. NWR | 7.51 | 3.08 | 165 | 7.75 | 2.74 | 58 | 111 | -0.555 | 1.984 | DNS |
| TRDN | LE20 | 7.55 | 3.02 | 155 | 7.81 | 3.28 | 50 | 78 | -0.497 | 1.996 | DNS |
| | GT20. LT40 | 7.55 | 3.02 | 155 | 7.11 | 1.63 | 12 | 18 | 0.831 | 2.101 | DNS |
| | GE40 | 7.81 | 3.28 | 50 | 7.11 | 1.63 | 12 | 35 | 1.059 | 2.036 | DNS |
| DSEX | MALE. FE | 7.57 | 3.07 | 203 | 7.63 | 2.18 | 20 | 27 | -0.113 | 2.086 | DNS |
| DEXP | LT2 | 7.64 | 2.20 | 9 | 7.56 | 2.86 | 53 | 13 | 0.096 | 2.160 | DNS |
| | 2 TO 5 | 7.64 | 2.20 | 9 | 7.57 | 3.09 | 161 | 10 | 0.091 | 2.228 | DNS |
| | GT5 | 7.56 | 2.86 | 53 | 7.57 | 3.09 | 161 | 95 | -0.022 | 1.990 | DNS |
| DEDU | SEC. UNIV | 3.49 | 1.79 | 323 | 8.03 | 3.49 | 72 | 80 | -10.728 | 1.996 | DS |
| DFAM | LE10 | 7.92 | 3.10 | 84 | 7.84 | 3.10 | 54 | 113 | 0.148 | 1.983 | DNS |
| | GT10. LE20 | 7.92 | 3.10 | 84 | 7.03 | 2.78 | 85 | 165 | 1.964 | 1.960 | DS |
| | GT20 | 7.84 | 3.10 | 54 | 7.03 | 2.78 | 85 | 104 | 1.562 | 1.986 | DNS |
| ACTN | SD. DIST | 7.54 | 3.27 | 131 | 7.61 | 2.56 | 92 | 218 | -0.179 | 1.960 | DNS |
| ACDT | 0 | 7.25 | 3.00 | 171 | 7.58 | 3.39 | 33 | 42 | -0.521 | 2.020 | DNS |
| | 1 | 7.25 | 3.00 | 171 | 5.95 | 1.45 | 19 | 38 | 3.217 | 2.024 | DS |
| | GT1 | 7.58 | 3.39 | 33 | 5.95 | 1.45 | 19 | 47 | 2.406 | 2.014 | DS |
| VLTN | 0 | 7.87 | 2.85 | 146 | 7.46 | 3.64 | 54 | 78 | 0.747 | 1.996 | DNS |
| | 1 | 7.87 | 2.85 | 146 | 5.93 | 1.32 | 23 | 61 | 5.352 | 1.999 | DS |
| | GT1 | 7.46 | 3.64 | 54 | 5.93 | 1.32 | 23 | 74 | 2.700 | 1.996 | DS |
| DAGE | LT30 | 7.18 | 2.62 | 46 | 7.61 | 3.20 | 139 | 93 | -0.911 | 1.989 | DNS |
| | 30 TO 45 | 7.18 | 2.62 | 46 | 7.93 | 2.59 | 38 | 79 | -1.314 | 1.995 | DNS |
| | GT45 | 7.61 | 3.20 | 139 | 7.93 | 2.59 | 38 | 71 | -0.640 | 1.998 | DNS |
| NTLY | NAR. ARA | 7.50 | 3.07 | 182 | 7.89 | 2.62 | 41 | 67 | -0.833 | 2.000 | DNS |
| TMGP | LAG. GAP | 7.00 | 2.73 | 148 | 8.69 | 3.19 | 75 | 130 | -3.918 | 1.960 | DS |
| NREJ | 0 | 9.91 | 5.09 | 265 | 6.51 | 1.51 | 70 | 329 | 9.418 | 1.960 | DS |
| | 1 | 9.91 | 5.09 | 265 | 4.42 | 0.86 | 31 | 268 | 15.742 | 1.960 | DS |
| | GT1 | 6.51 | 1.51 | 70 | 4.42 | 0.86 | 31 | 93 | 8.798 | 1.989 | DS |
| AREJ | 0. GT0 | 7.98 | 4.21 | 10 | 7.13 | 1.51 | 32 | 10 | 0.626 | 2.228 | DNS |
| AENT | 0. GT0 | 7.66 | 3.17 | 190 | 7.02 | 1.59 | 34 | 89 | 1.794 | 1.991 | DNS |
| MJTP | 7.55 | 7.55 | 3.04 | 213 | 8.10 | 1.66 | 10 | 12 | -0.974 | 2.179 | DNS |
| MNTP | PC. LV | 7.58 | 3.04 | 195 | 7.86 | 2.68 | 28 | 38 | -0.508 | 2.024 | DNS |
| MJSD | LE30 | 6.15 | 1.82 | 15 | 6.19 | 1.57 | 112 | 17 | -0.081 | 2.110 | DNS |
| | GT30. LE45 | 6.15 | 1.82 | 15 | 9.40 | 3.41 | 96 | 32 | -5.558 | 2.040 | DS |
| | GT45 | 6.19 | 1.57 | 112 | 9.40 | 3.41 | 96 | 129 | -8.485 | 1.960 | DS |
| MNSD | 0 | 7.09 | 2.62 | 188 | 11.18 | 4.01 | 17 | 17 | -4.126 | 2.110 | DS |
| | GT0. LE20 | 7.09 | 2.62 | 188 | 9.17 | 2.89 | 18 | 20 | -2.940 | 2.086 | DS |
| | GT20 | 11.18 | 4.01 | 17 | 9.17 | 2.89 | 18 | 29 | 1.693 | 2.045 | DNS |
| MJVL | LE 2 | 8.80 | 3.00 | 228 | 7.20 | 3.62 | 52 | 68 | 2.964 | 1.996 | DS |
| | GE3. LE4 | 9.57 | 4.96 | 228 | 5.15 | 1.35 | 36 | 202 | 11.101 | 1.960 | DS |
| | GT4 | 7.20 | 3.62 | 52 | 5.15 | 1.35 | 36 | 69 | 3.726 | 1.995 | DS |
| MNVL | LE1 | 7.25 | 2.96 | 37 | 7.80 | 3.08 | 111 | 64 | -0.969 | 1.995 | DNS |
| | 2 | 7.25 | 2.96 | 37 | 7.49 | 2.89 | 75 | 70 | -0.407 | 1.990 | DNS |
| | GT2 | 7.80 | 3.08 | 111 | 7.49 | 2.89 | 75 | 166 | 0.699 | 1.960 | DNS |
| QSIZ | 0. GT0 | 8.27 | 3.33 | 126 | 6.67 | 2.20 | 97 | 216 | 4.309 | 1.960 | DS |
| TLDL | 0 | 10.35 | 3.54 | 35 | 8.32 | 2.55 | 46 | 59 | 2.873 | 2.002 | DS |
| | GT0. LE10 | 10.35 | 3.54 | 35 | 6.64 | 2.46 | 142 | 42 | 5.861 | 2.019 | DS |
| | GT10 | 8.32 | 2.55 | 46 | 6.64 | 2.46 | 142 | 74 | 3.917 | 1.994 | DS |
| DEAD | LE0. GT0 | 6.45 | 2.19 | 48 | 7.88 | 3.11 | 175 | 105 | -3.630 | 1.984 | DS |
| DEAS | LE0. GT0 | 6.89 | 2.83 | 91 | 8.04 | 3.02 | 132 | 201 | -2.901 | 1.960 | DS |
| DEAG | LT5 | 5.03 | 0.56 | 60 | 7.49 | 1.53 | 137 | 191 | -16.468 | 1.960 | DS |
| | 5 TO 10 | 5.03 | 0.56 | 60 | 13.86 | 3.07 | 26 | 26 | -14.561 | 2.056 | DS |
| | GT 10 | 7.49 | 1.53 | 137 | 13.86 | 3.07 | 26 | 27 | -10.339 | 2.052 | DS |
| DAMR | LE0. GT0 | 7.21 | 3.00 | 122 | 8.01 | 2.94 | 101 | 215 | -2.004 | 1.960 | DS |

LT = Less than. LE = Less than or equal. GT = Greater than. GE = Greater than or equal
PC = Passenger Car; LV = Large Vehicle; NAR = Nonarabs; DNS = Difference is not significant;
DS = Difference is significant.

* Note: t-Tests for different levels of a given variable are arranged as following:
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.

** The null hypothesis for this test is: Average accepted gap for level i equals average accepted gap for level j of the concerned variable

Table 5.17: Average Rejected Gaps and the Relevant t-tests for Maneuver 3

| Variable Name | Variable Level * | Av. Rejted Gap for Level i | Standard Deviation | Number of Observations | Av. Rej. Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated | t-Table Value | Rsult of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2,GT3 | 3.41 | 1.82 | 501 | 3.64 | 1.58 | 62 | 82 | -1.062 | 1.996 | DNS |
| VAGE | LT5 | 3.56 | 1.77 | 324 | 3.77 | 1.77 | 182 | 375 | -1.281 | 1.960 | DNS |
| | 5 TO 10 | 3.56 | 1.77 | 324 | 3.25 | 1.91 | 88 | 130 | 1.371 | 1.960 | DNS |
| | GT10 | 3.77 | 1.77 | 182 | 3.25 | 1.91 | 88 | 161 | 2.147 | 1.960 | DS |
| EGCA | 4, GT4 | 3.46 | 1.82 | 458 | 3.49 | 1.74 | 136 | 230 | -0.175 | 1.960 | DNS |
| TRAN | MAN, AUT | 3.54 | 1.77 | 451 | 3.24 | 1.87 | 143 | 228 | 1.693 | 1.960 | DNS |
| TRPS | WRK, NWR | 3.50 | 1.85 | 432 | 3.39 | 1.66 | 162 | 320 | 0.697 | 1.960 | DNS |
| TRDN | LE20 | 3.56 | 1.81 | 420 | 3.21 | 1.76 | 128 | 215 | 1.957 | 1.960 | DNS |
| | GT20, LT40 | 3.56 | 1.81 | 420 | 3.66 | 1.69 | 30 | 34 | -0.312 | 2.036 | DNS |
| | GE40 | 3.21 | 1.76 | 128 | 3.66 | 1.69 | 30 | 45 | -1.302 | 2.016 | DNS |
| DSEX | MALE, FE | 3.47 | 1.80 | 543 | 3.45 | 1.86 | 51 | 59 | 0.074 | 2.001 | DNS |
| DEXP | LT2 | 3.11 | 1.58 | 13 | 3.46 | 1.83 | 157 | 15 | -0.758 | 2.131 | DNS |
| | 2 TO 5 | 3.11 | 1.58 | 13 | 3.48 | 1.80 | 424 | 13 | -0.828 | 2.160 | DNS |
| | GT5 | 3.46 | 1.83 | 157 | 3.48 | 1.80 | 424 | 275 | -0.118 | 1.960 | DNS |
| DEDU | SEC, UNIV | 3.49 | 1.79 | 373 | 3.43 | 1.82 | 221 | 456 | 0.391 | 1.960 | DNS |
| DFAM | LE10 | 3.44 | 1.81 | 228 | 3.74 | 1.77 | 147 | 317 | -1.588 | 1.960 | DNS |
| | GT10, LE20 | 3.44 | 1.81 | 228 | 3.30 | 1.79 | 219 | 445 | 0.822 | 1.960 | DNS |
| | GT20 | 3.74 | 1.77 | 147 | 3.30 | 1.79 | 219 | 316 | 2.321 | 1.960 | DS |
| ACTN | SD, DIST | 3.37 | 1.80 | 367 | 3.62 | 1.79 | 227 | 481 | -1.650 | 1.960 | DNS |
| ACDT | 0 | 3.56 | 1.79 | 455 | 3.21 | 1.78 | 104 | 154 | 1.807 | 1.960 | DNS |
| | 1 | 3.56 | 1.79 | 455 | 2.97 | 1.87 | 35 | 39 | 1.804 | 2.022 | DNS |
| | GT1 | 3.21 | 1.78 | 104 | 2.97 | 1.87 | 35 | 56 | 0.665 | 2.004 | DNS |
| VLTN | 0 | 3.57 | 1.82 | 373 | 3.42 | 1.78 | 151 | 283 | 0.868 | 1.960 | DNS |
| | 1 | 3.57 | 1.82 | 373 | 3.00 | 1.66 | 70 | 103 | 2.595 | 1.983 | DS |
| | GT1 | 3.42 | 1.78 | 151 | 3.00 | 1.66 | 70 | 143 | 1.710 | 1.960 | DNS |
| DAGE | LT30 | 3.57 | 1.74 | 166 | 3.39 | 1.85 | 334 | 348 | 1.066 | 1.960 | DNS |
| | 30 TO 45 | 3.57 | 1.74 | 166 | 3.55 | 1.72 | 94 | 195 | 0.090 | 1.960 | DNS |
| | GT45 | 3.39 | 1.85 | 334 | 3.55 | 1.72 | 94 | 159 | -0.783 | 1.960 | DNS |
| NTLY | NAR, ARA | 3.41 | 1.80 | 480 | 3.71 | 1.77 | 114 | 173 | -1.621 | 1.960 | DNS |
| TMGP | GAP, LAG | 3.40 | 1.66 | 447 | 4.47 | 1.84 | 147 | 229 | -6.262 | 1.960 | DS |
| NREJ | 0 | 4.45 | 1.84 | 151 | 3.38 | 1.82 | 119 | 255 | 4.773 | 1.960 | DS |
| | 1 | 4.45 | 1.84 | 151 | 3.04 | 1.59 | 324 | 258 | 8.110 | 1.960 | DS |
| | GT1 | 3.38 | 1.82 | 119 | 3.04 | 1.59 | 324 | 188 | 1.801 | 1.960 | DNS |
| AREJ | 0, GT0 | 3.63 | 1.71 | 19 | 4.41 | 1.74 | 41 | 36 | -1.633 | 2.036 | DNS |
| AENT | 0, GT0 | 3.47 | 1.80 | 594 | 4.16 | 1.34 | 7 | 6 | -1.348 | 2.447 | DNS |
| MJTP | PC, LV | 3.42 | 1.81 | 575 | 4.81 | 0.13 | 19 | 432 | -17.127 | 1.960 | DS |
| MNTP | PC, LV | 3.47 | 1.79 | 514 | 3.45 | 1.85 | 80 | 103 | 0.090 | 1.991 | DNS |
| MJSD | LE30 | 1.80 | 0.97 | 142 | 2.83 | 1.12 | 206 | 328 | -9.134 | 1.960 | DS |
| | GT30, LE45 | 1.80 | 0.97 | 142 | 5.08 | 1.12 | 246 | 329 | -30.291 | 1.960 | DS |
| | GT45 | 2.83 | 1.12 | 206 | 5.08 | 1.12 | 246 | 436 | -21.271 | 1.960 | DS |
| MNSD | 0 | 3.29 | 1.72 | 510 | 5.32 | 1.05 | 22 | 26 | -8.585 | 2.056 | DS |
| | GT0, LE20 | 3.29 | 1.72 | 510 | 4.24 | 2.09 | 62 | 71 | -3.440 | 1.995 | DS |
| | GT20 | 5.32 | 1.05 | 22 | 4.24 | 2.09 | 62 | 72 | 3.110 | 1.993 | DS |
| MJVL | LE 2 | 4.47 | 1.82 | 28 | 3.94 | 1.83 | 105 | 43 | 1.368 | 2.018 | DNS |
| | GE3, LE4 | 4.47 | 1.82 | 28 | 3.30 | 1.76 | 461 | 30 | 3.309 | 2.042 | DS |
| | GT4 | 3.94 | 1.83 | 105 | 3.30 | 1.76 | 461 | 151 | 3.257 | 1.960 | DS |
| MNVL | 1 | 3.54 | 1.76 | 331 | 3.53 | 1.88 | 205 | 411 | 0.061 | 1.960 | DNS |
| | 2 | 3.54 | 1.76 | 331 | 2.79 | 1.64 | 58 | 82 | 3.177 | 1.990 | DS |
| | GT2 | 3.53 | 1.88 | 205 | 2.79 | 1.64 | 58 | 103 | 2.934 | 1.987 | DS |
| QSIZ | 0,GTO | 3.55 | 1.86 | 350 | 3.35 | 1.70 | 244 | 551 | 1.357 | 1.960 | DNS |
| TLDL | 0 | 4.52 | 1.90 | 93 | 3.55 | 1.81 | 155 | 186 | 3.962 | 1.960 | DS |
| | GT0, LE10 | 4.52 | 1.90 | 93 | 3.14 | 1.65 | 346 | 132 | 6.387 | 1.960 | DS |
| | GT10 | 3.55 | 1.81 | 155 | 3.14 | 1.65 | 346 | 273 | 2.407 | 1.960 | DS |
| DAMR | 3.24 | 3.40 | 1.74 | 342 | 3.56 | 1.88 | 252 | 516 | -1.058 | 1.960 | DNS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal
PC = Passenger Car, LV = Large Vehicle, NAR = Nonarabs
* Note: t-Tests for different levels of a given variable are arranged as following;
Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.
** The null hypothesis for this test is: Average rejected gap for level i equals average rejected gap for level j of the concerned variable

a. Average rejected gaps/lags are significantly different at 5% level for levels (2,3) of VAGE and DFAM, levels (1,3) of VLTN, levels (1,2), (1,3) of NREJ, the two levels of MJSD, levels (1,3), (2,3) of both of the MJVL and MNVL, and for all levels of MJSD, MNSD and TLDL;

b. The average value of rejected gaps is significantly different from the average value of rejected lags with the former being shorter.

#### *5.5.3.2 Critical Gap/Lags for Maneuver 3*

**I. Values of the Critical Gaps/Lags**

Critical gaps/lags found for Maneuver 3 using Raff's method are given in Table 5.18. Main comments on this Table include the following:

a. The number of rejected gaps in Maneuver 3 is much higher than in Maneuver 1. Referring to Table 5.1, it can be concluded that the average number of rejected gaps per driver in Maneuver 3 is around 2.8 gaps/lags while the average number of rejected gaps/lags per driver in Maneuver 1 is only 0.62 gaps/lags. The graphical method of finding the critical gap is based on the gap length and the response to it as well. As the number of the rejected short gaps increases, the value of critical gap will decrease.

Table 5.18: Critical Gaps at Different Levels of the Studied Variables for Maneuver 3

| Variable Name and Level | | Critical Gap (Sec.) | Variable Name and Level | | Critical Gap (Sec.) |
|---|---|---|---|---|---|
| OCUP | LE 2 | 5.2 | TMGP | GAP | 4.9 |
| | GT 3 | 5.3 | | LAG | 5.8 |
| VAGE | LT 5 yr. | 5.1 | NREJ | 0 | 5.8 |
| | 5 to10 yr. | 5.2 | | 1 | 5.7 |
| | GT10 yr. | 5.3 | | GT1 | 4.7 |
| EGCA | LE 4 Cls. | 5.2 | AREJ | 0 | 5.1 |
| | GT 4 Cls. | 5.1 | | GT0 | 5.2 |
| TRAN | Manual | 5.3 | MJTP | Passenger Car | 5.2 |
| | Automatic | 5.1 | | Heavy Vehicle | 5.7 |
| TRPS | Work | 5.2 | MNTP | Passenger Car | 5.2 |
| | Non Work | 5.3 | | Heavy Vehicle | 5.5 |
| TRDN | LE 20 Min. | 5.2 | MJSD | LE 30 Kph | 4.7 |
| | GT20, LT 40 | 5.2 | | GT30, LE45 | 4.6 |
| | GE 40 Min. | 5.4 | | GT 45 | 6.2 |
| DSEX | Male | 5.2 | MNSD | 0 | 5.1 |
| | Female | 5.3 | | GT 0, LE 20 | 6.4 |
| DEXP | LT 2 yr. | 5.1 | | GT 20 | 6.0 |
| | 2 to 5 yr. | 5.2 | MJVL | LE 2 | 5.9 |
| | GT 5 yr. | 5.2 | | GE 3, LE 4 | 5.7 |
| DEDU | Secon. or less | 5.2 | | GT4 | 5.0 |
| | University | 5.3 | MNVL | LE1 | 5.1 |
| DFAM | LE10 Visits/WK | 5.3 | | 2 | 5.3 |
| | GT 10 to LE 20 | 5.3 | | GT2 | 5.1 |
| | GT 20 | 5.1 | QSIZ | 0 | 5.4 |
| ACTN | Speed | 5.1 | | GT 0 | 5.1 |
| | Distance | 5.4 | TLDL | 0 | 6.1 |
| ACDT | 0 | 5.3 | | GT 0, LE 10 | 5.9 |
| | 1 | 5.1 | | GT 10 | 4.9 |
| | GT 1 | 5.1 | NLTY | Non Arabs | 5.3 |
| VLTN | 0 | 5.4 | | Arabs | 5.2 |
| | 1 | 5.1 | DAMR | LE 0 | - |
| | GT 1 | 4.9 | | GT 0 | 5.5 |
| DAGE | LT 30 yr. | 5.0 | | | |
| | 30 to 45 yr. | 5.2 | | | |
| | GT 45 yr. | 5.4 | | | |

| |
|---|
| Critical gap/lag for Maneuver 3 = 5.2 seconds |
| 50th percentile accepted gap/lag for Maneuver 3 = 6.7 seconds |
| 85th percentile accepted gap/lag for Maneuver 3 = 9.9 seconds |

Abbreviations listed in the above table stands for the following:

LT = Less Than: LE = Less than or Equal to: GT = Greater Than: GE = Greater Than or Equal to:

Cls. = Cylinders

The high average number of rejected gaps per driver in Maneuver 3 means that the imposed delays at drivers are high. Consequently, drivers will accept shorter gaps. This will also result in shorter critical gaps. Referring to Table 5.3 it can be concluded that the average total delay (DLQH + DLIQ) per driver in Maneuver 3 is around 17.5 seconds while it does not exceed 5.4 seconds in Maneuver 1;

**b.** The direction of change (increase/decrease) in critical gaps at different levels of the attributes listed in Table 5.18 agrees with the expected driver behavior. For example the critical gap decreases as the total delay (TLDL) imposed on the driver increases.

## II. t - Tests for Critical Gaps/Lags

Table 5.19 gives the results of the t-tests performed to investigate whether the differences in the critical gaps for different levels of an attribute are significant at 5%. The main observation from this table is that the difference in critical gaps is significant for levels (1,3), (2,3) of each of AREJ, MJSD, and TLDL, levels (1,3) of MNSD, and levels (2,3) of MJVL. The different levels of variables are given in the table for convenience. Another observation is that the difference between critical gap and critical lag is significantly different.

Table 5.19: Critical Gaps and the Relevant t-tests for Maneuver 3

| Variable Name | Variable Level * | Critical Gap/Lag Gap for Level i | Standard Deviation | Number of Observations | Critical Gap/Lag Gap for Level j | Standard Deviation | Number of Observations | Degrees of Freedom | t-Calculated | Result of t-Test ** |
|---|---|---|---|---|---|---|---|---|---|---|
| OCUP | LE2.GT3 | 5.20 | 3.05 | 684 | 5.30 | 3.04 | 133 | 187 | -0.347 | DNS |
| VAGE | LT5 | 5.10 | 3.22 | 441 | 5.20 | 2.67 | 255 | 611 | -0.441 | DNS |
| | 5 TO 10 | 5.10 | 3.22 | 441 | 5.30 | 2.92 | 121 | 207 | -0.652 | DNS |
| | GT10 | 5.20 | 2.67 | 255 | 5.20 | 2.92 | 121 | 218 | 0.000 | DNS |
| EGCA | 4. GT4 | 5.20 | 2.97 | 633 | 5.10 | 3.12 | 184 | 286 | 0.387 | DNS |
| TRAN | MAN. AUT | 5.30 | 3.02 | 620 | 5.10 | 2.95 | 197 | 336 | 0.824 | DNS |
| TRPS | WRK. NWR | 5.20 | 3.08 | 597 | 5.30 | 2.74 | 220 | 436 | -0.447 | DNS |
| TRDN | LE20 | 5.20 | 3.02 | 575 | 5.20 | 3.28 | 178 | 276 | 0.000 | DNS |
| | GT20. LT40 | 5.20 | 3.02 | 575 | 5.40 | 1.63 | 64 | 118 | -0.835 | DNS |
| | GE40 | 5.20 | 3.28 | 178 | 5.40 | 1.63 | 64 | 217 | -0.626 | DNS |
| DSEX | MALE. FEM | 5.20 | 3.07 | 746 | 5.30 | 2.18 | 71 | 20 | -0.355 | DNS |
| DEXP | LT2 | 5.10 | 2.20 | 21 | 5.20 | 2.86 | 210 | 27 | -0.193 | DNS |
| | 2 TO 5 | 5.10 | 2.20 | 21 | 5.20 | 3.09 | 586 | 23 | -0.201 | DNS |
| | GT5 | 5.20 | 2.86 | 210 | 5.20 | 3.09 | 586 | 396 | 0.000 | DNS |
| DEDU | SEC. UNIV | 5.20 | 1.79 | 524 | 5.30 | 3.49 | 293 | 380 | -0.458 | DNS |
| DFAM | LE10 | 5.30 | 3.10 | 312 | 5.30 | 3.10 | 201 | 427 | 0.000 | DNS |
| | GT10. LE20 | 5.30 | 3.10 | 312 | 5.10 | 2.78 | 304 | 610 | 0.843 | DNS |
| | GT20 | 5.30 | 3.10 | 201 | 5.10 | 2.78 | 304 | 395 | 0.739 | DNS |
| ACTN | SD. DIST | 5.10 | 3.27 | 498 | 5.40 | 2.56 | 319 | 783 | -1.464 | DNS |
| ACDT | 0 | 5.30 | 3.00 | 626 | 5.10 | 3.39 | 137 | 185 | 0.638 | DNS |
| | 1 | 5.30 | 3.00 | 626 | 5.10 | 1.45 | 54 | 98 | 0.866 | DNS |
| | GT1 | 5.10 | 3.39 | 137 | 5.10 | 1.45 | 54 | 188 | 0.000 | DNS |
| VLTN | 0 | 5.40 | 2.85 | 519 | 5.10 | 3.64 | 205 | 308 | 1.059 | DNS |
| | 1 | 5.40 | 2.85 | 519 | 4.90 | 1.32 | 93 | 276 | 2.696 | DS |
| | GT1 | 5.10 | 3.64 | 205 | 4.90 | 1.32 | 93 | 286 | 0.693 | DS |
| DAGE | LT30 | 5.00 | 2.62 | 212 | 5.20 | 3.20 | 473 | 490 | -0.860 | DNS |
| | 30 TO 45 | 5.00 | 2.62 | 212 | 5.40 | 2.59 | 132 | 280 | -1.387 | DNS |
| | GT45 | 5.20 | 3.20 | 473 | 5.40 | 2.59 | 132 | 254 | -0.743 | DNS |
| NTLY | NAR. ARAB | 5.20 | 3.07 | 662 | 5.30 | 2.62 | 155 | 263 | -0.413 | DNS |
| TMGP | LAG. GAP | 4.90 | 2.73 | 595 | 5.80 | 3.19 | 222 | 349 | -3.725 | DS |
| NREJ | 0 | 5.80 | 5.09 | 223 | 5.70 | 1.51 | 357 | 247 | 0.286 | DNS |
| | 1 | 5.80 | 5.09 | 223 | 4.70 | 0.86 | 237 | 234 | 3.185 | DS |
| | GT1 | 5.70 | 1.51 | 357 | 4.70 | 0.86 | 237 | 580 | 10.256 | DS |
| AREJ | 0. GT0 | 5.10 | 4.21 | 29 | 5.20 | 1.51 | 788 | 28 | -0.128 | DNS |
| MJTP | 7.55 | 5.20 | 3.04 | 788 | 5.70 | 1.66 | 29 | 35 | -1.530 | DNS |
| MNTP | PC. LV | 5.20 | 3.04 | 709 | 5.50 | 2.68 | 108 | 152 | -1.064 | DNS |
| MJSD | LE30 | 4.70 | 1.82 | 157 | 4.60 | 1.57 | 318 | 274 | 0.589 | DNS |
| | GT30. LE45 | 4.70 | 1.82 | 157 | 6.20 | 3.41 | 342 | 486 | -6.390 | DS |
| | GT45 | 4.60 | 1.57 | 318 | 6.20 | 3.41 | 342 | 487 | -7.830 | DS |
| MNSD | 0 | 5.10 | 2.62 | 698 | 6.40 | 4.01 | 39 | 40 | -2.001 | DNS |
| | GT0. LE20 | 5.10 | 2.62 | 698 | 6.00 | 2.89 | 80 | 94 | -2.663 | DS |
| | GT20 | 6.40 | 4.01 | 39 | 6.00 | 2.89 | 80 | 58 | 0.556 | DNS |
| MJVL | LE 2 | 5.90 | 3.00 | 76 | 5.70 | 3.62 | 164 | 174 | 0.449 | DNS |
| | GE3. LE4 | 5.90 | 4.96 | 76 | 5.00 | 1.35 | 577 | 76 | 1.574 | DNS |
| | GT4 | 5.70 | 3.62 | 164 | 5.00 | 1.35 | 577 | 176 | 2.429 | DS |
| MNVL | LE1 | 5.10 | 2.96 | 368 | 5.30 | 3.08 | 316 | 658 | -0.862 | DNS |
| | 2 | 5.10 | 2.96 | 368 | 5.10 | 2.89 | 133 | 239 | 0.000 | DNS |
| | GT2 | 5.30 | 3.08 | 316 | 5.10 | 2.89 | 133 | 263 | 0.656 | DNS |
| QSIZ | 0. GT0 | 5.40 | 3.33 | 476 | 5.10 | 2.20 | 341 | 810 | 1.549 | DNS |
| TLDL | 0 | 6.10 | 3.54 | 128 | 5.90 | 2.55 | 201 | 210 | 0.554 | DNS |
| | GT0. LE10 | 6.10 | 3.54 | 128 | 4.90 | 2.46 | 488 | 161 | 3.613 | DS |
| | e | 5.90 | 2.55 | 201 | 4.90 | 2.46 | 488 | 361 | 4.727 | DS |

LT = Less than, LE = Less than or equal, GT = Greater than, GE = Greater than or equal

PC = Passenger Car, LV = Large Vehicle, NAR = Nonarabs: DNS = Difference is not significant; DS = Difference is significant.

* Note: t-Tests for different levels of a given variable are arranged as following;

Level 1 with level 2, level 1 with level 3, and level 2 with level 3, respectively.

** Null Hypothesis for this test is as follows: Critical Gap for Level i is Equal to Critical Gap for Level j

### 5.5.4 Summary of the Average and Critical Gap Analysis

This Section presents the basic findings of the analysis conducted for the average and critical gaps/lags for the three Maneuvers considered in the study.

#### *5.5.4.1 Basic Statistics for Average and Critical Gaps/Lags*

Table 5.20 gives a summary of the basic statistics related to the average and critical gaps/lags computed for different Maneuvers. The obtained values of the critical gaps are comparable to the values found in previous studies as discussed earlier. Table 5.20 shows that the 50% of the drivers have accepted gaps of 8.1, 7.4, and 6.7 seconds or less in Maneuvers 1, 2, and 3, respectively while 85% of the drivers have accepted 16.70, 12.5, and 9.9 seconds, respectively.

#### *5.5.4.2 Basic Findings of the Analysis*

The basic findings of the conducted analysis for average and critical gaps for the three maneuvers include:

a. Average and critical gaps computed at different levels of attributes are almost always significantly different from each other for a particular set of variables. These variables include the speed at major road (MJSD), the total delay imposed on the driver (TLDL), traffic volume at minor road (MNVL), and driver accident

record (ACDT). Such variables are expected to be significant in the gap acceptance models to be calibrated in Chapter 6;

b. Critical, average accepted, and average rejected lags are significantly higher than the critical, average accepted, and average rejected gaps. These results indicate that the driver react differently to gaps and lags with the tendency of rejecting lags being higher. Table 5.21 summarizes the computed averages for the rejected and accepted lags and gaps for the three Maneuvers. The table shows that the average accepted and rejected lags are visibly higher than the average accepted and rejected gaps. However, this issue will be further investigated through developing segmented gap acceptance models for lags and gaps;

c. Drivers with less ability to estimate the speed and the distance of the oncoming vehicles accept significantly longer gaps;

d. In general, driver gap acceptance behavior could be better represented by critical gaps compared to average accepted gaps. However, critical gap is sensitive to the number of the rejected gaps and there could be a need to develop supplementary measures to describe and characterize driver gap acceptance behavior;

e. It is believed that the $50^{th}$ percentile accepted gap could provide an adequate measure that can be used along with the critical gap measure to describe driver gap acceptance behavior. This value is a function of the size of the accepted gaps

Table 5.20: Basic Average and Critical Gap Statistics for the Three Studied Maneuvers

| Statistic | Maneuver 1 | Maneuver 2 | Maneuver 3 |
|---|---|---|---|
| Total number of the observed Gaps/Lags | 448 | 528 | 817 |
| Number of accepted Gaps/Lags | 275 | 366 | 223 |
| Critical Gap/Lag in seconds | 5.5 | 4.6 | 5.2 |
| Average accepted Gap/Lag (Seconds) | 10.1 | 8.8 | 7.6 |
| 50$^{th}$ percentile accepted Gap/Lag | 8.1 | 7.4 | 6.7 |
| 85$^{th}$ percentile accepted Gap/Lag | 16.7 | 12.5 | 9.9 |

Table 5.21: Summary of the Numbers and Average Sizes of the Accepted and Rejected Gaps and Lags for the Three Studied Maneuvers

| Statistic | Maneuver 1 | Maneuver 2 | Maneuver 3 |
|---|---|---|---|
| Total number of the observed Gaps/Lags | 448 | 528 | 817 |
| Number and average of the rejected Gaps | 70 (3.56) | 60 (2.70) | 447 (3.14) |
| Number and average of the accepted Gaps | 103 (7.11) | 101 (5.9) | 148 (7.01) |
| Number and Average of the rejected Lags | 103 (4.79) | 102 (4.24) | 147 (4.47) |
| Number and average of the accepted Lags | 172 (11.91) | 265 (9.1) | 75 (8.69) |

and the frequency of each of these gaps and hence, is not directly affected by special cases in which the average number of rejected gaps by a driver are high or low. The effect of the number of rejected gaps is, however, reflected in shortening the length of the accepted gaps themselves due to the effect of delay which is directly proportional to the number of rejected gaps. In this context, the $50^{th}$ percentile accepted gap could be less sensitive to the number of rejected gaps itself. A base for the above argument exists from the conducted analysis in this study. Taking Maneuver 3 as an example, it was found that out of the 223 accepted gaps only 47 gaps (21.1%) are less than or equal to 5.2 seconds (which is the value of the critical gap). Ninety two (92) gaps (41.3%) are less than or equal to 6 seconds and 117 gaps (50%) are less than or equal to 6.7 seconds (which is the value of the $50^{th}$ percentile accepted gap). This indicates that the $50^{th}$ percentile accepted gap could provide an adequate measure that represents the observed data adequately and, hence, provides better representation of the actual driver gap acceptance behavior. Similar results were obtained when the above analysis was carried out for Maneuvers 1 and 2. However, this observation is recommended to be a subject of further study.

The $50^{th}$ percentile accepted gaps/lags found at different levels of the studied attributes are given in Tables 5.22, 5.24 and 5.26 for Maneuvers 1,2, and 3, respectively. The $85^{th}$ percentile accepted gaps/lags found at different levels of the studied attributes for the three maneuvers are given in Tables 5.23, 5.25 and 5.27. Indications and observations derived from these tables are, in general,

Table 5.22: The 50th Percentile Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 1.

| Variable Name and Level | | 50th Percentile Accepted Gap/Lag | 50th Percentile Rejected Gap/Lag | Variable Name and Levels | | 50th Percentile Accepted Gap/Lag | 50th Percentile Rejected Gap/Lag |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 8.3 | 4.5 | TMGP | Gap | 10.6 | 4.3 |
| | GT 3 | 7.8 | 3.9 | | Lag | 6.6 | 3.5 |
| VAGE | LT 5 yr. | 8.3 | 4.3 | NREJ | 0 | 10.3 | 4.7 |
| | 5 to 10 yr. | 7.4 | 4.0 | | 1 | 7.3 | 3.5 |
| | GT 10 yr. | 8.7 | 5.3 | | GT 1 | 6.1 | 3.6 |
| EGCA | LE 4 Cls. | 8.1 | 4.3 | AREJ | 0 | 9.3 | 4.7 |
| | GT 4 Cls. | 7.9 | 4.2 | | GT 0 | 7.9 | 4.3 |
| TRAN | Manual | 8.3 | 4.3 | MJTP | PC | 7.7 | 4.3 |
| | Automatic | 7.9 | 3.9 | | HV | 17.0 | 4.3 |
| TRPS | Work | 7.9 | 4.2 | MNTP | PC | 7.9 | 4.3 |
| | Non Work | 8.4 | 4.3 | | HV | 9.0 | 5.7 |
| TRDN | LE 20 Mn. | 8.3 | 4.3 | MJSD | LE30 | 7.2 | 2.6 |
| | GT 20, LT40 | 7.4 | 4.7 | | GT30, LE45 | 7.9 | 3.5 |
| | GE 40 | 6.4 | 4.6 | | GT 45 | 15.5 | 4.7 |
| DSEX | Male | 7.9 | 4.3 | MNSD | 0 | 6.5 | 3.7 |
| | Female | 9.1 | 4.1 | | GT 0, LE20 | 9.1 | 4.9 |
| DEXP | LT 2 yr. | 5.3 | 4.0 | | GT 20 | 12.4 | 4.3 |
| | 2 to 5 yr. | 7.3 | 4.2 | MJVL | LE 2 | 9.7 | 4.7 |
| | GT 5 yr. | 8.9 | 4.5 | | GE 3, LE 4 | 7.5 | 4.6 |
| DEDU | Secondary | 7.9 | 4.3 | | GT 4 | 6.2 | 3.8 |
| | University | 8.5 | 4.3 | MNVL | 1 | 13.2 | 3.9 |
| DFAM | LE 10 | 9.2 | 4.3 | | 2 | 8.6 | 4.3 |
| | GT10, LE20 | 7.8 | 3.9 | | GT 2 | 7.4 | 4.7 |
| | GT 20 | 7.5 | 4.4 | QSIZ | 0 | 9.0 | 4.3 |
| ACTN | Speed | 8.3 | 4.3 | | GT 0 | 6.2 | 4.3 |
| | Distant | 7.5 | 4.3 | TLDL | 0 | 11.5 | 4.9 |
| ACDT | 0 | 8.7 | 4.4 | | GT 0, LE10 | 7.3 | 4.0 |
| | 1 | 6.7 | 3.8 | | GT 10 | 6.5 | 3.7 |
| | GT 1 | 5.2 | 3.7 | DEAD (mt.) | LE 0 | - | - |
| VLTN | LE 1 | 8.7 | 4.3 | | GT 0 | 8.4 | 4.3 |
| | GT 1 | 5.6 | 4.4 | DEAS Kph | LE 0 | - | - |
| DAGE | LT 30 yr. | 7.5 | 4.0 | | GT 0 | 10.6 | 4.3 |
| | 30 TO 45 yr. | 8.7 | 4.5 | DEAG (Sec.) | LT 5 | 4.2 | |
| | GT 45 yr. | 7.3 | 4.3 | | 5 to 10 | 7.3 | |
| NLTY | Non Arabs | 9.4 | 3.7 | | GT 10 | 25.6 | |
| | Arabs | 7.9 | 4.3 | DAMR | LE 0 | 4.9 | 3.8 |
| | | | | | GT 0 | 8.4 | 4.4 |
| 50th Percentile Accepted Gap/Lag for Maneuver 1 = 8.1 seconds | | | | | | | |
| 50th Percentile Rejected Gap/Lag for Maneuver 1 = 4.3 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:
LT = Less Than; LE = Less Than or Equal to; GT = Greater Than; GE = Greater Than or Equal to; PC = Passenger Car; HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

Table 5.23: The 85th Percentile Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 1.

| Variable Name and Level | | 85th Percentile Accepted Gap/Lag | 85th Percentile Rejected Gap/Lag | Variable Name and Levels | | 85th Percentile Accepted Gap/Lag | 85th Percentile Rejected Gap/Lag |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 16.3 | 2.7 | TMGP | Gap | 18.6 | 3.4 |
| | GT 3 | 18.7 | 2.7 | | Lag | 9.4 | 2.5 |
| VAGE | LT 5 yr. | 16.0 | 2.7 | NREJ | 0 | 18.5 | 3.4 |
| | 5 to 10 yr. | 16.2 | 2.7 | | 1 | 10.3 | 2.5 |
| | GT 10 yr. | 17.5 | 3.8 | | GT 1 | 7.9 | 2.3 |
| EGCA | LE 4 Cls. | 16.7 | 2.7 | AREJ | 0 | 15.2 | 2.7 |
| | GT 4 Cls. | 17.3 | 2.7 | | GT 0 | 16.9 | 2.7 |
| TRAN | Manual | 15.3 | 3.4 | MJTP | PC | 14.9 | 2.6 |
| | Automatic | 16.7 | 2.6 | | HV | 21.3 | 4.9 |
| TRPS | Work | 16.5 | 2.7 | MNTP | PC | 16.7 | 2.7 |
| | Non Work | 18.6 | 2.6 | | HV | 16.3 | 3.6 |
| TRDN | LE 20 Mn. | 16.4 | 2.6 | MJSD | LE30 | 12.3 | 1.65 |
| | GT 20, LT40 | 17.8 | 3.5 | | GT30, LE45 | 15.1 | 2.6 |
| | GE 40 | 13.3 | 3.4 | | GT 45 | 21.3 | 3.8 |
| DSEX | Male | 16.4 | 2.7 | MNSD | 0 | 9.8 | 2.6 |
| | Female | 24.3 | 2.8 | | GT 0, LE20 | 18.6 | 4.5 |
| DEXP | LT 2 yr. | 7.4 | 3.3 | | GT 20 | 19.5 | 3.4 |
| | 2 to 5 yr. | 10.6 | 2.6 | MJVL | LE 2 | 19.5 | 3.3 |
| | GT 5 yr. | 17.6 | 2.9 | | GE 3, LE 4 | 13.3 | 2.8 |
| DEDU | Secondary | 15.4 | 2.6 | | GT 4 | 8.8 | 2.6 |
| | University | 17.0 | 2.7 | MNVL | 1 | 26.2 | 2.6 |
| DFAM | LE 10 | 18.3 | 2.8 | | 2 | 15.3 | 2.7 |
| | GT10, LE20 | 14.6 | 2.6 | | | 13.4 | 3.0 |
| | GT 20 | 13.7 | 3.1 | QSIZ | 0 | 17.5 | 2.7 |
| ACTN | Speed | 15.7 | 2.9 | | GT 0 | 7.9 | 2.6 |
| | Distant | 18.3 | 2.6 | TLDL | 0 | 19.5 | 3.7 |
| ACDT | 0 | 17.7 | 2.8 | | GT 0, LE10 | 10.7 | 2.5 |
| | 1 | 11.3 | 2.6 | | GT 10 | 8.3 | 2.7 |
| | GT 1 | 10.2 | 2.6 | DEAD (mt.) | LE 0 | - | - |
| VLTN | LE 1 | 17.0 | 2.8 | | GT 0 | 17.0 | 2.7 |
| | GT 1 | 8.2 | 2.7 | DEAS Kph | LE 0 | - | - |
| DAGE | LT 30 yr. | 12.3 | 2.7 | | GT 0 | 19.6 | 2.7 |
| | 30 TO 45 yr. | 17.7 | 2.7 | DEAG (Sec.) | LT 5 | | |
| | GT 45 yr. | 14.1 | 2.6 | | 5 to 10 | | |
| NLTY | Non Arabs | 18.7 | 2.5 | | GT 10 | | |
| | Arabs | 15.5 | 2.7 | DAMR | LE 0 | 6.1 | 2.7 |
| | | | | | GT 0 | 16.9 | 2.7 |
| 85th Percentile Accepted Gap/Lag for Maneuver 1 = 16.7 seconds | | | | | | | |
| 85th Percentile Rejected Gap/Lag for Maneuver 1 = 2.7 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than; LE = Less Than or Equal to; GT = Greater Than; GE = Greater Than or Equal to; PC = Passenger Car; HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

Table 5.24: The 50th Percentile Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 2.

| Variable Name and Level | | 50th Percentile Accepted Gap/Lag | 50th Percentile Rejected Gap/Lag | Variable Name and Levels | | 50th Percentile Accepted Gap/Lag | 50th Percentile Rejected Gap/Lag |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 7.4 | 3.7 | TMGP | Gap | 5.8 | 2.7 |
| | GT 3 | 7.9 | 3.3 | | Lag | 8.4 | 4.2 |
| VAGE | LT 5 yr. | 7.8 | 3.5 | NREJ | 0 | 7.8 | 4.2 |
| | 5 to 10 yr. | 7.1 | 3.9 | | 1 | 7.1 | 2.6 |
| | GT 10 yr. | 7.4 | 4.2 | | GT 1 | 7.4 | 2.8 |
| EGCA | LE 4 Cls. | 7.3 | 3.6 | AREJ | 0 | 5.9 | 4.0 |
| | GT 4 Cls. | 8.3 | 4.2 | | GT 0 | 8.3 | 3.6 |
| TRAN | Manual | 7.7 | 4.1 | MJTP | PC | 7.4 | 3.6 |
| | Automatic | 6.9 | 2.4 | | HV | 7.2 | 4.2 |
| TRPS | Work | 7.3 | 3.5 | MNTP | PC | 7.4 | 3.5 |
| | Non Work | 8.4 | 4.2 | | HV | 7.5 | 4.4 |
| TRDN | LE 20 Mn. | 7.8 | 3.4 | MJSD | LE30 | 5.2 | 2.1 |
| | GT 20, LT40 | 7.4 | 4.2 | | GT30, LE45 | 7.7 | 2.8 |
| | GE 40 | 6.4 | 4.2 | | GT 45 | 15.1 | 4.3 |
| DSEX | Male | 7.3 | 3.6 | MNSD | 0 | 5.8 | 3.0 |
| | Female | 8.7 | 4.6 | | GT 0, LE20 | 17.8 | 4.4 |
| DEXP | LT 2 yr. | 9.1 | 4.7 | | GT 20 | 8.8 | 4.3 |
| | 2 to 5 yr. | 7.2 | 3.4 | MJVL | LE 2 | 8.3 | 4.3 |
| | GT 5 yr. | 7.4 | 3.9 | | GE 3, LE 4 | 6.6 | 3.9 |
| DEDU | Secondary | 7.3 | 3.5 | | GT 4 | 5.2 | 3.3 |
| | University | 8.0 | 4.0 | MNVL | 1 | - | - |
| DFAM | LE 10 | 8.3 | 3.6 | | 2 | 9.8 | 3.5 |
| | GT10, LE20 | 8.0 | 4.4 | | | 7.3 | 3.6 |
| | GT 20 | 6.8 | 3.4 | QSIZ | 0 | 8.6 | 3.8 |
| ACTN | Speed | 7.3 | 3.5 | | GT 0 | 5.8 | 3.3 |
| | Distant | 7.9 | 3.8 | TLDL | 0 | 9.7 | 4.4 |
| ACDT | 0 | 7.7 | 3.5 | | GT 0, LE10 | 6.7 | 3.4 |
| | 1 | 7.1 | 3.8 | | GT 10 | 5.8 | 3.2 |
| | GT 1 | 5.8 | 4.2 | DEAD (mt.) | LE 0 | - | - |
| VLTN | 0 | 7.9 | 3.6 | | GT 0 | 7.9 | 3.6 |
| | 1 | 7.3 | 3.8 | DEAS Kph | LE 0 | - | - |
| | GT 1 | 6.7 | 3.9 | | GT 0 | 10.5 | 3.6 |
| DAGE | LT 30 yr. | 7.4 | 3.4 | DEAG (Sec.) | LT 5 | | |
| | 30 TO 45 yr. | 7.9 | 3.7 | | 5 to 10 | | |
| | GT 45 yr. | 7.2 | 4.1 | | GT 10 | | |
| NLTY | Non Arabs | 7.7 | 3.5 | DAMR | LE 0 | 3.6 | 3.3 |
| | Arabs | 7.4 | 3.6 | | GT 0 | 7.7 | 3.8 |
| 50th Percentile Accepted Gap/Lag for Maneuver 2 = 7.4 seconds | | | | | | | |
| 50th Percentile Rejected Gap/Lag for Maneuver 2 = 3.6 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than: LE = Less Than or Equal to: GT = Greater Than: GE = Greater Than or Equal to:
PC = Passenger Car: HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

Table 5.25: The 85th Percentile Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 2.

| Variable Name and Level | | 85th Percentile Accepted Gap/Lag | 85th Percentile Rejected Gap/Lag | Variable Name and Levels | | 85th Percentile Accepted Gap/Lag | 85th Percentile Rejected Gap/Lag |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 11.9 | 2.7 | TMGP | Gap | 7.3 | 1.8 |
| | GT 3 | 16.7 | 2.0 | | Lag | 14.0 | 3.3 |
| VAGE | LT 5 yr. | 13.0 | 2.5 | NREJ | 0 | 14.0 | 3.3 |
| | 5 to 10 yr. | 11.6 | 2.7 | | 1 | 7.4 | 1.8 |
| | GT 10 yr. | 10.6 | 2.6 | | GT 1 | 5.4 | 2.0 |
| EGCA | LE 4 Cls. | 11.7 | 2.5 | AREJ | 0 | 7.3 | 2.7 |
| | GT 4 Cls. | 15.3 | 3.1 | | GT 0 | 13.6 | 2.5 |
| TRAN | Manual | 11.7 | 2.5 | MJTP | PC | 12.5 | 2.5 |
| | Automatic | 14.6 | 3.3 | | HV | 14.6 | 1.9 |
| TRPS | Work | 12.0 | 2.5 | MNTP | PC | 12.5 | 2.5 |
| | Non Work | 13.9 | 2.5 | | HV | 12.6 | 2.9 |
| TRDN | LE 20 Mn. | 12.9 | 2.4 | MJSD | LE30 | 6.1 | 1.5 |
| | GT 20, LT40 | 12.1 | 3.1 | | GT30, LE45 | 9.7 | 2.0 |
| | GE 40 | 8.0 | 2.5 | | GT 45 | 23.4 | 3.4 |
| DSEX | Male | 11.9 | 2.5 | MNSD | 0 | 7.3 | 2.0 |
| | Female | 14.6 | 2.7 | | GT 0, LE20 | 23.4 | 3.5 |
| DEXP | LT 2 yr. | 17.2 | 3.9 | | GT 20 | 13.5 | 3.3 |
| | 2 to 5 yr. | 12.7 | 2.0 | MJVL | LE 2 | 13.3 | 3.0 |
| | GT 5 yr. | 12.3 | 2.6 | | GE 3, LE 4 | 8.0 | 2.9 |
| DEDU | Secondary | 11.4 | 2.5 | | GT 4 | 6.6 | 2.4 |
| | University | 14.7 | 3.2 | MNVL | LE 2 | 15.8 | 2.1 |
| DFAM | LE 10 | 13.9 | 2.3 | | GT 2 | 11.3 | 2.6 |
| | GT10, LE20 | 15.2 | 2.6 | QSIZ | 0 | 15.3 | 2.7 |
| | GT 20 | 9.3 | 2.5 | | GT 0 | 7.4 | 2.2 |
| ACTN | Speed | 11.5 | 2.5 | TLDL | 0 | 17.3 | 3.5 |
| | Distant | 13.8 | 2.5 | | GT 0, LE10 | 7.6 | 2.5 |
| ACDT | 0 | 13.4 | 2.5 | | GT 10 | 7.7 | 2.2 |
| | 1 | 8.7 | 2.6 | DEAD (mt.) | LE 0 | - | - |
| | GT 1 | 7.3 | 1.7 | | GT 0 | 13.1 | 2.5 |
| VLTN | 0 | 13.9 | 2.5 | DEAS Kph | LE 0 | - | - |
| | 1 | 8.7 | 2.7 | | GT 0 | 18.4 | 2.5 |
| | GT 1 | 8.8 | 2.6 | DEAG (Sec.) | LT 5 | | |
| DAGE | LT 30 yr. | 11.7 | 2.0 | | 5 to 10 | | |
| | 30 TO 45 yr. | 13.2 | 2.8 | | GT 10 | | |
| | GT 45 yr. | 9.6 | 2.5 | DAMR | LE 0 | 3.9 | 2.0 |
| NLTY | Non Arabs | 13.9 | 2.5 | | GT 0 | 12.6 | 2.6 |
| | Arabs | 12.1 | 2.5 | | | | |
| 85th Percentile Accepted Gap/Lag for Maneuver 2 = 12.5 seconds | | | | | | | |
| 85th Percentile Rejected Gap/Lag for Maneuver 2 = 2.5 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than; LE = Less Than or Equal to; GT = Greater Than; GE = Greater Than or Equal to; PC = Passenger Car; HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

Table 5.26 : 50th Percentile Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 3

| Variable Name and Level | | 50th Percentile Accepted Gap/Lag | 50th Percentile Rejected Gap/Lag | Variable Name and Levels | | 50th Percentile Accepted Gap/Lag | 50th Percentile Rejected Gap/Lag |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 6.7 | 3.3 | TMGP | Gap | 6.2 | 3.0 |
| | GT 3 | 6.5 | 3.7 | | Lag | 8.5 | 5.1 |
| VAGE | LT 5 yr. | 6.9 | 3.1 | NREJ | 0 | 8.5 | 5.1 |
| | 5 to 10 yr. | 6.7 | 3.8 | | 1 | 8.1 | 2.9 |
| | GT 10 yr. | 6.7 | 3.1 | | GT 1 | 5.3 | 3.0 |
| EGCA | LE 4 Cls. | 6.7 | 3.4 | AREJ | 0 | 6.2 | 3.6 |
| | GT 4 Cls. | 7.2 | 3.5 | | GT 0 | 6.7 | 3.4 |
| TRAN | Manual | 6.9 | 3.5 | MJTP | PC | 6.7 | 3.3 |
| | Automatic | 6.5 | 3.0 | | HV | 8.5 | 4.9 |
| TRPS | Work | 6.5 | 3.5 | MNTP | PC | 6.7 | 3.4 |
| | Non Work | 7.2 | 3.2 | | HV | 6.7 | 3.4 |
| TRDN | LE 20 Mn. | 6.8 | 3.6 | MJSD | LE30 | 5.4 | 1.5 |
| | GT 20, LT40 | 6.5 | 2.9 | | GT30, LE45 | 5.7 | 2.8 |
| | GE 40 | 6.5 | 3.0 | | GT 45 | 5.1 | 8.9 |
| DSEX | Male | 6.5 | 3.4 | MNSD | 0 | 6.3 | 3.1 |
| | Female | 8.1 | 3.4 | | GT 0, LE20 | 10.9 | 5.5 |
| DEXP | LT 2 yr. | 6.7 | 3.0 | | GT 20 | 9.4 | 4.7 |
| | 2 to 5 yr. | 6.9 | 3.2 | MJVL | LE 2 | 8.5 | 4.9 |
| | GT 5 yr. | 6.5 | 3.5 | | GE 3, LE 4 | 7.5 | 3.9 |
| DEDU | Secondary | 6.5 | 3.4 | | GT 4 | 5.8 | 3.1 |
| | University | 6.8 | 3.4 | MNVL | 1 | 5.8 | 3.5 |
| DFAM | LE 10 | 7.3 | 3.3 | | 2 | 7.3 | 3.6 |
| | GT10, LE20 | 7.3 | 3.8 | | GT 2 | 6.7 | 2.5 |
| | GT 20 | 6.4 | 3.1 | QSIZ | 0 | 7.7 | 3.5 |
| ACTN | Speed | 6.7 | 3.2 | | GT 0 | 6.0 | 3.3 |
| | Distant | 6.8 | 3.7 | TLDL | 0 | 9.9 | 5.3 |
| ACDT | 0 | 6.9 | 3.6 | | GT 0, LE10 | 8.1 | 3.6 |
| | 1 | 6.5 | 3.0 | | GT 10 | 5.8 | 3.0 |
| | GT 1 | 5.4 | 2.5 | DEAD (mt.) | LE 0 | - | - |
| VLTN | 0 | 7.3 | 3.5 | | GT 0 | 7.3 | 3.4 |
| | 1 | 6.2 | 3.5 | DEAS Kph | LE 0 | - | - |
| | GT 1 | 5.3 | 2.6 | | GT 0 | 7.7 | 3.4 |
| DAGE | LT 30 yr. | 6.5 | 3.4 | DEAG (Sec.) | LT 5 | | |
| | 30 TO 45 yr. | 6.6 | 3.2 | | 5 to 10 | | |
| | GT 45 yr. | 7.5 | 3.7 | | GT 10 | | |
| NLTY | Non Arabs | 7.6 | 2.5 | DAMR | LE 0 | - | - |
| | Arabs | 6.5 | 3.4 | | GT 0 | 7.9 | 3.6 |
| 50th Percentile Accepted Gap/Lag for Maneuver 3 =6.7 seconds | | | | | | | |
| 50th Percentile Rejected Gap/Lag for Maneuver 3 = 3.4 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:
LT = Less Than; LE = Less Than or Equal to; GT = Greater Than; GE = Greater Than or Equal to; PC = Passenger Car; HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

Table 5.27 : The 85th Percentile Accepted and Rejected Gaps at Different Levels of the Studied Variables for Maneuver 3.

| Variable Name and Level | | 85th Percentile Accepted Gap/Lag | 85th Percentile Rejected Gap/Lag | Variable Name and Levels | | 85th Percentile Accepted Gap/Lag | 85th Percentile Rejected Gap/Lag |
|---|---|---|---|---|---|---|---|
| OCUP | LE 2 | 9.9 | 1.4 | TMGP | Gap | 9.2 | 1.3 |
| | GT 3 | 9.1 | 1.9 | | Lag | 11.8 | 2.1 |
| VAGE | LT 5 yr. | 9.8 | 1.4 | NREJ | 0 | 11.7 | 2.1 |
| | 5 to 10 yr. | 9.8 | 1.8 | | 1 | 9.9 | 1.4 |
| | GT 10 yr. | 9.7 | 1.2 | | GT 1 | 6.0 | 1.2 |
| EGCA | LE 4 Cls. | 9.8 | 1.4 | AREJ | 0 | 11.2 | 1.7 |
| | GT 4 Cls. | 10.1 | 1.5 | | GT 0 | 9.8 | 1.4 |
| TRAN | Manual | 9.8 | 1.5 | MJTP | PC | 9.9 | 1.4 |
| | Automatic | 9.9 | 1.2 | | HV | 9.7 | 4.3 |
| TRPS | Work | 9.8 | 1.4 | MNTP | PC | 9.9 | 1.5 |
| | Non Work | 9.9 | 1.5 | | HV | 9.3 | 1.0 |
| TRDN | LE 20 Mn. | 9.9 | 1.5 | MJSD | LE30 | 6.5 | 0.7 |
| | GT 20, LT40 | 11.3 | 1.3 | | GT30, LE45 | 7.7 | 1.7 |
| | GE 40 | 9.1 | 1.5 | | GT 45 | 12.3 | 3.8 |
| DSEX | Male | 9.9 | 1.4 | MNSD | 0 | 9.2 | 1.4 |
| | Female | 9.1 | 1.5 | | GT 0, LE20 | 13.1 | 4.7 |
| DEXP | LT 2 yr. | 8.7 | 1.5 | | GT 20 | 12.0 | 1.6 |
| | 2 to 5 yr. | 9.8 | 1.5 | MJVL | LE 2 | 12.4 | 2.3 |
| | GT 5 yr. | 9.9 | 1.4 | | GE 3, LE 4 | 10.0 | 1.8 |
| DEDU | Secondary | 9.8 | 1.5 | | GT 4 | 9.2 | 1.4 |
| | University | 10.0 | 1.4 | MNVL | 1 | 9.7 | 1.5 |
| DFAM | LE 10 | 9.9 | 1.5 | | 2 | 9.9 | 1.4 |
| | GT10, LE20 | 11.1 | 1.9 | | GT 2 | 9.9 | 1.2 |
| | GT 20 | 9.5 | 1.3 | QSIZ | 0 | 11.5 | 1.5 |
| ACTN | Speed | 9.8 | 1.4 | | GT 0 | 8.6 | 1.4 |
| | Distant | 9.8 | 1.5 | TLDL | 0 | 13.0 | 1.9 |
| ACDT | 0 | 9.9 | 1.5 | | GT 0, LE10 | 9.9 | 1.5 |
| | 1 | 9.4 | 1.4 | | GT 10 | 8.5 | 1.4 |
| | GT 1 | 7.4 | 1.2 | DEAD (mt.) | LE 0 | - | - |
| VLTN | 0 | 10.0 | 1.5 | | GT 0 | 9.9 | 1.4 |
| | 1 | 9.8 | 1.4 | DEAS Kph | LE 0 | - | - |
| | GT 1 | 7.3 | 1.3 | | GT 0 | 10.0 | 1.4 |
| DAGE | LT 30 yr. | 9.8 | 1.8 | DEAG (Sec.) | LT 5 | | |
| | 30 TO 45 yr. | 9.8 | 1.3 | | 5 to 10 | | |
| | GT 45 yr. | 10.0 | 1.5 | | GT 10 | | |
| NLTY | Non Arabs | 9.8 | 1.7 | DAMR | LE 0 | - | - |
| | Arabs | 9.8 | 1.4 | | GT 0 | 10.1 | 1.5 |
| 85th Percentile Accepted Gap/Lag for Maneuver 2 = 9.9 seconds | | | | | | | |
| 85th Percentile Rejected Gap/Lag for Maneuver 2 = 1.4 seconds | | | | | | | |

Abbreviations listed in the above table stands for the following:

LT = Less Than; LE = Less Than or Equal to; GT = Greater Than; GE = Greater Than or Equal to; PC = Passenge Crar; HV = Heavy Vehicle; Cls. = Cylinders; NA = Not Applicable.

similar to the observations and indications that were derived from the analysis of the critical and average accepted gaps/lags;

f. The $50^{th}$ percentile accepted gaps/lags for Maneuvers 1, 2, and 3 are shorter than the corresponding average accepted gaps that are given in Tables 5.5, 5.10, and 5.15. This means that the $50^{th}$ percentile accepted gaps/lags are less sensitive to the long gaps/lags that occur during low traffic volume conditions at the major road. These long gaps are accepted by default and they constitute no real benefit in testing gap acceptance behavior. Hence, the less sensitivity of the $50^{th}$ percentile accepted gap to these gaps/lags is considered to be an advantage for this measure which is proposed to be used in parallel to the critical gap to describe and characterize driver gap acceptance behavior.

## 5.6 VARIABLE SHORT LISTING PROCEDURE

Studied variables were short-listed based on the analysis of correlation matrices which were studied to diagnose any possible collinearities among the independent variables. The model should not include highly correlated independent variables. Some of the studied variables are linear transformations of other variables. For example, the variables describing different gaps in meters (GMET, PMET, SMET, and AMET) are obtained by multiplying the relevant speed by the relevant time gap. For example gap size in meters is equal to the gap size in seconds multiplied by the speed of the oncoming vehicle at major road, i.e., GMET = (1/3.6) (GSEC) (MJSD). The time and distance gap variables (say GMET & GSEC) are developed to not be modeled simultaneously but to

check which of them can describe the driver gap acceptance behavior in a better way. In such cases the variable which has higher correlation with the independent variables (RESP) will be retained in the Model. For the above mentioned case, as an example, GSEC was found to be highly correlated to the dependent variable which indicates that the gap size in seconds (GSEC) can describe driver behavior better than the gap size in meters (GMET). The main purpose of analyzing the correlation matrix for the independent variables is to ensure that no highly correlated independent variables are included in the model.

The elimination criterion in this process is that if two of the independent variables are highly correlated only the one with higher correlation with the dependent variable will be retained. In this context, a correlation coefficient in the vicinity of 0.5 or above will be considered high to the degree that may create collinearity problems. The searching process for highly correlated independent variables will be comprehensive in terms that each independent variable is checked against all other independent variables. The result of this process is the identification of the group of the independent variables that are not highly correlated.

In addition to correlation matrices, the plotting capabilities of LIMDEP package were used to get the scatter diagrams for different variables drawn against each other and against the variable representing the size of the evaluated gaps/lags. These plots were used to help in diagnosing the direction and the strength of the relationships different variables. Samples of the mentioned scatter diagrams are given in Appendix B.

# CHAPTER 6

# MODEL CALIBRATION AND VALIDATION

## 6.1 INTRODUCTION

This chapter describes the modeling procedure followed in this study and presents the calibrated Driver Gap Acceptance Models along with the results of the statistical tests performed on these models. The developed models are of the Binomial Logit type that has been earlier discussed and formulated in Chapter 3. The significant variables for each model are identified based on the results of the correlation analyses and other preliminary modeling works.

## 6.2 MODELING PROCEDURE

As indicated previously, the main aim of this research is to investigate the effects of the newly introduced driver, vehicle, trip, and driver-inter-influence factors on driver gap acceptance behavior. In this context, it should be noted that having one or more of these factors significant at 5% level in the calibrated models might ***not*** provide sufficient evidence to claiming that these variables are significant in explaining driver gap acceptance behavior. The statistical comparison of gap acceptance models calibrated with and without these factors forms a more reliable method for checking the significance and importance of these factors. Since the reliability of the calibrated models increases as the used sample size increases, the data collected from the two studied sites was combined to calibrate models without and with the newly introduced factors. Models calibrated considering traffic, gap, and delay attributes only are referred to as the BASIC models while the models calibrated incorporating traffic, gap, and delay variables along with the newly introduced driver, vehicle and trip attributes are referred to as the FULL models. The BASIC and FULL models for each maneuver will be statistically tested to find out whether they are significantly different, i.e., to check whether the addition of the new variables has added significantly to the explanation power of the model. This is done using the relevant log likelihood ratio test and the t-tests that were applied to the individual pairs of the corresponding model coefficients.

The issue of combining the data collected at the two studied sites is basically based on the fact that the two sites are very similar geometrically. Hence, any potential variations in driver gap acceptance behavior at one site compared to the other would, most

likely, be attributed to the variations in driver characteristics at the two sites. Some of these variations could still, however, be related to certain site-specific effects.

In this study, only one type of sites (T-junctions at single carriageways) is considered since studying the effects of junction type and geometry is beyond the scope of this work as discussed in Chapter 1. However, to check the transferability of the calibrated models to similar junctions, the potential site specific effects were tested in a reverse back manner as detailed in the adopted modeling procedure. This approach was necessary to achieve the main goal of the study in an appropriate manner and to check the transferability of the calibrated models at the same time.

The modeling procedure for this research is summarized as follows:

a. Calibrate and validate a pooled model for each of the studied maneuvers using gap, traffic, and delay attributes. This model is referred to as the BASIC pooled Model;

b. Introduce Driver, Vehicle and Trip attributes to the model calibrated and validated in (a) and find out which of these attributes is significant in explaining Driver Gap Acceptance Behavior at the desired level of significance which is 5% in this case. The model developed in this step is referred to as the FULL pooled Model;

c. Validate the Full model calibrated in step (c) using the data portion reserved for this purpose which is 25% of the original data;

d. Test the assumption that driver action or response to Gaps is different from their response to Lags. To perform this test, segmented Models for Gaps and Lags were calibrated and tested against the pooled model calibrated for Gaps and Lags combined. In this context it should be mentioned that calibrating other segmented models for different levels of categorical and continuos variables is possible technically but is beyond the originally defined scope of this study. Variations in Driver Gap Acceptance Behavior at different levels of the studied variables are highlighted based on the results of the Average and Critical Gap analyses carried out in Chapter 5. Detailed analyses of these variations and calibration of segmented models for different levels of the studied variables and attributes is, however, a potential subject for future study;

e. Model special cases in which some of the variables and attributes apply only for subsets of the collected data samples. These variables include the following groups:

   i. Variables which apply to the accepted gaps only. These include the driver estimate of the speed and distance of the approaching vehicle which creates the gap he accepts and the difference between the actual and the estimated values of the accepted gap as measured by the variables DEAD, DEAS, and DEAG.

ii. Variables which apply to the cases which involved gap rejection decisions. These include the size of the preceding gap, (i.e. the gap which was available to the driver in precedence to the current gap) as measured by PSEC, PMET and the difference between the accepted and maximum rejected gap (DAMR).

iii. Variables which apply to the cases in which the effect on an ahead driver exists. These include the size of the gap accepted (ASEC, AMET) and the number of the gaps rejected (AREJ) by the ahead driver and the number of the ahead entries (AENT) in the accepted gap.

Separate models will be developed for Cases (ii) and (iii) since the available sample size for both of the cases is adequate. It should be noted that no separate model of the type formulated here can incorporate variables relevant to case (i). These variables apply only for cases in which the dependent variable (Driver Response) always takes the value 1 which means that there is no variation in the dependent variables for these observations.

Models calibrated for the above discussed subsets of the collected data are summarized and discussed in one section in this chapter.

f. Check the issue of model transferability by developing a separate model for each site with an identical specification to the FULL pooled model discussed in (b) and use the log likelihood ratio test and t-tests to check whether Site 1 model is significantly different from Site 2 model. Insignificantly different site models will,

indicate that the calibrated models are transferable to similar sites. However, it should be cautioned that the obtained models and results are applicable to traffic and socioeconomic conditions considered in this study and to similar conditions. Before generalizing these results, similar studies at similar junctions under different driving and socioeconomic conditions should be conducted. This could be a subject for further study.

## 6.3 MODEL CALIBRATION AND VALIDATION FOR LEFT TURNS FROM MAJOR STREAM (MANEUVER 1)

### 6.3.1 The BASIC Pooled Model for Maneuver 1

Using the pooled data and modeling traffic, gap, and delay attributes as first step, it was revealed that the size of gap in seconds (GSEC), the speed of the oncoming vehicle on major road in Kmph (MJSD), the total delay imposed on the driver (delay in queue plus delay at queue head), and traffic volume at minor road (MNVL) are significant at 5% or better levels. Summary of the BASIC pooled model calibrated for Maneuver 1 is given in Table 6.1. The detailed model is given in Appendix C. The relevant likelihood ratio validation test concluded that the observed and the predicted driver behaviors are ***not significantly*** different at 5% level. The calculated statistic for this test is 3.7 while the table value is 11.1. The detailed unrestricted and restricted models developed for the

**Table 6.1 : The BASIC Pooled Model for Maneuver 1 Using Data from Sites 1 and 2 Combined.**

**Prob. (accept) = $1/(1+ e^{2.39 - 1.30\ GSEC + 0.19\ MJSD - 0.10\ TLDL - 0.83\ MNVL})$**

| Variable/Statistic | Coefficient | Significance | Marginal Effect |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | -2.391 | 0.079 | -0.1195 |
| GSEC (Gap Size in Seconds) | 1.303 | 0.000 | 0.0651 |
| MJSD (Speed at Major Road in Km/hr) | -0.185 | 0.000 | -0.0093 |
| TLDL (Total Delay Imposed on Driver) | 0.095 | 0.001 | 0.0047 |
| MNVL (Traffic Volume at Minor Road) | 0.829 | 0.003 | 0.0414 |
| n (Number of observations) | 337 | | |
| L (β) (Log Likelihood value at maximum) | -65.34 | | |
| L (C) (restricted Log Likelihood value) | -227.28 | | |
| $\chi^2$ (Log Likelihood Ratio) | 323.88 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.713 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.695 | | |
| PCP (% correctly predicted observations | 89.32% | | |

purpose of conducting this test and more details about the validation test itself are given in Appendix D.

The main comments on the BASIC pooled model for Maneuver 1 include the following:

a. Signs of the variable coefficients agree with the expected driver gap acceptance behavior as formulated in Chapter 3. It is expected that the probability of accepting a gap increases as each of the gap size (GSEC), total delay (TLDL) and traffic voiume at minor road (MNVL) increases and is expected to decrease as the speed of the oncoming vehicle at major road increases. These assumptions are correctly reflected by positive signs taken by the former three variables and a negative sign taken by the last variable in the utility function. The constant term in the model is called the "accept choice-specific constant" as interpreted from Ben Akiva and Lerman (1985). This constant reflects the difference in the utility of the "accept choice" from that of the "reject choice" when "all else are equal". In this case, it should be noted that only one choice-specific constant is defined. It would make no sense to define two choice-specific constants because all that matters is their difference. The choice-specific constant in this case is defined for the "accept choice" (the dependent variable takes the value 1 for the " accept choice" and 0 for the "reject choice"). Given that "all else are equal", a positive choice-specific constant indicates a relative preference to accept gaps while a negative constant indicates a relative preference to reject gaps;

b. The constant term is not significantly different from zero at 5%;

c. The null hypothesis that all the estimated coefficients (except the constant term) are not significantly different from each other and from zero can be rejected at 0% level of significance which indicates that the model is highly significant;

d. GSEC and MNVL have the highest marginal effects on the probability of gap acceptance;

e. The adjusted value of the goodness of fit index ($\bar{\rho}^2$) is 0.69 which means that (after correcting for the effect of the number of the estimated parameters) about 69% of the initial likelihood value is explained by the model. This value along with the high percentage of the correctly predicted observations (89.3%) is an indicator of the good capability of the model in replicating driver gap acceptance behavior adequately.

### 6.3.2 Studying the Effects of Driver, Vehicle, and Trip Attributes for Maneuver 1

So far, the discussed BASIC pooled model includes gap, traffic, and delay attributes only. At this stage driver, vehicle, and trip attributes are considered. Avoiding the variables that might cause multicollinearity, the FULL pooled model summarized in Table

**Table 6.2: The FULL Pooled Model for Maneuver 1.**

Prob. (accept) $=1/(1+e^{5.85 - 1.83GSEC + 0.22 MJSD - .12 TLDL - 1.07 MNVL - 0.81 ACDT - 0.60 VLTN - 0.12 DEXP + 0.06 TRDN})$

| Variable/Statistic | Coefficient | Significance | Marginal Effect |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | -5,851 | 0,0023 | -0,1091 |
| GSEC (Gap Size in Seconds) | 1,831 | 0,0000 | 0,0342 |
| MJSD (Speed at Major Road in Km/hr) | -0,224 | 0,0000 | -0,0042 |
| TLDL (Total Delay Imposed on Driver) | 0,118 | 0,0007 | 0,0022 |
| MNVL (Traffic Volume at Minor Road) | 1,074 | 0,0028 | 0,0200 |
| ACDT (Accident Experience in last 2 yr.) | 0,811 | 0,0023 | 0,0151 |
| VLTN (Violation Experience in last 1 yr.) | 0,595 | 0,0118 | 0,0111 |
| DEXP (Driving Experience in Yr.) | 0,125 | 0,0055 | 0,0023 |
| TRDN (Trip Duration in Minutes) | -0,055 | 0,0423 | -0,0010 |
| n (Number of observations) | 337 | | |
| L (β) (Log Likelihood value at maximum) | -49.08 | | |
| L (C) (restricted Log Likelihood value) | -227.28 | | |
| $\chi^2$ (Log Likelihood Ratio) | 356.41 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 8 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.784 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.749 | | |
| PCP (% correctly predicted observations) | 92.88% | | |

6.2 was calibrated. The details of the model are given in Appendix C. The following new variables were found to be significant at 5% or better levels:

a. Driver accident experience (ACDT) which represents the number of accidents in the last two years;

b. Driver traffic violations experience (VLTN) which represents the number of violations in the last year;

c. Driving experience in years (DEXP);

d. Trip duration in minutes (TRDN).

Coefficient signs of the newly introduced variables indicate that the probability of accepting a gap increases as each of driver accident and violation experience (ACDT, VLTN), and driver experience (DEXP) increases. While it decreases as the trip duration (TRDN) increases. The increase in gap acceptance probability with the increase in each of the ACDT, VLTN, and DEXP agrees with the expected driver behavior as formulated in Chapter 3. It is expected that "higher risk taking" drivers who have higher accident and traffic violation records will accept shorter gaps. The more experienced drivers are also expected to accept shorter gaps.

The decrease in gap acceptance probability with the increase in trip duration indicates that drivers making longer trips tend to wait for longer gaps. This could be related to the fact that the delay that is imposed on a driver while waiting for longer gap is relatively low when compared to trip duration itself in these cases. This is to say that the

weight or importance the drivers give to a second of delay in longer trips could be less than the weight they give to a second of delay in shorter trips. Another observation that can contribute in explaining this result is that shorter trips are usually work trips in which the drivers have less patience to wait. It was found that the average duration of Non-Work trips is around 3 minutes higher than the average duration of the Work trips.

### 6.3.3 Marginal Effects of the Attributes Included in the FULL Pooled Model of Maneuver 1

In the context of Gap Acceptance Behavior the "marginal effect" of a given attribute ($x_i$) is defined as "*the rate of change in gap acceptance probability per one unit change in the considered attribute*", ceteris paribus, (i.e., holding constant the effect of all other attributes). This definition is adapted form Mcguigan and Mayer (1986).

The main purpose of analyzing the marginal effects of different variables in the model is to investigate the effect of these variables on gap acceptance probability. In the nonlinear models the coefficients of variables do not give full information about the effect of these variables since variable coefficients in such models are not equal to the marginal effects of the variables as quoted from Greene, 1995;

*"For non linear models in almost no case is the reported coefficient equal to a marginal effect, or derivative of an expected value with respect to a variable".* [Greene, 1995, page 124]

The marginal effects analyzed here are produced automatically by the used package. These effects are computed at the overall means of the data set used to calibrate the model. Marginal effects can also be obtained for any stratification. In this case, marginal effects are computed at the means of the variable strata.

In this context, it should be mentioned that *marginal effect* of a variable on gap acceptance probability is different from the *elasticity* of gap acceptance probability with respect to that variable. The marginal effect of given variable is equivalent to the partial derivative of the model with respect to that variable because, the derivative of a function at a point represents the tangent slope at that point. This slope itself measures the rate of change in the function. Hence, the marginal effect of an attribute ($x_i$) can be represented by the partial derivative of the probability function with respect to $x_i$ as follows:

$$ME_{Xi}(p\,(a)) = \partial p\,(a)/\partial x_i$$

The Marginal Effect as formulated above forms the first term in the formulation of the *"Elasticity"*. Where the *"Point Elasticity"* of the probability of accepting a gap P(a) with respect to an attribute ($x_i$) is expressed as follows [Ben -Akiva & Lerman 1985 and Manheim 1979]:

$$E_{xi}(p(a)) = \{\partial p(a)/\partial x_i\}\{x_i/p(a)\}$$

The *elasticity* is defined as *"the percentage change in the Gap Acceptance Probability for one percent change in the considered attribute"*. Comparing the definitions of *marginal effect* and *elasticity*, it can be concluded that *marginal effect* is sensitive to the unit of the considered attribute ($x_i$) while the elasticity is not, i.e., it is normalized for ($x_i$) unit. For the Gap Acceptance Model formulated in this study, the probability of accepting a gap/lag P(a) is expressed as;

$$P(a) = 1/(1 + e^{\Sigma \beta i\, xi})$$

It can be shown that the Marginal Effect, $Me_{xi}(p(a))$, and the Elasticity, $E_{xi}(P(a))$, of Gap Acceptance Probability P(a) with respect to an attribute ($x_i$) can be expressed as;

$$ME_{xi}(p(a)) = (\beta_i e^{\Sigma \beta i\, xi}) / (1 + e^{\Sigma \beta i\, xi})^2$$

$$E_{xi}(p(a)) = (\beta_i e^{\Sigma \beta i\, xi}) / (1 + e^{\Sigma \beta i\, xi})$$

The marginal effects of the FULL pooled model are summarized in Table 6.2. Referring Table 6.2 the following can be noted:

a. The "accept choice-specific" constant has the highest marginal effect on Gap Acceptance Probability P(a). This indicates that the highest rate of change in P(a) in this case is attributed to this constant. The negative sign of this coefficient indicates

that (every thing else is equal) the drivers tend to reject Gaps/Lags. The cases in which the same driver rejects several gaps along with the fact that drivers have high tendency to reject lags could be possible reasons underlying this result;

**b.** Gap/Lag in seconds (GSEC) has the second highest marginal effect on the probability of accepting a gap. This effect is positive and means that the rate of change in P(a) for 1 unit (1 second) change in GSEC is 0.0342;

**c.** Traffic volume at minor road (MNVL) also has a relatively high positive marginal effect (0.02) on the probability of accepting a gap;

**d.** The marginal effects for other attributes in the model range from an absolute value of 0.001 to 0.02. Noticeably, accident and violation experiences of the driver (ACDT, VLTN) have the highest effects among these attributes;

**e.** The marginal effects of the speed of the oncoming vehicle on the major road (MJSD) and the trip duration (TRDN) are negative as expected since the probability of accepting a gap decreases as each of these variables increases.

### 6.3.4 Validation of the FULL Pooled Model of Maneuver 1

Restricted and unrestricted models with a specification identical to the FULL pooled model (the model given in Table 6.2) were calibrated using the data portion (111 observations) which is reserved for validation purposes. The unrestricted model is obtained by restricting the coefficients to the values given in Table 6.2. The likelihood ratio test showed that the unrestricted and the restricted models are not significantly different which indicates that the observed and the predicted Gap Acceptance Behaviors are not significantly different. Details of the validation test are as follows:

- $H_0$ : Imposed restrictions are correct or, alternatively, the observed and the predicted driver gap acceptance behaviors are not different;
- Log likelihood value for the unrestricted model = -15.59;
- Log likelihood Value for the Restricted Model = - 22.17;
- Likelihood Ratio Test Statistic = -2(-22.17 - (-15.59)) = 13.16;
- Degrees of Freedom for the test are (9) which is the number of the imposed restrictions;
- $\chi^2$- table value at (0.05, 9) = 16.92;
- Test Result: $\chi^2$ calculated is less than the table value. Therefore, there is no enough statistical evidence to reject $H_0$. This indicates that the observed and the predicted driver gap acceptance behaviors are not significantly different.

Full details of the unrestricted and the restricted models used in the above test are given in Appendix D.

### 6.3.5 Driver Response to Gaps and Lags in Maneuver 1

One concern of this study is to test whether driver response/reaction to lags and gaps is significantly different. This can be tested by applying the log likelihood ratio test between the pooled model calibrated for lags and gaps combined and the segmented models calibrated for lags and gaps separately. Table 6.3 gives a summary of the models calibrated for lags and gaps separately. The detailed models developed for gaps and lags are given in Appendix E. The result of the log likelihood ratio test shows that the gap's and lag's models presented in Table 6.3 are significantly different from each other at 5% level of confidence. Details of the mentioned test are:

- $H_0$: Coefficients vector of gaps model is not different from the coefficients vector of lags model ($\beta_{gap} = \beta_{lag}$);
- Log likelihood for the pooled model (Table 6.2) = -49.08;
- Log likelihood for lag's model (Table 6.3) = -30.92;
- Log likelihood for gap's model (Table 6.3) = -8.48;
- Likelihood Ratio Test Statistic (Chi-Squared calculated)

= -2(-49.08-(-30.92+(-8.48))) = 11.78;

- Chi- Squared table value at (0.05,5) = 11.07;

**Table 6.3: Gaps and Lags Models Calibrated Separately for Maneuver 1 Along with the t-Tests Performed on their Coefficients.**

| Variable/ Statistic | Gaps Model | | | Lags Model | | | t-Statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant (Accept-Choice Specific Constant) | -21.6120 | 10.9760 | 0.0490 | -5.5611 | 2.3266 | 0.0168 | -0.8414 |
| GSEC (Gap Size in Seconds) | 5.8994 | 2.5011 | 0.0183 | 1.4598 | 0.3018 | 0.0000 | 1.6940 |
| MJSD (Speed at Major Road in Km/hr) | -0.4814 | 0.2157 | 0.0256 | -0.1859 | 0.0430 | 0.0000 | -0.6011 |
| TLDL (Total Delay Imposed on Driver) | 0.2231 | 0.1504 | 0.1379 | 0.1228 | 0.0724 | 0.0899 | 0.0443 |
| MNVL (Traffic Volume at Minor Road) | 2.9199 | 1.7222 | 0.0900 | 1.1458 | 0.4655 | 0.0139 | -0.7082 |
| ACDT (Accident Experience in last 2 yr.) | 2.2266 | 1.5918 | 0.1619 | 0.8133 | 0.3248 | 0.0123 | 0.7153 |
| VLTN (Violation Experience in last 1 yr.) | 1.2745 | 1.0454 | 0.2228 | 0.4396 | 0.2506 | 0.0793 | 0.4992 |
| DEXP (Driving Experience in Yr.) | 0.4054 | 0.1918 | 0.0345 | 0.0997 | 0.0521 | 0.0557 | 0.5348 |
| TRDN (Trip Duration in Minutes) | -0.2012 | 0.1259 | 0.1101 | -0.0503 | 0.0384 | 0.1901 | 0.2002 |
| n (Number of observations) | 136 | | | 201 | | | |
| L (β) (Log Likelihood value at maximum) | -8.48 | | | -30.92 | | | |
| L (C) (restricted Log Likelihood value) | -92.48 | | | -134.69 | | | |
| $\chi^2$ (Log Likelihood Ratio) | 168 | | | 207.45 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 8 | | | 8 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.908 | | | 0.770 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.822 | | | 0.711 | | | |
| PCP (% correctly predicted observations) | 97.79% | | | 92.04% | | | |

- Test result: Since the calculated Chi-Squared value exceeds the table value, the null hypothesis can be rejected at 5% level.

To further investigate this issue, two steps are undertaken:

***i- t-tests for the coefficients of gaps and lags models of Maneuver 1***

T-tests are performed for the relevant pairs of coefficients in gaps and lags models. The t-statistics for the test are calculated as described by Ben Akiva and Lerman (1985), considering gaps and lags as the two market segments (refer to Chapter 3, Section 3.6,(a-iii) for the details of this test). The computed statistics for the mentioned t-tests are given in Table 6.3. The table value for t-tests at 5% is 1.96 since degrees of freedom are larger than 120 and the test is double-sided.

The results of the t-tests conducted on the two vectors of coefficients for gap and lag models show that none of the gap's model coefficients is significantly different from its counterpart coefficient in the lags model at 5% level. This indicates that lags model is not significantly different from gaps model. This result apparently conflicts with the result of the previously performed likelihood ratio test.

As discussed by Ben Akiva and Lerman (1985), it can be possible that the overall test result based on t-tests is different (disagree) with the result of the overall likelihood ratio test as happened in this case (refer to Chapter 3, Section 3.6, point b-iv for more

details on this issue). However, t-statistics for GSEC variable is relatively high (though not high enough to reject $H_0$ at 5% level). The difference in gap size (GSEC) coefficients is only significant at around 7% level while the difference in the coefficients of both of the MNVL and ACDT coefficients is significant at around 24% level. Hence, the difference in drivers' action to lags and gaps could be attributed to the difference in their response to these variables in the two cases.

***ii- Analysis of Marginal Effects for Gaps and Lags Models of Maneuver 1***

The marginal effects of different variables in the two models are given in Table 6.4. It was found that none of the marginal effects in gaps model is significantly different from its counterpart in lags model at 5% or any other reasonable level. Table 6.4 also shows that the marginal effects of all of the attributes are higher in the case of gaps model.

## 6.4 MODEL CALIBRATION AND VALIDATION FOR RIGHT TURNS FROM MINOR STREAM (MANEUVER 2)

### 6.4.1 The BASIC Pooled Model for Maneuver 2

The BASIC pooled model calibrated for Maneuver 2 using data collected at Sites 1 and 2 combined is given in Table 6.5. The significant variables in this model are the gap size in seconds (GSEC), the total delay (TLDL), and the volume of traffic at the minor

**Table 6.4 : Marginal Effects of Variables Included In Gaps and Lags Models for Maneuver 1 Along With the relevant t-Statistics.**

| Variable/ Statistic | Gaps Model | | Lags Model | | Coeff. Ratio (Gaps/Lags) | t-statistic |
|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Coefficient | St. Error | | |
| Constant (Accept-Choice Specific Constant) | -0.074859 | 0.148930 | -0.085292 | 0.069165 | 0.88 | 0.06 |
| GSEC (Gap Size in Seconds) | 0.020434 | 0.040575 | 0.022389 | 0.017310 | 0.91 | -0.04 |
| MJSD (Speed at Major Road in Km/hr) | -0.001668 | 0.003383 | -0.002851 | 0.002527 | 0.58 | 0.28 |
| TLDL (Total Delay Imposed on Driver) | 0.000773 | 0.001466 | 0.001883 | 0.001772 | 0.41 | -0.48 |
| MNVL (Traffic Volume at Minor Road) | 0.010114 | 0.020029 | 0.017573 | 0.015939 | 0.58 | -0.29 |
| ACDT (Accident Experience in last 2 yr.) | 0.007712 | 0.015010 | 0.012473 | 0.011801 | 0.62 | -0.25 |
| VLTN (Violation Experience in last 1 yr.) | 0.004415 | 0.010902 | 0.006743 | 0.006723 | 0.65 | -0.18 |
| DEXP (Driving Experience in Yr.) | 0.001404 | 0.002830 | 0.001529 | 0.001569 | 0.92 | -0.04 |
| TRDN (Trip Duration in Minutes) | -0.000697 | 0.001323 | -0.000772 | 0.000859 | 0.90 | 0.05 |

**Table 6.5: The BASIC Pooled Model for Maneuver 2 Using Data from Sites 1and 2 Combined**

| Variable / Statistic | Coefficient | Significance level | Marginal Effect |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | - 16.115 | 0.0000 | - 0.0982 |
| GSEC (Gap Size in Seconds) | 2.264 | 0.0000 | 0.0138 |
| TLDL (Total Delay Imposed on Driver) | 0.163 | 0.0000 | 0.0001 |
| MNVL (Traffic Volume at Minor Road) | 0.925 | 0.0034 | 0.0056 |
| n (Number of observations) | 396 | | |
| L (β) (Log Likelihood value at maximum) | - 58.41 | | |
| L (C) (restricted Log Likelihood value) | - 249.20 | | |
| $\chi^2$ (Log Likelihood Ratio) | 381.57 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 3 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.766 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.754 | | |
| PCP (% correctly predicted observations) | 94.19 | | |

road (MNVL). Validation test for the BASIC model of Maneuver 2 concluded that the observed and the predicted driver behaviors are not significantly different. The computed likelihood ratio test statistic is 9.46 while the table value is 9.49. Details of this test along with the calibrated models to conduct it are given in Appendix D

The main comments on the BASIC pooled model of Maneuver 2 include:

a. Signs of variable coefficients agree with the expected driver gap acceptance behavior as formulated in Chapter 3 and as discussed in Section 6.3.1;

b. The constant term is significant at high level. The negative sign of the constant indicates that, ceteris paribus, drivers tend to reject gaps/lags. Cases in which a driver rejects several gaps could be a contributing factor to this behavior as indicated by having higher absolute values for this constant in models developed for observations which involved driver gap/lag rejection decisions;

c. The null hypothesis that all the estimated coefficients except the constant are <u>not</u> significantly different from each other and from zero can be rejected at 0% level;

d. Excluding the "accept specific constant", GSEC and MNVL have the highest marginal effects on the probability of accepting a gap. The rates of change in this probability per unit change in these two variables are 0.0138 and 0.00564, respectively.

### 6.4.2 Studying the Effects of Driver, Vehicle, and Trip Attributes for Maneuver 2

Driver, vehicle, and trip attributes include more than 15 variables. The FULL pooled model including the significant set of these variables along with gap, traffic, and delay attributes which are already identified to be significant in Section 6.4.1 is summarized in Table 6.6. More details on the model are given in Appendix C. Among the whole set of the modeled driver, vehicle, and trip attributes, only driver sex (DSEX), driver age (DAGE), and trip duration (TRDN) were found to be significant at 5% or better levels.

The signs of coefficients and the signs of the marginal effects for the newly introduced variables indicate that the probability of accepting a gap decreases as the driver age increases. This result agrees with the results cited in literature [Darzentas et. al., 1980] and with the expected driver behavior as formulated in Chapter 3. The negative coefficient taken by driver sex means that the probability of accepting a gap by a driver decreases when the driver is *female* because driver sex is coded as a binary dummy variable which takes the value 1 when the driver is female and the value 0 when the driver is male. This result again agrees with the expected driver gap acceptance behavior. The interpretation of the negative sign taken by the trip duration coefficient is discussed in Section 6.3.2.

**Table 6.6: The FULL Pooled Model for Maneuver 2.**

$$\text{Prob(accept)} = 1/\left(1+e^{(16.38 - 2.73\,GSEC - 0.18\,TLDL - 1.22\,MNVL + 1.56\,DSEX + 0.061\,DAGE + 0.025\,TRDN)}\right)$$

| Variable / Statistic | Coefficient | Level of Significance | Marginal Effect | | |
|---|---|---|---|---|---|
| | | | Males Segment | Females Segment | Whole Sample |
| Constant (Accept specific constant) | - 16.377 | 0.0000 | - 0.0392 | - 0.0031 | - 0.0292 |
| GSEC (Gap Size in Seconds) | 2.728 | 0.0000 | 0.0065 | 0.00052 | 0.0049 |
| TLDL (Total Delay in Seconds) | 0.176 | 0.0000 | 0.0004 | 0.000034 | 0.0003 |
| MNVL (Traffic volume at minor road) | 1.217 | 0.0006 | 0.0029 | 0.00023 | 0.0022 |
| DSEX (Driver Sex) | - 1.561 | 0.525 | - 0.0037 | - 0.0003 | - 0.0028 |
| DAGE (Driver Age) | - 0.061 | 0.0266 | - 0.00015 | - 0.000012 | - 0.0001 |
| TRDN (Trip duration in minutes) | - 0.025 | 0.0326 | - 0.00006 | - 0.000005 | - 0.000044 |
| n (Number of observations) | 396 | | | | |
| L (β) (Log Likelihood value at maximum) | - 50.19 | | | | |
| L (C) (restricted Log Likelihood value) | - 249.20 | | | | |
| $\chi^2$ (Log Likelihood Ratio) | 398.01 | | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 6 | | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | | |
| $\rho^2$ (Goodness of fit Index) | 0.799 | | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.775 | | | | |
| PCP (% correctly predicted observations) | 94.70 | | | | |

The unadjusted and adjusted rho-squared values of 0.8 and 0.78, respectively and the "percent correctly predicted" of 94.7% indicate the strength of the calibrated model and its capability in explaining the driver gap acceptance behavior. The corresponding values for the BASIC model were 0.77, 0.75, and 94.2%, respectively which indicates the addition of the new variables has improved the fit.

### 6.4.3 Marginal Effects of the Attributes Included in the FULL Pooled Model of Maneuver 2

The marginal effects of the significant attributes in the FULL pooled model of Maneuver 2 are given in Table 6.6. These effects are given separately for driver sex strata (males and females) and for the whole sample as well. The following main comments can be observed by investigating the last column in Table 6.6:

a. The rate of change in gap acceptance probability for one unit change in gap size (GSEC) is much higher for male drivers compared to female drivers. The rate of change in male's stratum is around 13 times higher than the rate in female's stratum. This indicates that male drivers are much more sensitive and responsive to gap size. The same comment, actually, applies for all the variables included in the model. The rate of change in the probability of accepting a gap if the driver is male is around 12 times higher than the rate of change if the driver is female. This result applies (more or less) to all of the modeled variables;

b. A t-test of the form described in Section 3.6 (a-iii) is used to check whether each of the marginal effects for female's stratum is significantly different from its counterpart in male's stratum. The t-statistics computed for this test are given in Table 6.7. The t-table value at 5% is 1.96 (degrees of freedom are more than 120 and the test is double - sided). Inspecting the t-statistics in Table 6.7 it can be concluded that none of the marginal effects for Male's stratum is significantly different from its counterpart in Female's stratum. The interpolation in t-distribution table shows that the differences in marginal effects of the two strata could become significant only if the level of significance is relaxed to around 20%;

c. Among the modeled variables and attributes, gap size (GSEC), traffic volume at minor road (MNVL) and driver sex (DSEX) have the highest marginal effects on gap acceptance probability in both of the strata. However, the relative effect of these variables within each stratum is visibly different. For example, the marginal effect of gap size (GSEC) is around 16 times higher than the marginal effect of the total delay (TLDL). The t-tests can be used to check whether these differences are statistically significant. For the GSEC and TLDL example in males' strata, the computed t-statistic is 1.22 which indicates that the difference in their marginal effects is not significant at 5% level and would be significant only at around 12% level.

**Table 6.7: The t-tests for the Marginal Effects of Gender Strata in the FULL Pooled Model of Maneuver 2.**

| **Variable/ Statistic** | **Driver Sex (DSEX)** | | | | t-statistic |
|---|---|---|---|---|---|
| | Male | | Female | | |
| | Coefficient | St. error | Coefficient | St. error | |
| Constant (Accept-Choice Specific Constant) | - 0.0392 | 0.0305 | - 0.00313 | 0.00405 | - 1.172 |
| GSEC (Gap Size in Seconds) | 0.0065 | 0.0050 | 0.00052 | 0.00066 | 1.186 |
| TLDL (Total Delay Imposed on Driver) | 0.0004 | 0.00034 | 0.000034 | 0.000044 | 1.139 |
| MNVL (Traffic Volume at Minor Road) | 0.0029 | 0.0023 | -0.00023 | 0.00031 | 1.068 |
| DSEX (Driver Sex) | - 0.0037 | 0.0032 | - 0.0003 | 0.000473 | - 1.051 |
| DAGE (Driver Age) | - 0.00015 | 0.00013 | - 0.000012 | 0.0000154 | - 1.054 |
| TRDN (Trip duration in minutes) | - 0.00006 | 0.00005 | - 0.0000048 | 0.0000062 | - 1.096 |
| Sample Size | 494 | | 34 | | |

### 6.4.4 Validation of the FULL Pooled Model of Maneuver 2

To validate the FULL pooled model presented in Table 6.6, it is needed to use the validation data set to calibrate unrestricted and restricted models with an identical specification to the FULL pooled model. In the restricted model, coefficients will be restricted to the values given in Table 6.6. The log likelihood test can then be applied to check whether the unrestricted and the restricted models are significantly different. Details of the test applied to Maneuver 2 validation models are listed below:

- $H_0$ : Imposed restrictions are correct (observed and predicted behaviors are not different).
- Log likelihood value for the unrestricted model = -24.32.
- Log likelihood value for the restricted model = -31.17.
- Likelihood ratio test statistic = -2 (-31.17 - (-24.32)) = 13.7.
- Chi - squared table value at (0.05,7) = 14.07.
- Test result: No enough statistical evidence to reject $H_0$.

Details of the unrestricted and restricted models used in the above test are given in Appendix D.

### 6.4.5 Driver Response to Gaps and Lags in Maneuver 2.

Gap acceptance Models with an identical specification to the FULL pooled model given in Table 6.6 were calibrated for gaps and lags separately. These models are summarized in Table 6.8. The detailed models are given in Appendix E. The likelihood ratio test detailed in Section 3.6, (b-v) can be used to test whether driver response to gaps and lags is significantly different. Details of this test are listed below:

- $H_0$: Coefficients vector of gaps' model is not different from coefficients vector of lags' model, i.e. $\beta_{Gaps} = \beta_{Lags}$.
- Log likelihood for the pooled model (Table 6.6) = -50.19.
- Log likelihood for the gaps' model = -15.72.
- Log likelihood for lags' model = -15.23.
- Degrees of freedom for the test = 7.
- Likelihood ratio test statistic = -2 (-50.19 - (-15.72 + (-15.23)) = 38.48.
- $\chi^2$ - table value at (0.05,7) = 14.07.
- Test result: Reject $H_0$.

The result of this test indicates that drivers' response to gaps is different from their response to lags. To further investigate this result and to highlight the possible reasons and variables that underline this behavior, two steps of analysis are performed:

**Table 6.8: Gaps and Lags Models Calibrated Separately for Maneuver 2 Along With the t-Tests Performed on Their Coefficients.**

| Variable / Statistic | Gaps Model | | | Lags Model | | | t-statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | Coefficient | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant (Accept-Choice Specific Constant) | - 20.1360 | 5.7112 | 0.0004 | - 21.246 | 5.1681 | 0.0000 | 0.1441 |
| GSEC (Gap Size in Seconds) | 3.99 | 0.8003 | 0.0000 | 3.443 | 0.7787 | 0.0000 | - 0.1301 |
| TLDL (Total Delay Imposed on Driver) | 0.162 | 0.0659 | 0.0141 | 0.188 | 0.0447 | 0.0000 | - 0.3287 |
| MNVL (Traffic Volume at Minor Road) | 1.231 | 0.8016 | 0.1245 | 1.211 | 0.6582 | 0.0658 | 0.0195 |
| DSEX (Driver Sex) | 0.395 | 2.9189 | 0.8924 | - 3.859 | 3.2053 | 0.2286 | 0.9813 |
| DAGE (Driver Age) | 0.017 | 0.0674 | 0.8000 | - 0.077 | 0.0564 | 0.1748 | 1.0650 |
| TRDN (Trip duration in minutes) | - 0.002 | 0.0289 | 0.9367 | - 0.022 | 0.0187 | 0.2484 | 0.5600 |
| n (Number of observations) | 123 | | | 270 | | | |
| L (β) (Log Likelihood value at maximum) | - 15.72 | | | - 15.23 | | | |
| L (C) (restricted Log Likelihood value) | - 82.7 | | | - 161.40 | | | |
| $\chi^2$ (Log Likelihood Ratio) | 133.95 | | | 292.35 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 6 | | | 6 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.81 | | | 0.91 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.74 | | | 0.87 | | | |
| PCP (% correctly predicted observations) | 95.93% | | | 98.52% | | | |

***i- t-tests for the coefficients of gaps and lags models of Maneuver 2***

The t-test described in Chapter 3, (Section 3.6, a-iii) is used to check whether each of the variable coefficients in gaps model is significantly different from its counterpart in lags model. The computed statistics for these tests are given in the last column in Table 6.8. None of the computed statistics is greater than 1.96 (t-table value) which means that none of the gaps model coefficients is significantly different form its counterpart coefficient in lags model. Coefficients of driver age (DAGE) are significantly different only at around 15% significance level while the coefficients of driver sex (DSEX) are significantly different only at around 17.5% level. Other pairs of coefficients are not significantly different from each other at any reasonable level of significance.

***ii- Analysis of Marginal effects for Gaps and Lags Models of Maneuver 2***

Marginal effects of different attributes along with the computed ratios and t-statistics for these effects are given in Table 6.9. The following main comments and conclusions are derived from the table:

a. Using t-test for pair wise testing of the significance of the difference between the relevant pairs of the marginal effects, it can be concluded that none of these effects is significantly different from its counterpart at 5% level. However, the marginal effects of gap size (GSEC), total delay (TLDL) and traffic volume at minor road

**Table 6.9: Marginal Effects of Variables Included in Gaps and Lags Models for Maneuver 2 Along With the t-Tests performed on their coefficients.**

| Variable / Statistic | Gaps Model | | Lags Model | | Coef. ratio | t-statistic |
|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Coefficient | St. Error | (Gaps/Lags) | |
| Constant (Accept-Choice Specific Constant) | - 1.5720 | 1.1447 | - 0.00125 | 0.0027 | 1261.5 | - 1.3722 |
| GSEC (Gap Size in Seconds) | 0.2575 | 0.1750 | 0.00020 | 0.000425 | 1275.3 | 1.4708 |
| TLDL (Total Delay Imposed on Driver) | 0.0126 | 0.0110 | 0.00001 | 0.000024 | 1145.8 | 1.1509 |
| MNVL (Traffic Volume at Minor Road) | 0.0961 | 0.1069 | 0.00007 | 0.000153 | 1353.3 | 0.8986 |
| DSEX** (Driver Sex) | 0.0308 | 0.2210 | - 0.00023 | 0.000522 | - 136.3 | 0.1406 |
| DAGE** (Driver Age) | 0.0013 | 0.0049 | - 0.000004 | 0.000009 | - 297.0 | 0.2750 |
| TRDN (Trip duration in minutes) | - 0.0002 | 0.0023 | - 0.000001 | 0.000003 | 141.7 | - 0.0773 |

** Sign of the Coefficient in the two models is different.

(MNVL) in gaps model become significantly different from their counterparts in lags model at around 9%, 13%, and 20% levels, respectively. This analysis along with the coefficient ratios given in Table 6.9 shows that the effects of gap size and total delay on gap acceptance probability are higher when the driver is evaluating a gap rather than a lag. This result is considered expected and reasonable. The driver always evaluates a lag at the first moment he is in situation to enter the intersection. At this moment no delays (specially at queue head) are imposed on him yet, and hence the probability to accept that lag will be less due (in one part) to the absence of delay pressure;

b. The marginal effects of driver sex (DSEX) and driver age (DAGE) exhibit different signs in the two models. In gaps model the rates of change in gap acceptance probability for (DAGE) and for female drivers are positive while the rates of change in lags model are negative. This means that the probability of accepting a gap increases with driver age and when the driver is female. This may indicate that female drivers and old drivers have higher tendency to accept gaps rather than lags which means that they usually reject their lags (note that each driver faces only one lag at the moment he is ready to enter the intersection) and accept some succeeding gap. This behavior is considered to be reasonable since it indicates that females and old drivers have higher tendency to reject the first choice they face (the lag).

## 6.5 MODEL CALIBRATION AND VALIDATION FOR LEFT TURNS FROM MINOR STREAM (MANEUVER 3)

Maneuver 3 in this study represents the left turns from minor road to major road. The following sections present and discuss driver gap acceptance models calibrated for this maneuver.

### 6.5.1 The BASIC Pooled Model for Maneuver 3

The BASIC pooled model developed for maneuver 3 using data collected at sites 1 and 2 combined is summarized in Table 6.10. The detailed model is given in Appendix C. A quick investigation of Table 6.10 indicates that the gap size in seconds (GSEC), speed at major road (MJSD), total delay (TLDL) and traffic volume at minor road (MNVL) are significant variables in the model at 5% or better levels. The relevant likelihood ratio validation test concluded that the observed and the predicted driver gap acceptance behaviors are not significantly different at 5% level where the calculated test statistic is 7.26 while the table value of the statistic is 11.07. Details of this test along with the models calibrated to conduct the test are given in Appendix D.

The main comments on the BASIC model of Maneuver 3 include:

**Table 6.10: The BASIC Pooled Model Calibrated for Maneuver 3 Using Data Collected from Sites 1 and 2 Combined.**

| Variable/ Statistic | Coefficient | Significance | Marginal Effect |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | -7.5083 | 0.0000 | -0.5928 |
| GSEC (Gap Size in Seconds) | 2.5096 | 0.0000 | 0.1981 |
| MJSD (Speed at Major Road in Km/hr) | -0.2127 | 0.0000 | -0.0168 |
| TLDL (Total Delay Imposed on Driver) | 0.0611 | 0.0001 | 0.0048 |
| MNVL (Traffic Volume at Minor Road) | 1.0876 | 0.0000 | 0.0859 |
| n (Number of observations) | 624 | | |
| L (β) (Log Likelihood value at maximum) | -70.81 | | |
| L (C) (restricted Log Likelihood value) | -359.42 | | |
| $\chi^2$ (Log Likelihood Ratio) | 577.22 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.803 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.792 | | |
| PCP (% correctly predicted observations) | 95.35% | | |

a. Signs of the variable coefficients agree with the expected driver gap acceptance behavior as discussed in the other two maneuvers. The probability of accepting a gap increases as each of the gap size (GSEC), total delay (TLDL) and traffic volume at minor road increases and decreases as the speed of the oncoming vehicle increases. As the total delay imposed on a driver increases, he becomes less patient and hence his tendency to accept a gap increases. The increase in gap acceptance probability with MNVL indicates that drivers behavior during traffic peak hours is different than their behavior during off-peak hours. In addition, the increase in MNVL will usually produce higher delays and queues that make the driver less patient and increases his tendency to accept gaps. The negative sign taken by the coefficient of (MJSD) means that drivers at the minor road are hesitant to cross the path of speedy vehicles on the major road. The effect of speed on any possible accident in this case could be a controlling factor in this process. It should be mentioned that (MJSD) was found to be a significant variable in driver gap acceptance models calibrated for Maneuvers 1 and 3 but not in the model calibrated for Maneuver 2. In this context the basic difference between Maneuvers 1 and 3 at one side and Maneuver 2 at the other side is that the driver needs to cross the path of the oncoming vehicle in the former maneuvers while he just needs to merge in the path of the oncoming vehicles in the last maneuver. Hence a potential accident in the first case would be a right-angle type while it would be a rear-end type in the second case. This could be a main reason of having the (MJSD) significant in Maneuvers 1 and 3 but not in Maneuver 2;

**b.** The overall model is significant at 0% level. Hence all of the variable coefficients are significantly different from each other and from zero;

c. The constant term "accept specific-constant" is significantly different from zero at 0%. The negative sign of this constant indicates that, everything else is equal, the drivers have a higher tendency to reject gaps. This is really a not clear result and could be a subject for further research to investigate the underlying reasons of the phenomenon and to identify the needed data and modeling frameworks to understand it. Reviewing the binary logit gap acceptance models given in Madanat et al. (1994) paper it was observed that the constant terms in the models are also negative and significantly different from zero at 0% level (t-statistics greater than 6.5). Madanat et. al. models were formulated to predict the probability that a driver will accept a given gap in the conflicting traffic stream. The mentioned paper, however, does not include any discussion about the constant term (refer to Chapter 2, Section 2.5.2 for more details on the models developed by Madanat et. al. (1994));

**d.** Reviewing the marginal effects of model variables it can be seen that a unit change in Gap size (GSEC) and traffic volume at minor road (MNVL) can produce the highest rates of change in gap acceptance probability. These rates are 0.198 and 0.086, respectively.

### 6.5.2 Studying the Effects of Driver, Vehicle, and Trip Attributes in Maneuver 3

Driver, vehicle and trip attributes were studied to identify the group of the unhighly correlated variables that can be added to the BASIC pooled model developed in Section 6.5.1. The FULL pooled model obtained after adding these variables to the BASIC pooled model (the Model described in Section 6.5.1) is summarized in Table 6.11. The detailed model is given in Appendix C. Out of more than 15 investigated variables in these groups, only three variables were found to be significant at 5% or better level. These variables are the driver accident experience (ACDT), driving experience (DEXP), and trip duration (TRDN). Signs taken by the newly introduced variables are as expected. The interpretations given elsewhere for (ACDT) and (TRDN) apply here. The positive sign taken by (DEXP) means that the driver gap acceptance probability increases as his driving experience increases. Having this variable significant in this maneuver in particular is very reasonable since it is the most difficult among the three studied maneuvers.

### 6.5.3 Marginal Effects of the Attributes Included in the FULL Pooled Model of Maneuver 3

The Marginal Effects for variables included in the FULL pooled model of Maneuver 3 are given in Table 6.11. The main notes on the table include:

**Table 6.11: The FULL Pooled Model For Maneuver 3.**

| Variable/ Statistic | Coefficients | | Marginal Effect | |
|---|---|---|---|---|
| | Value | Sig. Level | Value | Sig. Level |
| Constant (Accept-Choice Specific Constant) | -9.145 | 0.0000 | -0.5916 | 0.0000 |
| GSEC (Gap Size in Seconds) | 2.746 | 0.0000 | 0.1776 | 0.0001 |
| MJSD (Speed at Major Road in Km/hr) | -0.229 | 0.0000 | -0.0148 | 0.0000 |
| TLDL (Total Delay Imposed on Driver) | 0.083 | 0.0000 | 0.0054 | 0.0003 |
| MNVL (Traffic Volume at Minor Road) | 1.235 | 0.0000 | 0.0799 | 0.0008 |
| ACDT (Accident Experience in last 2 yr.) | 0.676 | 0.0168 | 0.0437 | 0.0230 |
| DEXP (Driver Experience in, yr.) | 0.095 | 0.0128 | 0.0062 | 0.0214 |
| TRDN (Trip duration in minutes) | -0.049 | 0.0139 | -0.0031 | 0.0213 |
| n (Number of observations) | 624 | | | |
| L (β) (Log Likelihood value at maximum) | -62.44 | | | |
| L (C) (restricted Log Likelihood value) | -359.42 | | | |
| $\chi^2$ (Log Likelihood Ratio) | 593.96 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 7 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.826 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.807 | | | |
| PCP (% correctly predicted observations) | 95.83 | | | |

a. Gap Size (GSEC) and traffic volume at minor road (MNVL) have the highest marginal effects on gap acceptance probability. The rates of change in gap acceptance probability for 1 unit change in these two variables, ceteris paribus, are around 0.18 and 0.08, respectively;

b. The marginal effect of driver accident (ACDT) is around 0.044. This effect is higher than the marginal effects of other important variables such as the oncoming vehicle speed (MJSD) and the total delay (TLDL). This indicates the importance of this variable in explaining driver gap acceptance behavior in this case;

c. All of the marginal effects are significantly different from 0 at 5% level as concluded from the t-test results. (Significance level for each coefficient is edited automatically by LIMDEP).

### 6.5.4 Validation of the FULL Pooled Model of Maneuver 3

Unrestricted and restricted models with an identical specification to the model given in Table 6.11 were calibrated using the validation data set which contains 193 observations. The details of the likelihood ratio validation test are listed below. The detailed models calibrated for the purpose of this test are given in Appendix D:

- $H_0$: Imposed restrictions are correct (observed and predicted driver gap acceptance behaviors are not different).
- Log likelihood value for the unrestricted model = - 16.28.
- Log likelihood value for the restricted model = -23.19.
- Likelihood ratio test statistic = -2(-23.19-(-16.28)) = 13.82
- $\chi^2$ table value at (0.05, 8) = 15.51
- Test result: No enough statistical evidence to reject $H_0$.

The result of this test along with the high values of $\rho^2$, adjusted $\rho^2$, and the "percent correctly predicted" observations demonstrate the good capability of the model in describing and predicting driver gap acceptance behavior adequately.

### 6.5.5 Driver Response to Gaps and Lags in Maneuver 3

Separate gap acceptance models with an identical specification to the FULL pooled model of Maneuver 3 were calibrated using the time type of gap (gap/lag) as a stratification variable. These models are summarized in Table 6.12. The detailed models are given in Appendix E. Details of the likelihood ratio test which is used to check whether drivers response/reaction to gaps is significantly different from their response/reaction to lags are listed below:

**Table 6.12: Gaps and Lags Models Calibrated Separately for Maneuver 3 Along With The t-Tests Performed on Their Coefficients.**

| Variable/ Statistic | Gaps Model | | | Lags Model | | | t-Statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant (Accept-Choice Specific Constant) | -11.5060 | 2.4956 | 0.0000 | -10.2830 | 3.8343 | 0.0073 | -0.2673 |
| GSEC (Gap Size in Seconds) | 3.6917 | 0.5928 | 0.0000 | 2.3774 | 0.7189 | 0.0009 | 1.4106 |
| MJSD (Speed at Major Road in Km/hr) | -0.2722 | 0.0445 | 0.0000 | -0.2218 | 0.0865 | 0.0103 | -0.5180 |
| TLDL (Total Delay Imposed on Driver) | 0.0774 | 0.0255 | 0.0024 | 0.0371 | 0.0298 | 0.2127 | 1.0275 |
| MNVL (Traffic Volume at Minor Road) | 1.1875 | 0.3629 | 0.0011 | 2.4048 | 0.8201 | 0.0034 | -1.3574 |
| ACDT (Accident Experience in last 2 yr.) | 0.8289 | 0.4004 | 0.0384 | 0.4138 | 0.7405 | 0.5763 | 0.4931 |
| DEXP (Driving Experience in Yr.) | 0.1190 | 0.0498 | 0.0170 | 0.0471 | 0.1308 | 0.7089 | 0.5140 |
| TRDN (Trip Duration in Minutes) | -0.0484 | 0.0281 | 0.0850 | -0.0520 | 0.0500 | 0.2979 | 0.0638 |
| n (Number of observations) | 461 | | | 162 | | | |
| L (β) (Log Likelihood value at maximum) | -39.42 | | | -10.35 | | | |
| L (C) (restricted Log Likelihood value) | -258.96 | | | -98.45 | | | |
| $\chi^2$ (Log Likelihood Ratio) | 439.08 | | | 176.18 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 7 | | | 7 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.848 | | | 0.895 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.821 | | | 0.824 | | | |
| PCP (% correctly predicted observations) | 96.75% | | | 98.15% | | | |

- $H_0$: Drivers response to gaps is ***not*** different from their response to lags. In statistical terms this could be expressed as $H_0$: ($\beta_{gaps} = \beta_{lags}$).
- Log Likelihood value for the pooled model = - 62.44.
- Summation of log likelihoods for gaps and lags models = -49.77.
- Likelihood ratio test statistic = -2(-62.44-(-49.77)) = 25.34.
- $\chi^2$ table value at (0.05, 8) = 15.51.
- Test Result: Reject $H_0$ at 5% level of significance.

To further investigate this result and to identify attributes responsible for the difference in driver response to gaps and lags, t-tests are performed on the individual pairs of model coefficients and marginal effects of model variables are investigated in detail.

***i- t-Tests for the Coefficients of Gaps and Lags Models of Maneuver 3***

The t-statistics needed to check whether each coefficient in gaps model is significantly different from its counterpart in lags model are given in the last column of Table 6.12. Knowing that t-table value is 1.96, it can be concluded that none of the gaps' model coefficients is significantly different from its counterpart in lags' model at 5%. Differences in the coefficients of GSEC, TLDL, and MNVL are only significant at around 9%, 6.5% and 9.5%, respectively.

Therefore, the difference in driver action to lags and gaps could be attributed to these variables. It should be noted, however, that the total delay variable itself is only significant at 21.3% level in lags model as can be seen from Table 6.12. The only delay effect that could be imposed on the driver at the time of evaluating a lag is the delay he has experienced in the queue (if any). This means that unless the driver has waited in a queue, he would be free from the pressure effect of delay while evaluating his lag (note that each driver is offered a one single lag). If he rejects the lag, he will be waiting (delayed) at the junction and the effect of "queue head" delay will be increasing as he rejects more gaps.

Driver and vehicle attributes are over represented in gaps model. The attributes of a driver/vehicle who rejects (n) gaps will be repeated (n) times. In lags case these characteristics will be repeated only once since there is only one lag for each driver. This could explain why driver and vehicle attributes are significant in gaps model but not in lags model.

***ii -Analysis of Marginal Effects for Gaps and Lags Models of Maneuver 3***

The main results of analyzing the marginal effects of variables included in gaps and lags models calibrated separately for Maneuver 3 include;

a. The Detailed outputs of gaps model showed that all marginal effects of the included attributes are significantly different from zero at 5% except the effects of DEXP,

ACDT and TRDN which are different from zero at 6.2%, 9.6%, and 11.5% levels, respectively. On the other hand none of the marginal effects in lags model is significantly different from zero at 5% level. Effects of traffic attributes (GSEC, MJSD, and MNVL) in lags model are significant only at around 30% or lower levels;

b. The marginal effects themselves along with the computed t-statistics to test whether these effects are significantly different from each other are given in Table 6.13. The t-statistics presented in the last column of Table 6.13 are low and indicate that none of the marginal effects in gaps model is significantly different from its counterpart in lags model at 5% or any other reasonable level;

c. As can be concluded from the sixth column in table 6.13, the absolute values of all of the marginal effects in gaps model are lower than their counterparts in lags model except for driver experience (DEXP). Since marginal effects represent the slopes of the gap acceptance probability function taken at the average values of the attributes, it can be concluded that the *lag probability function* is steeper than the *gap function*;

d. In conclusion, the difference in driver response to gaps and lags as revealed from the likelihood ratio test can not be fully explained based on t-tests and the analysis of marginal effects. Further investigation of this phenomenon is a possible field for further study.

**Table 6.13: Marginal Effects of t Variables Included in Gaps and Lags Models for Maneuver 3 Along With the Relevant t-Statistics.**

| Variable/ Statistic | Gaps Model | | Lags Model | | Coef. Ratio (Gaps/Lags) | t-statistic |
|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Coefficient | St. Error | | |
| Constant (Accept-Choice Specific Constant) | -0.36140 | 0.131590 | -0.766150 | 0.470630 | 0.47 | 0.83 |
| GSEC (Gap Size in Seconds) | 0.115940 | 0.045983 | 0.177140 | 0.107180 | 0.65 | -0.52 |
| MJSD (Speed at Major Road in Km/hr) | -0.008549 | 0.003790 | -0.016528 | 0.009782 | 0.52 | 0.76 |
| TLDL (Total Delay Imposed on Driver) | 0.002431 | 0.001183 | 0.002766 | 0.002634 | 0.88 | -0.12 |
| MNVL (Traffic Volume at Minor Road) | 0.037294 | 0.017389 | 0.179180 | 0.101840 | 0.21 | -1.37 |
| ACDT (Accident Experience in last 2 yr.) | 0.026033 | 0.015658 | 0.030831 | 0.052450 | 0.84 | -0.09 |
| DEXP (Driving Experience in Yr.) | 0.003737 | 0.002005 | 0.003506 | 0.009927 | 1.07 | 0.02 |
| TRDN (Trip Duration in Minutes) | -0.001519 | 0.000965 | -0.003878 | 0.004496 | 0.39 | 0.51 |

### 6.5.6 Driver Response to Near Side and Far Side Gaps/Lags in Maneuver 3

Separate Gap Acceptance Models with a specification identical to the FULL pooled model of Maneuver 3 are developed for near side and far side gaps/lags. These models are used to check whether driver's reaction to one of them is significantly different from his reaction to the other (refer to Chapter 4 Figure 4.4 for a schematic illustration of the near side and far side gap/lag terms). The calibrated models for far side and near side gaps/lags are summarized in Table 6.14 while the detailed models are given in Appendix F. The two models are compared and tested against each other using likelihood ratio test, interpretation of coefficient signs, t-tests, and marginal effects as follows:

#### *i. Likelihood Ratio Test*

The likelihood ratio test described in Chapter 3 (Section 3.6, b- iv) is used to check whether the near-side gaps/lags model is significantly different from the far-side gaps/lags model. Details of this test are listed below:

- $H_0$: The near side and far side gaps/lags models are not different ($\beta_{near\ side} = \beta_{far\ side}$);
- Log likelihood for the pooled model = -62.44;
- Summation of Log likelihoods for the near-side and far-side Gap/lag models

  = -29.45+ (-29.01) = -58.46;

**Table 6.14: Models Calibrated for Near-Side and Far-Side Gaps / Lags in Maneuver 3.**

| Variable/ Statistic | Near-side Gaps/Lags Model | | | Far-side Gaps/Lags Model | | | t-Statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant (Accept-Choice Specific Constant) | -9.2394 | 2.8165 | 0.0010 | -10.0590 | 2.3443 | 0.0000 | 0.2237 |
| GSEC (Gap Size in Seconds) | 2.9585 | 0.5206 | 0.0000 | 2.9752 | 0.5383 | 0.0000 | -0.0223 |
| MJSD (Speed at Major Road in Km/hr) | -0.2629 | 0.0514 | 0.0000 | -0.2287 | 0.0445 | 0.0000 | -0.5024 |
| TLDL (Total Delay Imposed on Driver) | 0.0842 | 0.0285 | 0.0031 | 0.0795 | 0.0248 | 0.0013 | 0.1251 |
| MNVL (Traffic Volume at Minor Road) | 1.3692 | 0.4984 | 0.0060 | 1.4969 | 0.4008 | 0.0002 | -0.1997 |
| ACDT (Accident Experience in last 2 yr.) | 0.3896 | 0.4205 | 0.3542 | 0.9060 | 0.4061 | 0.0257 | -0.8832 |
| DEXP (Driving Experience in Yr.) | 0.1441 | 0.0597 | 0.0158 | 0.0086 | 0.0183 | 0.6396 | 2.1712 |
| TRDN (Trip Duration in Minutes) | -0.0389 | 0.0317 | 0.2206 | -0.0678 | 0.0307 | 0.0274 | 0.6541 |
| n (Number of observations) | 328 | | | 296 | | | |
| L (β) (Log Likelihood value at maximum) | -29.45 | | | -29.01 | | | |
| L (C) (restricted Log Likelihood value) | -183.34 | | | -175.63 | | | |
| $\chi^2$ (Log Likelihood Ratio) | 307.77 | | | 293.23 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 7 | | | 7 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.839 | | | 0.835 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.801 | | | 0.795 | | | |
| PCP (% correctly predicted observations) | 96.34% | | | 95.95% | | | |

• Likelihood ratio test statistic = -2(-62.44-(-58.46)) = 7.96;

• $\chi^2$ table value at (0.05, 8) = 15.51;

• Test result: No enough statistical evidence to reject $H_0$.

The result of this test indicates that the drivers' action to nearside gaps/lags is not significantly different from their action to far-side gaps/lags.

*ii- Signs of Variable Coefficients*

Signs taken by the coefficients of all variables in both of the models agree with the expected driver gap acceptance behavior as formulated in Chapter 3. These signs could be interpreted in the same way as discussed for the previous models.

*iii- t-tests*

The last column in Table 6.14 gives the t-statistics needed to check whether a given coefficient in the nearside gaps/lags models is significantly different from its counterpart in the far-side gaps/lags model. As can be concluded from Table 6.14, none of the coefficients except the coefficient of (DEXP) is significantly different from its counter part at 5%. The t-statistics for traffic and delay attributes (except the speed of the oncoming vehicle are visibly low compared to the statistics of driver attributes. This indicates that the difference (though not significantly different at 5%) in driver action to nearside and far-side gaps/lags could be, basically, related to driver characteristics. An interesting result in this regard is that driving experience (DEXP) is the only variable that

has significantly different coefficients in the two models. As DEXP increases, the probability of accepting a gap will increase in both of the cases but with lower rate in the case of far side gaps/lags as expected. This is a reasonable result since Maneuver 3 is the most difficult among the studied maneuvers which helps in discovering the effects of driver experience. Driver accident record is the second most significant variable in explaining the driver action to near side and farside gaps/lags.

***iv- Analysis of Marginal Effects***

The marginal effects for the near-side and far-side Gap/Lag models along with their significance levels and t-statistics needed to conduct a pair-wise tests on these effects are given in Table 6.15. As can be concluded from Table 6.15, the driving experience (DEXP) is the only variable that has significantly different marginal effects at 5% level. The marginal effects of traffic attributes in both of the models are almost equal as can be concluded from the $8^{th}$ column in Table 6.15. Hence, the statistics presented in Table 6.15 confirm the previously stated conclusion that the difference in driver action to nearside and far-side gaps/lags is basically attributed to driver rather than traffic characteristics. Among traffic attributes, the speed of the oncoming vehicle at major road has the most significantly different coefficients and marginal effects. However, this difference is only significant at around 30% level.

Again the marginal effect of the ACDT in far-side model is higher. This means that drivers with higher accident records tend to accept shorter far-side gaps/lags. If this

**Table 6.15: Marginal Effects For The Variables Included in the Near-side And Far-side Gaps/Lags Models Calibrated For Maneuver 3 Along with the Relevant t-Statistics.**

| Variable/ Statistic | Near-side Gaps/Lags Model | | | Far-side Gaps/Lags Model | | | Coef. Ratio (Near/Far) | t-Statistic |
|---|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | | |
| Constant (Accept-Choice Specific Constant) | -0.535190 | 0.183200 | 0.0035 | -0.530150 | 0.193370 | 0.0061 | 1.01 | -0.02 |
| GSEC (Gap Size in Seconds) | 0.171370 | 0.061221 | 0.0051 | 0.156810 | 0.059026 | 0.0079 | 1.09 | 0.17 |
| MJSD (Speed at Major Road in Km/hr) | -0.015228 | 0.006149 | 0.0133 | -0.012056 | 0.004799 | 0.0120 | 1.26 | -0.41 |
| TLDL (Total Delay Imposed on Driver) | 0.004880 | 0.002037 | 0.0166 | 0.004192 | 0.001856 | 0.0239 | 1.16 | 0.25 |
| MNVL (Traffic Volume at Minor Road) | 0.079310 | 0.034933 | 0.0232 | 0.078895 | 0.033423 | 0.0183 | 1.01 | 0.01 |
| ACDT (Accident Experience in last 2 yr.) | 0.022570 | 0.025109 | 0.3687 | 0.047750 | 0.024344 | 0.0498 | 0.47 | -0.72 |
| DEXP (Driving Experience in Yr.) | -0.002253 | 0.001833 | 0.2191 | -0.003573 | 0.001935 | 0.0648 | 0.63 | 0.50 |
| TRDN (Trip Duration in Minutes) | 0.008344 | 0.003694 | 0.0239 | 0.000452 | 0.000960 | 0.6381 | 18.48 | 2.07 |

statement is reversed, it can be concluded that drivers who accept shorter far-side gaps have higher accident records. This result is expected due to the high risk involved in accepting short gaps in general and short farside gaps in particular.

## 6.6 TESTING THE SIGNIFICANCE OF DRIVER, VEHICLE, AND TRIP ATTRIBUTES

Some of the newly studied driver, vehicle, and trip attributes were found to be significant in the gap acceptance behavioral models calibrated for the three maneuvers considered in this study. To check the statistical significance and the importance of these attributes in explaining driver gap acceptance behavior three levels of analysis related to likelihood ratio tests, signs of variable coefficients, and goodness of fit indices were considered:

***i- Likelihood Ratio Tests***

The Likelihood Ratio Test discussed in Chapter 3 (Section 3.6, test b-vi) was used to check whether the FULL and the BASIC pooled models calibrated for the three studied maneuvers are significantly different. The test statistic for the mentioned test equals twice the difference of the Log likelihoods of the two models. This statistic is $\chi^2$ distributed

with degrees of freedom equivalent to the difference in the number of variables in the two models. The null hypothesis for this test is:

> $H_0$: The BASIC and the FULL pooled models for a given maneuver are not different

This hypothesis will be rejected at 5% level of significance if the calculated test statistic is larger than the table value of $\chi^2$. The results of this test along with the basis statistics needed to conduct it are summarized in Table 6.16. The last row in Table 6.16 indicates that the null hypothesis is rejected which means that the BASIC and the FULL pooled models are significantly different at 5% level. Hence, the addition of driver, vehicle, and trip attributes has improved the explanation and the predicting power of the models significantly.

***ii- Signs of Model coefficients:***

Signs taken by the coefficients of all of the driver, vehicle, and trip attributes in the FULL pooled models are according to the expected driver gap acceptance behavior as formulated in Chapter 3. The interpretations of these signs are discussed in the previous sections of this chapter.

**Table 6.16: Likelihood Ratio Tests Between BASIC and FULL Pooled Models**

| Statistic | M1 ** | M2 | M3 |
|---|---|---|---|
| $H_0$: FULL and BASIC Pooled Models are not different | | | |
| Log Likelihood for BASIC Pooled Model L(BASIC) | -65.34 | -58.41 | -70.81 |
| Log Likelihood for FULL Pooled Model L(FULL) | -49.08 | -50.19 | -62.44 |
| Test Statistic = -2 [L(FULL) - L(BASIC)] | 32.5 | 16.44 | 16.74 |
| Test Degrees of Freedom (D.F.F - D.F.B) | 4 | 3 | 3 |
| Chi-Square, Table Value at 5% level | 9.49 | 7.81 | 7.81 |
| Test Result | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |

** Mn: The $n^{th}$ maneuver

***iii- Goodness of fit measures***

The $\rho^2$, the adjusted $\rho^2$, and the percent of correctly predicted observations of the FULL pooled models are high and they reflect a good fit to the modeled data and a good prediction capability of the calibrated models. The goodness of fit measures for FULL pooled models are also higher than the goodness of fit measures for the BASIC pooled models which indicates that the FULL pooled models are more powerful in replicating the observed driver gap acceptance behavior.

## 6.7 MODEL COMPARISON

This section presents the results of comparing the BASIC and FULL pooled models calibrated for the three maneuvers and highlights the basic similarities and differences between these models.

### 6.7.1 Comparison of the BASIC Pooled Models for the Three Maneuvers.

The BASIC pooled models calibrated for the three maneuvers including gap, traffic, and delay attributes are summarized in Table 6.17. The basic comments on these models include:

**Table 6.17: Summary of The BASIC Pooled Models For Maneuvers 1,2, and 3.**

| Variable/ Statistic | Maneuver 1 | | | Maneuver 2 | | | Maneuver 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level | Marginal Effect |
| Constant (Accept-Choice Specific Constant) | -2.391 | 0.079 | -0.1195 | -16.115 | 0.0000 | -0.0982 | -7.508 | 0.0000 | -0.5928 |
| GSEC (Gap Size in Seconds) | 1.303 | 0.000 | 0.0651 | 2.264 | 0.0000 | 0.0138 | 2.510 | 0.0000 | 0.1981 |
| MJSD (Speed at Major Road in Km/hr) | -0.185 | 0.000 | -0.0093 | - | - | - | -0.213 | 0.0000 | -0.0168 |
| TLDL (Total Delay Imposed on Driver) | 0.095 | 0.000 | 0.0047 | 0.163 | 0.0000 | 0.0010 | 0.061 | 0.0001 | 0.0048 |
| MNVL (Traffic Volume at Minor Road) | 0.829 | 0.003 | 0.0414 | 0.925 | 0.0034 | 0.0056 | 1.088 | 0.0000 | 0.0859 |
| n (Number of observations) | 337 | | | 396 | | | 624 | | |
| L (β) (Log Likelihood value at maximum) | -65.34 | | | -58.41 | | | -70.81 | | |
| L (C) (restricted Log Likelihood value) | -227.28 | | | -249.20 | | | -359.42 | | |
| $\chi^2$ (Log Likelihood Ratio) | 323.88 | | | 381.57 | | | 577.22 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | | 3 | | | 4 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | | 0.000 | | | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.713 | | | 0.766 | | | 0.803 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.695 | | | 0.754 | | | 0.792 | | |
| PCP (% correctly predicted observations) | 89.32% | | | 94.19% | | | 95.35% | | |

a. Gap size (GSEC), total delay imposed on driver (TLDL), and traffic volume at minor road (MNVL) are significant variables in all of the BASIC pooled models regardless of the studied maneuver;

b. Speed of oncoming vehicle at major road (MJSD) is significant in the models calibrated for Maneuvers 1 and 3 but not in the model of Maneuver 2. As discussed earlier, the effect of speed on driver gap acceptance behavior could be, basically, related to potential accident risks. A driver executing either maneuver 1 or 3 needs to cross the path of the oncoming vehicle. Any possible accident in this case would be of the right angle type in which the speed effect is predominant. In Maneuver 1 at the other side, the driver merges into the path of the oncoming vehicle. Any possible accident in this case would be of the rear end type in which the effect of speed is less. Actually, the effective speed in such an accident would be the difference between the speed of the oncoming vehicle ($S_o$) and the speed of the merging vehicle ($S_m$), i.e. ($S_o$ - $S_m$). This could explain why (MJSD) is significant in Maneuvers 1 and 3 models but not in the Maneuver 2 model;

c. The visibly higher marginal effect of the constant term in the model of Maneuver 3 could be related to the fact that the average number of rejected gaps/lags per driver in Maneuver 3 is more than 4 times higher than the average number of rejected gaps/lags per driver in Maneuvers 1 and 2. The constant term takes negative signs in

the three models which indicates that, everything else being equal, drivers have higher tendency to reject gaps/lags;

d. The marginal effect of (MJSD) in Maneuver 3 is around twice its effect in Maneuver 1. This indicates the importance of (MJSD) in explaining driver behavior in this maneuver. This result could also be related to the discussion presented in (a) above;

e. The marginal effect of gap size (GSEC) in Maneuvers 1 and 3 in which the driver needs to cross the path of the approaching vehicle is higher than its effect in Maneuver 2 in which the driver only merges in the path of the approaching vehicle. (GSEC) has the highest marginal effect in the model calibrated for Maneuver 3 which is considered to be the most difficult one among the studied maneuvers;

f. The goodness of fit indices and the percent correctly predicted observations for the three models are comparable and have high values that indicate good explanation and prediction capabilities of the calibrated models.

### 6.7.2 Comparison of the FULL Pooled Models for the Three Maneuvers

The FULL pooled models calibrated for the three maneuvers after introducing the significant driver, vehicle and trip attributes are summarized in Table 6.18. The main comments on these models include:

**Table 6.18: Summary of the FULL Pooled Models For Maneuvers 1,2, and 3.**

| Variable/ Statistic | Maneuver 1 | | | Maneuver 2 | | | Maneuver 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coeff. | Sig. Level | Marginal effect | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level | Marginal effect |
| Constant (Accept-Choice Specific Constant) | -5.851 | 0.0023 | -0.1091 | -16.38 | 0.0000 | -0.0292 | -9.145 | 0.0000 | -0.5916 |
| GSEC (Gap Size in Seconds) | 1.831 | 0.0000 | 0.0342 | 2.728 | 0.0000 | 0.0049 | 2.746 | 0.0000 | 0.1776 |
| MJSD (Speed at Major Road in Km/hr) | -0.224 | 0.0000 | -0.0042 | - | - | - | -0.229 | 0.0000 | -0.0148 |
| TLDL (Total Delay Imposed on Driver) | 0.118 | 0.0007 | 0.0022 | 0.176 | 0.0000 | 0.0003 | 0.083 | 0.0000 | 0.0054 |
| MNVL (Traffic Volume at Minor Road) | 1.074 | 0.0028 | 0.0200 | 1.217 | 0.0006 | 0.0022 | 1.235 | 0.0000 | 0.0799 |
| ACDT (Accident Experience in last 2 yr.) | 0.811 | 0.0023 | 0.0151 | - | - | - | 0.676 | 0.0168 | 0.0437 |
| VLTN (Violation Experience in last 1 yr.) | 0.595 | 0.0118 | 0.0111 | - | - | - | - | - | - |
| DEXP (Driving Experience in yr.) | 0.125 | 0.0055 | 0.0023 | - | - | - | 0.095 | 0.0128 | 0.0062 |
| DSEX (Driver Sex, Male or Female) | - | - | - | -1.561 | 0.0525 | -0.0028 | - | - | - |
| DAGE (Driver Age in yr.) | - | - | - | -0.061 | 0.0266 | -0.00011 | - | - | - |
| TRDN (Trip Duration in Minutes) | -0.055 | 0.0423 | -0.0010 | -0.025 | 0.0326 | -0.00004 | -0.049 | 0.0139 | -0.0031 |
| n (Number of observations) | 337 | | | 396 | | | 624 | | |
| L (β) (Log Likelihood value at maximum) | -49.08 | | | -50.19 | | | -62.44 | | |
| L (C) (restricted Log Likelihood value) | -227.28 | | | -249.20 | | | -359.42 | | |
| $\chi^2$ (Log Likelihood Ratio) | -356.41 | | | 398.01 | | | 593.96 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 8 | | | 6 | | | 7 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | | 0.000 | | | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.784 | | | 0.799 | | | 0.826 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.749 | | | 0.775 | | | 0.807 | | |
| PCP (% correctly predicted observations) | 92.88% | | | 94.70% | | | 95..83% | | |

a. The comments made in Section 6.7.1 about the BASIC pooled models presented in Table 6.17 also apply for the FULL pooled models which are given in Table 6.18;

b. Signs of the coefficients of the new variables in the FULL pooled models agree with the expected driver behavior as explained previously;

c. Each of the FULL pooled models in Table 6.18 is significantly different from its counterpart BASIC pooled model as discussed in Section 6.6 which indicates that introducing driver, vehicle, and trip attributes has improved the models significantly;

d. In terms of the significant variables, the FULL pooled models for Maneuvers 1 and 3 are similar. The only difference in this regard is that driver traffic violation experience (VLTN) is significant in Maneuver 1 and not in Maneuvers 3. In Maneuver 3, driver accident and violation experiences (ACDT, VLTN) were found to be highly correlated. The model including ACDT is, however, found to be better;

e. None of the ACDT, VLTN and DEXP variables is significant in the model of Maneuver 2. In this model, the driver age (DAGE) and his driving experience (DEXP) were found to be highly correlated and it was found that the model with (DAGE) in this case is better. Regarding driver sex, it was found to be significant only in the FULL pooled model of Maneuver 2 which represent the right turn from minor stream to major stream;

f. The marginal effects of ACDT and DEXP in Maneuver 3 model are higher compared to their effects in Maneuver 1 model.

The above discussion indicates that the FULL pooled models are significantly different form the basic models and that the driver gap acceptance models for Maneuvers 1 and 3 are very similar while the model of Maneuver 2 includes a unique variable which is the driver sex (DSEX).

## 6.8 MODELING OF SPECIAL CASES

There are some variables that apply only for subsets of the collected data as discussed in Section 6.2 in this chapter. In this regard, separate models were developed for cases (ii) and (iii) described in that section while the effects of variables included in group (i) are investigated based on the results of the average and critical gap analyses conducted in Chapter 5.

### 6.8.1 Cases Which Involved Driver Gap/Lag Rejection Decisions

The additional variables which are relevant to the cases that involved gap/lag rejection decisions include PMET, PSEC, and DAMR. The final models calibrated for

the three maneuvers using observations relevant to this case are summarized in Table 6.19. The detailed separate models calibrated for each maneuver along with the detailed discussions and interpretations of these models are given in Appendix G. The main comments on Table 6.19 include:

a. Signs of the coefficients for all of the variables included in the models are according to the expected driver behavior;

b. Vehicle occupancy (OCUP) is significant at 5% level in the models developed for the three maneuvers. This indicates that drivers of vehicles with high occupancies tend to accept longer gaps in order to avoid any risk of an accident;

c. Models of Maneuvers 1 and 3 are similar except that (ACDT) and (DEXP) are significant in the model calibrated for Maneuver 3 but not in the model calibrated for Maneuver 1. This could be related to two reasons; the smaller sample available for Maneuver 1, and the relatively higher difficulty of Maneuver 3 which allow for the variations in gap acceptance behavior which are caused by differences in driver characteristics to appear. However, a model calibrated for Maneuver 3 without (ACDT) and (DEXP) was found to be *not* significantly different from the model with (ACDT) and (DEXP) if the significance level is relaxed to 10% instead of 5%;

d. The variable that measures the driver gap acceptance consistency is significant in the models of Maneuvers 1 and 3 but not in the model of Maneuver 2. The relative

**Table 6.19: Summary of Models Calibrated for Cases Which Involved Driver Gap/Lag Rejection Actions in Maneuvers 1,2 and 3.**

| Variable/ Statistic | Maneuver 1 | | | Maneuver 2 | | | Maneuver 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coeff. | Sig. Level | Marginal effect | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level | Marginal effect |
| Constant (Accept-Choice Specific Constant) | -7.677 | 0.0885 | -0.5501 | -29.93 | 0.0029 | -0.0844 | -12.33 | 0.0000 | -0.2714 |
| GSEC (Gap Size in Seconds) | 2.833 | 0.0003 | 0.2030 | 5.087 | 0.0027 | 0.0144 | 4.270 | 0.0000 | 0.0940 |
| MJSD (Speed at Major Road in Km/hr) | -0.263 | 0.0026 | -0.0188 | - | - | - | -0.318 | 0.0000 | -0.0070 |
| TLDL (Total Delay Imposed on Driver) | 0.154 | 0.0353 | 0.0111 | 0.428 | 0.0142 | 0.0012 | 0.066 | 0.0177 | 0.0015 |
| MNVL (Traffic Volume at Minor Road) | 2.335 | 0.0171 | 0.1674 | - | - | - | 1.191 | 0.0029 | 0.0262 |
| ACDT (Accident Experience in last 2 yr.) | - | - | - | - | - | - | 0.663 | 0.0469 | 0.0146 |
| DEXP (Driving Experience in yr.) | - | - | - | - | - | - | 0.124 | 0.0183 | 0.0027 |
| DFAM (Driver Familiarity, visiting times per week) | - | - | - | 0.133 | 0.0480 | 0.0004 | - | - | - |
| OCUP (Vehicle Occupancy) | -0.579 | 0.0259 | -0.0415 | -1.348 | 0.0377 | -0.0038 | -0.240 | 0.0505 | -0.0053 |
| DAMR (Diff. between accepted & max. rejected gap) | -0.875 | 0.0420 | -0.0627 | - | - | - | -0.390 | 0.0592 | -0.0086 |
| SSEC (Succeeding Gap, seconds) | - | - | - | -1.197 | 0.0241 | 0.0034 | - | - | - |
| n (Number of observations) | 135 | | | 126 | | | 460 | | |
| L (β) (Log Likelihood value at maximum) | -14.04 | | | -7.99 | | | -34.37 | | |
| L (C) (restricted Log Likelihood value) | -91.93 | | | -84.63 | | | -260.85 | | |
| $\chi^2$ (Log Likelihood Ratio) | 155.80 | | | 153.29 | | | 453.00 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 6 | | | 5 | | | 8 | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | 0.0000 | | | 0.0000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.847 | | | 0.906 | | | 0.868 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.782 | | | 0.847 | | | 0.838 | | |
| PCP (% correctly predicted observations) | 96.30% | | | 97.62% | | | 97.17% | | |

difficulty of Maneuvers 1 and 3 allows for the variations in driver gap acceptance behavior to appear.

e. Values of $\rho^2$ and percentages of the correctly predicted observations for the three models are comparable. The high values of these statistics indicate the good ability of the calibrated models to explain driver behavior.

### 6.8.2 Cases in Which the Effect of an Ahead Driver Exists

The additional variables relevant to the cases in which the effect of an ahead driver exists are ASEC, AMET, AREJ, and AENT. The final models calibrated for the three maneuvers using observations relevant to these cases are given in Table 6.20. The detailed models calibrated for each maneuver along with the detailed interpretations and discussions on these models are given in Appendix G. The main comments on Table 6.20 include the following:

a. Signs of the coefficients in the three models agree with the expected driver gap acceptance behavior. The positive signs of (GSEC, TLDL, and MNVL) have been already interpreted elsewhere. The positive sign of (ACTN) means that drivers who base their gap acceptance decisions on estimating the distance of the oncoming vehicles accept longer gaps compared to drivers who base their gap acceptance decisions on estimating the speed of the oncoming vehicles. The positive sign of (AREJ) is expected since this variable is another measure of the delay (particularly

**Table 6.20: Summary of the Models Calibrated for Cases in Which the Effect of an Ahead Driver Exists in Maneuvers 1,2 and 3.**

| Variable/ Statistic | Maneuver 1 | | | Maneuver 2 | | | Maneuver 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coeff. | Sig. Level | Marginal effect | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level | Marginal effect |
| Constant (Accept-Choice Specific Constant) | -1.577 | 0.6014 | -0.0115 | -22.674 | 0.0000 | -0.9741 | -9.902 | 0.0167 | -1.2722 |
| GSEC (Gap Size in Seconds) | 1.721 | 0.0128 | 0.0125 | 2.844 | 0.0000 | 0.1222 | 2.140 | 0.0021 | 0.2749 |
| MJSD (Speed at Major Road in Km/hr) | -0.277 | 0.0054 | -0.0020 | - | - | - | -0.168 | 0.0186 | -0.0216 |
| TLDI. (Total Delay Imposed on Driver) | 0.233 | 0.0519 | 0.0017 | 0.247 | 0.0001 | 0.0106 | 0.078 | 0.0573 | 0.0100 |
| MNVL (Traffic Volume at Minor Road) | - | - | - | 1.145 | 0.0448 | 0.0492 | - | - | - |
| ACTN (Gap Acceptance Criteria) | - | - | - | 1.603 | 0.0981 | 0.0689 | - | - | - |
| AREJ (Number of Gaps Rejected by the Ahead Driver) | 1.578 | 0.0189 | 0.0115 | - | - | - | 5.596 | 0.0383 | 0.0766 |
| n (Number of observations) | 66 | | | 156 | | | 73 | | |
| L (β) (Log Likelihood value at maximum) | -10.15 | | | -21.44 | | | -9.63 | | |
| L (C) (restricted Log Likelihood value) | -44.65 | | | -99.97 | | | -48.60 | | |
| $\chi^2$ (Log Likelihood Ratio) | 68.99 | | | 157.08 | | | 77.94 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | | 4 | | | 4 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | | 0.0000 | | | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.773 | | | 0.786 | | | 0.802 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.683 | | | 0.746 | | | 0.720 | | |
| PCP (% correctly predicted observations) | 92.42% | | | 94.87% | | | 94.52% | | |

the delay in queue) imposed on the driver. Hence, it is expected that gap acceptance probability will increase as (AREJ) increases;

b. Models of Maneuvers 1 and 3 are identical in terms of the significant variables in the two models. The variable representing the number of rejected gaps by the ahead driver (AREJ) is significant at levels better than the total delay variable (TLDL). This indicates that the effect of the delay imposed on driver in this case is better represented by (AREJ);

c. Values of the goodness of fit indices ($\rho^2$) and percentages of the correctly predicted observations for the three models are comparable and indicate that the explanation capability of the models is good.

### 6.8.3 Effects of Variables Which Measure Driver Estimation Ability

Three variables were defined in this study to investigate the effect of driver ability to estimate the speed of the oncoming vehicle and the size of the gap/lag he accepted on his behavior. During field interviews, each of the interviewed drivers was asked to estimate the speed and the distance of the oncoming vehicle that created the gap he accepted. These estimates were later compared to the actual values extracted from video records to create the three variables mentioned above. These variables represent the difference between the actual and the estimated values of each of the speed of the

oncoming vehicle and the time and distance size of the accepted gap. The variables are abbreviated as:

DEAS = difference between the actual and the estimated speed;

DEAG = difference between the actual and the estimated time size of the accepted gaps/lags);

DEAD = difference between the actual and the estimated distance size of the accepted gap.

As discussed previously, these variables cannot be modeled using the formulation adopted in this study. The effects of these variables were discussed in Chapter 5 based on the results of the average and critical gap analyses that were conducted in that chapter.

## 6.9 MODEL TRANSFERABILITY

As discussed in Section 6.2, the transferability of the calibrated models to similar intersections was checked using likelihood ratio and t-tests. A model with an identical specification to the FULL pooled model of the concerned maneuver was calibrated for each of the studied sites separately. The basic statistics needed to conduct the above mentioned likelihood ratio and t-tests along with the results of these tests are summarized in Tables 6.21 and 6.22. The summarized and the detailed models calibrated for Sites 1 and 2 separately are given in Appendix H. As can be concluded from the t-statistics given

Table 6.21: Coefficients of the FULL Models Calibrated for Individual Sites Along with the Relevant t-Test Statistics

| Variable | Maneuver 1 | | | | | Maneuver 2 | | | | | Maneuver 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Site 1 Model | | Site 2 Model | | t-Statistic | Site 1 Model | | Site 2 Model | | t-statistic | Site 1 Model | | Site 2 Model | | t-Statistic |
| | Coeff.t | St. Er. | Coeff.t | St. Er. | | Coeff. | St. Er. | Coeff.t | St. Er. | | Coeff. | St. Er. | Coeff. | St. Er. | |
| Constant | -7.2447 | 2.9171 | -10.728 | 4.0876 | 0.6936 | -29.779 | 7.5235 | -22.297 | 5.1620 | -0.8200 | -11.245 | 3.9005 | -8.4811 | 1.8450 | -0.6406 |
| GSEC | 1.9515 | 0.4130 | 2.5271 | 0.6429 | -0.7533 | 3.8014 | 0.8514 | 2.9633 | 0.5662 | 0.8197 | 3.3958 | 0.8624 | 2.8314 | 0.4429 | 0.5822 |
| MJSD | -0.1720 | 0.0496 | -0.2926 | 0.0777 | 1.3088 | | | | | | -0.3262 | 0.0946 | -0.2296 | 0.0400 | -0.9400 |
| TLDL | 0.2439 | 0.0800 | 0.2339 | 0.0778 | 0.0901 | 0.3221 | 0.0857 | 0.2253 | 0.0529 | 0.9612 | 0.1590 | 0.0595 | 0.0600 | 0.0188 | 1.5867 |
| MNVL | 1.1347 | 0.4484 | 2.5532 | 0.9075 | -1.4014 | 1.8920 | 0.7448 | 0.7599 | 0.5208 | 1.2457 | 2.5353 | 0.8421 | 1.1412 | 0.3486 | 1.5297 |
| DSEX | | | | | | 3.5115 | 1.3189 | 3.3516 | 1.2313 | 0.0886 | | | | | |
| DAGE | | | | | | 0.0339 | 0.0349 | 0.0360 | 0.0525 | -0.0334 | | | | | |
| ACDT | 0.0768 | 0.4975 | 1.3649 | 0.5834 | -1.6802 | | | | | | 0.8542 | 0.5049 | 0.5187 | 0.3286 | 0.5571 |
| VLTN | 0.6518 | 0.3812 | 1.3453 | 0.7245 | -0.8471 | | | | | | | | | | |
| DEXP | 0.0493 | 0.0600 | 0.1351 | 0.0892 | -0.7992 | | | | | | 0.1419 | 0.0775 | 0.0106 | 0.0582 | 1.3554 |
| TRDN | -0.1349 | 0.0502 | -0.0456 | 0.0333 | -1.4828 | -0.0280 | 0.0283 | -0.0200 | 0.0246 | -0.2144 | -0.1095 | 0.0432 | -0.0227 | 0.0251 | -1.7380 |
| n | 176 | | 161 | | | 216 | | 180 | | | 265 | | 359 | | |
| L(B) | -23.13 | | -18.53 | | | -19.56 | | -25.31 | | | -15.56 | | -42.48 | | |
| L(C) | -117.41 | | -109.65 | | | -133.76 | | -115.25 | | | -159.7 | | -198.8 | | |
| Chi-squared | 188.56 | | 182.24 | | | 228.4 | | 179.88 | | | 288.28 | | 312.64 | | |
| D. F | 8 | | 8 | | | 6 | | 6 | | | 7 | | 7 | | |
| Sig. Level | 0.0000 | | 0.0000 | | | 0.0000 | | 0.0000 | | | 0.0000 | | 0.0000 | | |
| Rho-squared | 0.803 | | 0.831 | | | 0.85 | | 0.78 | | | 0.903 | | 0.786 | | |
| Adj. Rho-square | 0.735 | | 0.758 | | | 0.81 | | 0.73 | | | 0.859 | | 0.751 | | |
| % correctly pred | 93.75% | | 95.65% | | | 98.15% | | 93.33% | | | 98.11% | | 95.54% | | |

**Table 6.22:Likelihood Ratio Tests for Site Effect for Maneuvers 1, 2, and 3**

$H_0$: Vector of coefficients of site 1 model equals the vector of coefficients of Site 2 model or , alternatively, Site 1 model is not different from Site 2 model

| Maneuver | $L_{pooled}$ | $L_{Site\ 1}$ | $L_{Site2}$ | LRTS | D.F | Table Value | Test Result |
|---|---|---|---|---|---|---|---|
| Maneuver | -49.08 | -23.13 | -18.53 | 14.84 | 9 | 16.92 | Accept $H_0$ |
| Maneuver | -50.19 | -19.56 | -25.31 | 10.64 | 7 | 14.07 | Accept $H_0$ |
| Maneuver | -62.44 | -15.56 | -42.48 | 4.4 | 8 | 15051 | Accept $H_0$ |

in Table 6.21, none of the Site 1 model coefficients is significantly different from the corresponding coefficient in Site 2 model. Furthermore, the likelihood ratio tests given in Table 6.22 show that the Site 1 model is ***not*** significantly different from the Site 2 model at 5% level of significance. This result also applies for Maneuvers 1, 2, and 3. Hence, the conducted tests clearly indicate that site by itself (at least in this case) is not a source for variations in driver gap acceptance behavior and that the calibrated models can be transferred to similar sites. However, it should be emphasized that the results of this study are applicable to the type of the studied junction (T- intersections at single carriageways) under the studied traffic, enforcement, and socioeconomic conditions. Similar studies should be conducted for similar sites but under different driving, enforcement, and socioeconomic characteristics before being able to generalize the results of this study.

## 6.10 OTHER BINARY CHOICE MODELS

Models other than the binomial logit model which are applicable to qualitative response situations in which the dependent variable is inherently discrete (takes the values 0 and 1 in binary choice cases) include the Binary Probit and the Maximum Score models, [Greene, 1995]. Summary information on these models is given in Appendix I. Discussing the details of these models is beyond the scope of this study. *The main purpose of this section is to demonstrate the possibility of applying binary choice models other than the binomial logit model which is considered in the study.* Data collected for

Maneuver 1 is used for this demonstration. The considered model is identical in its specification to the BASIC pooled model given in Table 6.1. The summary of the obtained models is given in Table 6.23 while the detailed models are given in Appendix I. The main comments on models given in Table 6.23 include:

a. The goodness of fit index for Binomial Logit and Binary Probit models and the percent correctly predicted observations for the three models are comparable. The values obtained for logit and probit models are almost identical;

b. Signs of the coefficients in the three models are identical and agree with the expected driver gap acceptance behavior;

c. Coefficient values for the Probit and the Maximum Score models are near to each other but visibly different from the coefficients of the Logit model. However, the Probit model coefficients can be obtained by factoring down the Logit model coefficients by a factor of around 0.58;

d. Although the coefficients of the Probit and the Logit models are visibly different, the marginal effects of the two models are less different. Again, it is observed that the Probit marginal effects can be obtained by factoring up the Logit model values by a factor of around 1.25;

**Table 6.23: Summary of the Basic Logit, Probit, and Maximum Score Models Calibrated For Maneuver 1.**

| Variable/ Statistic | Binomial Logit Model | | | Binary Probit Model | | | Maximum Score Model | |
|---|---|---|---|---|---|---|---|---|
| | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level | Marginal Effect | Coeff. | Sig. Level |
| Constant (Accept-Choice Specific Constant) | -2.391 | 0.0787 | 0.1195 | -1.395 | 0.0685 | -0.1509 | 0.284 | 0.6637 |
| GSEC (Gap Size in Seconds) | 1.303 | 0.0000 | 0.0651 | 0.738 | 0.0000 | 0.0799 | 0.756 | 0.0362 |
| MJSD (Speed at Major Road in Km/hr) | -0.185 | 0.0000 | -0.0093 | -0.106 | 0.0000 | -0.0115 | -0.162 | 0.0427 |
| TLDL (Total Delay Imposed on Driver) | 0.095 | 0.0008 | 0.0047 | 0.055 | 0.0004 | 0.0059 | 0.049 | 0.7352 |
| MNVL (Traffic Volume at Minor Road) | 0.829 | 0.0028 | 0.0414 | 0.496 | 0.0014 | 0.0536 | 0.564 | 0.3326 |
| n (Number of observations) | 337 | | | 337 | | | 337 | |
| L (β) (Log Likelihood value at maximum) | -65.34 | | | -64.19 | | | N.A* | |
| L (C) (restricted Log Likelihood value) | -227.28 | | | -227.28 | | | N.A | |
| $\chi^2$ (Log Likelihood Ratio) | 323.88 | | | 326.18 | | | N.A | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | | 4 | | | N.A | |
| Sig. Level for $\chi^2$ Test | 0.000 | | | 0.000 | | | N.A | |
| $\rho^2$ (Goodness of fit Index) | 0.713 | | | 0.718 | | | N.A | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.695 | | | 0.700 | | | N.A | |
| PCP (% correctly predicted observations) | 89.32% | | | 89.61% | | | 91.69 | |

* Not Applicable

e. The significance levels for the estimated coefficients in Logit and Probit models are close to each other but visibly different from the significance levels in the Maximum Score model. The TLDL and MNVL variables are significant at high levels in Logit and Probit models but significant only at 73.5% and 33.3% levels, respectively in the Maximum Score model;

f. An interesting different result in the Maximum Score model is the positive sign taken by the "accept-choice specific constant". This could be a more reasonable result than the results obtained from Logit and Probit models in this regard since the positive sign of the constant term means that, every thing else is equal, drivers prefer to accept gaps.

The detailed investigations of the applicability of binary choice models other than the Binomial Logit model to study driver gap acceptance behavior and to compare the results obtained from theses models are recommended as a topic for further future research.

## 6.11 SUMMARY

More than 40 variables were considered for analysis and around 30 gap acceptance models were calibrated according to the modeling procedure detailed in Section 6.2. The significant variables and the implications and results derived from the developed models

were discussed. Due statistical tests were carried out for the calibrated models and the possibility of applying other types of binary choice models was demonstrated. All of the developed models are significant at 0% level and have relatively high values of the goodness of fit indices and of the "percent correctly predicted" observations. Some of the driver, vehicle, and trip attributes were found to be significant in explaining driver gap acceptance behavior at 5% or better levels. The main models developed for each of the studied maneuvers include:

a. BASIC pooled model which include gap, traffic, and delay attributes only;
b. FULL pooled model which include driver, vehicle and trip attributes in addition to gap, traffic, and delay attributes;
c. Separate models for Gaps and Lags;
d. Models for cases that include gap rejection decisions;
e. Models for cases in which the effect of an ahead driver exists;
f. Separate models for Sites 1 and 2.

# CHAPTER 7

# APPLICATIONS OF GAP ACCEPTANCE ANALYSIS

## 7.1: INTRODUCTION

The first and main objective of this research was to develop behavioral models for driver gap acceptance at priority intersections, explore out the effects of the main driver, traffic, gap, and trip characteristic on driver behavior, and establish a more clear picture about the effects of these factors.

Nevertheless, a secondary, though important, part of the research was directed to demonstrate some of the potential applications in traffic engineering field. Further demonstrations of the applicability of the developed models and results are also recommended as a subject for further research in this field. These issues along with the

main applications of gap acceptance concepts addressed in literature are discussed in this chapter.

## 7.2: APPLICATIONS ADDRESSED IN LITERATURE

### 7.2.1: Prediction of Capacity and Delay

One purpose of studying driver gap acceptance behavior at priority intersections (especially roundabouts) is to estimate delay and capacity at those intersections [Bottom and Ashworth (1978), Chung et al. (1992), Darzentas (1989), Fitzpatrick (1991), Mahmassani and Sheffi (1981), Robertson (1994), Troutbeck (1984) and Wald (1976)]. The use of gap acceptance method for this purpose is well entrenched into literature. Analytical and simulation techniques have been the two main methods used for this purpose [Troutbeck (1984)]. Empirical relationships were also developed [Kimber (1989) and Kimber et al. (1986)]. The gap acceptance model is a necessary component of all analytical models developed to predict delay [Bottom and Ashworth (1978)].

Capacity and delay estimation along with other priority intersection operation measures like queue length depend on many factors that include [Cheng and Allam (1992)]:

a. Headway (gap) distribution on major stream;

b. Gap acceptance characteristics for drivers on minor road described by gap acceptance function;

c. Critical gaps distribution;

d. Move-up time distribution on minor stream;

e. Arrival pattern on minor stream.

Assumptions regarding these factors have significant impacts on the predicted values of capacity and delay especially at higher major stream flow rates [Akcelik (1994) and Cheng and Allam (1992)]. As cited by Cheng and Allam (1992), the earliest and probably the most widely used priority intersection model was developed by Tanner (1962). Average delay and capacity were expressed as functions of major and minor road flows, major stream headway, constant critical gap (step gap acceptance function) and constant move-up time. After Tanner's work, many prediction models were built based, mainly, on the consistent driver behavior concepts and probabilistic gap acceptance functions including probit and logit models.

### 7.2.2: Other Applications

In addition to capacity and delay predictions, gap acceptance concepts can form the base for other priority intersection analyses. These include accident risk and conflict studies [Adebisi (1982a), Ashton (1971), Darzentas (1989), Darzentas and Mcdowell (1981), Dickinson and Waterfall (1984), Fitzpatrick (1991) and Wald

(1976)], merging process at on-ramps [Mahmassani and Sheffi (1981), Makigami and Matsuo (1990), Polus et al. (1985) and Wald (1976)], intersections control requirements [Adebisi (1982a), Adebisi (1982b), Maze (1981), Wald (1976)], pedestrian crossing [Mahmassani and Sheffi (1981), Troutbeck (1975) and Wald (1976)], lane changing maneuvers [Mahmassani and Sheffi (1981) and Wald (1976)], signal warrants [Fitzpatrick (1991), Neudorff (1985) and Robertson (1994)], and sight distance requirements [Fitzpatrick (1991) and Mason et al. (1989)]. Literature has cited the above as potential application areas of gap acceptance concepts. However, few and limited studies were conducted to explain some of these applications by researchers like Fitzpatrick (1991), Mason et al. (1989) and Neudorff (1985). The brief and limited trails to develop gap based concepts for establishing signal warrants is basically based on the concept that "it is major stream gap availability, not solely volume, that determines the necessity of a traffic signal" [Neudorff (1985)]. Mason, et al. (1989) discussed the idea of using gap acceptance concept to establish practical intersection sight distance. They stated that the criterion in this context is that "drivers on minor road should have sight distance which is at least equal to the length of their critical distance gap".

## 7.3: APPLICATIONS DEMONSTRATED IN THIS RESEARCH

### 7.3.1: Conceptual Development

Gap acceptance principles have many possible applications as discussed in Section 7.2. The applicability of gap acceptance concepts , in general, and the developed models , in particular, were demonstrated in the following three areas:

a. Establishment of sight distance requirements at priority intersections;

b. Establishment of traffic control strategies;

c. Establishment of the basic gap acceptance relationships and indexes that can be used in the design and analysis of priority intersections.

Capacity and delay predictions are not included in this research because much of the work done earlier is concentrated in this field with a number of analytical, simulation, and empirical models have been developed to predict these two parameters.

#### *7.3.1.1: Sight Distance Requirements*

**I. General**

Some previous researchers have mentioned that gap acceptance data can be used to determine sight distance (S.D) requirements at priority intersections [Fitzpatrick

(1991) and Mason et al. (1989)]. Nevertheless, very limited research was conducted in this area. Mason, et al (1989) indicated that intersection S.D based on AASHTO specifications need to be evaluated.

Estimating practical sight distance requirements based on gap lengths safely accepted by the minor road drivers can be a good alternative approach to AASHTO specifications which are mainly based on speed, intersection type, control and vehicle type.

In gap acceptance context, a driver accepts the gap which is long enough for him to safely execute his maneuver. Hence his S.D should be at least equal to his critical gap expressed in distance terms [Mason et al. (1989)]. Therefore, S.D requirements will be a function of all variables that affect driver gap acceptance behavior. For example, it can be reasonably expected that sight distance requirements for old drivers is higher than young drivers due to factors like slower reactions and different decision making process of old drivers. This situation is acknowledged in gap acceptance studies since old drivers, usually, accept longer gaps.

Gap acceptance models developed in this research will be used to predict critical gaps and S.D requirements for the studied locations based on the criteria discussed above. These S.D requirements will be compared to AASHTO standards for the same sites. For the purpose of this demonstration, gap lengths to be used in computing Sight Distance requirements is the length corresponding to an acceptance probability of 0.5 in the full model developed for the concerned maneuver when all variables included in the

model (except the considered variable) are kept at their average values. Sight Distance requirements at acceptance probability of 0.85 will also be demonstrated.

**II. Sight Distance Requirements According to AASHTO:**

Maneuver 1 in this study represents vehicles turning left from the major stream into minor stream. Hence, this maneuver can be represented by "Case V-Stopped Vehicle Turning left from a major highway" in AASHTO, 1995. The required sight distance (S.D.) for this maneuver is given as [AASHTO, 1995];

$$S.D = 0.28V(j + t_a)$$

where,

S.D: Required sight distance for the vehicle turning left from the major road;

V: Design speed for the main road;

j: Driver perception and reaction time (2 seconds as per AASHTO);

$t_a$: Time required to accelerate and traverse the distance to clear traffic in the approaching lane. This time depends on the traversed distance and on the type of vehicle as given in Figure 7.1 which is extracted from AASHTO, 1995.

The distance to be traversed in Maneuver 1 is similar to the distance to be traversed by a vehicle turning left from minor road into major road. This distance is function of the geometry of the junction and is computed for left turns from minor road into 2-lane major road as [AASHTO, 1995];

$$S_T = D + 1.5(\text{Lane Width}) + \pi R/2 - R$$

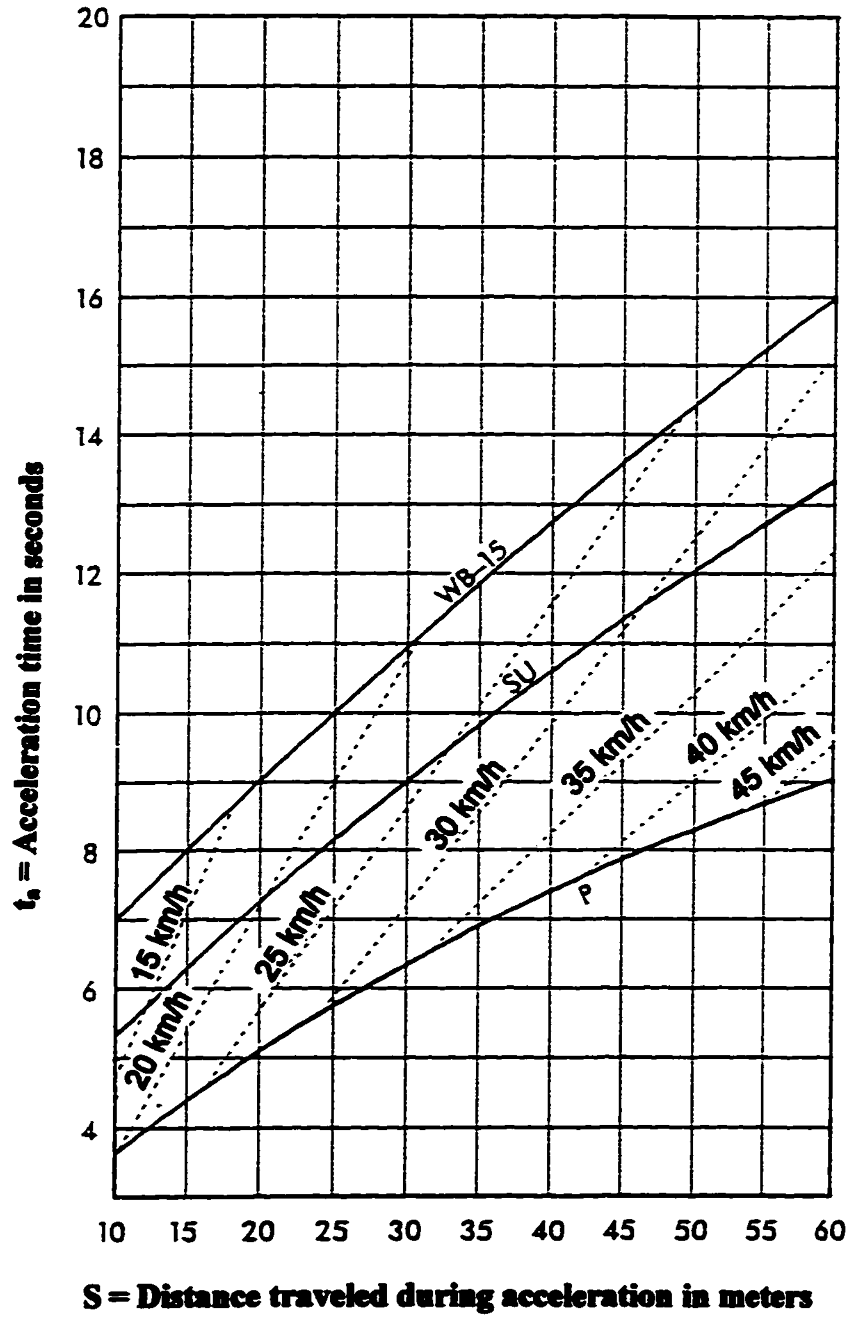



**Figure 7.1: Acceleration time ($t_a$) needed to traverse a distance of S meters**

Source: [AASHTO, 1994]

where,

D: The distance from the edge of the traveled way to the front of the vehicle waiting at the minor road. However, in the case of left turns from major road, D is assumed to be zero;

R: Radius of the curve at the intersection. {The studied site has radii of around 12.5 meters and lane width of 3.5 meters}.

Substituting these values in the above formula and considering zero value for D will produce a value of $S_T$ equal to around 12.4 meters. Entering Figure 7.1 with this value and considering the curve representing passenger cars (p), it can be seen that the value of $t_a$ is around 4.0 seconds. Substituting j and $t_a$ values, the formula will reduce to:

$$S.D = 1.68(V)$$

For the purpose of computing and comparing the required sight distance using AASHTO method and the Gap Analysis method, a range of design speeds from 25 Km/hr to 70 Km/hr is considered. The main reason for selecting this range is that the majority (around 85%) of the observed speeds are within this range.

## III. Sight Distance Requirements According to Gap Acceptance Analysis

Sight Distance requirements according to gap acceptance analysis are (as discussed earlier) defined based on gap size which corresponds to 0.5 probability of accept when all the attributes in the full model of the concerned maneuver are kept at

their average values except the variable considered for the analysis. The case of 0.85 accept probability will also be considered. For the 0.5 probability, the model will reduce to:

$$-F(x) = 0, \quad \text{where}$$

F(x): Utility function of the model

For the 0.85 probability the model will reduce to:

$$-F(x) = -1.735, \quad \text{where,}$$

-1.735 is the natural logarithm of the value (0.15/0.85).

The reduced forms of the models for the two considered probabilities (0.5 and 0.85) are given below:

$$-1.831(GSEC) + 0.224\,(MJSD) + 1.574 = 0 \quad \{\text{for prob(accept)} = 0.5\};$$

$$-1.831\,(GSEC) + 0.224\,(MJSD) + 1.574 = -1.735 \quad \{\text{for prob(accept)} = 0.85\}.$$

Substituting the selected speed values in the above equations and solving for GSEC will produce the required gap sizes (GSEC). The obtained gap sizes along with the computed sight distances based on AASHTO and Gap Analysis methods are given in Table 7.1. The main comment on this table is that the sight distances computed based on the two methods are very close to each other at low speeds. As speed increases, values start to depart from each other with the values computed based on gap analysis becoming higher. Figure 7.2 is a graphical presentation of the data given in Table 7.1.

This result supports the statement of Mason et. al. (1989) about the need to evaluate AASHTO procedures related to intersection Sight Distance.

Another application in this field is to demonstrate the effect of delay imposed on minor stream drivers at sight distance requirements. Maneuver 1 is used again for this demonstration. The delay histogram for Maneuver 1 (Figure 6.2) shows that delay values change over the range from 0 to 40 seconds with few observations in delay intervals higher than 20 Seconds. Therefore, a range from 0 to 25 Seconds will be considered. In this case, the reduced forms of the model for accept probabilities of 0.5 and 0.85 are;

$$-1.831\,(GSEC) - 0.118\,(TLDL) + 10.8 = 0 \quad \{\text{for Prob(accept)} = 0.5\};$$

$$-1.831\,(GSEC) - 0.118\,(TLDL) + 10.8 = -1.735 \quad \{\text{for Prob(accept)} = 0.85\}.$$

Table 7.2 presents the calculated gap sizes and sight distances based on the two methods. Note that sight distance computed on AASHTO bases is constant and equals 1.68(V) where V is design speed which is taken as 1.18 of the observed average speed at main road, i.e., the observed average speed is considered to be equivalent to 85 percent of the design speed. The observed average speed for Maneuver 1 is 38.93 Km/hr which means that the AASHTO sight distance will be constant at 77.2 meters.

As can be seen from Table 7.2 and Figure 7.3, the sight distance requirements based on AASHTO are very close to sight distance requirements based on the 0.5 accept probability at low delay levels (0-5 Seconds). However, the two values depart

**Table (7.1): Sight Distance Requirements for Maneuver 1**

**Based on AASHTO and Gap Analysis Methods**

| *Speed (Km/Hr)* | *Gap Size from the Model* | | *Gap Analysis S. D.* | | *AASHTO S.D.* |
|---|---|---|---|---|---|
| | **P(a) = 0.50** | **P(a) = 0.85** | **P(a) = 0.50** | **P(a) = 0.85** | |
| 35 | 5.14 | 6.09 | 50.39 | 59.68 | 58.80 |
| 40 | 5.75 | 6.70 | 64.44 | 75.05 | 67.20 |
| 45 | 6.36 | 7.31 | 80.20 | 92.14 | 75.60 |
| 50 | 6.98 | 7.92 | 97.67 | 110.94 | 84.00 |
| 55 | 7.59 | 8.54 | 116.86 | 131.46 | 92.40 |
| 60 | 8.20 | 9.15 | 137.76 | 153.69 | 100.80 |
| 65 | 8.81 | 9.76 | 160.37 | 177.63 | 109.20 |
| 70 | 9.42 | 10.37 | 184.70 | 203.28 | 117.60 |

**Table (7.2) : Effect of Delay on Sight Distance Requirements**

| *Delay Seconds* | *Speed (Km/Hr)* | *Gap Size from Model* | | *Gap Analysis S.D.* | | *AASHTO* S.D. |
|---|---|---|---|---|---|---|
| | | **P(a) = 0.50** | **P(a) = 0.85** | **P(a) = 0.50** | **P(a) = 0.85** | |
| 0 | 45.93 | 5.90 | 6.85 | 75.86 | 88.08 | 77.16 |
| 5 | 45.93 | 5.60 | 6.53 | 71.99 | 83.93 | 77.16 |
| 10 | 45.93 | 5.30 | 6.20 | 68.13 | 79.79 | 77.16 |
| 15 | 45.93 | 5.00 | 5.88 | 64.27 | 75.65 | 77.16 |
| 20 | 45.93 | 4.70 | 5.56 | 60.40 | 71.50 | 77.16 |
| 25 | 45.93 | 4.40 | 5.24 | 56.54 | 67.36 | 77.16 |

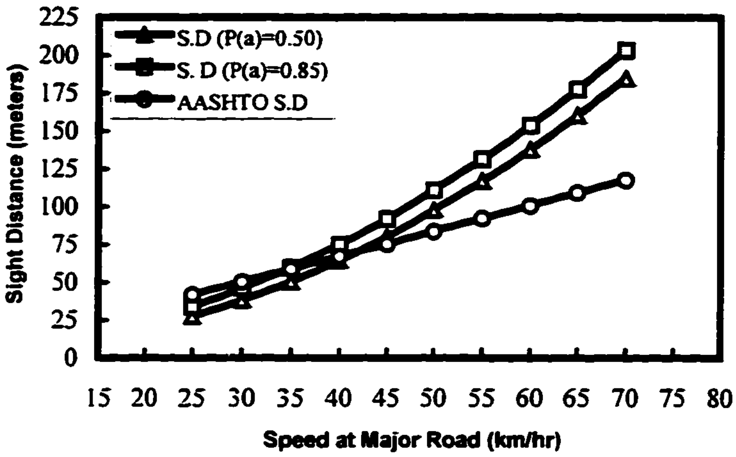



**Figure (7.2): Comparison of Sight Distance Requirements based on AASHTO and Gap Acceptance analyses**

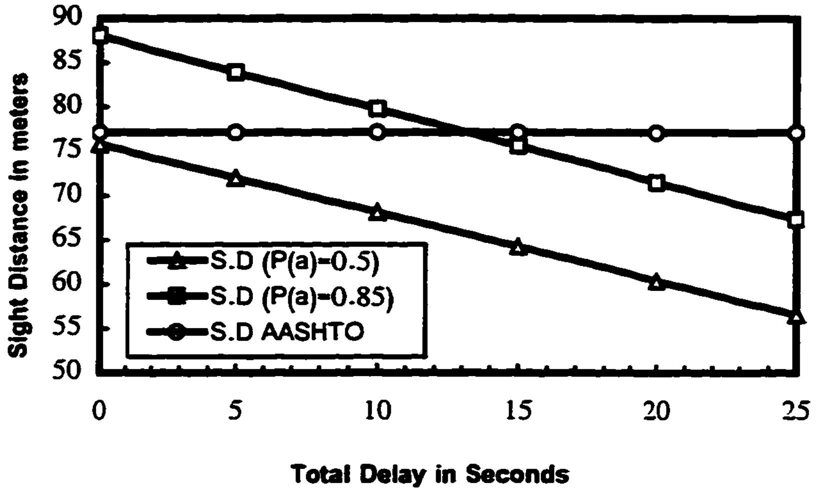



Figure ( 7.3): Effect of Delay on Sight Distance Requirements

quickly as delay increases with values based on gap analysis becoming smaller due to the pressure effect of delay which result in accepting shorter gaps.

These results indicate that driver gap acceptance behavior which is a major factor affecting sight distance requirements for drivers (as stated in literature) is not considered in finding sight distance needs according to AASHTO Standards. Hence, incorporating the concepts and findings of Gap Acceptance Behavior in different AASHTO design methodologies especially sight distance requirements is highly recommended. However, further research is also recommended in this field to produce wider and more representative gap acceptance behavior information to be used in enhancing AASHTO standards.

### *7.3.1.2: Establishment of a Traffic Control Strategy*

**I. Conceptual Development:**

Some previous researchers [Fitzpatrick (1991), Neudorff (1985), and Robertson (1994)] have indicated that gap acceptance data can be used to establish traffic signal warrants and that, it is not solely traffic volume, but availability of gaps and gap acceptance criteria that should be used to develop traffic signal warrants. Here, another application of gap acceptance data is discussed. That is, an establishment of a control strategy similar to ramp metering technique. The suggested strategy is better applicable to situations with limited sight distances and/or high-risk levels caused by any reason.

It is also recommended as a better alternative than partially actuated signals at high volume major stream - low volume minor stream situations.

In the suggested strategy, entrance of vehicles from minor to major stream will be regulated (metered) based on availability of gaps in major stream and gap acceptance model for minor stream drivers. Gaps occurring in the major stream can be measured using traffic detectors. Whenever an appropriate gap for a specific maneuver is available, a green indication will be given to that maneuver. Length of green will, of course, depend on the length of the available gap and the gap acceptance characteristics of minor stream drivers. Many of the basic and very important variables which are included in the developed gap acceptance models like type and speed of oncoming vehicle, major stream volume, gap length, queue size and delay at minor stream can be automatically collected using the same detectors which are needed to measure gaps in this type of control. Embedding a simplified gap acceptance model based, at least, on these readily collected variables will enable estimating the proper gap length based on the prevailing traffic conditions instead of using some fixed pre specified value, as it is the case in ramp metering, which is usually very conservative and cause delays. Therefore, the suggested strategy is different than on-ramp metering in that:

**a.** It is applicable to priority intersection as well as the on-ramps;

**b.** It is based on using variable gap length to initiate green for minor stream vehicle based on prevailing traffic conditions.

On the other hand the suggested methodology is different than the known partially actuated signal in that:

a. No signal heads, at all, are needed for major stream;

b. Major stream will never stop in favor of the minor stream as may happen in partially actuated signals (especially if major stream vehicles arrive at the time when green indication is given to minor stream). Simply, because green indication in the suggested methodology will not be given to the minor stream unless a long enough gap sufficient to execute the maneuver is available , i.e., green will be given for minor stream based only on gap availability in the major stream. Hence, this method is applicable for situations in which proper gaps are available in major stream but minor stream drivers are unable to utilize these gaps efficiently due to any physical or operational constraint like visibility restrictions;

c. No fixed maximum green value is assigned to the minor stream as it is the case in partially actuated signals. The green length is variable depending on the available gap in major stream. However, the minimum green for minor road should be, at least, equal to the length of the critical gap. Hence, the minimum green itself is also variable since critical gap length is function of the prevailing traffic, geometric, and driver conditions. In summary, the suggested control strategy aims to "inform the minor road driver about the existence of safe (long enough) gaps at sites where he either can not see these gaps or can not decide

whether an available gap is proper or not". Hence this strategy is expected to reduce delay and to improve safety especially at sites with poor visibility conditions and hence, high accident risks.

**II. Demonstrating the Use of Gap Acceptance Results:**

The applicability of the developed model in this field will be elaborated at the theoretical and conceptual levels only. Field testing of this technique is, however, beyond the scope of this research.

An accepted practice in traffic engineering is to use the $85^{th}$ percent values to represent driver behavior. For example the $85^{th}$ percent of the design speed is a controlling factor in deciding the posted speed limits and in finding sight distance requirements as discussed in Section 7.3.1.2. If the gap size corresponding to an accept probability of 0.85 is considered as adequate and safe representation of driver behavior, the maximum green time for the minor road as per the above discussed strategy will vary with the speed of the vehicles on the oncoming road as shown in Table 7.1. A detector placed at known distance upstream on major road will measure the speed of the oncoming vehicle and the time it needs to arrive the junction. The controller will turn the signal head at minor road green if the available gap at the measured speed is longer than the gap size corresponding to the 0.85 accept probability.

For example, according to the data in Table 7.1 the head will turn green for the case 70 Km/hr speed of the oncoming vehicle if the available gap is more than 10.37

Seconds while the gap needed to turn the head green at 35 Km/hr speed is only 6.1 Seconds. The effect of other variables is already considered since gap size in Table 7.1 is computed at the averages of those variables. This shows how the discussed methodology can be dynamically adapted to traffic and driver characteristics.

### *7.3.1.3: Development of Basic Gap Acceptance Relationships and Indices*

**I. General:**

Collected gap acceptance data and developed gap acceptance models can be used to establish some basic relationships between different variables that affect driver gap acceptance behavior (and consequently affect all traffic operations and design elements that can be influenced by this behavior). Many of the basic relationships between average accepted and critical gaps at one side and the different levels of the studied variables were developed and discussed in Chapter 5. In this section only some of the possible applications and implications of these relationships will be considered. Again the results obtained for Maneuver 1 will be used.

**II. Examples:**

**a.** It was found that the critical gap for vehicles with "automatic transmission" are lower than the critical gap for "vehicles with manual transmission" (5.8 seconds versus 5.3 seconds). This result can be used to adjust for, say the move up-time

delay in delay-capacity computations. If the predominant type of vehicles have automatic transmission, then lost time as well as sight distance requirements can be reduced by 0.9 factor. It should be mentioned here that the percentage of vehicles with automatic transmission for Maneuver 1 is around 24%;

b. The critical gap for non-work trips (5.6 Seconds) was found to be longer than the critical gap for work trips (5.4 Seconds). This may indicate the need to design priority junctions within recreational and shopping areas to a more relaxed standards in terms of sight distance and other relevant operational standards;

c. Female drivers have critical gap (6.1 Seconds) which is longer than male drivers (5.5 Seconds). This fact can be used to adjust for the relevant design elements. Such adjustments could be related to the percentage of females in driver population. In this particular case females constitute around 8 percent of the interviewed drivers;

d. It was found that drivers with high accidents and traffic violations records accept significantly shorter gaps and also have significantly shorter critical gaps. This result could be helpful in accident analysis and prevention methodologies. This behavior could be related to driver characteristics and to deficient design elements including the inadequacy of sight distances as well. Considering this in accident analysis may give more insight into the actual causes of these accidents and hence could help in developing adequate remedial measures;

e. The average accepted gaps, critical gaps, and $50^{th}$ percentile accepted gaps decrease significantly when delay at minor road increases. Accepting shorter gaps at higher delay levels may itself lead to accident occurrence. Therefore, this result could be helpful in deciding the proper control of the junction i.e., priority versus signal control. This means that it is recommended to use a combination of delay at minor road and traffic volume at the junction rather than traffic volume alone as it is the current practice as a warrant for the identification of the signal need;

f. The average accepted gap increases significantly as the ability of the minor road driver to estimate the speed and the distance of the oncoming vehicle decreases. Hence, training drivers and increasing their ability in this regard will significantly enhance traffic operations and safety at priority junctions.

# CHAPTER 8

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### 8.1 INTRODUCTION

This chapter summarizes the basic findings, similarities and differences between the developed models along with the main derived conclusions about the effects of the studied driver, trip, gap, vehicle and traffic attributes on driver gap acceptance behavior at priority junctions. The chapter is concluded by listing the main recommendations for future research in this field.

## 8.2 SUMMARY

The main objective of this research was to investigate the effect of the basic driver, vehicle, gap, traffic and trip attributes on driver gap acceptance behavior at priority intersections. To achieve this objective binary logit gap acceptance behavioral models were calibrated and validated utilizing data collected from two T-junctions at single carriageways. Data was collected using field administered questionnaire and video camera. A secondary objective of the study was to demonstrate some of the potential applications and implications of the developed models in traffic engineering field. Models were calibrated using the LIMDEP package available at King Fahd University of Petroleum and Minerals.

A preliminary analysis was conducted to derive the basic descriptive statistics for the collected data and to derive the average accepted, average rejected, critical gap, $50^{th}$ and $85^{th}$ percentile acceptedand rejected gaps/lags. All these measures were derived at different levels of the studied variables.

After conducting the preliminary statistical analysis for the collected data, more than 40 attributes were defined and modeled. Models were calibrated for three maneuvers at T-junctions; Left turn from major stream into minor stream (Maneuver 1), right turn from minor stream into major stream (Maneuver 2), and left turn from minor stream into major stream (Maneuver 3). A total of around 30 models were calibrated and tested in addition to numerous preliminary modeling works conducted to

identify the significant variables for different models. The following models were calibrated for each of the studied maneuvers:

a. BASIC pooled model for each of the studied maneuvers. The BASIC model included traffic and delay attributes only;

b. FULL pooled model for each maneuver including all of the traffic, delay, driver, vehicle, and trip attributes;

c. Validation models for the FULL pooled Model mentioned in (b);

d. Separate models for Gaps and Lags for each maneuver;

e. Separate models for nearside and farside gaps/lags in Maneuver 3;

f. Models for special cases that included cases (observations) which involved gap/lag rejection decisions and cases in which the effect of an ahead driver exists.

The developed models were tested and validated using different statistical tests and prediction success ratios as discussed in Chapter 6. Finally some of the potential applications of the developed models were demonstrated and the basic findings and conclusions of the study were summarized along with the recommendations for future research in driver Gap Acceptance Behavior area.

## 8.3 CONCLUSIONS

Based on analyses conducted in this research the following main conclusions were derived:

a. Driver, vehicle, and trip attributes are significant in explaining driver gap acceptance behavior. It was found that these attributes add significantly to the explanation of gap acceptance behavior as concluded from the results of the relevant tests conducted on the calibrated models (refer to table 8.1). The driver, vehicle and trip attributes which were found to be significant in the calibrated models include driver's age (DAGE), Sex (DSEX), experience (DEXP), familiarity to the site (DFAM), accident and traffic violation records (ACDT and VLTN), driver gap acceptance criteria (ACTN), vehicle occupancy (OCUP) and trip duration (TRDN);

b. According to the results of the likelihood ratio tests performed on pooled and segmented models for lags and gaps, drivers' reaction to gaps was found to be significantly different from their reaction to lags. However, the pairwise T-tests performed on the corresponding pairs of coefficients in segmented models along with T-tests on the marginal effects of the segmented models have failed to give clear justification to this result. Where the corresponding pairs of coefficients and marginal effects of the segmented models was found to be indifferent at 5%. This is a phenomenon which is recognized in the choice modeling (see Ben-Akiva and Lerman (1985));

**Table (8.1) :Log likelihood Ratio Tests Between BASIC and FULL Pooled Models developed for Maneuvers 1, 2, and 3**

| Statistic | M1 ** | M2 | M3 |
|---|---|---|---|
| $H_0$ : FULL and BASIC Pooled Models are not Different | | | |
| Log likelihood for BASIC Pooled Model L(BASIC) | -65.34 | -58.41 | -70.81 |
| Log likelihood for FULL Pooled Model L(FULL) | -49.08 | -50.19 | -62.44 |
| Test Statistic = -2 [L(FULL) - L(BASIC)] | 32.5 | 16.44 | 16.74 |
| Test Degrees of Freedom (D.F.F - D.F.B) | 4 | 3 | 3 |
| Chi-Square, Table Value at 5% level | 9.49 | 7.81 | 7.81 |
| Test Result | Reject $H_0$ | Reject $H_0$ | Reject $H_0$ |

** Mn : the $n^{th}$ Maneuver;

D.F.F: degrees of freedom of the FULL pooled model; D.F.B: degrees of freedom of the BASIC pooled model.

c. The Gap size (GSEC), traffic volume at minor road (MNVL) and total delay (TLDL) imposed on the driver are significant variables in all of the calibrated models regardless of the studied case or type of maneuver. Speed on major road (MJSD) was found to be significant in all models except the models of Maneuver 3. Vehicle occupancy (OCUP) is a predominantly significant variable in all of the models developed for cases which have involved driver gap/lag rejection decisions;

d. All of the models calibrated in this study are significant at 0.0000000% ($\chi^2$ test results) and can predict the observed driver gap acceptance significantly at 5% (validation results). All of the models have high values of the goodness of fit index, $\rho^2$ (ranging from 0.70 to 0.91), and high percentages of the correctly predicted observations (ranging from 89.3% to 98.5%). In addition, the signs of the parameter estimates in all of the models are as expected;

e. Marginal effects defined as "the rate of change in the probability of accepting a gap for one unit change in the concerned attribute, ceteris paribus," and computed at the mean of the attribute showed to be a useful tool in analyzing and comparing the effects of different attributes on driver gap acceptance behavior;

f. The $50^{th}$ percentile accepted gap could provide an adequate gap acceptance measure that can be used along with the critical gap measure to describe and characterize driver gap acceptance behavior. This statement is based on the observation that the $50^{th}$ percentile accepted gap is more related to the values and

frequencies of the accepted gaps and less sensitive to the number of rejected gaps as explained in Chapter 6;

g. The calibrated models and the obtained gap acceptance results (average and critical gaps) can be used in different applications in traffic engineering. Results obtained from gap analysis are recommended to be integrated in the conventional methods in practices such as the determination of sight distance requirements and the type of control needed at priority intersections specially in identifying the need for signalization;

h. The models of maneuvers 1 and 3 are similar in many aspects while the model of Maneuver 2 is distinguished by including some unique variables like driver's sex and age (DSEX, DAGE). This could be attributed to the fact that maneuvers 1 and 3 are similar in their nature;

i. Binary choice models other than the binomial logit were calibrated for demonstration and comparison purposes. These models include the binary probit model and the maximum score model. The coefficients of probit and logit models are different from each other by a scale factor, nevertheless the results of the two models in terms of the significance levels of the variables, the goodness of fit indexes, the percent of observations correctly predicted, and the marginal effects are similar. The results of the maximum score model are comparable with the other two models with respect to the percent of the observations correctly

predicted but different in other aspects like the significance levels of variables in the model;

j. Other conclusions are presented and discussed in the report.

## 8.4 RECOMMENDATIONS FOR FUTURE RESEARCH

The basic recommendations for future research in the area are listed below:

a. Development of similar models for similar type of intersections under different traffic, driving, and socioeconomic characteristics to check the transferability of the calibrated models;

b. Driver reaction to gaps and lags need to be further studied. Possible variables and attributes and adequate modeling and testing frameworks capable of capturing and explaining the reasons underlying the differences in driver reaction to gaps and lags need to be further investigated;

c. The negative sign taken by the "accept-choice specific constant" means that, everything else is equal, drivers tend to reject gaps/lags. This phenomenon needs further investigation. However, this study has shown that the number of rejected gaps by a driver is a controlling factor in this regard. The marginal effect of the constant term showed to be much higher in cases in which the average number of rejected gaps is high;

d. A limited demonstration performed in this study showed that gap acceptance phenomenon can be modeled using models other than the binomial logit model. Identifying models applicable to the phenomenon and conducting comparisons between the results of these models can be further studied;

e. The development of adequate measures to replace or supplement the currently used critical gap measures could be an area for further research;

f. Development of pooled and segmented gap acceptance models for different levels of attributes which affect driver gap acceptance behavior can provide a base for identifying possible variations in gap acceptance behavior between different segments of the population and hence can lead to a better understanding of the driver gap acceptance phenomenon;

g. The applicability of the models and results obtained from gap acceptance analysis to some of the traffic engineering field was demonstrated. However, further analyses in this regard are recommended. These analyses should identify the potential fields of applicability and should compare the results found based on gap analysis with the results obtained from other methods currently used in the investigated fields.

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# APPENDICES

# Appendix A

## Study Forms and Questionnaires

# Form (A-1)

## Driver Gap Acceptance Behavior at Priority Junctions
## A Questionnaire for Roadside Interviews

**Interviewer Name and Number: Name:** ................................................ **Number:**..............

***Serial No.:*** ..........

***Part one: Vehicle Characteristics and Attributes***

1. Vehicle plate number (last three digits only): [ ] [ ] [ ] Vehicle color:............
2. Type of vehicle: [1] Private PC [2] Taxi [3] Large vehicle (truck/bus)
3. Vehicle occupancy (total number of persons including the driver):................persons
4. What is the make year and brand of your vehicle?: Year: 19 __ Brand:...............
5. What is the capacity of the engine of your vehicle?:
   [1] cylinders:........... [2] liters:..........
6. What is the type of movement transmission in your vehicle?:
   [ 1 ] Automatic [ 2 ] Manual

***Part Two: Trip Characteristics and Attributes***

1. What is the purpose of your trip?: [1] Work [2] Shopping [3] Educational/study [4] Medical [5] Social/Recreational [6] Others: ..................
2. How much time this trip will take?: (perceived total trip duration in minutes): ..............

***Part Three: Driver Characteristics and Attributes***

1. Driver sex: [ 1 ] Male [ 2 ] Female
2. How long is your driving experience?: ........................................... years
3. What is your education level?: [1] Primary or less
   [2] Intermediate or secondary [3] University degree
4. How frequent you pass this intersection?: ..................................... times every month
5. What is your estimation of the speed and distance of the oncoming vehicle?:
   [1]Speed:............................... (Km/Hr.) [2] Distance:.................... (meters)
6. On what criteria do you base your gap acceptance decision?:
   [1] Speed of the oncoming vehicle [2] Distance of the oncoming vehicle
7. In how many accidents you were involved in the last two years?: [ ]
8. How many traffic violations have been issued to you in the last year?: [ ]
9. What is your age?: .................................................. years
10. What is your nationality?: [1] U.A.E [2] Other Gulf Countries [3] Other Arabs
    [4] Europe/America [5] Asia [6] Africa [7] Others:......

# نموذج(أ-١)

## دراسة خصائص قبول السائقين للفجوات الزمنية على التقاطعات غير المحكومة بإشارات ضوئية

## استبيان المقابلات الميدانية للسائقين

اسم مجري المقابلة ورقمه: الاسم:............................................ الرقم:............

الرقم المتسلسل: ....................

**الجزء الأول: معلومات عن المركبة**

١. رقم لوحة المركبة (آخر ثلاثة أرقام من الجهة اليمنى): [ ] [ ] [ ]
٢. نوع المركبة؟: [ 1 ] مركبة صغيرة خاصة [ 2 ] مركبة صغيرة عامة [ 3 ] مركبة كبيرة/حافلة
٣. عدد الأفراد داخل المركبة بما فيهم السائق؟: ...................... فرد
٤. ما هي سنة صنع (موديل) مركبتك؟: ١٩______
٥. ما هي سعة محرك مركبتك؟: [1] عدد الاسطوانات:...... [2] سعة المحرك باللترات: ......
٦. ما هو نوع ناقل الحركة في مركبتك؟: [ 1 ] أوتوماتيك [ 2 ] يدوي

**الجزء الثاني: معلومات عن الرحلة**

١. ما هو هدف هذه الرحلة أو الغرض منها؟ [ 1 ] العمل [ 2 ] الدراسة/التعليم [ 3 ] العلاج [ 4 ] اجتماعي/ترفيهي [ 5 ] أخرى: .......
٢. ما هو الزمن الكلي الذي تستغرقه هذه الرحلة بالدقائق؟: ................ دقيقة

**الجزء الثالث: معلومات عن السائق**

١. جنس السائق؟ [ 1 ] ذكر [ 2 ] أنثى
٢. ما هو عمرك بالسنوات؟: ...................... سنة
٣. ما هو عدد سنوات خبرتك في قيادة المركبات؟: ...................... سنة
٤. ما هو مستوى تعليمك؟ [ 1 ] ابتدائي أو اقل [ 2 ] إعدادي أو ثانوي [ 3 ] جامعي
٥. ما هو معدل عدد المرات التي تمر فيها على هذا التقاطع في الشهر؟: ............ مرة
٦. ما هو تقديرك لسرعة ومسافة المركبة القادمة التي دخلت أمامها؟:
[ 1 ] سرعة المركبة القادمة : ......... كم/ساعة [ 2 ] مسافة المركبة القادمة:...... متر
٧. على ماذا بنيت قرارك بقبول الفجوة الزمنية التي دخلت فيها؟:
[ 1 ] على سرعة المركبة القادمة [ 2 ] على مسافة (بعد) المركبة القادمة
٨. ما هو عدد حوادث السير التي كنت طرفا فيها خلال العامين الماضيين؟: .........حادث
٩. ما هو عدد مخالفات المرور التي حررت لك خلال العام الماضي؟: ............ مخالفة
١٠. ما هي جنسيتك؟: [ 1 ] خليجي [ 2 ] عرب آخرون [ 3 ] أوروبي/امريكي [ 4 ] آسيوي [ 5 ] أفريقي [ 7 ] اخرى: ......

**Driver Gap Acceptance Behavior at Priority Intersections**

**Form A-2: Summary form for data collected from road side interviews**

Junction: ........................................ Time:........................ Day and Date:..............

| | Vehicle Characteristics and Attributes | | | | | | | | Trip Attrib. | | Driver Characteristics and Attributes | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial Number | Plate Number | Color | Type | Occupancy | Make year | Brand | Engine Capacity | Movement Transmission | Trip Purpose | Trip Duration | Sex | Driving Experience | Education | Familiarity to site | Speed estimate | Distance estimate | Acceptance criteria | Accident experience | Violation experience | Age | Nationality |
| | | | | | | | | | | | | | | | | | | | | | |
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## Driver Gap Acceptance Behavior at Priority Intersections

## Form A-3: Summary form for data extracted from video record

Junction:............................................................................ Time:................................. Day and Date:.................................

Movement Type: [ 1 ]: Left turn from major stream to minor stream [ 2 ]: Right turn from minor steam to major stream
[ 3 ]: Left turn from minor stream to major stream

| veh. Id. | | Gap Attributes | | | | | | | | | | | | | Vehicle and Traffic Attributes | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | General | | | | | | | | | Accepted Gap | | | | Type | | | | | Speed Km/hr | | Traff. Vol. vph | | | Delay (sec.) | |
| | | Respons | yp | Size | | | Ahead driver | | | | Precede ga | | Succeed g | | Major st | | Minor Stream | | | | | | | | | |
| Order | Plate Number | (1) Accept (0) Reject | (1) lag (2) gap | Seconds | Meters | No. of rejected gaps | Accepted gap (sec.) | Accepted gap (Mt.) | Rejected gaps (No.) | No. of ahead entries | Seconds | Meters | Seconds | Meters | Passenger car | large vehicle | Private passenger car | Public transport taxi | large vehicle | Oncoming vehicle | Studied vehicle | Major stream | Minor stream | Queue size | In queue | At queue head |

## DRIVER GAP ACCEPTANCE BEHAVIOR AT PRIORITY JUNCTIONS

**Form A-4: Form for extracting Driver Response and Gap type information from video tape**

**Junction :------------------------** **Maneuver Type:----- -**
**Observer Name: ------------------** **Date:-----------------**

| Serial Number of the gap/lag | Gap Type & Response | Serial Number of the gap/lag | Gap Type & Response |
|---|---|---|---|
| 1 | $L_0$ | | |
| 2 | $G_0$ | | |
| 3 | $G_0$ | | |
| . | → | | |
| . | → | | |
| 4 | $L_0$ | | |
| 5 | $L_0$ | | |
| . | $L_0$ | | |
| . | $G_0$ | | |
| . | . | | |
| . | . | | |
| . | . | | |
| . | . | | |
| . | . | | |
| . | . | | |
| . | . | | |
| . | . | | |

***Note: Insert an arrow when minor stream vehicle accepts a gap or lag :***

**$L_0$ - Rejected Lag**
**$G_0$ - Rejected Gap**
**$L_1$ - Accepted Lag**
**$G_1$ - Accepted Gap**

***For Maneuver 3 :***
**F - Far Lag/ gap**
**N - Near lag/gap**

**DRIVER GAP ACCEPTANCE BEHAVIOR AT PRIORITY JUNCTIONS**

**Form A-5: Form for extracting Number of Ahead Entries and Queue Size information from video tape.**

**Junction :--------------------------------** **Maneuver Type:------------**
**Observer Name: ------------------- ----** **Date:-----------------------**

| S. No. | No. of Ahead Entries (AENT) | Queue Size (QSIZ) | S. No. | No. of Ahead Entries (AENT) | Queue Size (QSIZ |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |

## DRIVER GAP ACCEPTANCE BEHAVIOR AT PRIORITY JUNCTIONS

**Form (A-6): Form for extracting the type of major stream vehicle from video tape**

**Junction:** ------------------------------ **Maneuver Type:**---------------
**Name of the observer:** ------------------ **Date:** -------------------------

| S. No. | Vehicle Type | S. No. | Vehicle Type | S. No. | Vehicle Type |
|---|---|---|---|---|---|
| 1 | S | | | | |
| 2 | S | | | | |
| 3 | L | | | | |
| 4 | S | | | | |
| | → | | | | |
| 5 | S | | | | |
| 6 | S | | | | |
| 7 | L | | | | |

***Vehicle Codes :***

*S - Small Vehicle*
**L - Large Vehicle**

*Note: Insert an arrow where the minor stream vehicle accepts a gap.*

**DRIVER GAP ACCEPTANCE BEHAVIOR AT PRIORITY JUNCTIONS**

**Form A-7: Form for extracting type and color of the minor stream vehicle from video tapes**

**Junction:**.................................................. **Maneuver Type:**..............................
**Name of observer:**................................ **Date:** ..............................................

| S. No. | Type and color Of the minor str. vehicle | S. No. | Type and color Of the minor str. vehicle | S. No | Type and color Of the minor str. vehicle |
|---|---|---|---|---|---|
| 1 | SW | | | | |
| 2 | SR | | | | |
| | | | | | |

***Type of Vehicle Codes:***

*S : Small Vehicle*
*L : Large Vehicle*

***Color Codes:***

*W-White, B-Black, BL-Blue*
*R-Red, G-Green, Y-Yellow*
*GR-Gray BR-Brown*

# Appendix B

## Detailed Statistical Outputs and Graphs

**B1: Averages and Standard Errors**

**B2: Samples of Histograms**

**B3: Samples of Scatter Diagrams**

**B4: Samples of Critical Gap Identification Graphs for Maneuver 1**

# Appendix B1

## Averages and Standard Errors

Table B1.1: Descreptive Statistics for the Data Collected for Maneuver 1

| Variable | Mean | Std. Dev. | Skew. | Kurt. | Minimum | Maximum | Cases |
|---|---|---|---|---|---|---|---|
| RESP | 0.6138 | 0.4874 | -0.5 | 1.2 | 0.0000 | 1.0000 | 448 |
| MJSD | 38.9286 | 11.6692 | 0.3 | 2.5 | 12.7000 | 73.3000 | 448 |
| MNSD | 10.7643 | 13.4251 | 0.8 | 2.2 | 0.0000 | 51.6000 | 448 |
| MJVL | 3.6317 | 2.1851 | 0.3 | 2.2 | 0.0000 | 10.0000 | 448 |
| MNVL | 2.2277 | 0.9326 | 1.1 | 4.7 | 1.0000 | 5.0000 | 448 |
| QSIZ | 0.4196 | 0.8913 | 1.8 | 4.9 | 0.0000 | 4.0000 | 448 |
| DLIQ | 2.6663 | 5.1506 | 2.3 | 7.7 | 0.0000 | 23.4000 | 448 |
| DLQH | 2.7257 | 4.2662 | 2.0 | 7.8 | 0.0000 | 26.6000 | 448 |
| TLDL | 5.3920 | 6.9567 | 1.8 | 6.7 | 0.0000 | 40.3000 | 448 |
| NREJ | 0.6429 | 1.0857 | 2.4 | 9.9 | 0.0000 | 7.0000 | 448 |
| GSEC | 7.8656 | 5.3892 | 1.8 | 6.5 | 1.3000 | 34.8000 | 448 |
| GMET | 86.4239 | 80.2372 | 3.2 | 17.5 | 8.1611 | 714.9500 | 448 |
| SSEC | 8.9779 | 8.0349 | 2.5 | 11.9 | 1.1000 | 64.8000 | 448 |
| SMET | 58.4846 | 31.2355 | 1.2 | 5.1 | 5.9278 | 193.8222 | 448 |
| TMGP | 0.6138 | 0.4874 | -0.5 | 1.2 | 0.0000 | 1.0000 | 448 |
| DEXP | 10.9487 | 6.5169 | 0.3 | 2.3 | 1.0000 | 32.0000 | 448 |
| DFAM | 17.6540 | 17.7604 | 2.5 | 13.7 | 0.0000 | 135.0000 | 448 |
| ACDT | 0.3772 | 0.8344 | 2.9 | 12.7 | 0.0000 | 5.0000 | 448 |
| VLTN | 0.5960 | 0.9669 | 2.9 | 18.2 | 0.0000 | 8.0000 | 448 |
| DAGE | 35.5580 | 8.3407 | 0.2 | 2.4 | 20.0000 | 57.0000 | 448 |
| DSEX | 0.0647 | 0.2463 | 3.5 | 13.5 | 0.0000 | 1.0000 | 448 |
| DEDU | 0.3080 | 0.4622 | 0.8 | 1.7 | 0.0000 | 1.0000 | 448 |
| NTLY | 0.1116 | 0.3152 | 2.5 | 7.1 | 0.0000 | 1.0000 | 448 |
| ACTN | 0.4844 | 0.5003 | 0.1 | 1.0 | 0.0000 | 1.0000 | 448 |
| OCUP | 2.4710 | 3.4420 | 6.4 | 51.0 | 1.0000 | 33.0000 | 448 |
| VAGE | 4.8013 | 3.5932 | 1.2 | 4.3 | 0.0000 | 20.0000 | 448 |
| EGCA | 4.4353 | 0.9923 | 2.0 | 6.9 | 1.0000 | 8.0000 | 448 |
| TRAN | 0.2210 | 0.4154 | 1.3 | 2.8 | 0.0000 | 1.0000 | 448 |
| MJTP | 0.0826 | 0.2756 | 3.0 | 10.2 | 0.0000 | 1.0000 | 448 |
| MNTP | 0.1451 | 0.3526 | 2.0 | 5.1 | 0.0000 | 1.0000 | 448 |
| TRPS | 0.1920 | 0.3943 | 1.6 | 3.4 | 0.0000 | 1.0000 | 448 |
| TRDN | 16.1853 | 10.8551 | 1.5 | 4.9 | 3.0000 | 55.0000 | 448 |
| ASEC | 8.3276 | 3.1084 | 1.2 | 5.1 | 3.5000 | 19.6000 | 87 |
| AREJ | 1.2759 | - 1.6960 | 2.4 | 9.4 | 0.0000 | 8.0000 | 87 |
| AMET | 66.2529 | 31.1981 | 1.1 | 5.8 | 0.4000 | 200.0000 | 87 |
| AENT | 0.0938 | 0.3279 | 3.7 | 17.0 | 0.0000 | 2.0000 | 448 |
| DEAD | 73.3906 | 101.6676 | 2.0 | 9.8 | -153.2917 | 669.9500 | 276 |
| DEAS | -5.4098 | 15.3308 | 0.3 | 2.8 | -43.4000 | 41.1000 | 276 |
| DEAG | 9.5971 | 5.9064 | 1.4 | 4.7 | 2.4444 | 34.6457 | 276 |
| SDES | 40.8514 | 10.1918 | 0.0 | 3.7 | 10.0000 | 70.0000 | 276 |
| DTES | 32.7971 | 33.3217 | 2.9 | 13.0 | 8.0000 | 200.0000 | 276 |
| GPES | 0.5011 | 0.4211 | 0.9 | 3.2 | 0.0417 | 1.9097 | 276 |
| DAMR | 1.7433 | 1.9738 | 0.0 | 2.9 | -4.0000 | 7.2000 | 275 |
| PSEC | 4.2023 | 1.4227 | 0.5 | 3.4 | 1.3000 | 8.5000 | 174 |
| PMET | 53.9893 | 26.2035 | 0.8 | 4.1 | 8.1611 | 163.5667 | 174 |

Table B1.2: Descriptive Statistics for the Data Collected for Maneuver 2

| Variable | Mean | Std. Dev. | Skew. | Kurt. | Minimum | Maximum | Cases |
|---|---|---|---|---|---|---|---|
| RESP | 0.6932 | 0.4616 | -0.8 | 1.7 | 0.0000 | 1.0000 | 528 |
| MJSD | 39.7180 | 11.9703 | 0.9 | 3.4 | 15.3000 | 79.3000 | 528 |
| MNSD | 14.7805 | 16.3683 | 0.4 | 1.5 | 0.0000 | 46.2000 | 528 |
| MJVL | 2.5227 | 2.8907 | 1.3 | 4.3 | 0.0000 | 12.0000 | 528 |
| MNVL | 3.5114 | 1.0916 | 0.8 | 4.7 | 0.0000 | 8.0000 | 528 |
| QSIZ | 1.3504 | 2.1198 | 1.5 | 4.6 | 0.0000 | 9.0000 | 528 |
| DLIQ | 8.3134 | 12.4930 | 1.6 | 5.1 | 0.0000 | 62.1000 | 528 |
| DLQH | 2.0778 | 4.4480 | 3.7 | 20.7 | 0.0000 | 34.7000 | 528 |
| TLDL | 10.3913 | 12.8319 | 1.3 | 4.1 | 0.0000 | 62.1000 | 528 |
| NREJ | 0.5985 | 1.4545 | 4.8 | 31.8 | 0.0000 | 13.0000 | 528 |
| GSEC | 7.2225 | 4.6655 | 2.1 | 9.1 | 1.4000 | 35.3000 | 528 |
| GMET | 88.1003 | 77.8909 | 2.4 | 9.4 | 9.1250 | 477.4000 | 348 |
| SSEC | 6.7153 | 4.1666 | 1.7 | 7.0 | 1.3000 | 28.3000 | 528 |
| SMET | 51.9947 | 24.7588 | 0.9 | 5.6 | 9.1000 | 197.9000 | 528 |
| TMGP | 0.7178 | 0.5245 | 1.0 | 13.1 | 0.0000 | 5.0000 | 528 |
| DEXP | 10.7533 | 6.7809 | 0.9 | 4.2 | 0.2500 | 40.0000 | 528 |
| DFAM | 19.5966 | 17.1035 | 2.5 | 14.0 | 0.2500 | 150.0000 | 528 |
| ACDT | 0.2424 | 0.5245 | 2.4 | 10.1 | 0.0000 | 4.0000 | 528 |
| VLTN | 0.4716 | 0.9948 | 3.1 | 14.5 | 0.0000 | 6.0000 | 528 |
| DAGE | 37.1174 | 9.8748 | 0.4 | 2.5 | 20.0000 | 65.0000 | 528 |
| DSEX | 0.1212 | 0.3267 | 2.3 | 6.4 | 0.0000 | 1.0000 | 528 |
| DEDU | 0.2367 | 0.4255 | 1.2 | 2.5 | 0.0000 | 1.0000 | 528 |
| NTLY | 0.1061 | 0.3082 | 2.6 | 7.5 | 0.0000 | 1.0000 | 528 |
| ACTN | 0.3902 | 0.4882 | 0.4 | 1.2 | 0.0000 | 1.0000 | 528 |
| OCUP | 2.0341 | 1.8188 | 5.1 | 52.4 | 1.0000 | 25.0000 | 528 |
| VAGE | 5.2595 | 3.9082 | 0.8 | 2.6 | 0.0000 | 16.0000 | 528 |
| EGCA | 4.3106 | 0.7950 | 2.3 | 8.2 | 2.0000 | 8.0000 | 528 |
| TRAN | 0.2576 | 0.4377 | 1.1 | 2.2 | 0.0000 | 1.0000 | 528 |
| MJTP | 0.0379 | 0.1911 | 4.8 | 24.4 | 0.0000 | 1.0000 | 528 |
| MNTP | 0.1023 | 0.3033 | 2.6 | 7.9 | 0.0000 | 1.0000 | 528 |
| TRPS | 0.1761 | 0.3813 | 1.7 | 3.9 | 0.0000 | 1.0000 | 528 |
| TRDN | 22.1383 | 17.2874 | 2.0 | 9.6 | 1.0000 | 120.0000 | 528 |
| ASEC | 6.4493 | 1.5293 | 0.7 | 3.2 | 3.5000 | 11.0000 | 207 |
| AREJ | 0.7681 | 1.1760 | 3.1 | 15.9 | 0.0000 | 7.0000 | 207 |
| AMET | 61.9113 | 21.4239 | 1.7 | 10.3 | 24.6056 | 197.4000 | 207 |
| AENT | 0.4411 | 1.3950 | 4.2 | 21.5 | 0.0000 | 10.0000 | 526 |
| DEAD | 67.4377 | 102.2663 | 0.9 | 6.0 | -255.4167 | 447.4000 | 247 |
| DEAS | -12.3801 | 15.5278 | -0.5 | 3.4 | -57.9000 | 30.4000 | 366 |
| DEAG | 8.2174 | 4.9518 | 2.1 | 8.0 | 1.5333 | 35.2199 | 366 |
| SDES | 48.4317 | 13.3831 | 0.9 | 3.2 | 20.0000 | 85.0000 | 366 |
| DTES | 33.1230 | 39.9762 | 4.0 | 21.4 | 8.0000 | 300.0000 | 366 |
| GPES | 0.5777 | 0.4568 | 0.9 | 3.4 | 0.0347 | 2.2222 | 366 |
| DAMR | 1.4481 | 1.4688 | -0.3 | 2.3 | -1.7000 | 5.2000 | 264 |
| PSEC | 3.6787 | 1.1413 | 0.3 | 3.2 | 1.4000 | 7.6000 | 160 |
| PMET | 55.4405 | 26.0439 | 0.6 | 2.2 | 24.6278 | 112.3417 | 34 |

Table B1.3: Descriptive Statistics for the Data Collected for Maneuver 3

| Variable | Mean | Std. Dev. | Skew. | Kurt. | Minimum | Maximum | Cases |
|---|---|---|---|---|---|---|---|
| RESP | 0.2729 | 0.4457 | 1.0 | 2.0 | 0.0000 | 1.0000 | 817 |
| MJSD | 42.6612 | 13.4235 | 0.2 | 2.4 | 11.9000 | 75.9000 | 817 |
| MNSD | 3.7011 | 9.9900 | 2.8 | 9.9 | 0.0000 | 52.1000 | 817 |
| MJVL | 5.8923 | 2.5371 | -0.1 | 2.2 | 0.0000 | 11.0000 | 817 |
| MNVL | 1.6977 | 0.9382 | 0.7 | 3.8 | 0.0000 | 5.0000 | 817 |
| QSIZ | 1.5692 | 2.2213 | 1.4 | 4.1 | 0.0000 | 9.0000 | 817 |
| DLIQ | 8.3369 | 13.6328 | 2.0 | 6.9 | 0.0000 | 81.5000 | 817 |
| DLQH | 9.1296 | 10.0357 | 1.9 | 8.2 | 0.0000 | 67.4000 | 817 |
| TLDL | 17.4665 | 16.2831 | 1.2 | 4.2 | 0.0000 | 81.5000 | 817 |
| NREJ | 2.5728 | 2.8336 | 1.8 | 7.7 | 0.0000 | 19.0000 | 817 |
| GSEC | 4.5871 | 2.8535 | 1.5 | 7.6 | 0.1000 | 21.8000 | 817 |
| GMET | 59.5194 | 47.1707 | 1.6 | 7.6 | 0.4278 | 363.9389 | 817 |
| SSEC | 4.5343 | 3.5953 | 3.0 | 19.6 | 0.1000 | 36.5000 | 817 |
| SMET | 49.6460 | 38.9325 | 1.6 | 7.9 | 0.0000 | 301.4000 | 763 |
| TMGP | 0.2717 | 0.4451 | 1.0 | 2.1 | 0.0000 | 1.0000 | 817 |
| TRGP | 0.5165 | 0.5000 | -0.1 | 1.0 | 0.0000 | 1.0000 | 817 |
| DEXP | 11.3602 | 7.3264 | 0.6 | 2.6 | 0.5000 | 40.0000 | 816 |
| DFAM | 20.1292 | 21.0993 | 3.1 | 17.6 | 0.0000 | 150.0000 | 817 |
| ACDT | 0.3439 | 0.7783 | 3.3 | 17.2 | 0.0000 | 5.0000 | 817 |
| VLTN | 0.5998 | 1.0433 | 2.3 | 9.1 | 0.0000 | 6.0000 | 817 |
| DAGE | 35.9988 | 9.1261 | 0.8 | 3.6 | 21.0000 | 70.0000 | 817 |
| DSEX | 0.0869 | 0.2819 | 2.9 | 9.6 | 0.0000 | 1.0000 | 817 |
| DEDU | 0.3586 | 0.4799 | 0.6 | 1.3 | 0.0000 | 1.0000 | 817 |
| NTLY | 0.1897 | 0.3923 | 1.6 | 3.5 | 0.0000 | 1.0000 | 817 |
| ACTN | 0.3905 | 0.4882 | 0.4 | 1.2 | 0.0000 | 1.0000 | 817 |
| OCUP | 2.1848 | 1.9744 | 2.6 | 11.0 | 1.0000 | 12.0000 | 817 |
| VAGE | 5.4468 | 4.0995 | 0.9 | 2.9 | 0.0000 | 17.0000 | 817 |
| EGCA | 4.5459 | 1.0850 | 1.9 | 5.5 | 4.0000 | 8.0000 | 817 |
| TRAN | 0.2411 | 0.4280 | 1.2 | 2.5 | 0.0000 | 1.0000 | 817 |
| MJTP | 0.0355 | 0.1851 | 5.0 | 26.2 | 0.0000 | 1.0000 | 817 |
| MNTP | 0.1322 | 0.3389 | 2.2 | 5.7 | 0.0000 | 1.0000 | 817 |
| TRPS | 0.2693 | 0.4439 | 1.0 | 2.1 | 0.0000 | 1.0000 | 817 |
| TRDN | 18.2332 | 13.0961 | 1.4 | 4.9 | 10.0000 | 60.0000 | 817 |
| ASEC | 6.9804 | 1.6307 | 0.5 | 3.1 | 4.0000 | 12.8000 | 102 |
| AREJ | 3.1961 | 3.1055 | 0.8 | 2.7 | 0.0000 | 12.0000 | 102 |
| AMET | 75.7676 | 26.1885 | 0.9 | 3.7 | 20.8000 | 156.8000 | 102 |
| AENT | 0.0526 | 0.2728 | 6.0 | 43.6 | 0.0000 | 3.0000 | 817 |
| DEAD | 43.4578 | 71.4781 | 0.1 | 5.7 | -265.7667 | 333.9389 | 223 |
| DEAS | 2.0521 | 14.6934 | -0.4 | 3.6 | -53.1000 | 38.4000 | 223 |
| DEAG | 7.1950 | 2.9949 | 1.8 | 7.5 | 2.2333 | 21.5917 | 223 |
| SDES | 41.1525 | 12.4305 | 0.6 | 3.5 | 10.0000 | 80.0000 | 223 |
| DTES | 52.2197 | 52.1794 | 1.9 | 7.3 | 5.0000 | 300.0000 | 223 |
| GPES | 0.3772 | 0.4112 | 2.8 | 13.8 | 0.0278 | 2.7778 | 223 |
| DAMR | 0.6404 | 1.8862 | 0.8 | 3.6 | -3.0000 | 8.0000 | 745 |
| PSEC | 3.4530 | 1.8028 | 0.2 | 2.1 | 0.1000 | 8.5000 | 594 |
| PMET | 45.8241 | 34.9141 | 0.8 | 2.8 | 0.4278 | 167.4167 | 594 |

# Appendix B2

# Samples of Histograms

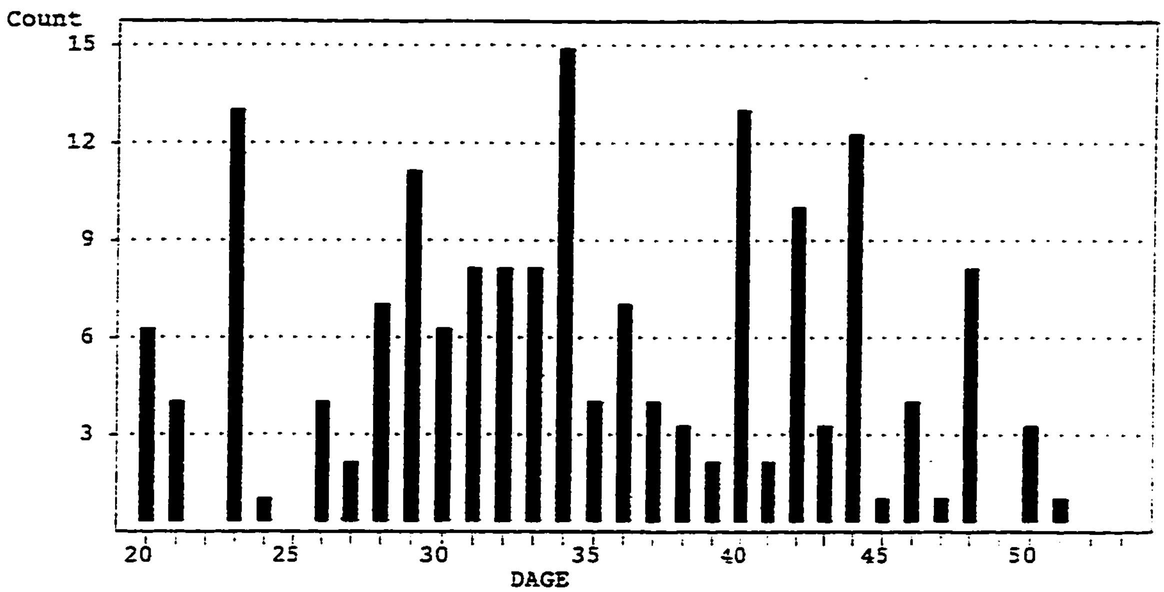



Figure B2.1: The histogram of driver age for maneuver1

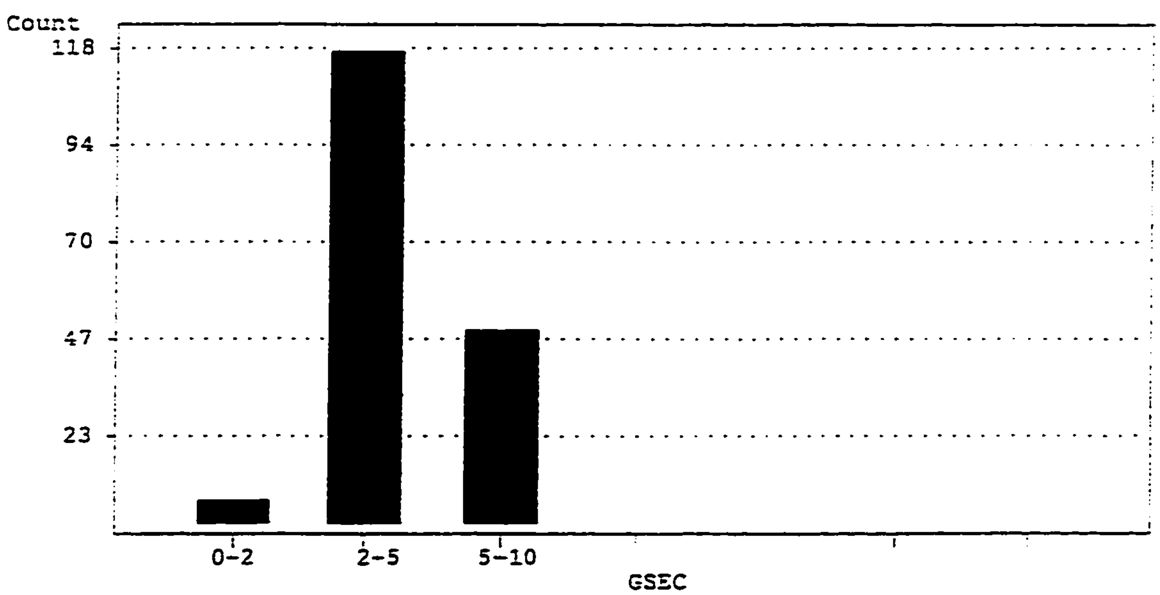



Figure B2.2: Histogram for gap size (GSEC), maneuver1

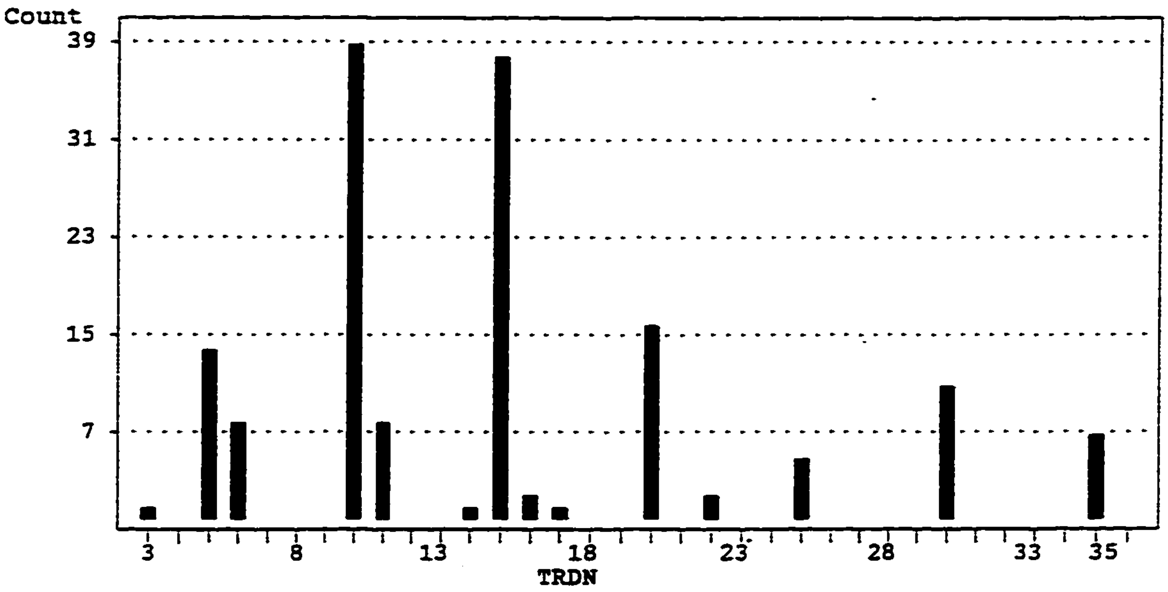



Figure B2.3 :histogram for trip duration, maneuver1

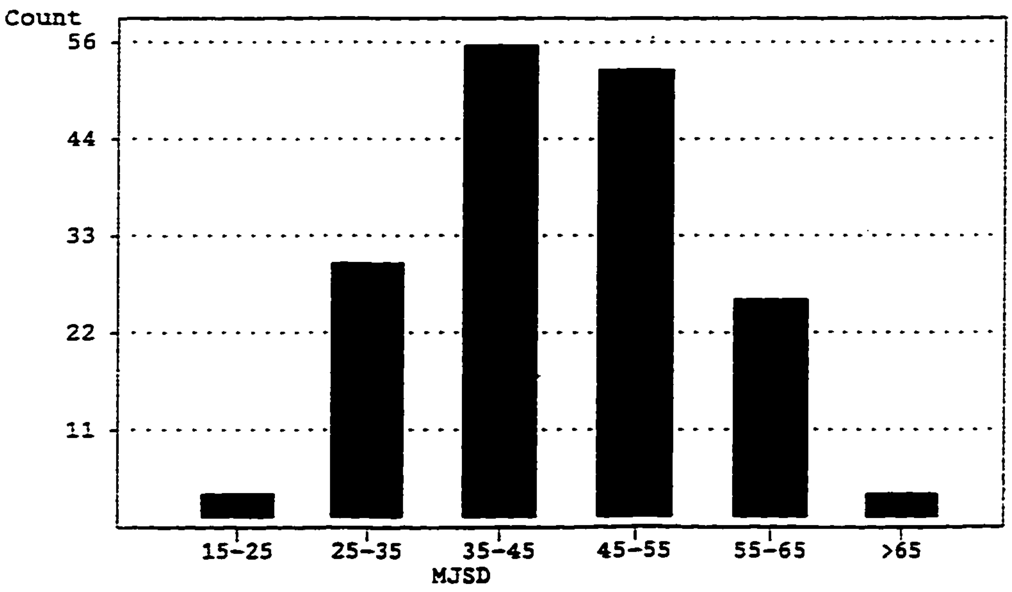



Figure B2.4: Histogram for major speed, maneuver1

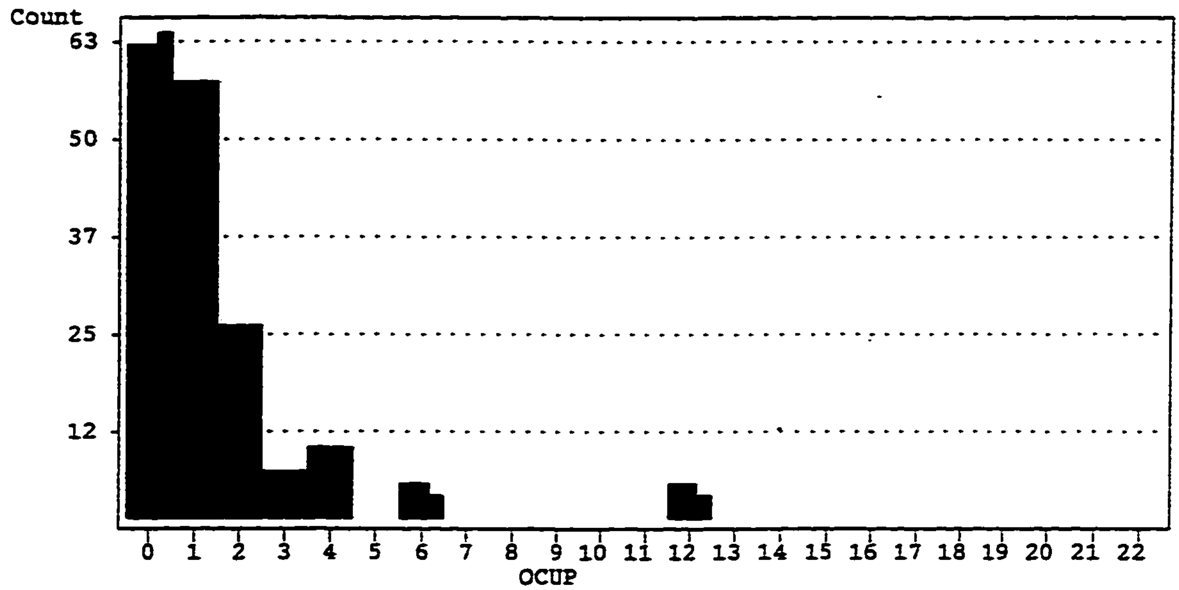
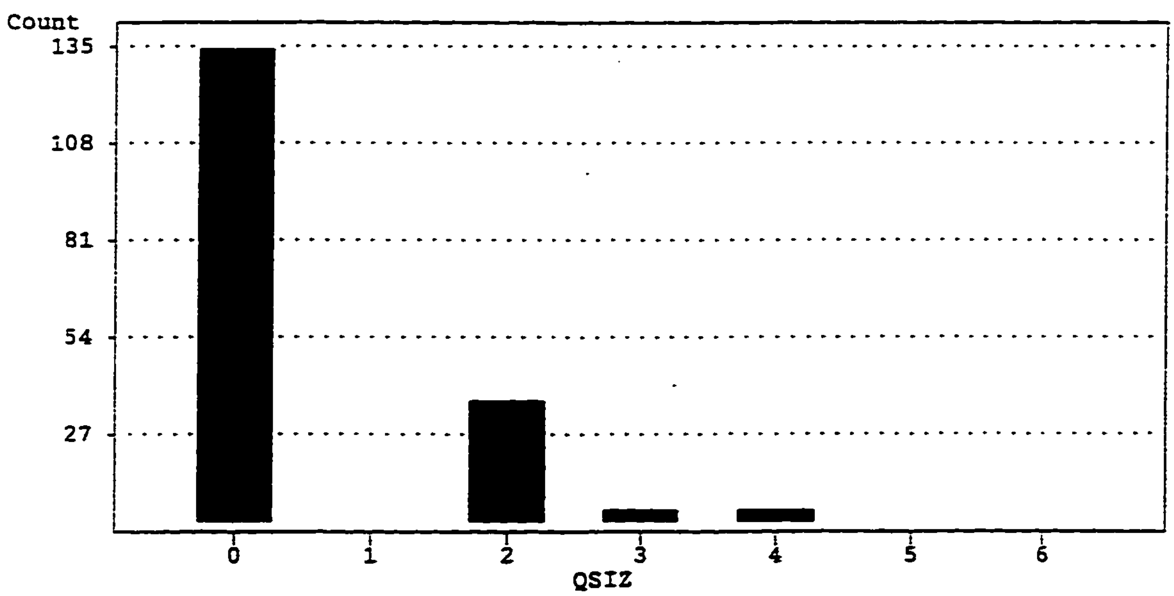



Figure B2.5: Histogram for vehicle occupancy, maneuver1.




Figur B2.6: Histogram for queue size, maneuver 1.

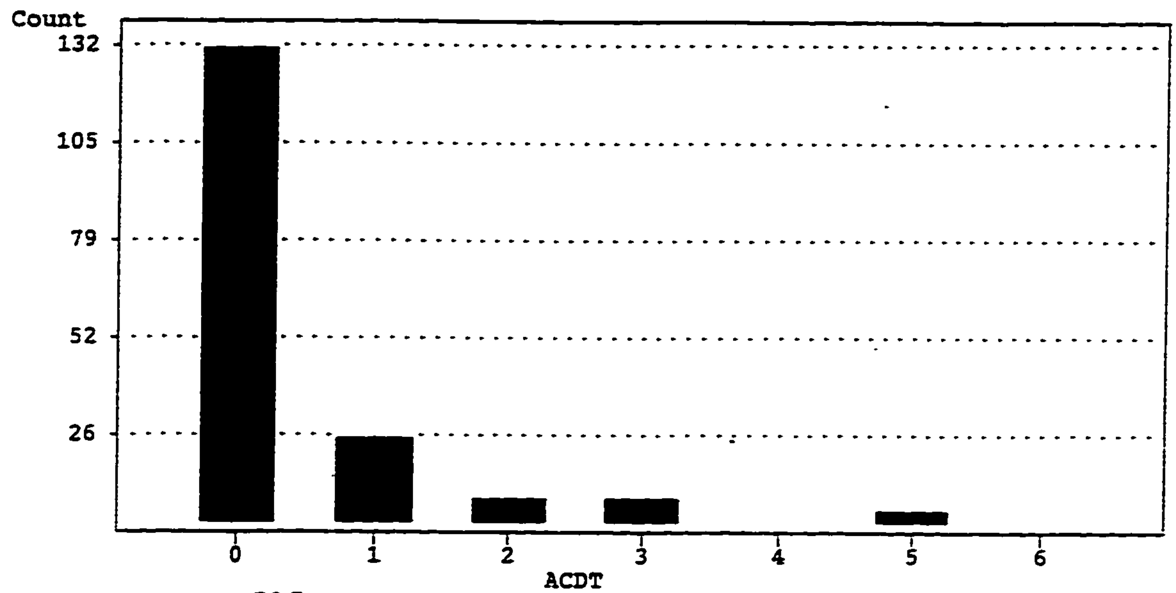


Figure B2.7: Histogram for number of accidents per driver, maneuver 1

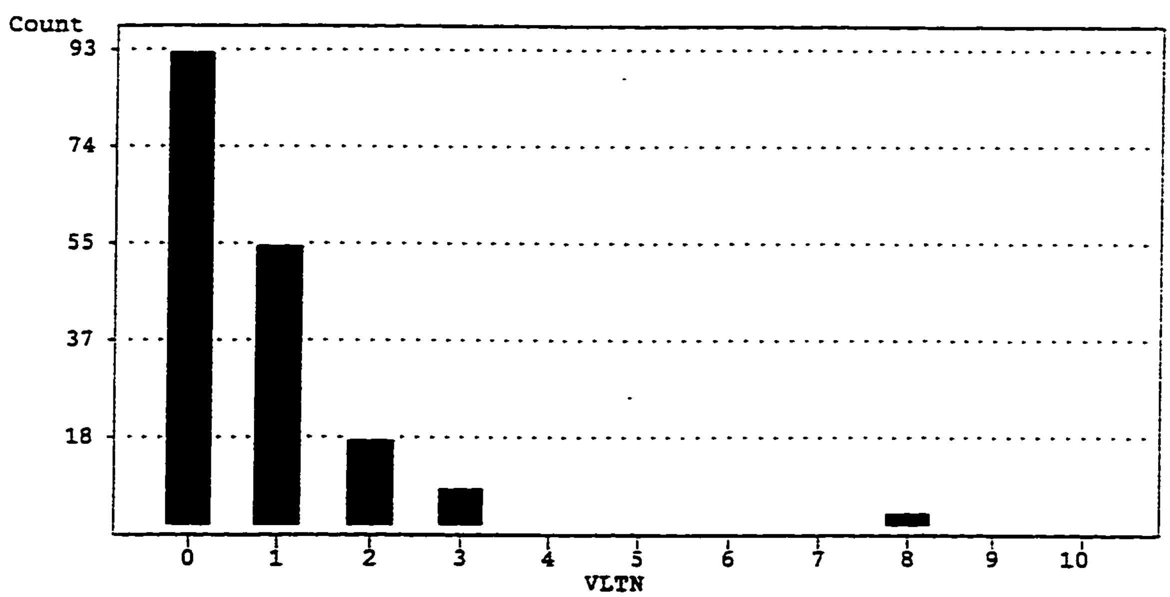


Figure B2-8: Histogram for number of Violations per driver, maneuver 1

# Appendix B3

# Samples of Scatter Diagrams

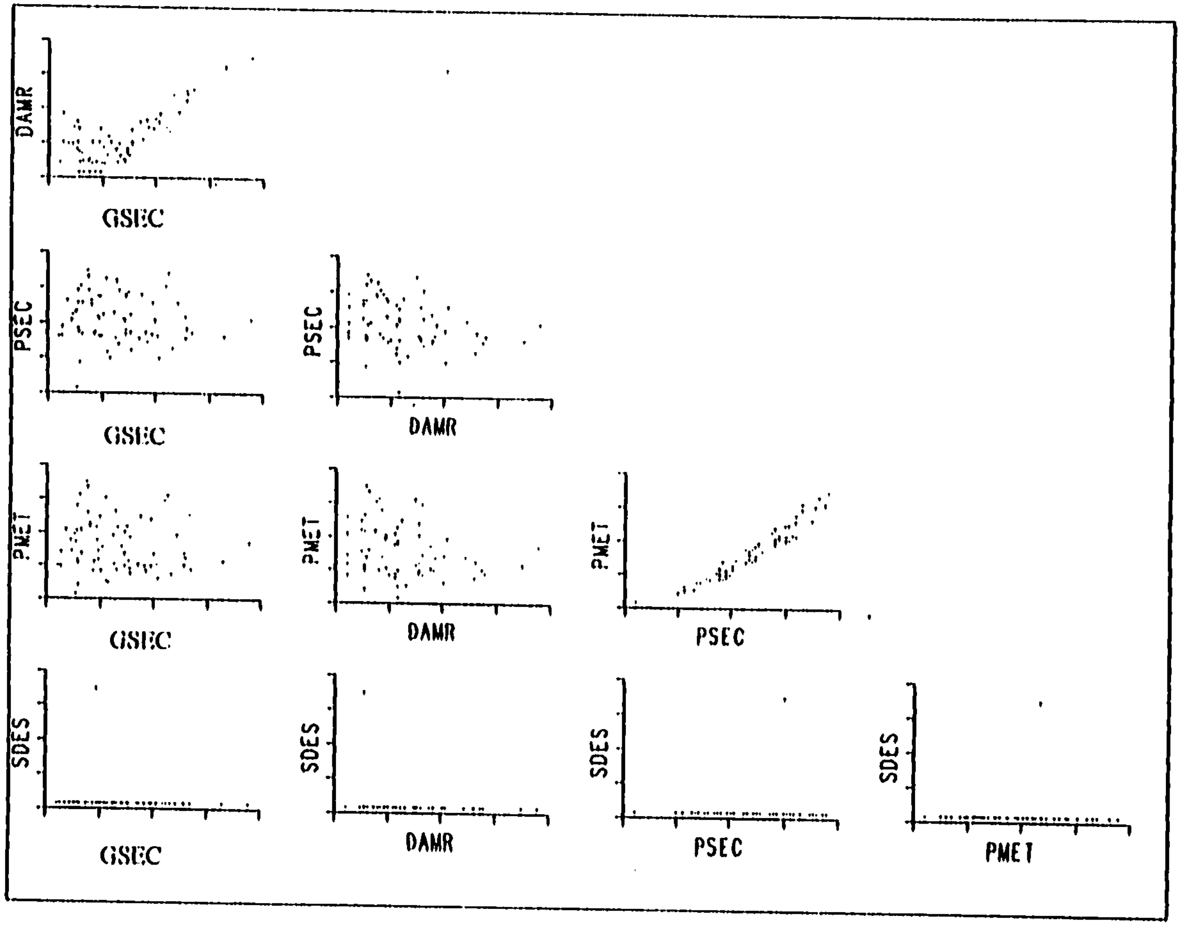



Figure B3.1: Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver 1

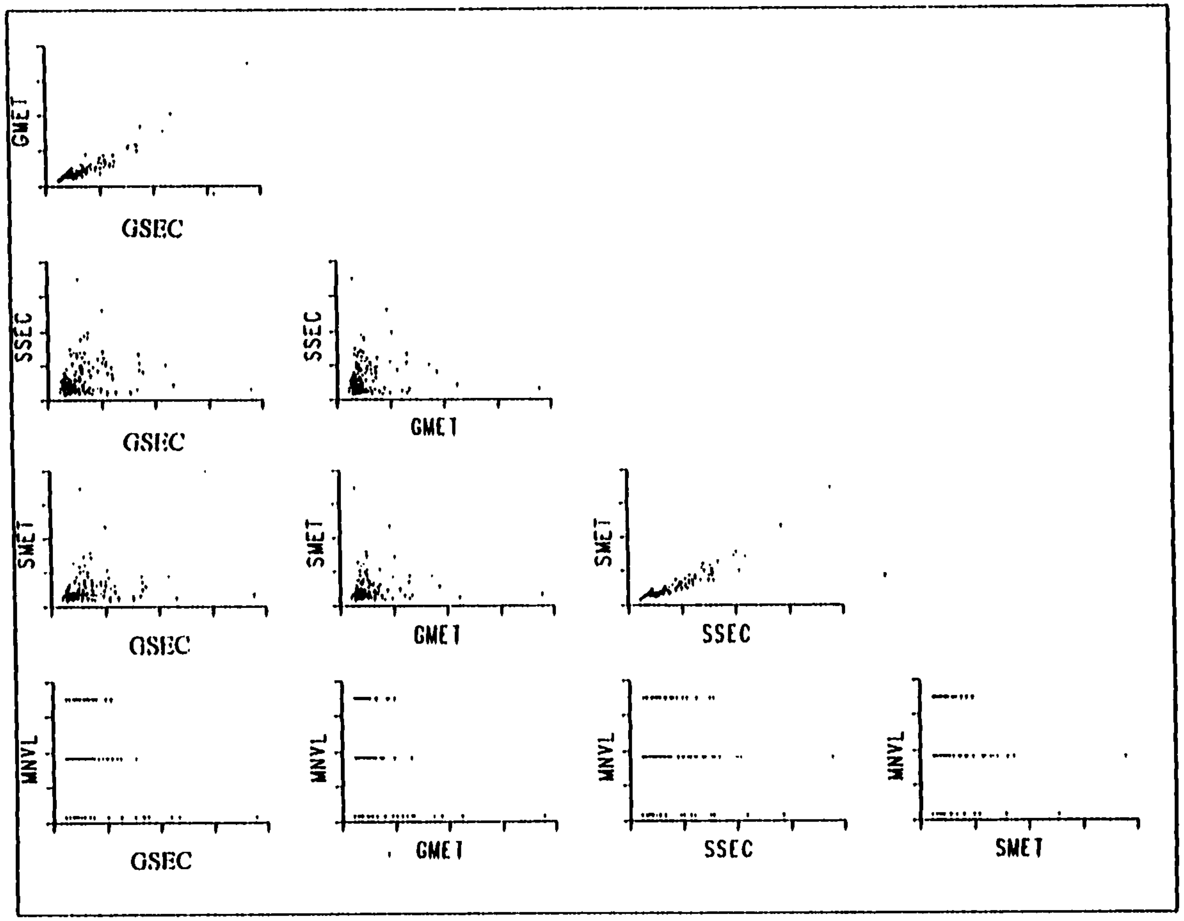



Figure B3.1 "Continued": Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver I

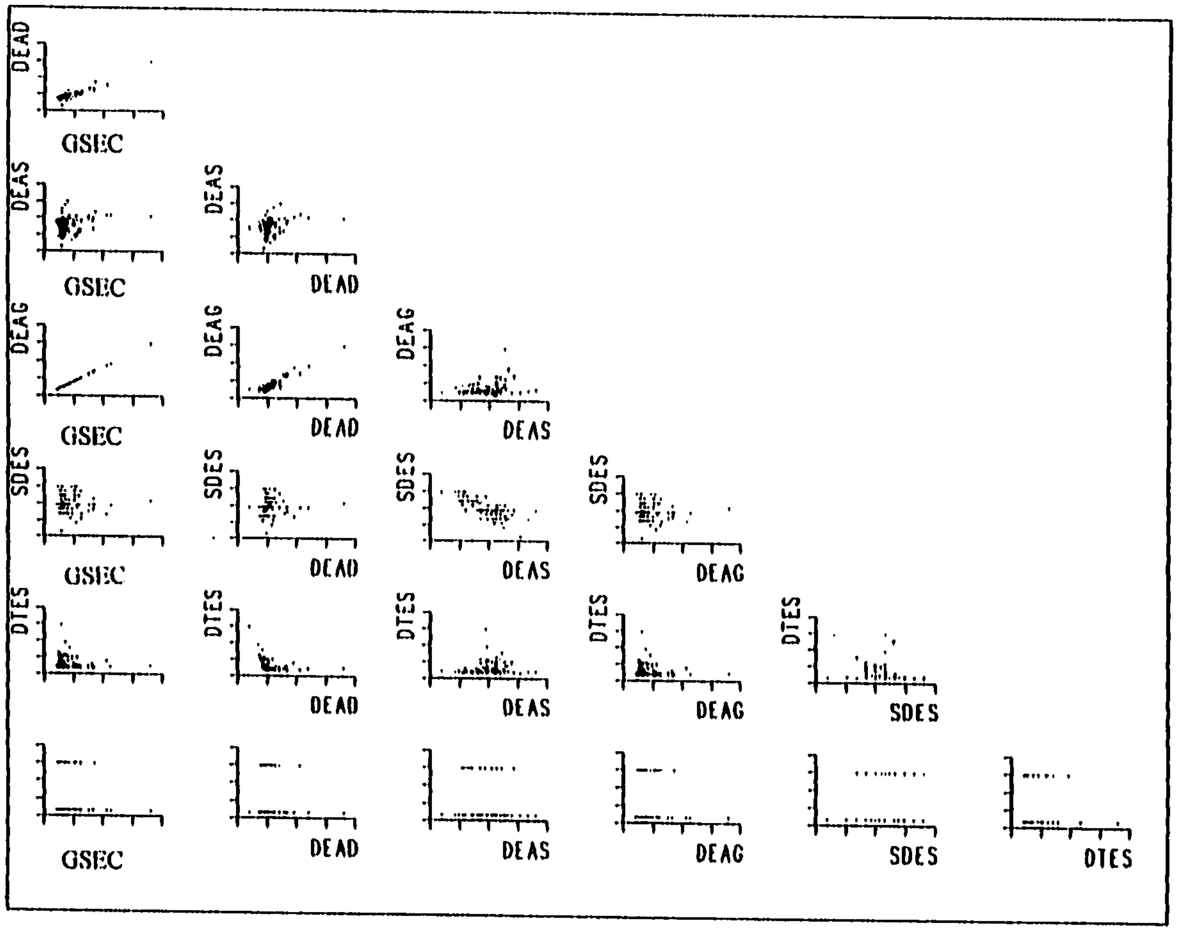



Figure B3.1 "Continued": Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver I

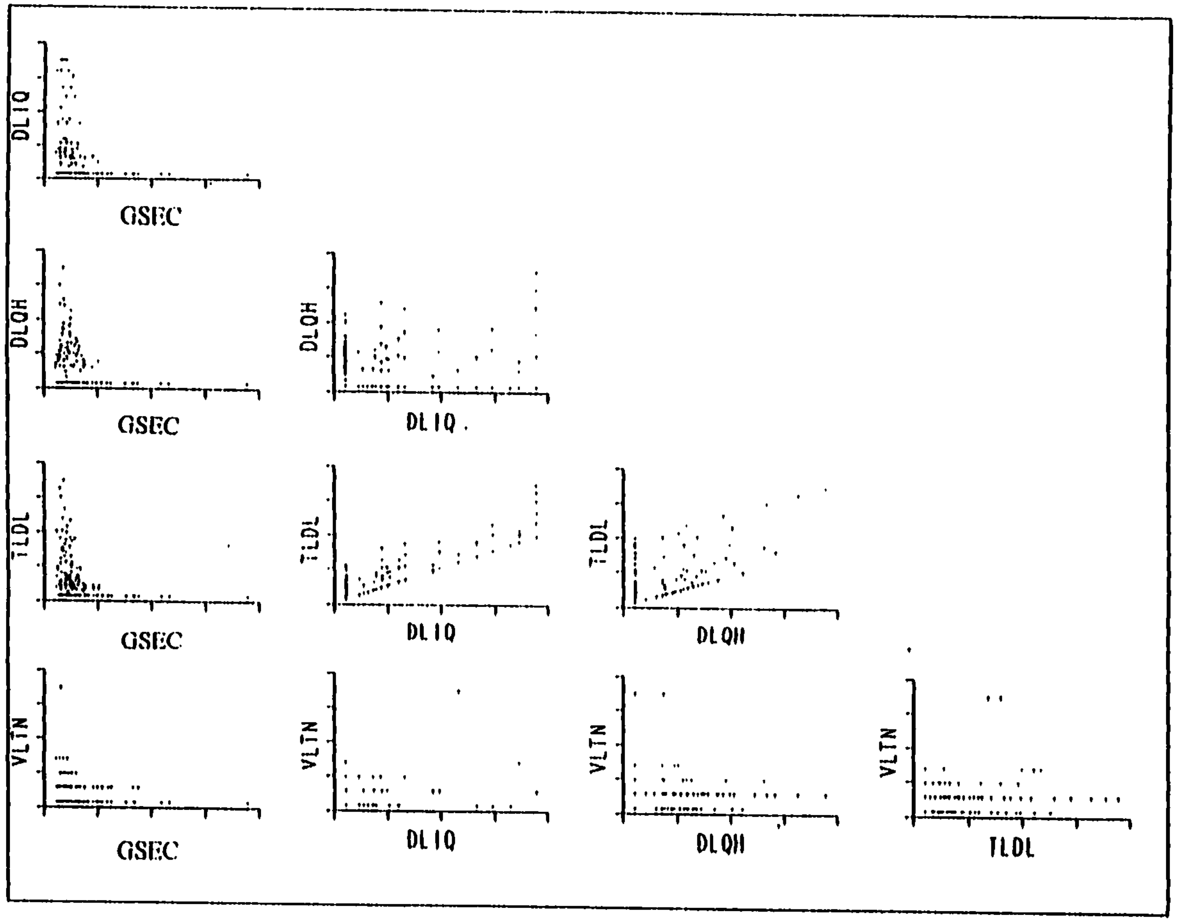



Figure B3.1 "Continued": Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver I

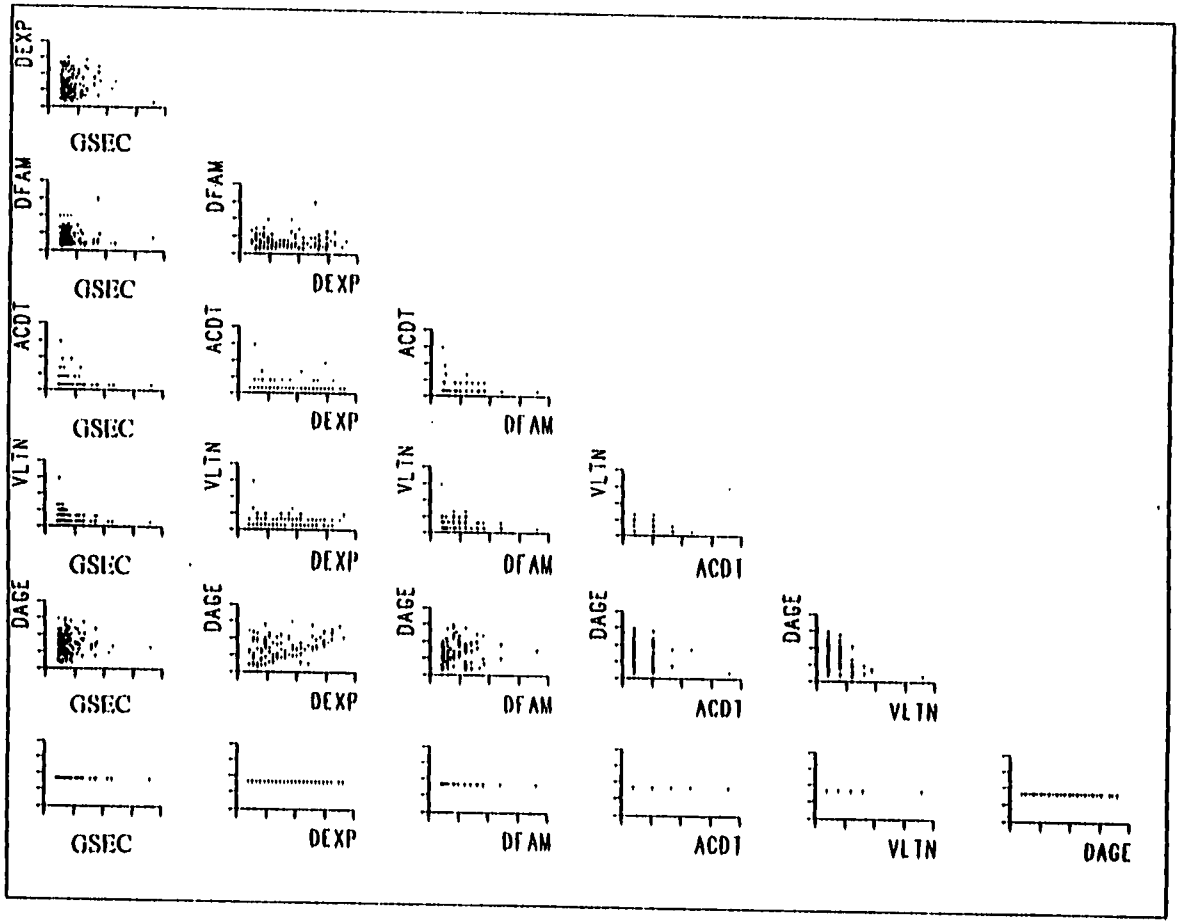



Figure B3.1 "Continued": Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver I

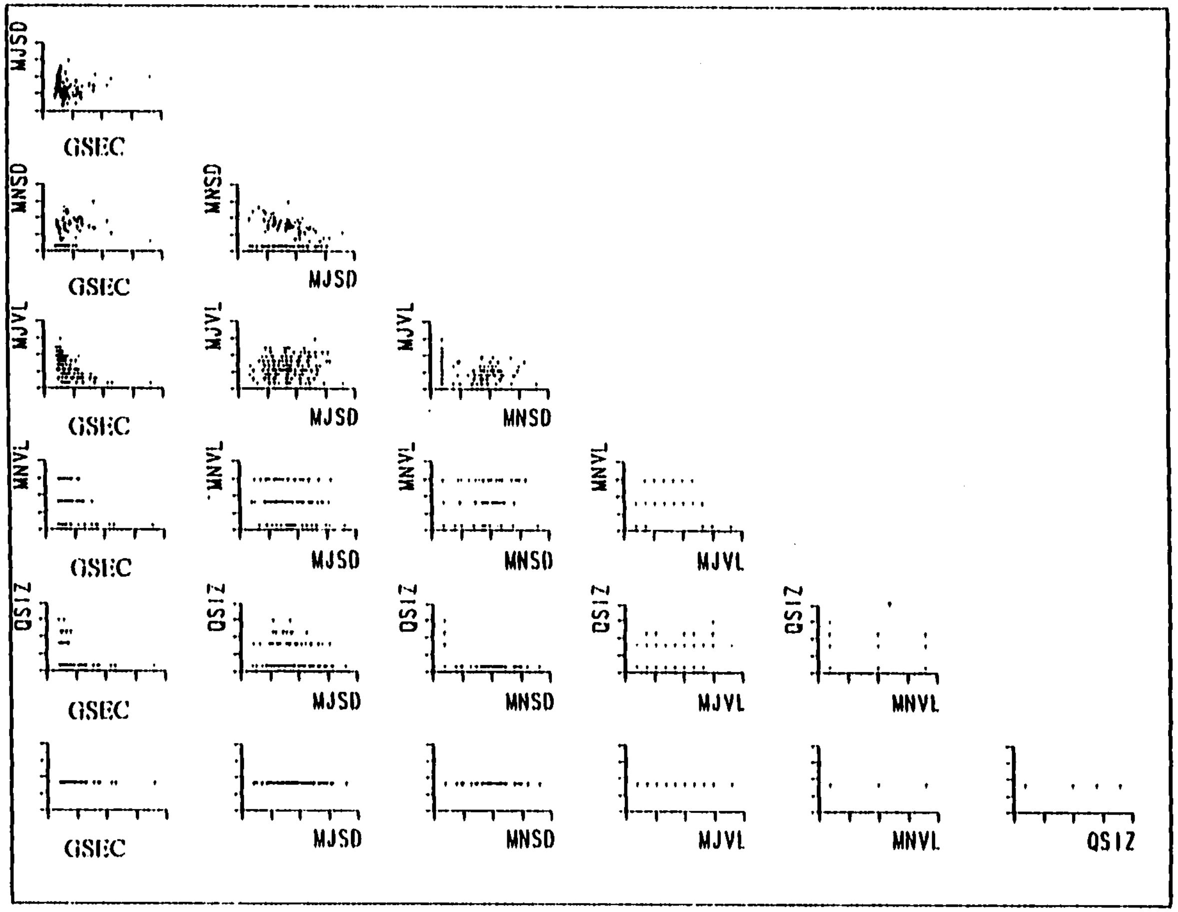



Figure B3.1 "Continued": Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver 1

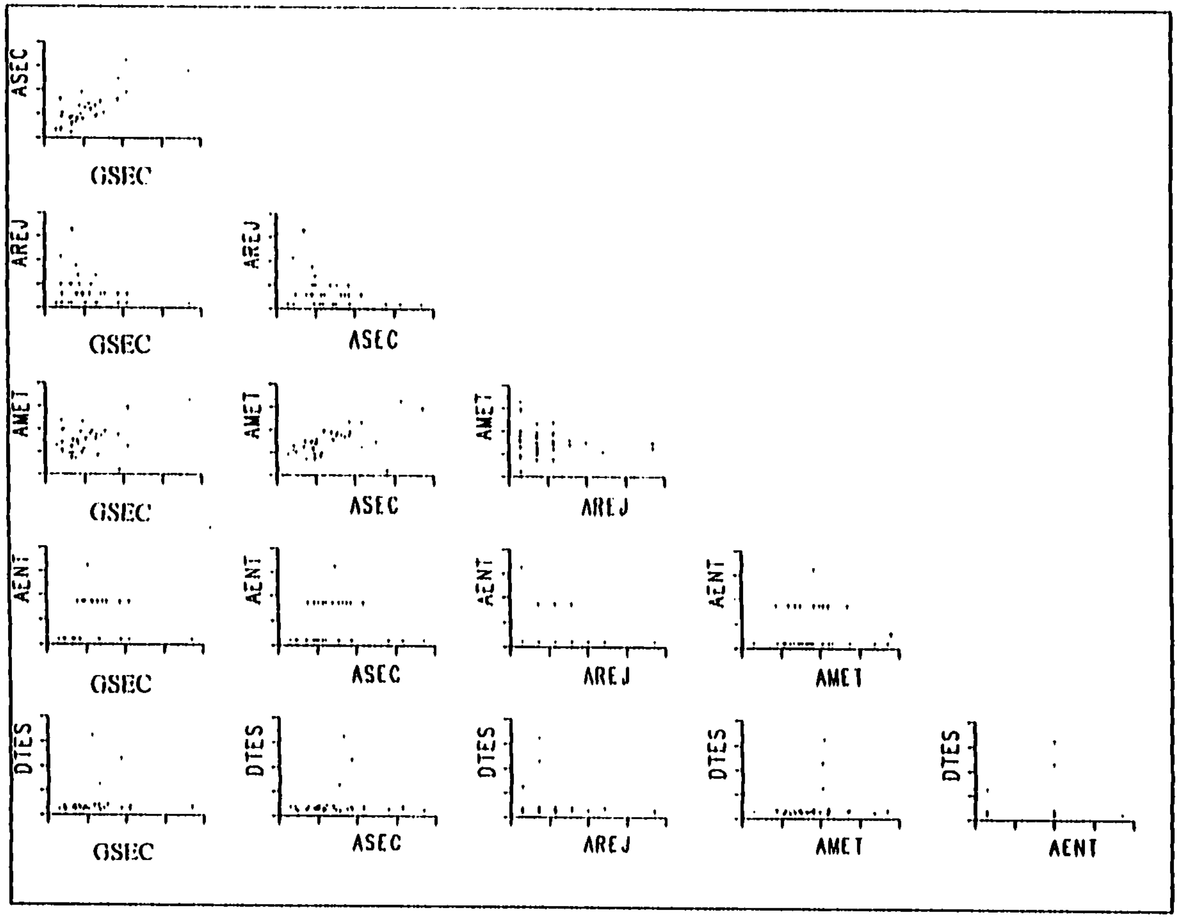



Figure B3.1 "Continued": Samples of the Scatter Diagrams Drawn Using Data Collected for Maneuver I

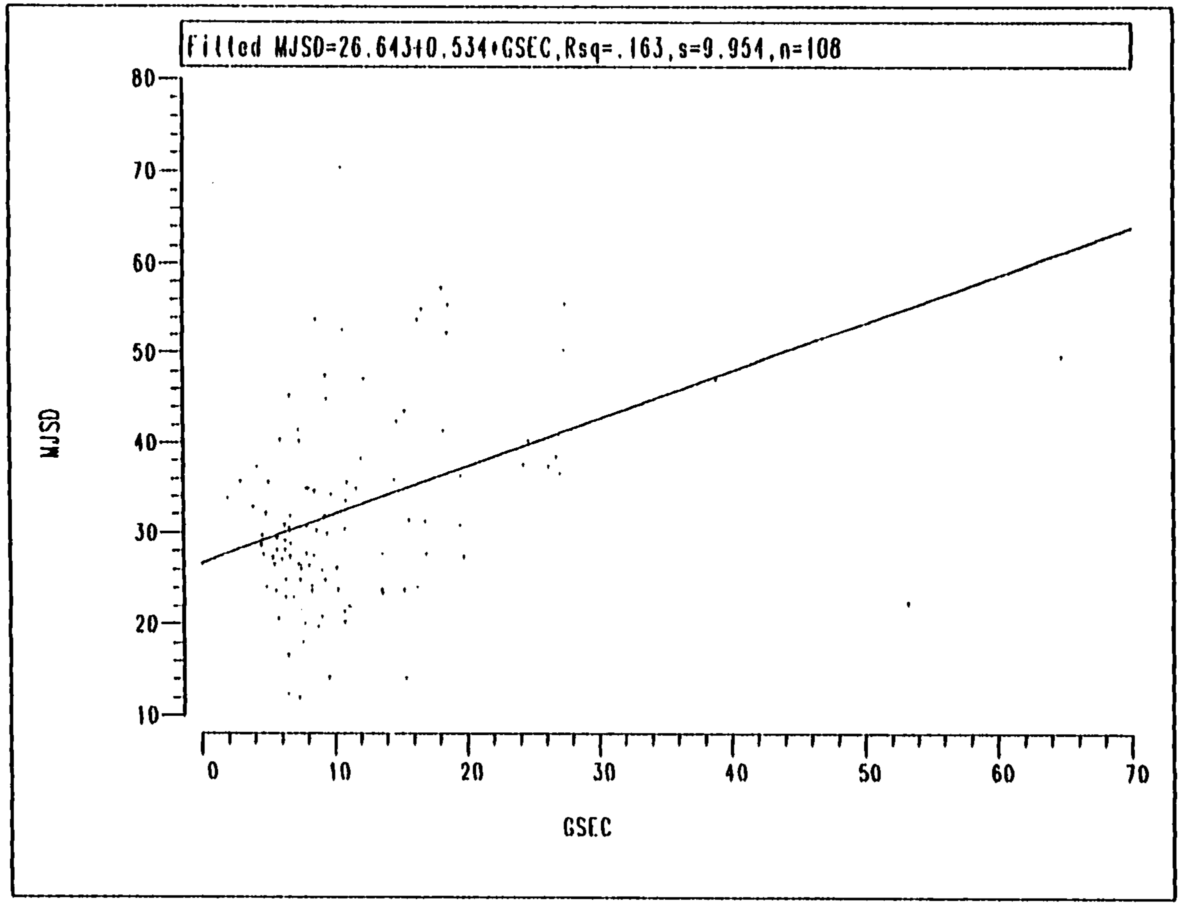



Figure B3.2: Scatter Diagram and the Linear Regression Fit Between Accepted Gap Size (GSEC) and Speed at Major Road (MJSD).

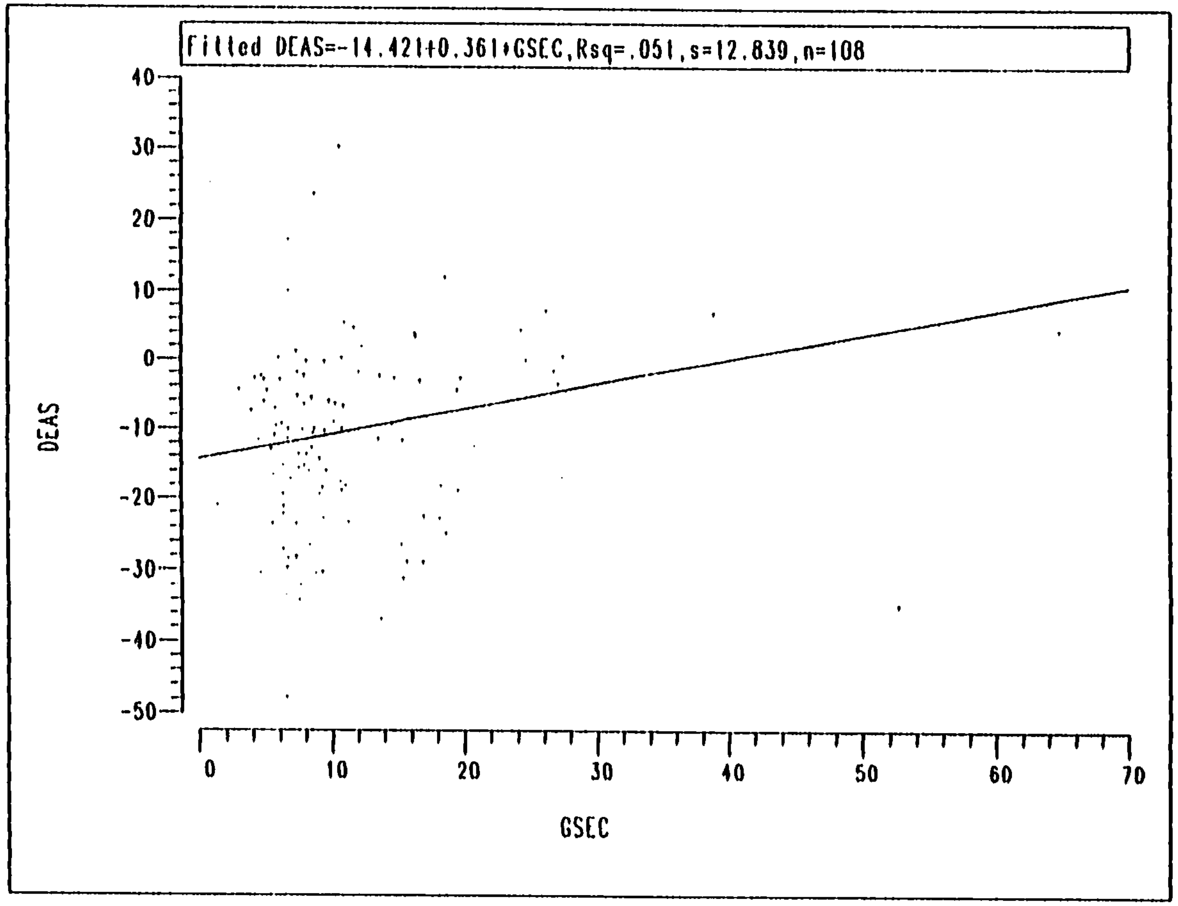



Figure B3.3: Scatter Diagram and the Linear Regression Fit Between the Accepted Gap Size (GSEC) and the Difference Between the Actual and the Estimated Speed of the Approaching Vehicle (DEAS).

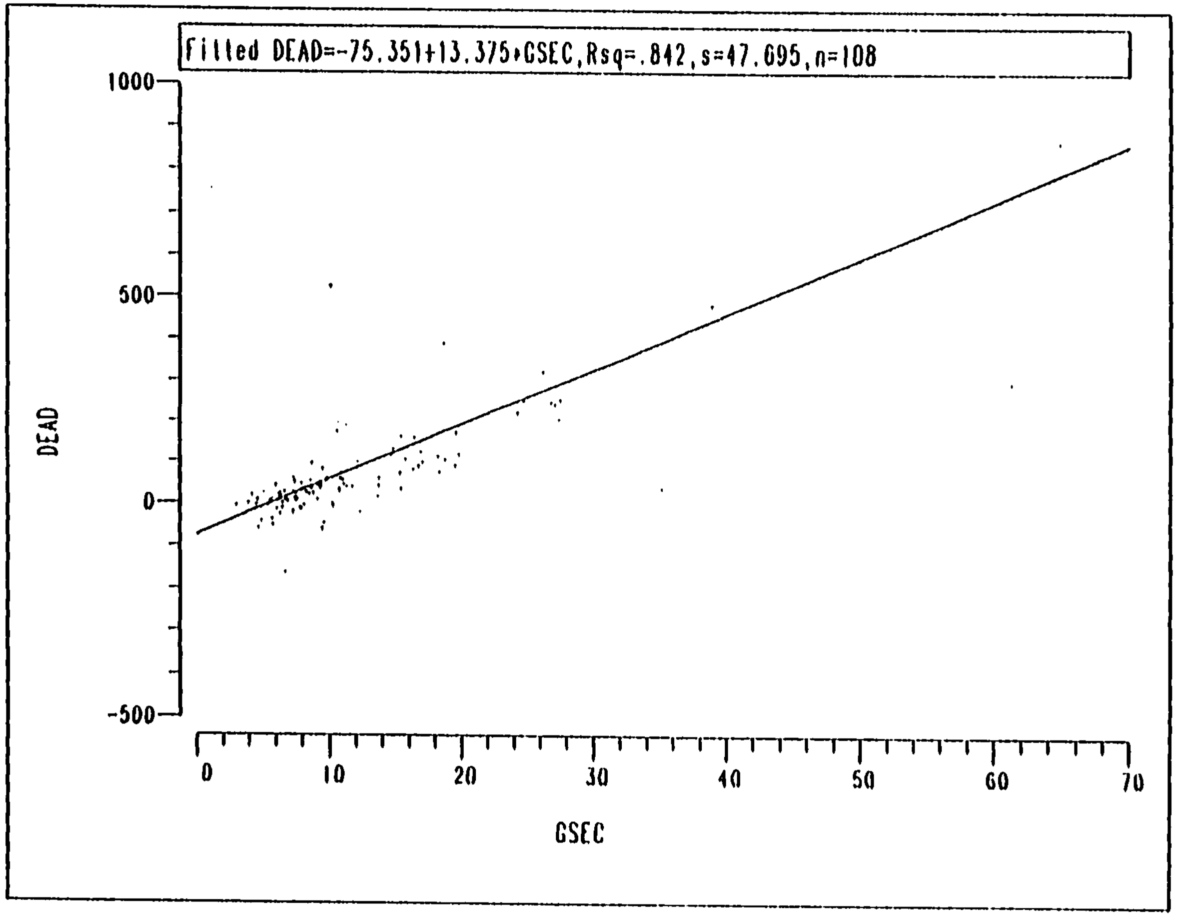



Figure B3.4: Scatter Diagram and the Linear Regression Fit Between the Accepted Gap Size (GSEC) and the Difference Between the Actual and the Estimated Distance of the Approaching Vehicle (DEAD).

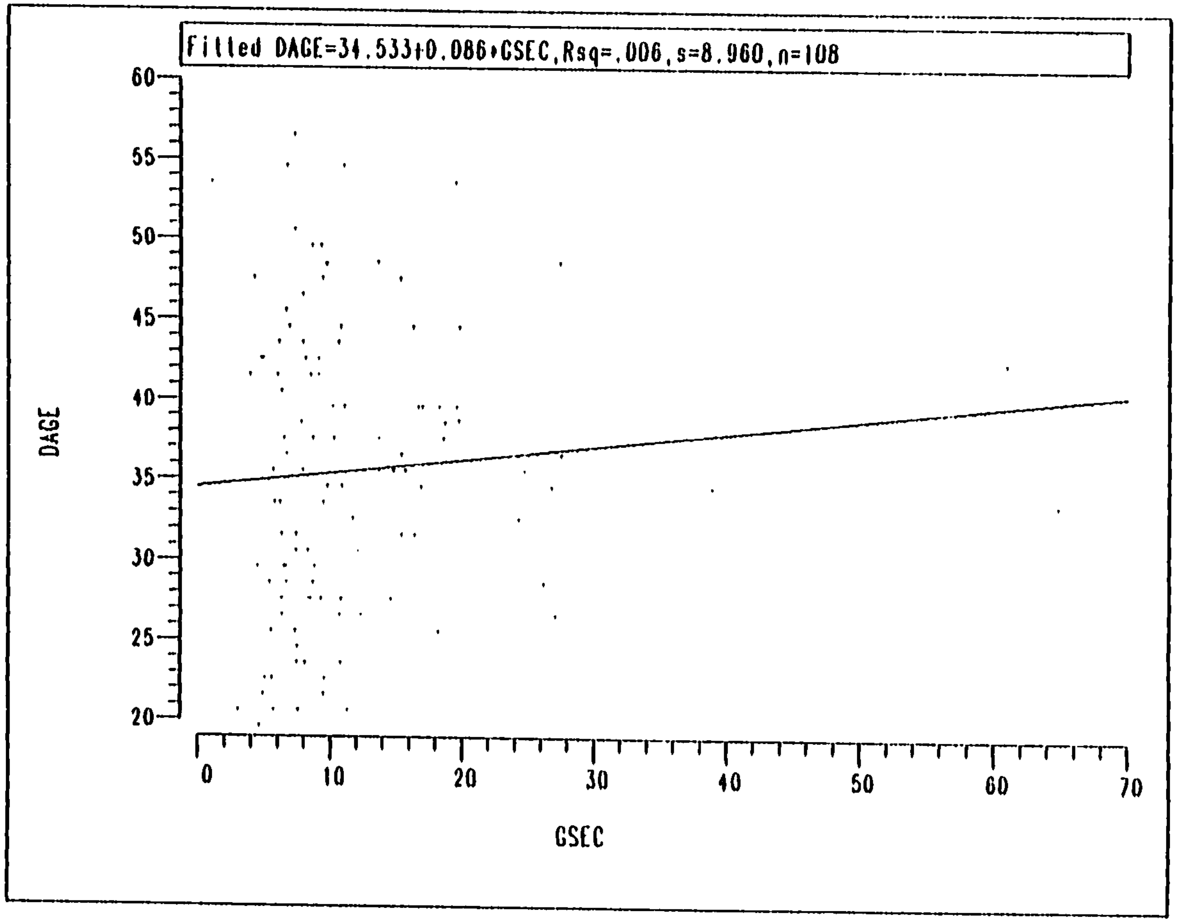



Figure B3.5: Scatter Diagram and the Linear Regression Fit Between Accepted Gap Size (GSEC) and Driver Age (DAGE).

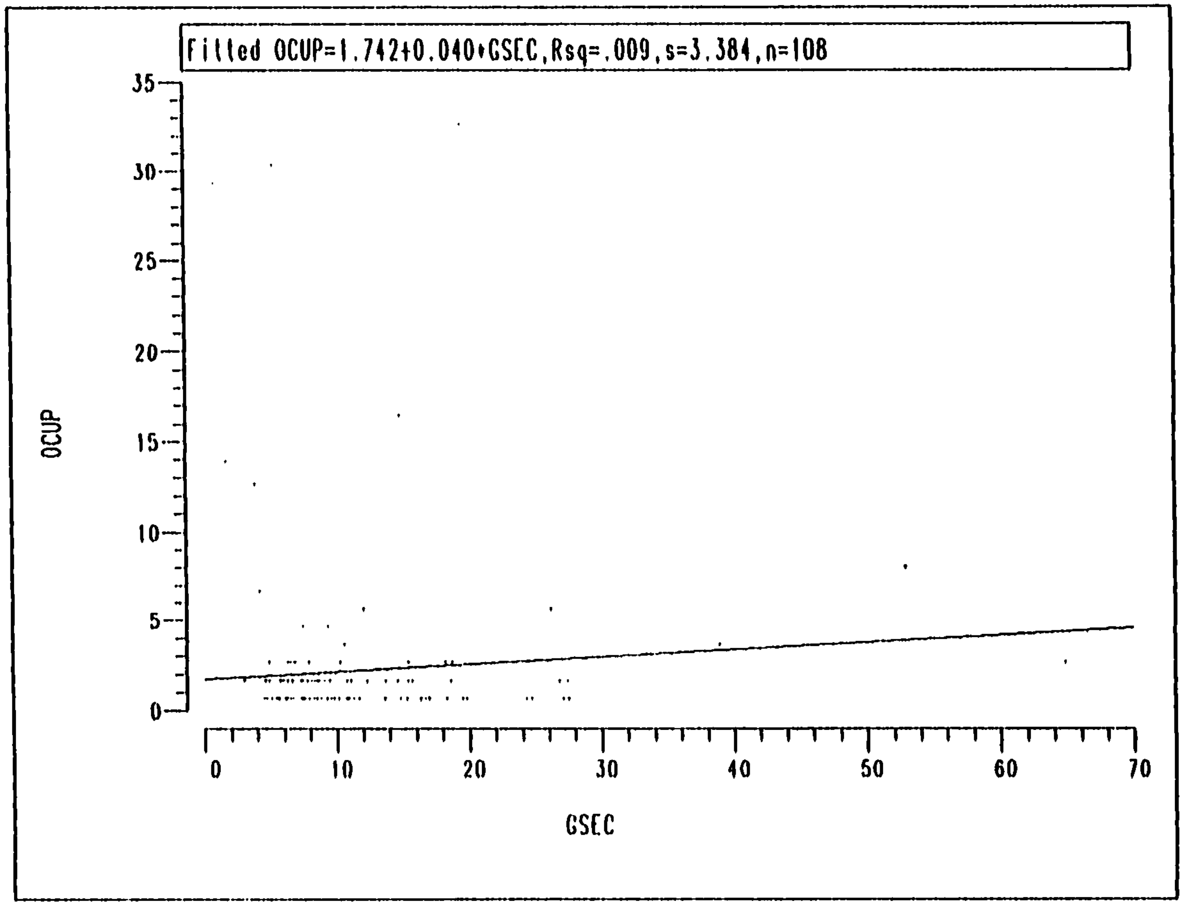



Figure B3.6: Scatter Diagram and the Linear Regression Fit Between Accepted Gap Size (GSEC) and Occupancy of the Vehicle at the Minor Road.

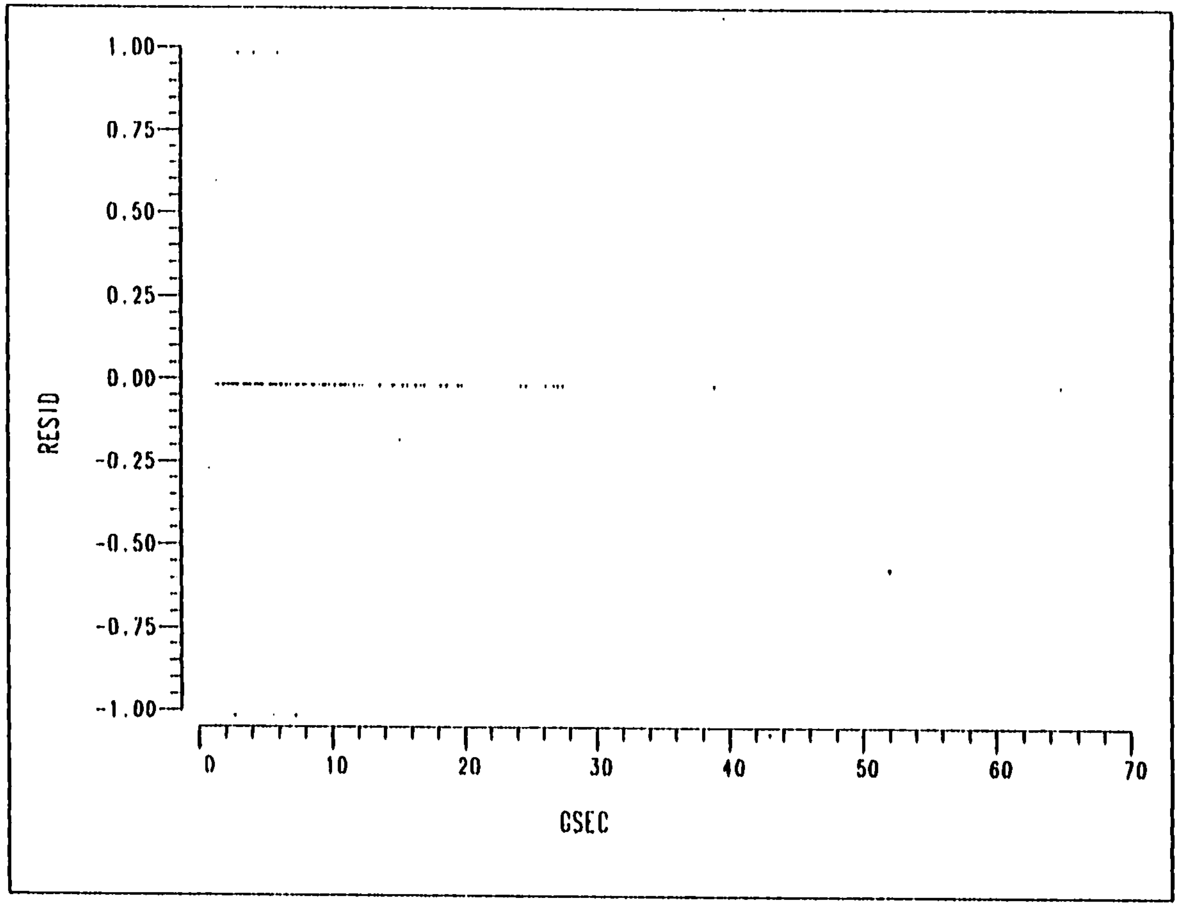



Figure B3.7: The Plot of the Error Term (Model Residuals) Against Gap Size in Seconds (GSEC).

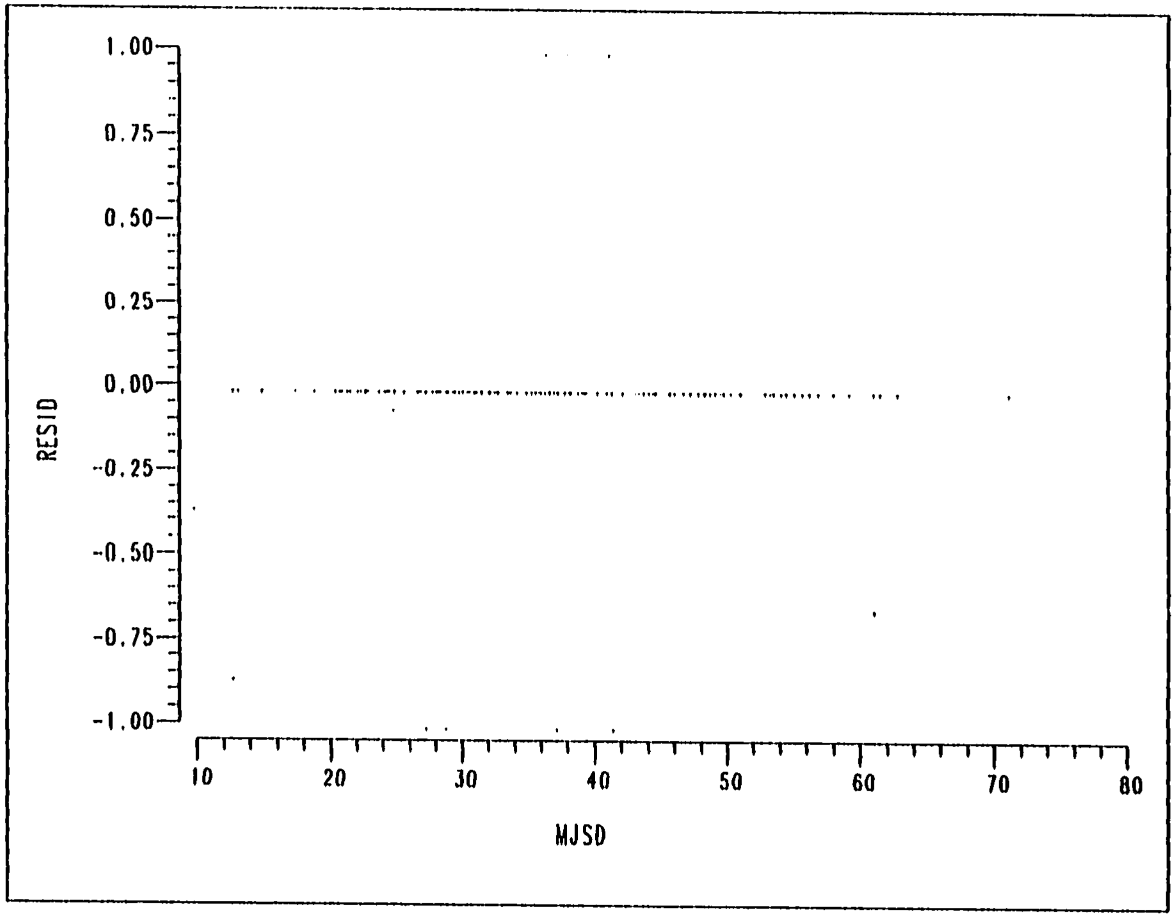



Figure B3.8: The Plot of the Error Term (Model Residuals) Against the Speed of the Approaching Vehicle (MJSD).

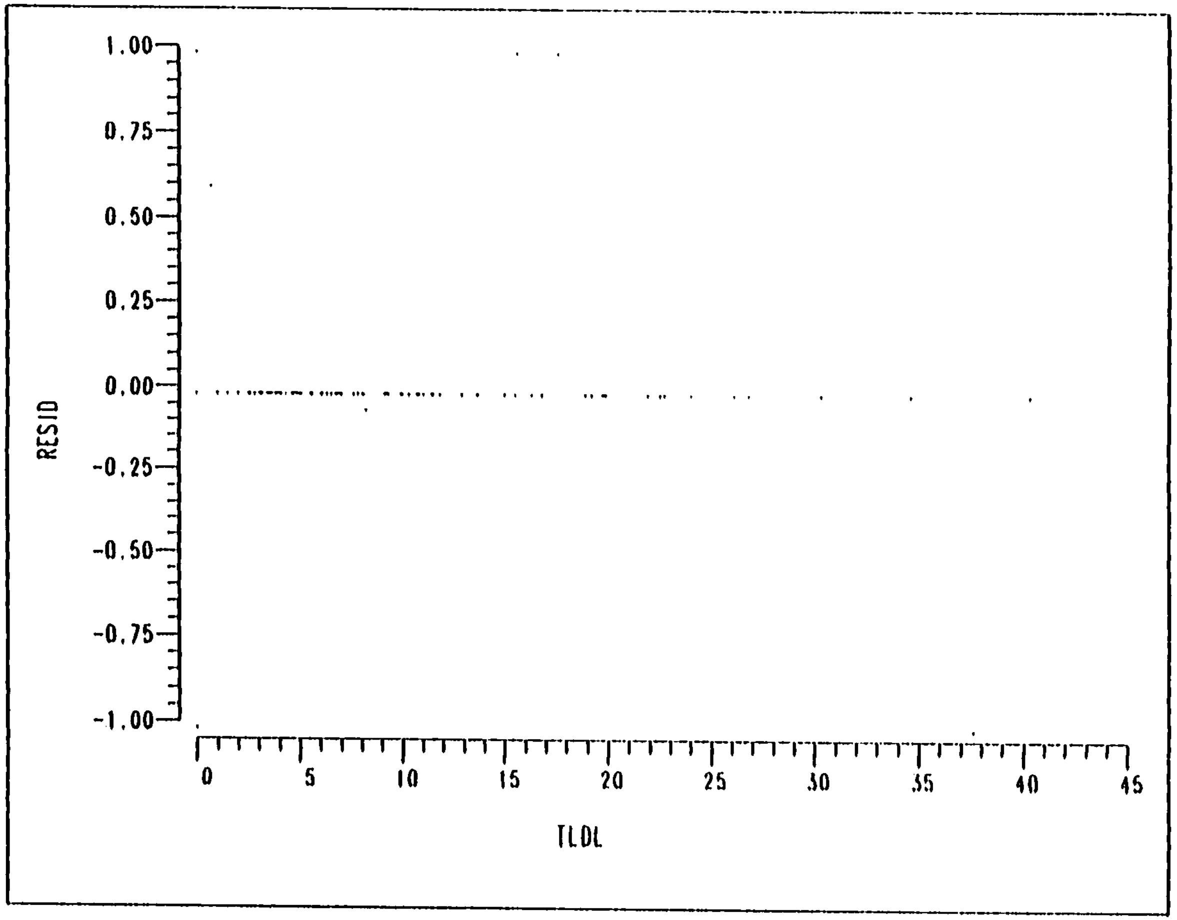
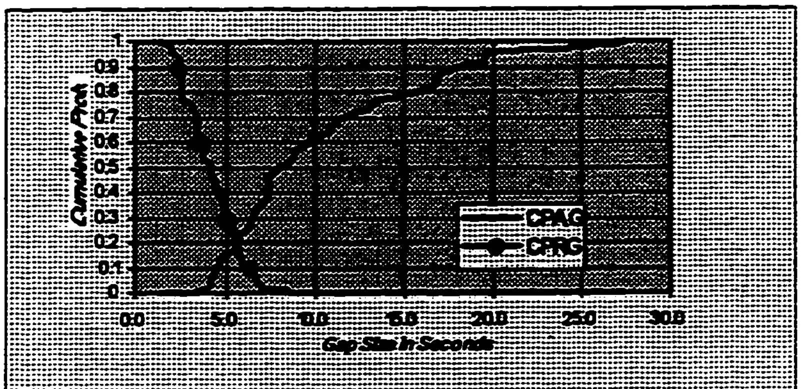



Figure B3.9: The Plot of the Error Term (Model Residuals) Against the Total Delay Imposed on the Driver (TLDL).

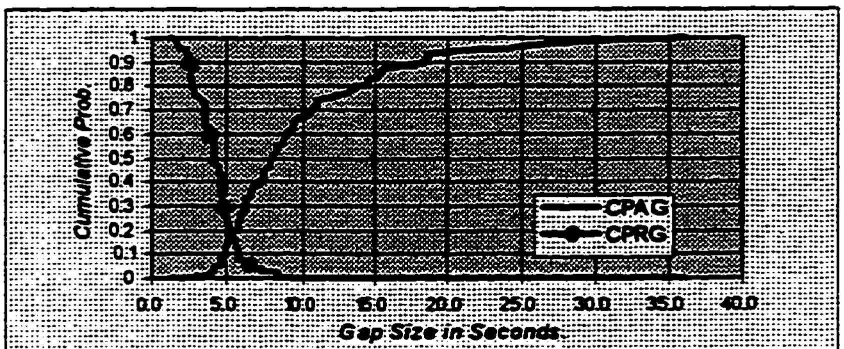
# Appendix B4

## Samples of Critical Gap Identification Graphs for Maneuver 1




Critical Gap = 5.6 Sec

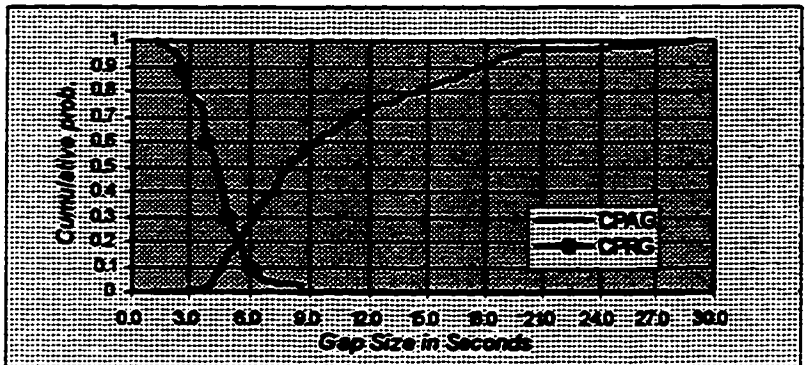
**Figure B4.1: Critical Gap for Occupancy equal to 1**




Critical Gap = 5.3 Sec

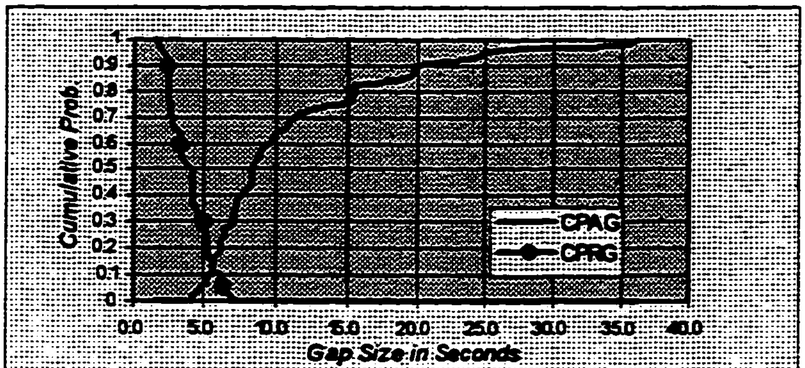
**Figure B4.2: Critical Gap for Occupancy > 1**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*




**Critical Gap = 5.4 Sec**

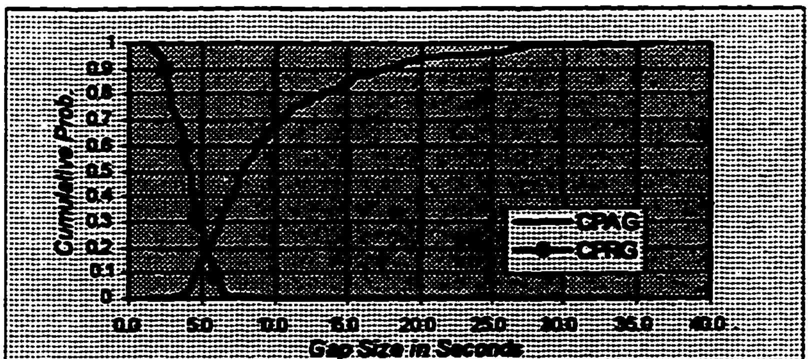
***Figure B4.3:* Critical Gap for Work Trips**




**Critical Gap = 5.6 Sec**

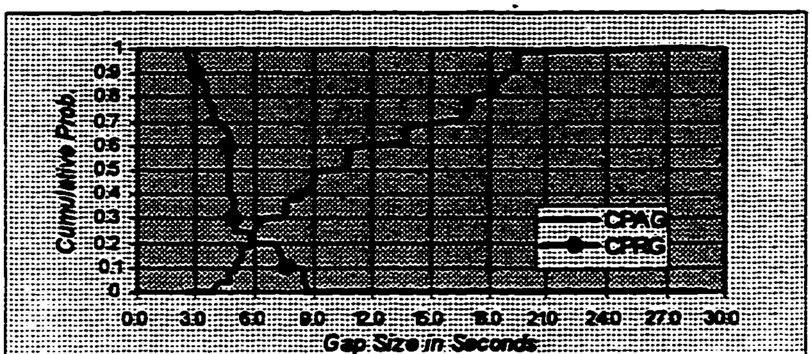
***Figure B4.4:* Critical Gap for Non-Work Trips**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*



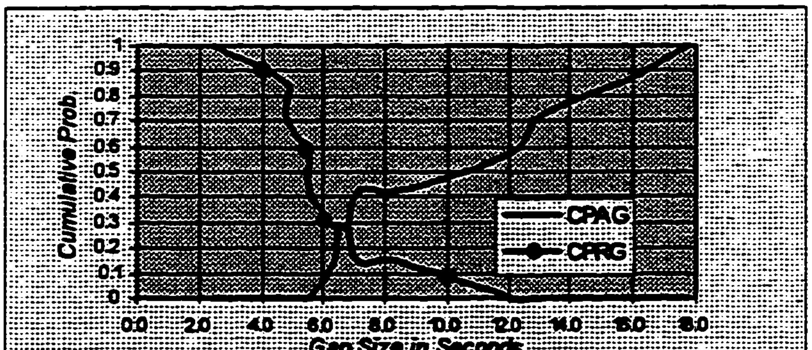

Critical Gap = 5.4 Sec

**Figure B4.5:** Critical Gap for Trip Duration Uptill 20 Mns.




Critical Gap = 5.7 Sec

**Figure B4.6:** Critical Gap for Trip Duration 21 - 40 Mns.




Critical Gap = 6.5 Sec

**Figure B4.7:** Critical Gap for Trip Duration > 40 Mns.

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*

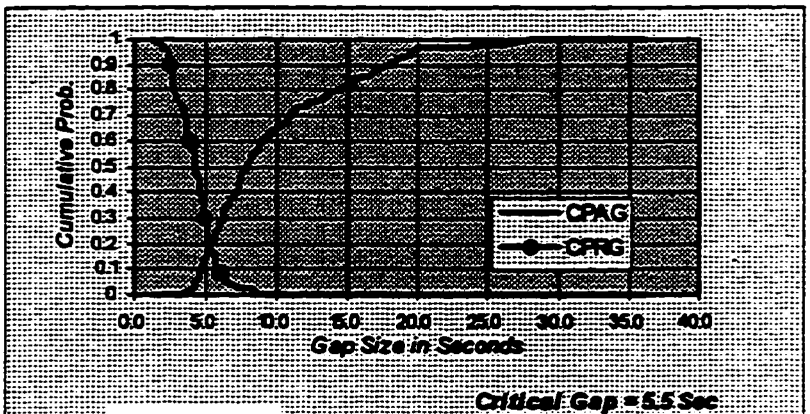



**Figure B4.8: Critical Gap for Male Drivers**

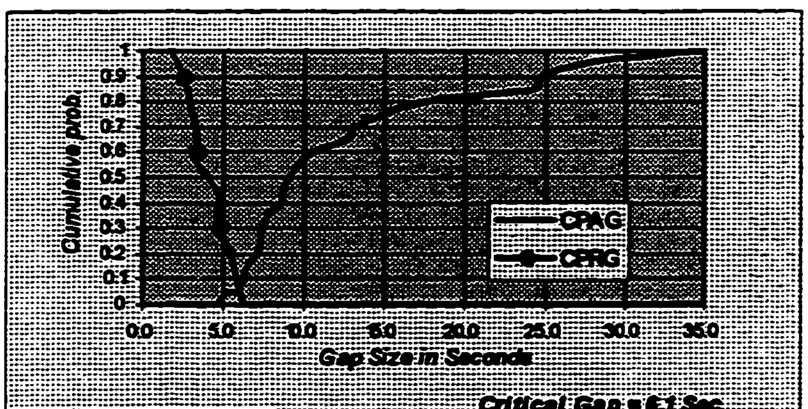
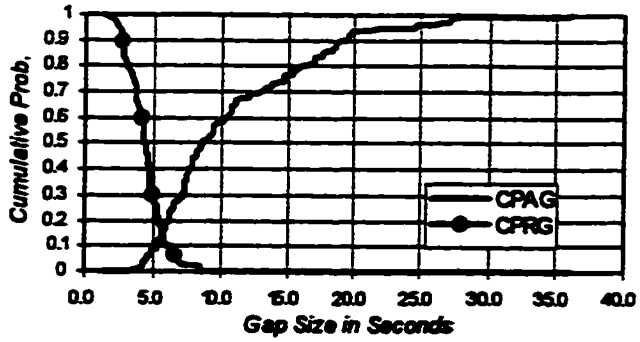


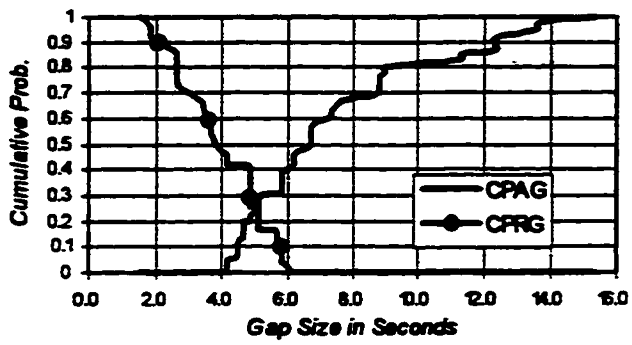

**Figure B4.9: Critical Gap for Female Drivers**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*



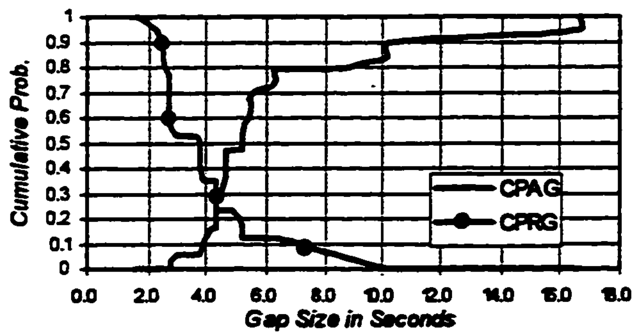

**Critical Gap = 5.7 Sec**

**Figure B4.10: Critical Gap for Zero Accidents**




**Critical Gap = 5.1 Sec**

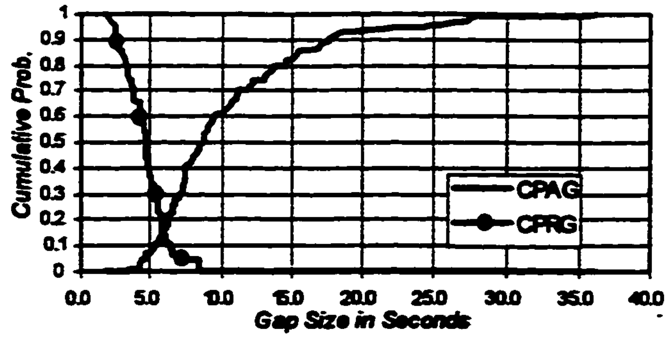
**Figure B4.11: Critical Gap for 1 Accident**




**Critical Gap = 4.4 Sec**

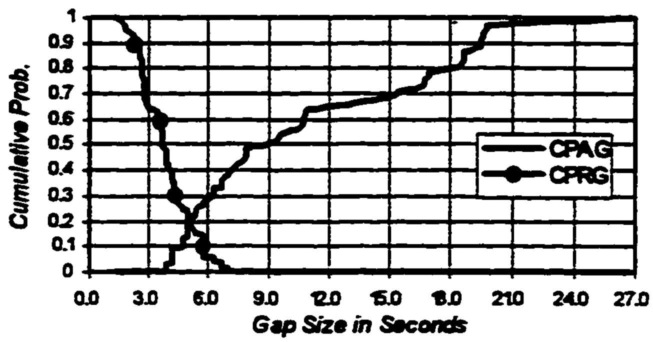
**Figure B4.12: Critical Gap for >1 Accidents**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*



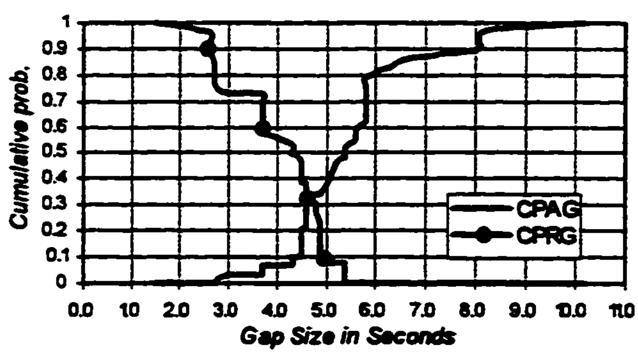

***Critical Gap = 6.0 Sec***

***Figure B4.13: Critical Gap for Zero Violations***




***Critical Gap = 5.1 Sec***

***Figure B4.14: Critical Gap for 1 Violation***




***Critical Gap = 4.6 Sec***

***Figure B4.15: Critical gap for > 1 Violations***

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*

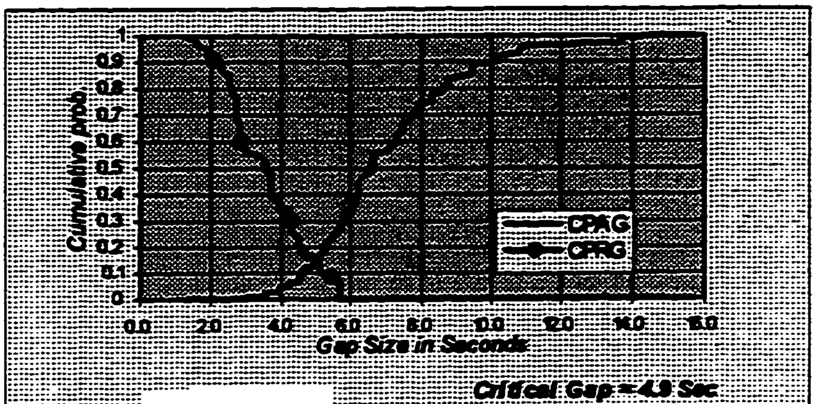



***Figure B4.16:* Critical Gap for Gaps**

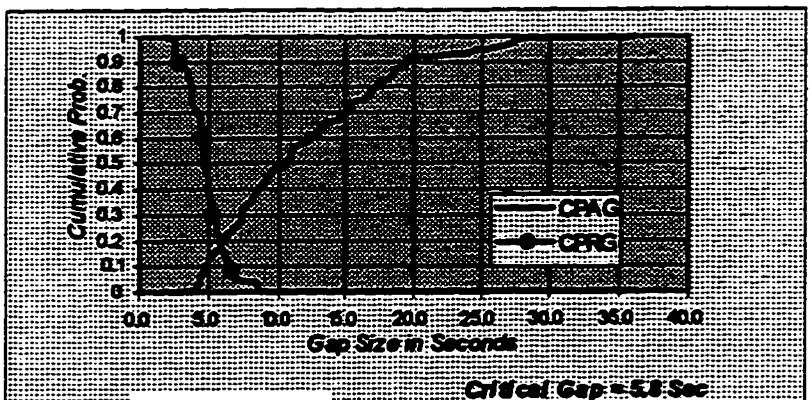



***Figure B4.17:* Critical Gap for Lags**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*

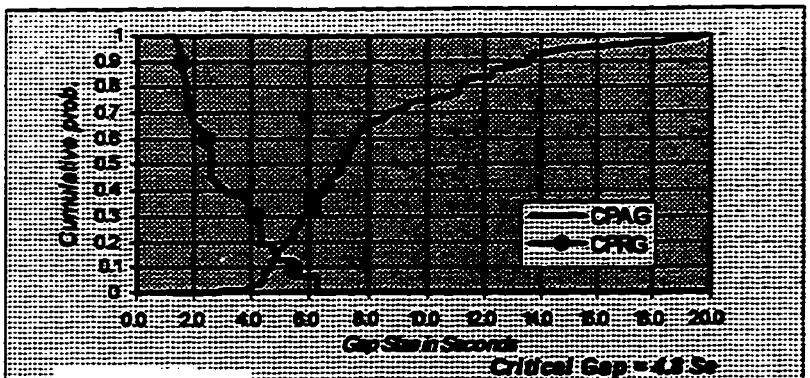



**Figure B4.18:** **Critical Gap for Major Stream Vehicle Speed 0-30 KPH**

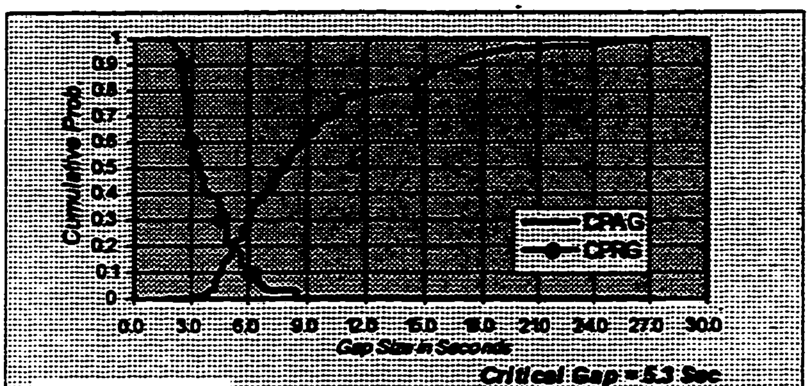



**Figure B4.19:** **Critical Gap for Major Stream Vehicle Speed 30.1 - 45 KPH**

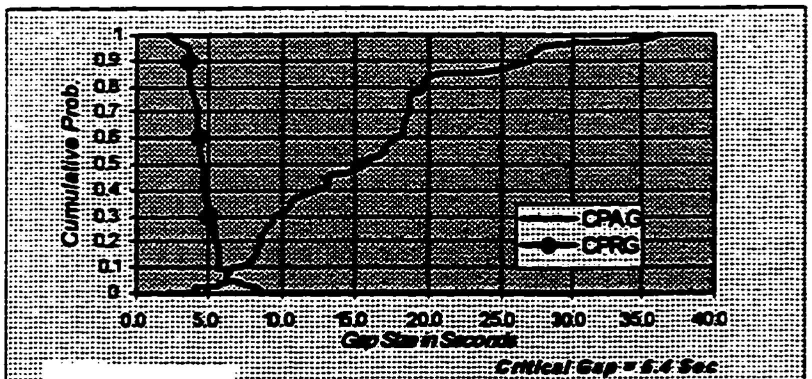
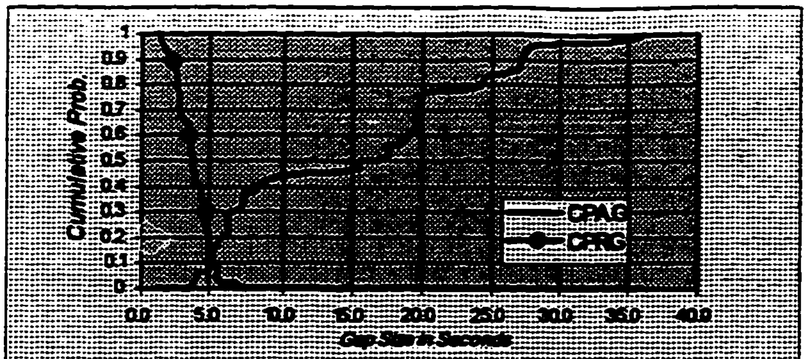


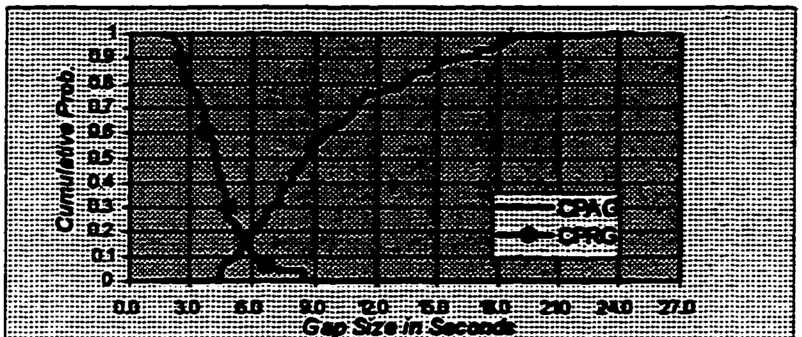

**Figure B4.20:** **Critical Gap for Major Stream Vehicle Speed > 45 KPH**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*



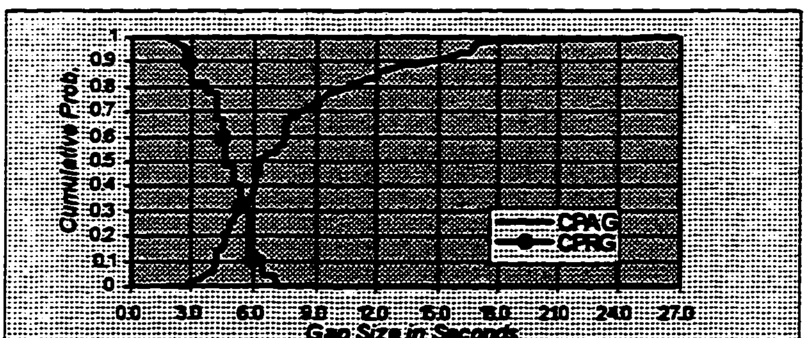

Critical Gap = 5.2 Sec

**Figure B4.21: Critical Gap for Minor Stream Volume of 1 Vehicle/Half Minute**




Critical Gap = 5.7 Sec

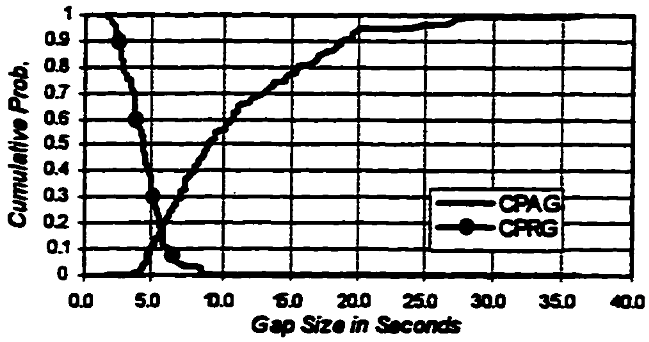
**Figure B4.22: Critical Gap for Minor Stream Volume of 2 Vehicles/Half Minute**




Critical Gap = 5.8 Sec

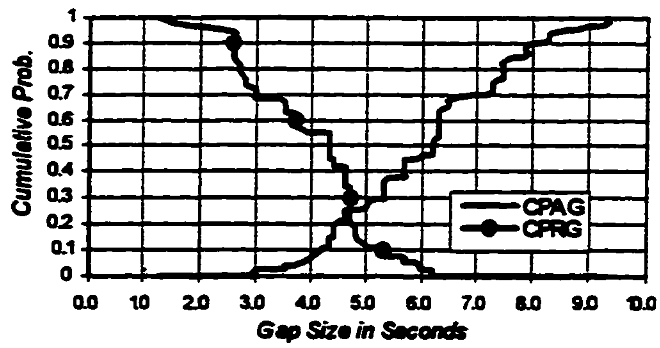
**Figure B4.23: Critical Gap for Minor Stream Volume > 2 Vehicles/Half Minute**

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*




**Critical Gap = 5.7 Sec**

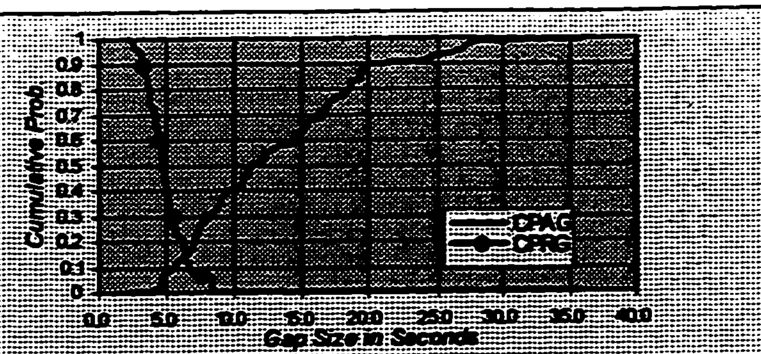
***Figure B4.24: Critical Gap for Queue Size = 0***




**Critical Gap = 4.7 Sec**

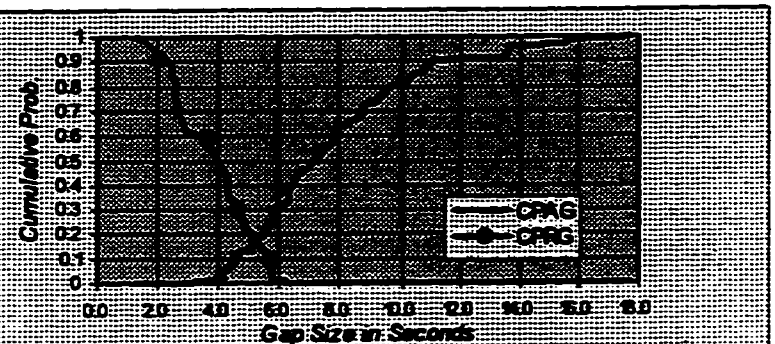
***Figure B4.25: Critical Gap for Queue Size > 0***

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*



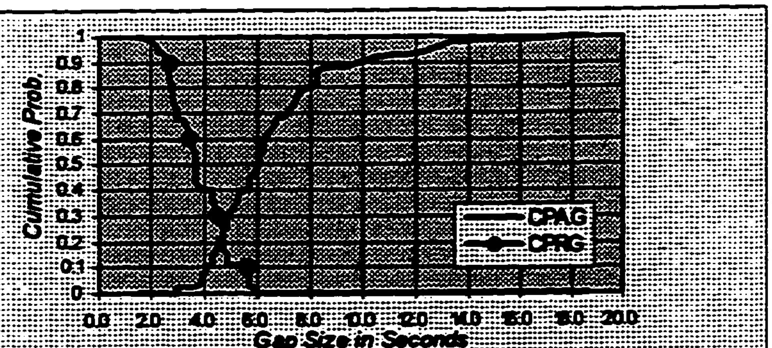

Critical Gap = 6.5 Sec

**Figure B4.26:** Critical Gap for Total Delay at Stop Line = 0 Sec




Critical Gap = 5.3 Sec

**Figure B4.27:** Critical Gap for Total Delay at Stop Line Ranging from 1-10 Sec




Critical Gap = 4.7 Sec

**Figure B4.28:** Critical Gap for Total Delay at Stop Line > 10 Sec

*Key: CPAG: Cumulative probability of accepting a gap of length shorter than (t)*
*CPRG: Cumulative probability of Rejecting a gap of length longer than (t)*

# Appendix C

## Details of the BASIC and the FULL Models

C1: Details of the BASIC and the FULL Models For Maneuver 1

C2: Details of the BASIC and the FULL Models For Maneuver 2

C3: Details of the BASIC and the FULL Models For Maneuver 3

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## Appendix C1

## Details of the BASIC and the FULL Models For Maneuver 1

Table C1.1: Correlation Matrix Obtained Using the Data Collected for Maneuver 1.

Correlation matrix

| | RESP | GSEC | GMET | SSEC | SMET | TMGP |
|---|---|---|---|---|---|---|
| RESP | 1.000 | | | | | |
| GSEC | 0.5456 | 1.000 | | | | |
| GMET | 0.3367 | 0.9126 | 1.000 | | | |
| SSEC | 0.3410 | 0.2374 | 0.1514 | 1.000 | | |
| SMET | 0.1651 | 0.1706 | 0.1396 | 0.5399 | 1.000 | |
| TMGP | 0.2608E-01 | 0.3269 | 0.3642 | 0.9277E-01 | 0.8031E-01 | 1.000 |

| | RESP | GSEC | GMET | SSEC | SMET | TMGP |
|---|---|---|---|---|---|---|
| MJSD | -0.3921 | 0.1271 | 0.4453 | -0.1668 | -0.2201E-01 | 0.2686 |
| MNSD | 0.2127 | 0.4420 | 0.3831 | 0.1967 | 0.7964E-01 | 0.6270 |
| MJVL | -0.4701 | -0.5562 | -0.4706 | -0.4551 | -0.2896 | -0.3876 |
| MNVL | 0.2393 | -0.5099E-01 | -0.1190 | 0.4541E-01 | 0.1135 | 0.1678 |
| QSIZ | -0.5354E-01 | -0.2437 | -0.2193 | -0.1278 | -0.1145E-01 | -0.2987 |
| DLIQ | -0.6488E-01 | -0.1878 | -0.1763 | -0.1453 | -0.8036E-01 | -0.7494E-01 |

| | MJSD | MNSD | MJVL | MNVL | QSIZ | DLIQ |
|---|---|---|---|---|---|---|
| MJSD | 1.000 | | | | | |
| MNSD | 0.3442E-01 | 1.000 | | | | |
| MJVL | 0.1621E-01 | -0.3755 | 1.000 | | | |
| MNVL | -0.1756 | 0.1562 | -0.1404 | 1.000 | | |
| QSIZ | -0.5207E-01 | -0.3721 | 0.2256 | -0.2935E-01 | 1.000 | |
| DLIQ | -0.4505E-01 | -0.3559 | 0.1298 | 0.2745E-01 | 0.5358 | 1.000 |

| | RESP | GSEC | GMET | SSEC | SMET | TMGP |
|---|---|---|---|---|---|---|
| DLQH | -0.2603E-01 | -0.2816 | -0.2981 | -0.9473E-01 | -0.7191E-01 | -0.7871 |
| TLDL | -0.6421E-01 | -0.3130 | -0.3146 | -0.1663 | -0.1040 | -0.5410 |
| NREJ | -0.4447E-01 | -0.3009 | -0.3012 | -0.1257 | -0.9203E-01 | -0.7312 |

| | MJSD | MNSD | MJVL | MNVL | QSIZ | DLIQ |
|---|---|---|---|---|---|---|
| DLQH | -0.1996 | -0.4974 | 0.4058 | -0.2042 | 0.2394 | 0.7513E-01 |
| TLDL | -0.1565 | -0.5709 | 0.3466 | -0.1055 | 0.5453 | 0.7886 |
| NREJ | -0.1919 | -0.4629 | 0.4435 | -0.2177 | 0.2725 | 0.6856E-01 |

| | DLQH | TLDL | NREJ |
|---|---|---|---|
| DLQH | 1.000 | | |
| TLDL | 0.6724 | 1.000 | |
| NREJ | 0.9526 | 0.6383 | 1.000 |

Table C1.1 "Continued": Correlation Matrix Obtained Using the Data Collected for Maneuver I.

| | RESP | GSEC | GMET | SSEC | SMET | TMGP |
|---|---|---|---|---|---|---|
| RESP | 1.000 | | | | | |
| GSEC | 0.5456 | 1.000 | | | | |
| GMET | 0.3367 | 0.9126 | 1.000 | | | |
| SSEC | 0.3410 | 0.2374 | 0.1514 | 1.000 | | |
| SMET | 0.1651 | 0.1706 | 0.1396 | 0.5399 | 1.000 | |
| TMGP | 0.2608E-01 | 0.3269 | 0.3642 | 0.9277E-01 | 0.8031E-01 | 1.000 |

| | RESP | GSEC | GMET | SSEC | SMET | TMGP |
|---|---|---|---|---|---|---|
| MJSD | -0.3921 | 0.1271 | 0.4453 | -0.1668 | -0.2201E-01 | 0.2686 |
| MNSD | 0.2127 | 0.4420 | 0.3831 | 0.1967 | 0.7964E-01 | 0.6270 |
| MJVL | -0.4701 | -0.5562 | -0.4706 | -0.4551 | -0.2896 | -0.3876 |
| MNVL | 0.2393 | -0.5099E-01 | -0.1190 | 0.4541E-01 | 0.1135 | 0.1678 |
| QSIZ | -0.5354E-01 | -0.2437 | -0.2193 | -0.1278 | -0.1145E-01 | -0.2987 |
| DLIQ | -0.6488E-01 | -0.1878 | -0.1763 | -0.1453 | -0.8036E-01 | -0.7494E-01 |

| | MJSD | MNSD | MJVL | MNVL | QSIZ | DLIQ |
|---|---|---|---|---|---|---|
| MJSD | 1.000 | | | | | |
| MNSD | 0.3442E-01 | 1.000 | | | | |
| MJVL | 0.1621E-01 | -0.3755 | 1.000 | | | |
| MNVL | -0.1756 | 0.1562 | -0.1404 | 1.000 | | |
| QSIZ | -0.5207E-01 | -0.3721 | 0.2256 | -0.2935E-01 | 1.000 | |
| DLIQ | -0.4505E-01 | -0.3559 | 0.1298 | 0.2745E-01 | 0.5358 | 1.000 |

| | RESP | GSEC | GMET | SSEC | SMET | TMGP |
|---|---|---|---|---|---|---|
| DLQH | -0.2603E-01 | -0.2816 | -0.2981 | -0.9473E-01 | -0.7191E-01 | -0.7871 |
| TLDL | -0.6421E-01 | -0.3130 | -0.3146 | -0.1663 | -0.1040 | -0.5410 |
| NREJ | -0.4447E-01 | -0.3009 | -0.3012 | -0.1257 | -0.9203E-01 | -0.7312 |

| | MJSD | MNSD | MJVL | MNVL | QSIZ | DLIQ |
|---|---|---|---|---|---|---|
| DLQH | -0.1996 | -0.4974 | 0.4058 | -0.2042 | 0.2394 | 0.7513E-01 |
| TLDL | -0.1565 | -0.5709 | 0.3466 | -0.1055 | 0.5453 | 0.7886 |
| NREJ | -0.1919 | -0.4629 | 0.4435 | -0.2177 | 0.2725 | 0.6856E-01 |

| | DLQH | TLDL | NREJ |
|---|---|---|---|
| DLQH | 1.000 | | |
| TLDL | 0.6724 | 1.000 | |
| NREJ | 0.9526 | 0.6383 | 1.000 |

Table C1.2: Details of the BASIC Model for Maneuver 1 Using Data Collected at Sites 1 and 2 Combined.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.58723 | 0.94814E-01 | 6.193 | 0.00000 | |
| GSEC | 0.59266E-01 | 0.35895E-02 | 16.511 | 0.00000 | 7.680 |
| MJSD | -0.18834E-01 | 0.16832E-02 | -11.189 | 0.00000 | 38.12 |
| TLDL | 0.61482E-02 | 0.26357E-02 | 2.333 | 0.01967 | 5.801 |
| MNVL | 0.10941 | 0.19802E-01 | 5.525 | 0.00000 | 2.160 |

MODEL FOR THE SIGNIFICANT TRAFFIC AND DELAY ATT., M1, SITES 1 & 2

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                  RESP
Number of observations               337
Iterations completed                   8
Log likelihood function        -65.34156
Restricted log likelihood      -227.2826
Chi-squared                     323.8821
Degrees of freedom                     4
Significance level             0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -2.3906 | 1.3596 | -1.758 | 0.07871 | |
| GSEC | 1.3027 | 0.17634 | 7.387 | 0.00000 | 7.680 |
| MJSD | -0.18539 | 0.29537E-01 | -6.276 | 0.00000 | 38.12 |
| TLDL | 0.94734E-01 | 0.28270E-01 | 3.351 | 0.00081 | 5.801 |
| MNVL | 0.82889 | 0.27699 | 2.993 | 0.00277 | 2.160 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.11953 | 0.71193E-01 | -1.679 | 0.09315 | |
| GSEC | 0.65135E-01 | 0.20681E-01 | 3.150 | 0.00164 | 7.680 |
| MJSD | -0.92696E-02 | 0.37428E-02 | -2.477 | 0.01326 | 38.12 |
| TLDL | 0.47369E-02 | 0.21109E-02 | 2.244 | 0.02483 | 5.801 |
| MNVL | 0.41446E-01 | 0.21502E-01 | 1.928 | 0.05391 | 2.160 |

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 118 | 18 | 136 |
| 1 | 18 | 183 | 201 |
| TOTAL | 136 | 201 | 337 |

Table C1.3: Sample of the Detailed Outputs of the Used Package Obtained for the BASIC Model of Maneuver 1.

(OBSERVED AND PREDICTED VALUES FOR THE FIRST 100 OBSERVATIONS)

Predicted Values =observation was not in estimating sample.

| Observation | Observed Y | Predicted Y | Residual | x(i)β | Pr[y=1] |
|---|---|---|---|---|---|
| 1 | 1.0000 | 1.0000 | 0.0000 | 0.9722 | 0.7256 |
| 2 | 1.0000 | 1.0000 | 0.0000 | 2.7734 | 0.9412 |
| 3 | 1.0000 | 1.0000 | 0.0000 | 12.3112 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 0.0000 | 12.0887 | 1.0000 |
| 5 | 0.00000 | 1.0000 | -1.0000 | 0.1713 | 0.5427 |
| 6 | 1.0000 | 1.0000 | 0.0000 | 4.8884 | 0.9925 |
| 7 | 1.0000 | 1.0000 | 0.0000 | 1.9505 | 0.8755 |
| 8 | 1.0000 | 1.0000 | 0.0000 | 3.5394 | 0.9718 |
| 9 | 0.00000 | 0.00000 | 0.0000 | -2.9761 | 0.0485 |
| 10 | 0.00000 | 0.00000 | 0.0000 | -3.3556 | 0.0337 |
| 11 | 1.0000 | 1.0000 | 0.0000 | 4.8617 | 0.9923 |
| 12 | 0.00000 | 0.00000 | 0.0000 | -2.2411 | 0.0961 |
| 13 | 1.0000 | 1.0000 | 0.0000 | 6.8413 | 0.9989 |
| 14 | 1.0000 | 1.0000 | 0.0000 | 14.2324 | 1.0000 |
| 15 | 1.0000 | 1.0000 | 0.0000 | 7.7994 | 0.9996 |
| 16 | 0.00000 | 0.00000 | 0.0000 | -0.5337 | 0.3697 |
| 17 | 1.0000 | 1.0000 | 0.0000 | 4.4756 | 0.9887 |
| 18 | 1.0000 | 1.0000 | 0.0000 | 5.6756 | 0.9966 |
| 19 | 1.0000 | 1.0000 | 0.0000 | 6.5741 | 0.9986 |
| 20 | 1.0000 | 1.0000 | 0.0000 | 7.3898 | 0.9994 |
| 21 | 1.0000 | 1.0000 | 0.0000 | 2.2963 | 0.9086 |
| 22 | 1.0000 | 1.0000 | 0.0000 | 6.4223 | 0.9984 |
| 23 | 1.0000 | 1.0000 | 0.0000 | 32.5923 | 1.0000 |
| 24 | 1.0000 | 1.0000 | 0.0000 | 2.9585 | 0.9507 |
| 25 | 1.0000 | 1.0000 | 0.0000 | 11.9451 | 1.0000 |
| 26 | 1.0000 | 1.0000 | 0.0000 | 9.5185 | 0.9999 |
| 27 | 0.00000 | 0.00000 | 0.0000 | -4.1166 | 0.0160 |
| 28 | 0.00000 | 0.00000 | 0.0000 | -2.4311 | 0.0808 |
| 29 | 1.0000 | 1.0000 | 0.0000 | 0.1084 | 0.5271 |
| 30 | 0.00000 | 0.00000 | 0.0000 | -4.1999 | 0.0148 |
| 31 | 0.00000 | 0.00000 | 0.0000 | -3.1533 | 0.0410 |
| 32 | 0.00000 | 0.00000 | 0.0000 | -2.0726 | 0.1118 |
| 33 | 1.0000 | 1.0000 | 0.0000 | 3.9577 | 0.9813 |
| 34 | 1.0000 | 1.0000 | 0.0000 | 16.7804 | 1.0000 |
| 35 | 1.0000 | 1.0000 | 0.0000 | 11.8488 | 1.0000 |
| 36 | 0.00000 | 0.00000 | 0.0000 | -2.5252 | 0.0741 |
| 37 | 1.0000 | 0.00000 | 1.0000 | -2.2234 | 0.0977 |
| 38 | 0.00000 | 0.00000 | 0.0000 | -2.0130 | 0.1178 |
| 39 | 1.0000 | 1.0000 | 0.0000 | 4.3450 | 0.9872 |
| 40 | 1.0000 | 1.0000 | 0.0000 | 1.2448 | 0.7764 |
| 41 | 0.00000 | 0.00000 | 0.0000 | -1.9040 | 0.1297 |
| 42 | 1.0000 | 1.0000 | 0.0000 | 3.5398 | 0.9718 |
| 43 | 0.00000 | 1.0000 | -1.0000 | 2.6649 | 0.9349 |
| 44 | 1.0000 | 1.0000 | 0.0000 | 13.4512 | 1.0000 |
| 45 | 1.0000 | 1.0000 | 0.0000 | 8.1689 | 0.9997 |
| 46 | 1.0000 | 1.0000 | 0.0000 | 1.9540 | 0.8759 |
| 47 | 1.0000 | 1.0000 | 0.0000 | 3.7372 | 0.9767 |
| 48 | 1.0000 | 1.0000 | 0.0000 | 7.9991 | 0.9997 |
| 49 | 0.00000 | 0.00000 | 0.0000 | -2.3389 | 0.0880 |

Table C1.3 "Continued": Sample of the Detailed Outputs of the Used Package Obtained for the BASIC Model of Maneuver I.

(OBSERVED AND PREDICTED VALUES FOR THE FIRST 100 OBSERVATIONS,"CONTINUED")

| Observation | Observed Y | Predicted Y | Residual | x(i)β | Pr[y=1] |
|---|---|---|---|---|---|
| 50 | 0.00000 | 0.00000 | 0.0000 | -3.2034 | 0.0390 |
| 51 | 1.0000 | 1.0000 | 0.0000 | 7.6688 | 0.9995 |
| 52 | 0.00000 | 0.00000 | 0.0000 | -2.7641 | 0.0593 |
| 53 | 0.00000 | 0.00000 | 0.0000 | -1.3462 | 0.2065 |
| 54 | 1.0000 | 1.0000 | 0.0000 | 3.9581 | 0.9813 |
| 55 | 0.00000 | 0.00000 | 0.0000 | -4.2671 | 0.0138 |
| 56 | 1.0000 | 0.00000 | 1.0000 | -1.2661 | 0.2199 |
| 57 | 1.0000 | 1.0000 | 0.0000 | 7.2598 | 0.9993 |
| 58 | 1.0000 | 1.0000 | 0.0000 | 0.4667 | 0.6146 |
| 59 | 0.00000 | 1.0000 | -1.0000 | 2.1349 | 0.8942 |
| 60 | 1.0000 | 1.0000 | 0.0000 | 10.3944 | 1.0000 |
| 61 | 0.00000 | 1.0000 | -1.0000 | 0.0566 | 0.5141 |
| 62 | 1.0000 | 1.0000 | 0.0000 | 10.0204 | 1.0000 |
| 63 | 0.00000 | 0.00000 | 0.0000 | -2.7220 | 0.0617 |
| 64 | 1.0000 | 0.00000 | 1.0000 | -0.0563 | 0.4859 |
| 65 | 0.00000 | 0.00000 | 0.0000 | -2.8467 | 0.0549 |
| 66 | 1.0000 | 1.0000 | 0.0000 | 6.0452 | 0.9976 |
| 67 | 0.00000 | 1.0000 | -1.0000 | 0.3171 | 0.5786 |
| 68 | 1.0000 | 1.0000 | 0.0000 | 7.9630 | 0.9997 |
| 69 | 1.0000 | 1.0000 | 0.0000 | 3.6089 | 0.9736 |
| 70 | 0.00000 | 0.00000 | 0.0000 | -4.2563 | 0.0140 |
| 71 | 0.00000 | 0.00000 | 0.0000 | -3.4232 | 0.0316 |
| 72 | 0.00000 | 0.00000 | 0.0000 | -3.8302 | 0.0212 |
| 73 | 0.00000 | 0.00000 | 0.0000 | -3.8060 | 0.0218 |
| 74 | 0.00000 | 0.00000 | 0.0000 | -2.9386 | 0.0503 |
| 75 | 1.0000 | 0.00000 | 1.0000 | -1.4678 | 0.1873 |
| 76 | 0.00000 | 0.00000 | 0.0000 | -2.6297 | 0.0672 |
| 77 | 0.00000 | 0.00000 | 0.0000 | -2.2220 | 0.0978 |
| 78 | 1.0000 | 1.0000 | 0.0000 | 0.6260 | 0.6516 |
| 79 | 1.0000 | 1.0000 | 0.0000 | 14.1972 | 1.0000 |
| 80 | 0.00000 | 0.00000 | 0.0000 | -5.0715 | 0.0062 |
| 81 | 0.00000 | 0.00000 | 0.0000 | -4.9499 | 0.0070 |
| 82 | 0.00000 | 0.00000 | 0.0000 | -4.3877 | 0.0123 |
| 83 | 1.0000 | 1.0000 | 0.0000 | 3.0595 | 0.9552 |
| 84 | 1.0000 | 1.0000 | 0.0000 | 7.5705 | 0.9995 |
| 85 | 1.0000 | 1.0000 | 0.0000 | 11.5010 | 1.0000 |
| 86 | 0.00000 | 1.0000 | -1.0000 | 0.4840 | 0.6187 |
| 87 | 1.0000 | 1.0000 | 0.0000 | 3.5436 | 0.9719 |
| 88 | 1.0000 | 1.0000 | 0.0000 | 23.8608 | 1.0000 |
| 89 | 0.00000 | 0.00000 | 0.0000 | -4.8623 | 0.0077 |
| 90 | 0.00000 | 0.00000 | 0.0000 | -4.8486 | 0.0078 |
| 91 | 1.0000 | 1.0000 | 0.0000 | 4.7367 | 0.9913 |
| 92 | 1.0000 | 1.0000 | 0.0000 | 7.7895 | 0.9996 |
| 93 | 0.00000 | 0.00000 | 0.0000 | -3.0406 | 0.0456 |
| 94 | 0.00000 | 0.00000 | 0.0000 | -1.9160 | 0.1283 |
| 95 | 0.00000 | 0.00000 | 0.0000 | -0.3861 | 0.4046 |
| 96 | 0.00000 | 1.0000 | -1.0000 | 0.4782 | 0.6173 |
| 97 | 0.00000 | 1.0000 | -1.0000 | 2.1143 | 0.8923 |
| 98 | 1.0000 | 1.0000 | 0.0000 | 2.7839 | 0.9418 |
| 99 | 0.00000 | 0.00000 | 0.0000 | -3.9363 | 0.0191 |

Table C1.4: Details of the FULL Model for Maneuver I Including VLTN.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 337 |
| Iterations completed | 9 |
| Log likelihood function | -49.07813 |
| Restricted log likelihood | -227.2826 |
| Chi-squared | 356.4089 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -5.8506 | 1.9205 | -3.046 | 0.00232 | |
| GSEC | 1.8312 | 0.27877 | 6.569 | 0.00000 | 7.680 |
| MJSD | -0.22422 | 0.38579E-01 | -5.812 | 0.00000 | 38.12 |
| TLDL | 0.11823 | 0.34898E-01 | 3.388 | 0.00070 | 5.801 |
| MNVL | 1.0735 | 0.35963 | 2.985 | 0.00284 | 2.160 |
| ACDT | 0.81051 | 0.26544 | 3.053 | 0.00226 | 0.3591 |
| VLTN | 0.59523 | 0.23642 | 2.518 | 0.01181 | 0.6053 |
| DEXP | 0.12479 | 0.44988E-01 | 2.774 | 0.00554 | 11.51 |
| TRDN | -0.55491E-01 | 0.27323E-01 | -2.031 | 0.04226 | 14.69 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.10913 | 0.62540E-01 | -1.745 | 0.08099 | |
| GSEC | 0.34157E-01 | 0.18168E-01 | 1.880 | 0.06011 | 7.680 |
| MJSD | -0.41823E-02 | 0.25514E-02 | -1.639 | 0.10116 | 38.12 |
| TLDL | 0.22054E-02 | 0.13447E-02 | 1.640 | 0.10099 | 5.801 |
| MNVL | 0.20023E-01 | 0.13560E-01 | 1.477 | 0.13976 | 2.160 |
| ACDT | 0.15118E-01 | 0.10081E-01 | 1.500 | 0.13368 | 0.3591 |
| VLTN | 0.11103E-01 | 0.74724E-02 | 1.486 | 0.13732 | 0.6053 |
| DEXP | 0.23276E-02 | 0.14519E-02 | 1.603 | 0.10890 | 11.51 |
| TRDN | -0.10351E-02 | 0.70464E-03 | -1.469 | 0.14185 | 14.69 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 125 | 11 | 136 |
| 1 | 13 | 188 | 201 |
| TOTAL | 138 | 199 | 337 |

Table C1.5: Details of the FULL Model for Maneuver I Excluding VLTN.

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 337
Iterations completed                     8
Log likelihood function          -52.81782
Restricted log likelihood        -227.2826
Chi-squared                       348.9295
Degrees of freedom                       7
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -4.8256 | 1.7945 | -2.689 | 0.00716 | |
| GSEC | 1.6807 | 0.25045 | 6.711 | 0.00000 | 7.680 |
| MJSD | -0.21149 | 0.35461E-01 | -5.964 | 0.00000 | 38.12 |
| TLDL | 0.12295 | 0.33486E-01 | 3.672 | 0.00024 | 5.801 |
| MNVL | 1.1036 | 0.35649 | 3.096 | 0.00196 | 2.160 |
| ACDT | 0.98559 | 0.27371 | 3.601 | 0.00032 | 0.3591 |
| TRDN | -0.53537E-01 | 0.26328E-01 | -2.033 | 0.04201 | 14.69 |
| DEXP | 0.84957E-01 | 0.39286E-01 | 2.163 | 0.03058 | 11.51 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.11767 | 0.62762E-01 | -1.875 | 0.06081 | |
| GSEC | 0.40983E-01 | 0.19200E-01 | 2.135 | 0.03279 | 7.680 |
| MJSD | -0.51570E-02 | 0.28303E-02 | -1.822 | 0.06845 | 38.12 |
| TLDL | 0.29981E-02 | 0.16126E-02 | 1.859 | 0.06301 | 5.801 |
| MNVL | 0.26910E-01 | 0.16042E-01 | 1.677 | 0.09346 | 2.160 |
| ACDT | 0.24033E-01 | 0.13534E-01 | 1.776 | 0.07577 | 0.3591 |
| TRDN | -0.13055E-02 | 0.83024E-03 | -1.572 | 0.11586 | 14.69 |
| DEXP | 0.20716E-02 | 0.13566E-02 | 1.527 | 0.12676 | 11.51 |

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 125 | 11 | 136 |
| 1 | 10 | 191 | 201 |
| TOTAL | 135 | 202 | 337 |

# Appendix C2

## Details of the BASIC and the FULL Models For Maneuver 2

Table C2.1: Details of the BASIC Model for Maneuver 2 Using Data Collected at Sites 1 and 2 Combined.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.10244 | 0.77930E-01 | -1.315 | 0.18866 | |
| GSEC | 0.61072E-01 | 0.43167E-02 | 14.148 | 0.00000 | 7.206 |
| TLDL | 0.84558E-02 | 0.16447E-02 | 5.141 | 0.00000 | 10.29 |
| MNVL | 0.72656E-01 | 0.18870E-01 | 3.850 | 0.00012 | 3.470 |

MODEL FOR THE SIGNIFICANT TRAFFIC AND DELAY ATT., M2, SITES 1 & 2

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 396
Iterations completed                     9
Log likelihood function          -58.40939
Restricted log likelihood        -249.1956
Chi-squared                       381.5725
Degrees of freedom                       3
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -16.115 | 2.2414 | -7.190 | 0.00000 | |
| GSEC | 2.2642 | 0.28220 | 8.023 | 0.00000 | 7.206 |
| TLDL | 0.16300 | 0.27340E-01 | 5.962 | 0.00000 | 10.29 |
| MNVL | 0.92505 | 0.31587 | 2.929 | 0.00341 | 3.470 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.98179E-01 | 0.57492E-01 | -1.708 | 0.08769 | |
| GSEC | 0.13794E-01 | 0.79106E-02 | 1.744 | 0.08120 | 7.206 |
| TLDL | 0.99308E-03 | 0.60338E-03 | 1.646 | 0.09979 | 10.29 |
| MNVL | 0.56358E-02 | 0.36640E-02 | 1.538 | 0.12401 | 3.470 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 119 | 9 | 128 |
| 1 | 14 | 254 | 268 |
| TOTAL | 133 | 263 | 396 |

Table C2.2: Details of the FULL Model for Maneuver 2.

```
LIMDEP Estimation Results                          Run log line    20   Page    1
Current sample contains     396 observations.
```

MODEL FOR ALL THE SIGNIFICANT ATTRIBUTES, MANEUVER2, SITES 1 & 2

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.17536 | 0.99217E-01 | -1.767 | 0.07715 | |
| GSEC | 0.60096E-01 | 0.43487E-02 | 13.819 | 0.00000 | 7.206 |
| TLDL | 0.83917E-02 | 0.16372E-02 | 5.126 | 0.00000 | 10.29 |
| MNVL | 0.66124E-01 | 0.19035E-01 | 3.474 | 0.00051 | 3.470 |
| DSEX | -0.32856E-01 | 0.60795E-01 | -0.540 | 0.58889 | 0.1162 |
| DAGE | 0.41306E-02 | 0.19898E-02 | 2.076 | 0.03790 | 36.49 |
| TRDN | -0.19074E-02 | 0.10814E-02 | -1.764 | 0.07775 | 22.87 |

MODEL FOR ALL THE SIGNIFICANT ATTRIBUTES, MANEUVER2, SITES 1 & 2

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 396
Iterations completed                     9
Log likelihood function          -50.18902
Restricted log likelihood        -249.1956
Chi-squared                       398.0133
Degrees of freedom                       6
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -16.377 | 2.5375 | -6.454 | 0.00000 | |
| GSEC | 2.7279 | 0.36900 | 7.393 | 0.00000 | 7.206 |
| TLDL | 0.17606 | 0.30059E-01 | 5.857 | 0.00000 | 10.29 |
| MNVL | 1.2174 | 0.35494 | 3.430 | 0.00060 | 3.470 |
| DSEX | -1.5612 | 0.80519 | -1.939 | 0.05251 | 0.1162 |
| DAGE | -0.61408E-01 | 0.27685E-01 | -2.218 | 0.02655 | 36.49 |
| TRDN | -0.24923E-01 | 0.11662E-01 | -2.137 | 0.03259 | 22.87 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 117 | 11 | 128 |
| 1 | 10 | 258 | 268 |
| TOTAL | 127 | 269 | 396 |

Table C2.3: The Marginal Effects for Males' and Females' Strata in the FULL Model of Maneuver 2.

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are MALE

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.39166E-01 | 0.30518E-01 | -1.283 | 0.19936 | |
| GSEC | 0.65239E-02 | 0.49663E-02 | 1.314 | 0.18897 | 7.005 |
| TLDL | 0.42105E-03 | 0.33606E-03 | 1.253 | 0.21025 | 10.65 |
| MNVL | 0.29115E-02 | 0.23202E-02 | 1.255 | 0.20952 | 3.469 |
| DSEX | -0.37337E-02 | 0.31774E-02 | -1.175 | 0.23997 | 0.0000 |
| DAGE | -0.14686E-03 | 0.12611E-03 | -1.164 | 0.24422 | 36.70 |
| TRDN | -0.59603E-04 | 0.50056E-04 | -1.191 | 0.23376 | 21.82 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are FEMALE

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.31291E-02 | 0.40471E-02 | -0.773 | 0.43943 | |
| GSEC | 0.52122E-03 | 0.66407E-03 | 0.785 | 0.43252 | 8.741 |
| TLDL | 0.33639E-04 | 0.43976E-04 | 0.765 | 0.44431 | 7.565 |
| MNVL | 0.23261E-03 | 0.30731E-03 | 0.757 | 0.44910 | 3.478 |
| DSEX | -0.29829E-03 | 0.47266E-03 | -0.631 | 0.52798 | 1.000 |
| DAGE | -0.11733E-04 | 0.15363E-04 | -0.764 | 0.44504 | 34.87 |
| TRDN | -0.47619E-05 | 0.62368E-05 | -0.764 | 0.44516 | 30.91 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.29223E-01 | 0.23723E-01 | -1.232 | 0.21801 | |
| GSEC | 0.48678E-02 | 0.38600E-02 | 1.261 | 0.20728 | 7.206 |
| TLDL | 0.31416E-03 | 0.26090E-03 | 1.204 | 0.22853 | 10.29 |
| MNVL | 0.21724E-02 | 0.18072E-02 | 1.202 | 0.22933 | 3.470 |
| DSEX | -0.27858E-02 | 0.25827E-02 | -1.079 | 0.28074 | 0.1162 |
| DAGE | -0.10958E-03 | 0.96714E-04 | -1.133 | 0.25721 | 36.49 |
| TRDN | -0.44473E-04 | 0.38531E-04 | -1.154 | 0.24842 | 22.87 |

Marginal Effects for MltLogit

| Variable | MALE | FEMALE | All Obs. |
|---|---|---|---|
| ONE | -0.0392 | -0.0031 | -0.0292 |
| GSEC | 0.0065 | 0.0005 | 0.0049 |
| TLDL | 0.0004 | 0.0000 | 0.0003 |
| MNVL | 0.0029 | 0.0002 | 0.0022 |
| DSEX | -0.0037 | -0.0003 | -0.0028 |
| DAGE | -0.0001 | 0.0000 | -0.0001 |
| TRDN | -0.0001 | 0.0000 | 0.0000 |

# Appendix C3

## Details of the BASIC and the FULL Models For Maneuver 3

Table C3.1: Details of the BASIC Model for Maneuver 3 Using Data Collected at Sites 1 and 2 Combined.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.22699E-01 | 0.44482E-01 | 0.510 | 0.60984 | |
| GSEC | 0.14454 | 0.47994E-02 | 30.116 | 0.00000 | 4.515 |
| MJSD | -0.14956E-01 | 0.97280E-03 | -15.374 | 0.00000 | 42.62 |
| TLDL | 0.49985E-02 | 0.68285E-03 | 7.320 | 0.00000 | 16.78 |
| MNVL | 0.82579E-01 | 0.11470E-01 | 7.199 | 0.00000 | 1.708 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 624
Iterations completed                     8
Log likelihood function          -70.80554
Restricted log likelihood        -359.4156
Chi-squared                       577.2200
Degrees of freedom                       4
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -7.5083 | 1.2842 | -5.847 | 0.00000 | |
| GSEC | 2.5096 | 0.28501 | 8.805 | 0.00000 | 4.515 |
| MJSD | -0.21267 | 0.27790E-01 | -7.653 | 0.00000 | 42.62 |
| TLDL | 0.61093E-01 | 0.15300E-01 | 3.993 | 0.00007 | 16.78 |
| MNVL | 1.0876 | 0.23827 | 4.565 | 0.00001 | 1.708 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.59278 | 0.11440 | -5.182 | 0.00000 | |
| GSEC | 0.19813 | 0.38601E-01 | 5.133 | 0.00000 | 4.515 |
| MJSD | -0.16790E-01 | 0.36621E-02 | -4.585 | 0.00000 | 42.62 |
| TLDL | 0.48233E-02 | 0.13469E-02 | 3.581 | 0.00034 | 16.78 |
| MNVL | 0.85869E-01 | 0.22663E-01 | 3.789 | 0.00015 | 1.708 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 449 | 11 | 460 |
| 1 | 18 | 146 | 164 |
| TOTAL | 467 | 157 | 624 |

Table C3.2: Details of the FULL Model for Maneuver 3.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.69031E-02 | 0.50399E-01 | 0.137 | 0.89106 | |
| GSEC | 0.14532 | 0.47630E-02 | 30.509 | 0.00000 | 4.515 |
| MJSD | -0.14989E-01 | 0.97003E-03 | -15.452 | 0.00000 | 42.62 |
| TLDL | 0.53544E-02 | 0.68421E-03 | 7.826 | 0.00000 | 16.78 |
| MNVL | 0.84594E-01 | 0.11432E-01 | 7.400 | 0.00000 | 1.708 |
| ACDT | 0.31792E-01 | 0.13827E-01 | 2.299 | 0.02149 | 0.3237 |
| TRDN | -0.20283E-02 | 0.73049E-03 | -2.777 | 0.00549 | 18.37 |
| DEXP | 0.27504E-02 | 0.14040E-02 | 1.959 | 0.05011 | 11.36 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 624
Iterations completed                     8
Log likelihood function          -62.43514
Restricted log likelihood        -359.4156
Chi-squared                       593.9608
Degrees of freedom                       7
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -9.1446 | 1.6239 | -5.631 | 0.00000 | |
| GSEC | 2.7457 | 0.33186 | 8.274 | 0.00000 | 4.515 |
| MJSD | -0.22892 | 0.31330E-01 | -7.307 | 0.00000 | 42.62 |
| TLDL | 0.82948E-01 | 0.18746E-01 | 4.425 | 0.00001 | 16.78 |
| MNVL | 1.2354 | 0.27877 | 4.431 | 0.00001 | 1.708 |
| ACDT | 0.67564 | 0.28255 | 2.391 | 0.01679 | 0.3237 |
| TRDN | -0.48679E-01 | 0.19783E-01 | -2.461 | 0.01387 | 18.37 |
| DEXP | 0.95376E-01 | 0.38325E-01 | 2.489 | 0.01282 | 11.36 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.59155 | 0.13551 | -4.365 | 0.00001 | |
| GSEC | 0.17762 | 0.40001E-01 | 4.440 | 0.00001 | 4.515 |
| MJSD | -0.14808E-01 | 0.36413E-02 | -4.067 | 0.00005 | 42.62 |
| TLDL | 0.53657E-02 | 0.14765E-02 | 3.634 | 0.00028 | 16.78 |
| MNVL | 0.79913E-01 | 0.23912E-01 | 3.342 | 0.00083 | 1.708 |
| ACDT | 0.43706E-01 | 0.19225E-01 | 2.273 | 0.02300 | 0.3237 |
| TRDN | -0.31489E-02 | 0.13673E-02 | -2.303 | 0.02127 | 18.37 |
| DEXP | 0.61697E-02 | 0.26811E-02 | 2.301 | 0.02138 | 11.36 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 449 | 11 | 460 |
| 1 | 15 | 149 | 164 |
| TOTAL | 464 | 160 | 624 |

# Appendix D1

## Details of the Validation Models

## for Maneuver 1

# Appendix D

## Details of the Validation Models

D1: Details of the Validation Models
for Maneuver 1

D2: Details of the Validation Models
for Maneuver 2

D3: Details of the Validation Models
for Maneuver 3

## D1.1: Unrestricted and Restricted BASIC Models Calibrated for Maneuver 1 Using the Validation Data

Table D1.1: Details of the Unrestricted and the Restricted BASIC Models for Maneuver 1.

UNREST. MODEL FOR VALIDATION DATA, TRAFFIC AND DELAY ATT., M1

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 111 |
| Iterations completed | 9 |
| Log likelihood function | -18.40063 |
| Restricted log likelihood | -70.65307 |
| Chi-squared | 104.5049 |
| Degrees of freedom | 4 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -3.2715 | 2.6401 | -1.239 | 0.21528 | |
| GSEC | 1.4634 | 0.38714 | 3.780 | 0.00016 | 8.428 |
| MJSD | -0.19353 | 0.47970E-01 | -4.034 | 0.00005 | 41.46 |
| TLDL | 0.13805 | 0.81270E-01 | 1.699 | 0.08938 | -4.994 |
| MNVL | 1.1819 | 0.54412 | 2.172 | 0.02984 | 2.441 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 33 | 4 | 37 |
| 1 | 3 | 71 | 74 |
| TOTAL | 36 | 75 | 111 |

REST. MODEL FOR VALIDATION DATA, TRAFFIC AND DELAY ATT., M1

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 111 |
| Iterations completed | 1 |
| Log likelihood function | -20.24686 |
| Restricted log likelihood | -70.65307 |
| Chi-squared | 100.8124 |
| Degrees of freedom | 4 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -2.3906 | ........(Fixed Parameter)....... | | | |
| GSEC | 1.3027 | ........(Fixed Parameter)....... | | | 8.428 |
| MJSD | -0.18539 | ........(Fixed Parameter)....... | | | 41.46 |
| TLDL | 0.94734E-01 | ........(Fixed Parameter)....... | | | -4.994 |
| MNVL | 0.82889 | ........(Fixed Parameter)....... | | | 2.441 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 34 | 3 | 37 |
| 1 | 6 | 68 | 74 |
| TOTAL | 40 | 71 | 111 |

## D1.2: Validation of the BASIC Model for Maneuver 1

Models with an identical specification to Maneuver 1 BASIC model were calibrated using the data portion (111 observations) reserved for validation purposes. The likelihood ratio test showed that the unrestricted and the restricted models calibrated using the "validation data", are not significantly different. Restricted model is obtained by restricting model coefficients to the values obtained from the "calibration data", i.e., coefficients of Maneuver 1 BASIC model. Details of the mentioned likelihood ratio test are ;

- $H_0$ :Imposed restrictions are correct or, alternatively, there exists no difference between the observed and the predicted behavior.
- Log likelihood for the unrestricted model = -18.40
- Log likelihood for the restricted model = -20.25
- Likelihood ratio test statistic (LRTS) = -2(-20.25-(-18.40)) = 3.70.
- Degrees of freedom for the test are equal to 5 which is the number of the imposed restrictions [Ben-Akiva and Lerman, (1985)]
- Chi Square- table value at (0.05, 5) = 11.07.
- Test Result: The calculated Chi-Squared is less than the table value, therefore, there is no enough statistical evidence to reject $H_0$. This indicates that the predicted and the observed driver gap acceptance behavior are not significantly different.

## D1.3: Unrestricted and Restricted FULL Models Calibrated for Maneuver 1 Using the Validation Data

Table D1.2: Details of the Unrestricted and the Restricted FULL Models for Maneuver 1 Including VLTN.

UNREST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, MANEUVER 1

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 111 |
| Iterations completed | 10 |
| Log likelihood function | -15.59140 |
| Restricted log likelihood | -70.65307 |
| Chi-squared | 110.1233 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -5.3788 | 4.0284 | -1.335 | 0.18180 | |
| GSEC | 1.6085 | 0.43522 | 3.696 | 0.00022 | 8.428 |
| MJSD | -0.22451 | 0.62109E-01 | -3.615 | 0.00030 | 41.46 |
| TLDL | 0.24333 | 0.11471 | 2.121 | 0.03390 | -4.994 |
| MNVL | 1.1280 | 0.84093 | 1.341 | 0.17978 | 2.441 |
| ACDT | 0.66940 | 0.61128 | 1.095 | 0.27348 | 0.4324 |
| VLTN | 0.63589 | 0.62080 | 1.024 | 0.30569 | 0.5676 |
| DEXP | 0.15367 | 0.94903E-01 | 1.619 | 0.10540 | 10.32 |
| TRDN | -0.81360E-03 | 0.49743E-01 | -0.016 | 0.98695 | 19.77 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 34 | 3 | 37 |
| 1 | 3 | 71 | 74 |
| TOTAL | 37 | 74 | 111 |

REST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, MANEUVER 1

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 111 |
| Iterations completed | 1 |
| Log likelihood function | -22.17831 |
| Restricted log likelihood | -70.65307 |
| Chi-squared | 96.94952 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -5.8506 | ........(Fixed Parameter)....... | | | |
| GSEC | 1.8312 | ........(Fixed Parameter)....... | | | 8.428 |
| MJSD | -0.22422 | ........(Fixed Parameter)....... | | | 41.46 |
| TLDL | 0.11823 | ........(Fixed Parameter)....... | | | -4.994 |
| MNVL | 1.0735 | ........(Fixed Parameter)....... | | | 2.441 |
| ACDT | 0.81051 | ........(Fixed Parameter)....... | | | 0.4324 |
| VLTN | 0.59523 | ........(Fixed Parameter)....... | | | 0.5676 |
| DEXP | 0.12479 | ........(Fixed Parameter)....... | | | 10.32 |
| TRDN | -0.55491E-01 | ........(Fixed Parameter)....... | | | 19.77 |

Frequencies of actual & predicted outcomes (Pred. outcome has maxi. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 35 | 2 | 37 |
| 1 | 6 | 68 | 74 |
| TOTAL | 41 | 70 | 111 |

Table D1.3: Details of the Unrestricted and the Restricted FULL Models for Maneuver 1 Excluding VLTN.

UNREST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, M1

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 111 |
| Iterations completed | 9 |
| Log likelihood function | -16.13175 |
| Restricted log likelihood | -70.65307 |
| Chi-squared | 109.0427 |
| Degrees of freedom | 7 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -3.2725 | 3.2597 | -1.004 | 0.31541 | |
| GSEC | 1.4938 | 0.39336 | 3.798 | 0.00015 | 8.428 |
| MJSD | -0.23708 | 0.63681E-01 | -3.723 | 0.00020 | 41.46 |
| TLDL | 0.21526 | 0.10485 | 2.053 | 0.04006 | -4.994 |
| MNVL | 0.97089 | 0.73707 | 1.317 | 0.18776 | 2.441 |
| ACDT | 0.81333 | 0.61015 | 1.333 | 0.18253 | 0.4324 |
| TRDN | -0.38623E-03 | 0.49012E-01 | -0.008 | 0.99371 | 19.77 |
| DEXP | 0.13769 | 0.92825E-01 | 1.483 | 0.13799 | 10.32 |

Frequencies of actual & predicted outcomes (Pred outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 34 | 3 | 37 |
| 1 | 3 | 71 | 74 |
| TOTAL | 37 | 74 | 111 |

REST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, M1

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 111 |
| Iterations completed | 1 |
| Log likelihood function | -22.09516 |
| Restricted log likelihood | -70.65307 |
| Chi-squared | 97.11583 |
| Degrees of freedom | 7 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -4.8256 | ........(Fixed Parameter)....... | | | |
| GSEC | 1.6807 | ........(Fixed Parameter)....... | | | 8.428 |
| MJSD | -0.21149 | ........(Fixed Parameter)....... | | | 41.46 |
| TLDL | 0.12295 | ........(Fixed Parameter)....... | | | -4.994 |
| MNVL | 1.1036 | ........(Fixed Parameter)....... | | | 2.441 |
| ACDT | 0.98559 | ........(Fixed Parameter)....... | | | 0.4324 |
| TRDN | -0.53537E-01 | ........(Fixed Parameter)....... | | | 19.77 |
| DEXP | 0.84957E-01 | ........(Fixed Parameter)....... | | | 10.32 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 34 | 3 | 37 |
| 1 | 6 | 68 | 74 |
| TOTAL | 40 | 71 | 111 |

# Appendix D2

## Details of the Validation Models

## for Maneuver 2

## D2.1: Unrestricted and Restricted BASIC Models Calibrated for Maneuver 2 Using the Validation Data

Table D2.1: Details of the Unrestricted and the Restricted BASIC Models for Maneuver 2.

UNREST. MODEL FOR VALIDATION DATA, TRAFFIC AND DELAY ATT., M2

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 132 |
| Iterations completed | 8 |
| Log likelihood function | -26.86721 |
| Restricted log likelihood | -75.30678 |
| Chi-squared | 96.87914 |
| Degrees of freedom | 3 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -10.823 | 2.3344 | -4.636 | 0.00000 | |
| GSEC | 1.8146 | 0.40084 | 4.527 | 0.00001 | 7.271 |
| TLDL | 0.81817E-01 | 0.28212E-01 | 2.900 | 0.00373 | 10.70 |
| MNVL | 0.44229 | 0.40145 | 1.102 | 0.27057 | 3.636 |

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 30 | 4 | 34 |
| 1 | 7 | 91 | 98 |
| TOTAL | 37 | 95 | 132 |

REST. MODEL FOR VALIDATION DATA, TRAFFIC AND DELAY ATT., M2

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 132 |
| Iterations completed | 1 |
| Log likelihood function | -31.59966 |
| Restricted log likelihood | -75.30678 |
| Chi-squared | 87.41425 |
| Degrees of freedom | 3 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error z=b/s.e. P[\|Z\|≥z] | Mean of X |
|---|---|---|---|
| Constant | -16.115 | .........(Fixed Parameter)....... | |
| GSEC | 2.2642 | .........(Fixed Parameter)....... | 7.271 |
| TLDL | 0.16300 | .........(Fixed Parameter)....... | 10.70 |
| MNVL | 0.92505 | .........(Fixed Parameter)....... | 3.636 |

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 31 | 3 | 34 |
| 1 | 8 | 90 | 98 |
| TOTAL | 39 | 93 | 132 |

### D2.2: Validation of the Basic Model for Maneuver 2

Unrestricted and restricted models with a specification identical to Maneuver 2 BASIC model were calibrated using the 132 observations reserved for validation purpose. The likelihood ratio test performed on these models has concluded that the restricted and the unrestricted models are ***not*** significantly different. The details of this test are listed below:

- $H_0$ : Imposed restrictions are correct.
- Log likelihood for the unrestricted model = -26.87.
- Log likelihood for the restricted model = -31.60.
- Likelihood ratio test statistic = -2(31.6 - (-26.87) = 9.46.
- Degrees of freedom for the test = 4.
- $\chi^2$ - table value at (0.05,4) = 9.49.
- Test result :No enough statistical evidence to reject $H_0$ at 5% level.

## D2.3: Unrestricted and Restricted FULL Models Calibrated for Maneuver 2 Using the Validation Data

Table D2.2: Details of the Unrestricted and the Restricted FULL Models for Maneuver 2.

UNREST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, M2

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 132 |
| Iterations completed | 9 |
| Log likelihood function | -24.32146 |
| Restricted log likelihood | -75.30678 |
| Chi-squared | 101.9706 |
| Degrees of freedom | 6 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -10.460 | 3.0368 | -3.444 | 0.00057 | |
| GSEC | 2.1251 | 0.49621 | 4.283 | 0.00002 | 7.271 |
| TLDL | 0.93319E-01 | 0.32206E-01 | 2.898 | 0.00376 | 10.70 |
| MNVL | 0.66171 | 0.53046 | 1.247 | 0.21225 | 3.636 |
| DSEX | -0.75160 | 1.2958 | -0.580 | 0.56190 | 0.1439 |
| DAGE | -0.30058E-01 | 0.40057E-01 | -0.750 | 0.45301 | 38.39 |
| TRDN | -0.63888E-01 | 0.35316E-01 | -1.809 | 0.07045 | 18.69 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 28 | 6 | 34 |
| 1 | 4 | 94 | 98 |
| TOTAL | 32 | 100 | 132 |

REST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, M2

| Multinomial Logit Model | |
|---|---|
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 132 |
| Iterations completed | 1 |
| Log likelihood function | -31.17026 |
| Restricted log likelihood | -75.30678 |
| Chi-squared | 88.27304 |
| Degrees of freedom | 6 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error z=b/s.e. P[\|Z\|≥z] | Mean of X |
|---|---|---|---|
| Constant | -16.377 | ........(Fixed Parameter)....... | |
| GSEC | 2.7279 | ........(Fixed Parameter)....... | 7.271 |
| TLDL | 0.17606 | ........(Fixed Parameter)....... | 10.70 |
| MNVL | 1.2174 | ........(Fixed Parameter)....... | 3.636 |
| DSEX | -1.5612 | ........(Fixed Parameter)....... | 0.1439 |
| DAGE | -0.61408E-01 | ........(Fixed Parameter)....... | 38.39 |
| TRDN | -0.24923E-01 | ........(Fixed Parameter)....... | 18.69 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 31 | 3 | 34 |
| 1 | 7 | 91 | 98 |
| TOTAL | 38 | 94 | 132 |

# Appendix D3

## Details of the Validation Models

## for Maneuver 3

## D3.1: Unrestricted and Restricted BASIC Models Calibrated for Maneuver 3 Using the Validation Data

Table D3.1: Details of the Unrestricted and the Restricted BASIC Models for Maneuver 3.

UNREST. MODEL FOR VALIDATION DATA, TRAFFIC AND DELAY ATT., M3

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 193 |
| Iterations completed | 8 |
| Log likelihood function | -19.25692 |
| Restricted log likelihood | -118.8140 |
| Chi-squared | 199.1141 |
| Degrees of freedom | 4 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -5.0397 | 2.1481 | -2.346 | 0.01897 | |
| GSEC | 3.2553 | 0.65399 | 4.978 | 0.00000 | 4.818 |
| MJSD | -0.34535 | 0.72087E-01 | -4.791 | 0.00000 | 42.79 |
| TLDL | 0.50080E-01 | 0.22363E-01 | 2.239 | 0.02513 | 22.04 |
| MNVL | 1.0790 | 0.53611 | 2.013 | 0.04414 | 1.663 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 132 | 2 | 134 |
| 1 | 4 | 55 | 59 |
| TOTAL | 136 | 57 | 193 |

REST. MODEL FOR VALIDATION DATA, TRAFFIC AND DELAY ATT., M3

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 193 |
| Iterations completed | 1 |
| Log likelihood function | -22.89881 |
| Restricted log likelihood | -118.8140 |
| Chi-squared | 191.8303 |
| Degrees of freedom | 4 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -7.5083 | ........(Fixed Parameter)....... | | | |
| GSEC | 2.5096 | ........(Fixed Parameter)....... | | | 4.818 |
| MJSD | -0.21267 | ........(Fixed Parameter)....... | | | 42.79 |
| TLDL | 0.61093E-01 | ........(Fixed Parameter)....... | | | 22.04 |
| MNVL | 1.0876 | ........(Fixed Parameter)....... | | | 1.663 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 130 | 4 | 134 |
| 1 | 5 | 54 | 59 |
| TOTAL | 135 | 58 | 193 |

## D3.2: Validation of the Basic Model for Maneuver 3

The main purpose of the validation process is to assess the capability of the calibrated model in predicting the observed behavior correctly. In this context, the percentage of observed cases in which the model prediction matches the observed behavior (Percent correctly predicted) can be considered a good indicator of the model prediction capability. A more specific statistical test applicable for this purpose is the likelihood ratio test which checks whether an unrestricted model calibrated for a prescribed portion of the data (Validation Data) is significantly different from a restricted model calibrated for the same data. In the restricted model, coefficients are restricted to the values obtained in the model developed using the "calibration data". The details of this test as applied to Maneuver 3 are listed below:

- $H_0$: Imposed restrictions are correct (observed and predicted behaviors are not different).
- Log Likelihood value for the unrestricted model = - 19.26.
- Log likelihood value for the restricted model = -22.89.
- Log likelihood ratio test statistic = -2(-22.49-(-19.26)) = 7.26.
- Degrees of freedom (No. of imposed restrictions) = 5.
- $\chi^2$ table value at (0.05, 5) = 11.07
- Test result: No enough Statistical evidence to reject $H_0$.

## D3.3: Unrestricted and Restricted FULL Models Calibrated for Maneuver 3 Using the Validation Data

Table D3.2: Details of the Unrestricted and the Restricted FULL Models for Maneuver 3.

UNREST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, M3

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 193 |
| Iterations completed | 10 |
| Log likelihood function | -16.28034 |
| Restricted log likelihood | -118.8140 |
| Chi-squared | 205.0672 |
| Degrees of freedom | 7 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -6.7062 | 2.8324 | -2.368 | 0.01790 | |
| GSEC | 4.3102 | 1.1087 | 3.888 | 0.00010 | 4.818 |
| MJSD | -0.43381 | 0.11292 | -3.842 | 0.00012 | 42.79 |
| TLDL | 0.88189E-01 | 0.33425E-01 | 2.638 | 0.00833 | 22.04 |
| MNVL | 1.4266 | 0.71379 | 1.999 | 0.04564 | 1.663 |
| ACDT | 0.16458 | 0.41863 | 0.393 | 0.69421 | 0.4093 |
| TRDN | -0.87558E-01 | 0.45871E-01 | -1.909 | 0.05629 | 22.74 |
| DEXP | 0.60411E-01 | 0.66183E-01 | 0.913 | 0.36136 | 11.38 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 133 | 1 | 134 |
| 1 | 4 | 55 | 59 |
| TOTAL | 137 | 56 | 193 |

REST. MODEL FOR VALIDATION DATA, ALL ATTRIBUTES, M3

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 193 |
| Iterations completed | 1 |
| Log likelihood function | -23.18923 |
| Restricted log likelihood | -118.8140 |
| Chi-squared | 191.2495 |
| Degrees of freedom | 7 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error z=b/s.e. P[\|Z\|≥z] | Mean of X |
|---|---|---|---|
| Constant | -9.1446 | ........(Fixed Parameter)....... | |
| GSEC | 2.7457 | ........(Fixed Parameter)....... | 4.818 |
| MJSD | -0.22892 | ........(Fixed Parameter)....... | 42.79 |
| TLDL | 0.82948E-01 | ........(Fixed Parameter)....... | 22.04 |
| MNVL | 1.2354 | ........(Fixed Parameter)....... | 1.663 |
| ACDT | 0.67564 | ........(Fixed Parameter)....... | 0.4093 |
| TRDN | -0.48679E-01 | ........(Fixed Parameter)....... | 22.74 |
| DEXP | 0.95376E-01 | ........(Fixed Parameter)....... | 11.38 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 129 | 5 | 134 |
| 1 | 5 | 54 | 59 |
| TOTAL | 134 | 59 | 193 |

# Appendix E

## Details of the Gaps and Lags Models

**E1: Details of the Gaps and Lags Models for Maneuver 1**

**E2: Details of the Gaps and Lags Models for Maneuver 2**

**E3: Details of the Gaps and Lags Models for Maneuver 3**

## Appendix E1

## Details of the Gaps and Lags Models

## for Maneuver 1

Table E1.1: Details of the Model Calibrated for Gaps Only, Maneuver 1.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 136 |
| Iterations completed | 11 |
| Log likelihood function | -8.482622 |
| Restricted log likelihood | -92.48076 |
| Chi-squared | 167.9963 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -21.612 | 10.976 | -1.969 | 0.04895 | |
| GSEC | 5.8994 | 2.5011 | 2.359 | 0.01834 | 5.580 |
| MJSD | -0.48141 | 0.21566 | -2.232 | 0.02560 | 34.53 |
| TLDL | 0.22312 | 0.15038 | 1.484 | 0.13790 | 10.60 |
| MNVL | 2.9199 | 1.7222 | 1.695 | 0.09000 | 1.971 |
| ACDT | 2.2266 | 1.5918 | 1.399 | 0.16187 | 0.3971 |
| VLTN | 1.2745 | 1.0454 | 1.219 | 0.22279 | 0.6985 |
| DEXP | 0.40538 | 0.19177 | 2.114 | 0.03453 | 10.63 |
| TRDN | -0.20120 | 0.12594 | -1.598 | 0.11013 | 16.04 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.74859E-01 | 0.14893 | -0.503 | 0.61521 | |
| GSEC | 0.20434E-01 | 0.40575E-01 | 0.504 | 0.61454 | 5.580 |
| MJSD | -0.16675E-02 | 0.33831E-02 | -0.493 | 0.62209 | 34.53 |
| TLDL | 0.77281E-03 | 0.14659E-02 | 0.527 | 0.59807 | 10.60 |
| MNVL | 0.10114E-01 | 0.20029E-01 | 0.505 | 0.61359 | 1.971 |
| ACDT | 0.77122E-02 | 0.15010E-01 | 0.514 | 0.60739 | 0.3971 |
| VLTN | 0.44146E-02 | 0.10902E-01 | 0.405 | 0.68553 | 0.6985 |
| DEXP | 0.14041E-02 | 0.28301E-02 | 0.496 | 0.61980 | 10.63 |
| TRDN | -0.69690E-03 | 0.13229E-02 | -0.527 | 0.59834 | 16.04 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 56 | 1 | 57 |
| 1 | 2 | 77 | 79 |
| TOTAL | 58 | 78 | 136 |

Table E1.2: Details of the Model Calibrated for Lags Only, Maneuver I.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 201 |
| Iterations completed | 9 |
| Log likelihood function | -30.91614 |
| Restricted log likelihood | -134.6873 |
| Chi-squared | 207.5424 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -5.5611 | 2.3266 | -2.390 | 0.01684 | |
| GSEC | 1.4598 | 0.30176 | 4.838 | 0.00000 | 9.101 |
| MJSD | -0.18589 | 0.43040E-01 | -4.319 | 0.00002 | 40.55 |
| TLDL | 0.12279 | 0.72400E-01 | 1.696 | 0.08988 | 2.555 |
| MNVL | 1.1458 | 0.46553 | 2.461 | 0.01385 | 2.289 |
| ACDT | 0.81327 | 0.32482 | 2.504 | 0.01229 | 0.3333 |
| VLTN | 0.43962 | 0.25055 | 1.755 | 0.07933 | 0.5423 |
| DEXP | 0.99691E-01 | 0.52098E-01 | 1.914 | 0.05568 | 12.11 |
| TRDN | -0.50312E-01 | 0.38398E-01 | -1.310 | 0.19010 | 13.78 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.85292E-01 | 0.69165E-01 | -1.233 | 0.21752 | |
| GSEC | 0.22389E-01 | 0.17310E-01 | 1.293 | 0.19587 | 9.101 |
| MJSD | -0.28510E-02 | 0.25268E-02 | -1.128 | 0.25919 | 40.55 |
| TLDL | 0.18833E-02 | 0.17722E-02 | 1.063 | 0.28792 | 2.555 |
| MNVL | 0.17573E-01 | 0.15939E-01 | 1.103 | 0.27023 | 2.289 |
| ACDT | 0.12473E-01 | 0.11801E-01 | 1.057 | 0.29055 | 0.3333 |
| VLTN | 0.67425E-02 | 0.67226E-02 | 1.003 | 0.31588 | 0.5423 |
| DEXP | 0.15290E-02 | 0.15769E-02 | 0.970 | 0.33223 | 12.11 |
| TRDN | -0.77164E-03 | 0.85894E-03 | -0.898 | 0.36899 | 13.78 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 70 | 9 | 79 |
| 1 | 7 | 115 | 122 |
| TOTAL | 77 | 124 | 201 |

## Appendix E2

## Details of the Gaps and Lags Models

## for Maneuver 2

Table E2.1: Details of the Model Calibrated for Gaps Only, Maneuver 2.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 123 |
| Iterations completed | 9 |
| Log likelihood function | -15.72471 |
| Restricted log likelihood | -82.69866 |
| Chi-squared | 133.9479 |
| Degrees of freedom | 6 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -20.136 | 5.7112 | -3.526 | 0.00042 | |
| GSEC | 3.2987 | 0.80032 | 4.122 | 0.00004 | 4.738 |
| TLDL | 0.16167 | 0.65862E-01 | 2.455 | 0.01410 | 13.64 |
| MNVL | 1.2314 | 0.80163 | 1.536 | 0.12452 | 3.325 |
| DSEX | 0.39504 | 2.9189 | 0.135 | 0.89235 | 0.1138 |
| DAGE | 0.17085E-01 | 0.67446E-01 | 0.253 | 0.80002 | 34.77 |
| TRDN | -0.22983E-02 | 0.28922E-01 | -0.079 | 0.93666 | 26.01 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -1.5720 | 1.1447 | -1.373 | 0.16964 | |
| GSEC | 0.25753 | 0.17496 | 1.472 | 0.14104 | 4.738 |
| TLDL | 0.12622E-01 | 0.10957E-01 | 1.152 | 0.24933 | 13.64 |
| MNVL | 0.96132E-01 | 0.10690 | 0.899 | 0.36851 | 3.325 |
| DSEX | 0.30840E-01 | 0.22098 | 0.140 | 0.88901 | 0.1138 |
| DAGE | 0.13338E-02 | 0.48664E-02 | 0.274 | 0.78401 | 34.77 |
| TRDN | -0.17943E-03 | 0.23040E-02 | -0.078 | 0.93793 | 26.01 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 46 | 3 | 49 |
| 1 | 2 | 72 | 74 |
| TOTAL | 48 | 75 | 123 |

Table E2.2: Details of the Model Calibrated for Lags Only, Maneuver 2.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 270 |
| Iterations completed | 10 |
| Log likelihood function | -15.22618 |
| Restricted log likelihood | -161.4017 |
| Chi-squared | 292.3510 |
| Degrees of freedom | 6 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -21.246 | 5.1681 | -4.111 | 0.00004 | |
| GSEC | 3.4431 | 0.77867 | 4.422 | 0.00001 | 8.376 |
| TLDL | 0.18783 | 0.44673E-01 | 4.204 | 0.00003 | 8.757 |
| MNVL | 1.2112 | 0.65823 | 1.840 | 0.06577 | 3.541 |
| DSEX | -3.8591 | 3.2053 | -1.204 | 0.22860 | 0.1185 |
| DAGE | -0.76559E-01 | 0.56418E-01 | -1.357 | 0.17478 | 37.34 |
| TRDN | -0.21584E-01 | 0.18701E-01 | -1.154 | 0.24843 | 21.59 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.12461E-02 | 0.26543E-02 | -0.469 | 0.63874 | |
| GSEC | 0.20194E-03 | 0.42450E-03 | 0.476 | 0.63428 | 8.376 |
| TLDL | 0.11016E-04 | 0.23860E-04 | 0.462 | 0.64430 | 8.757 |
| MNVL | 0.71034E-04 | 0.15330E-03 | 0.463 | 0.64311 | 3.541 |
| DSEX | -0.22633E-03 | 0.52220E-03 | -0.433 | 0.66470 | 0.1185 |
| DAGE | -0.44902E-05 | 0.94482E-05 | -0.475 | 0.63461 | 37.34 |
| TRDN | -0.12659E-05 | 0.29991E-05 | -0.422 | 0.67297 | 21.59 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 75 | 2 | 77 |
| 1 | 2 | 191 | 193 |
| TOTAL | 77 | 193 | 270 |

# Appendix E3

## Details of the Gaps and Lags Models

## for Maneuver 3

Table E3.1: Details of the Model Calibrated for Gaps Only, Maneuver 3.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.10682E-01 | 0.59848E-01 | 0.178 | 0.85834 | |
| GSEC | 0.16635 | 0.60159E-02 | 27.652 | 0.00000 | 4.084 |
| MJSD | -0.16820E-01 | 0.11737E-02 | -14.331 | 0.00000 | 40.59 |
| TLDL | 0.46544E-02 | 0.87907E-03 | 5.295 | 0.00000 | 18.80 |
| MNVL | 0.88676E-01 | 0.14512E-01 | 6.111 | 0.00000 | 1.592 |
| ACDT | 0.41054E-01 | 0.16486E-01 | 2.490 | 0.01277 | 0.3232 |
| TRDN | -0.20622E-02 | 0.84955E-03 | -2.427 | 0.01521 | 18.51 |
| DEXP | 0.33481E-02 | 0.16479E-02 | 2.032 | 0.04218 | 11.49 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                RESP
Number of observations             461
Iterations completed                 9
Log likelihood function      -39.42334
Restricted log likelihood    -258.9615
Chi-squared                   439.0763
Degrees of freedom                   7
Significance level           0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -11.506 | 2.4956 | -4.610 | 0.00000 | |
| GSEC | 3.6917 | 0.59281 | 6.227 | 0.00000 | 4.084 |
| MJSD | -0.27220 | 0.44457E-01 | -6.123 | 0.00000 | 40.59 |
| TLDL | 0.77394E-01 | 0.25486E-01 | 3.037 | 0.00239 | 18.80 |
| MNVL | 1.1875 | 0.36291 | 3.272 | 0.00107 | 1.592 |
| ACDT | 0.82891 | 0.40038 | 2.070 | 0.03842 | 0.3232 |
| TRDN | -0.48380E-01 | 0.28086E-01 | -1.723 | 0.08496 | 18.51 |
| DEXP | 0.11899 | 0.49838E-01 | 2.388 | 0.01696 | 11.49 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.36136 | 0.13159 | -2.746 | 0.00603 | |
| GSEC | 0.11594 | 0.45983E-01 | 2.521 | 0.01169 | 4.084 |
| MJSD | -0.85486E-02 | 0.37904E-02 | -2.255 | 0.02411 | 40.59 |
| TLDL | 0.24306E-02 | 0.11831E-02 | 2.054 | 0.03994 | 18.80 |
| MNVL | 0.37294E-01 | 0.17389E-01 | 2.145 | 0.03198 | 1.592 |
| ACDT | 0.26033E-01 | 0.15658E-01 | 1.663 | 0.09640 | 0.3232 |
| TRDN | -0.15194E-02 | 0.96517E-03 | -1.574 | 0.11543 | 18.51 |
| DEXP | 0.37370E-02 | 0.20048E-02 | 1.864 | 0.06233 | 11.49 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 341 | 5 | 346 |
| 1 | 10 | 105 | 115 |
| TOTAL | 351 | 110 | 461 |

Table E3.2: Details of the Model Calibrated for Lags Only, Maneuver 3.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.11218 | 0.93517E-01 | -1.200 | 0.23032 | |
| GSEC | 0.11226 | 0.72806E-02 | 15.420 | 0.00000 | 5.700 |
| MJSD | -0.10797E-01 | 0.16436E-02 | -6.569 | 0.00000 | 48.33 |
| TLDL | 0.56233E-02 | 0.10963E-02 | 5.129 | 0.00000 | 11.15 |
| MNVL | 0.11336 | 0.18830E-01 | 6.020 | 0.00000 | 2.037 |
| ACDT | 0.62570E-02 | 0.23034E-01 | 0.272 | 0.78590 | 0.3272 |
| TRDN | -0.16256E-02 | 0.13222E-02 | -1.229 | 0.21889 | 18.06 |
| DEXP | 0.21899E-02 | 0.24351E-02 | 0.899 | 0.36849 | 10.96 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 162
Iterations completed                     9
Log likelihood function          -10.35471
Restricted log likelihood        -98.44633
Chi-squared                       176.1833
Degrees of freedom                       7
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -10.283 | 3.8343 | -2.682 | 0.00732 | |
| GSEC | 2.3774 | 0.71886 | 3.307 | 0.00094 | 5.700 |
| MJSD | -0.22183 | 0.86486E-01 | -2.565 | 0.01032 | 48.33 |
| TLDL | 0.37117E-01 | 0.29783E-01 | 1.246 | 0.21268 | 11.15 |
| MNVL | 2.4048 | 0.82006 | 2.932 | 0.00336 | 2.037 |
| ACDT | 0.41380 | 0.74045 | 0.559 | 0.57627 | 0.3272 |
| TRDN | -0.52040E-01 | 0.49989E-01 | -1.041 | 0.29786 | 18.06 |
| DEXP | 0.47060E-01 | 0.13076 | 0.360 | 0.71892 | 10.96 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.76615 | 0.47063 | -1.628 | 0.10354 | |
| GSEC | 0.17714 | 0.10718 | 1.653 | 0.09839 | 5.700 |
| MJSD | -0.16528E-01 | 0.97824E-02 | -1.690 | 0.09111 | 48.33 |
| TLDL | 0.27655E-02 | 0.26342E-02 | 1.050 | 0.29379 | 11.15 |
| MNVL | 0.17918 | 0.10184 | 1.759 | 0.07850 | 2.037 |
| ACDT | 0.30831E-01 | 0.52450E-01 | 0.588 | 0.55665 | 0.3272 |
| TRDN | -0.38775E-02 | 0.44955E-02 | -0.863 | 0.38840 | 18.06 |
| DEXP | 0.35064E-02 | 0.99265E-02 | 0.353 | 0.72391 | 10.96 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 113 | 1 | 114 |
| 1 | 2 | 46 | 48 |
| TOTAL | 115 | 47 | 162 |

## Appendix F

## Details of Models for Nearside and Farside Gaps/Lags for Maneuver 3

Table F.1: Details of the Model Calibrated for the Nearside Gaps/Lags in Maneuver 3.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.99960E-01 | 0.66676E-01 | 1.499 | 0.13383 | |
| GSEC | 0.16168 | 0.71606E-02 | 22.579 | 0.00000 | 4.281 |
| MJSD | -0.17378E-01 | 0.13833E-02 | -12.563 | 0.00000 | 41.95 |
| TLDL | 0.56247E-02 | 0.87182E-03 | 6.452 | 0.00000 | 17.84 |
| MNVL | 0.44758E-01 | 0.16115E-01 | 2.777 | 0.00548 | 1.689 |
| ACDT | 0.26894E-01 | 0.19082E-01 | 1.409 | 0.15872 | 0.2805 |
| TRDN | -0.16688E-02 | 0.95264E-03 | -1.752 | 0.07980 | 17.77 |
| DEXP | 0.26324E-02 | 0.18296E-02 | 1.439 | 0.15022 | 11.45 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                    RESP
Number of observations                 328
Iterations completed                     9
Log likelihood function          -29.45212
Restricted log likelihood        -183.3392
Chi-squared                       307.7741
Degrees of freedom                       7
Significance level               0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -9.2394 | 2.8165 | -3.280 | 0.00104 | |
| GSEC | 2.9585 | 0.52063 | 5.683 | 0.00000 | 4.281 |
| MJSD | -0.26289 | 0.51398E-01 | -5.115 | 0.00000 | 41.95 |
| TLDL | 0.84243E-01 | 0.28452E-01 | 2.961 | 0.00307 | 17.84 |
| MNVL | 1.3692 | 0.49841 | 2.747 | 0.00601 | 1.689 |
| ACDT | 0.38964 | 0.42054 | 0.927 | 0.35417 | 0.2805 |
| TRDN | -0.38888E-01 | 0.31749E-01 | -1.225 | 0.22063 | 17.77 |
| DEXP | 0.14405 | 0.59657E-01 | 2.415 | 0.01575 | 11.45 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.53519 | 0.18320 | -2.921 | 0.00349 | |
| GSEC | 0.17137 | 0.61221E-01 | 2.799 | 0.00512 | 4.281 |
| MJSD | -0.15228E-01 | 0.61492E-02 | -2.476 | 0.01327 | 41.95 |
| TLDL | 0.48798E-02 | 0.20374E-02 | 2.395 | 0.01662 | 17.84 |
| MNVL | 0.79310E-01 | 0.34933E-01 | 2.270 | 0.02318 | 1.689 |
| ACDT | 0.22570E-01 | 0.25109E-01 | 0.899 | 0.36872 | 0.2805 |
| TRDN | -0.22526E-02 | 0.18331E-02 | -1.229 | 0.21912 | 17.77 |
| DEXP | 0.83444E-02 | 0.36937E-02 | 2.259 | 0.02388 | 11.45 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 241 | 6 | 247 |
| 1 | 6 | 75 | 81 |
| TOTAL | 247 | 81 | 328 |

Table F.2: Details of the Model Calibrated for the Farside Gaps/Lags in Maneuver 3.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.30962E-01 | 0.74520E-01 | -0.415 | 0.67778 | |
| GSEC | 0.13592 | 0.66075E-02 | 20.570 | 0.00000 | 4.775 |
| MJSD | -0.13443E-01 | 0.13951E-02 | -9.636 | 0.00000 | 43.36 |
| TLDL | 0.51745E-02 | 0.10892E-02 | 4.751 | 0.00000 | 15.61 |
| MNVL | 0.11519 | 0.16561E-01 | 6.955 | 0.00000 | 1.730 |
| ACDT | 0.33394E-01 | 0.19626E-01 | 1.701 | 0.08886 | 0.3716 |
| TRDN | -0.24980E-02 | 0.11228E-02 | -2.225 | 0.02609 | 19.05 |
| DEXP | 0.60126E-04 | 0.25737E-03 | 0.234 | 0.81528 | 7.837 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                   RESP
Number of observations                296
Iterations completed                    9
Log likelihood function         -29.01029
Restricted log likelihood       -175.6274
Chi-squared                      293.2342
Degrees of freedom                      7
Significance level              0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -10.059 | 2.3443 | -4.291 | 0.00002 | |
| GSEC | 2.9752 | 0.53826 | 5.527 | 0.00000 | 4.775 |
| MJSD | -0.22874 | 0.44475E-01 | -5.143 | 0.00000 | 43.36 |
| TLDL | 0.79525E-01 | 0.24768E-01 | 3.211 | 0.00132 | 15.61 |
| MNVL | 1.4969 | 0.40082 | 3.735 | 0.00019 | 1.730 |
| ACDT | 0.90598 | 0.40614 | 2.231 | 0.02570 | 0.3716 |
| TRDN | -0.67787E-01 | 0.30725E-01 | -2.206 | 0.02737 | 19.05 |
| DEXP | 0.85675E-02 | 0.18299E-01 | 0.468 | 0.63964 | 7.837 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.53015 | 0.19337 | -2.742 | 0.00611 | |
| GSEC | 0.15681 | 0.59026E-01 | 2.657 | 0.00789 | 4.775 |
| MJSD | -0.12056E-01 | 0.47987E-02 | -2.512 | 0.01199 | 43.36 |
| TLDL | 0.41915E-02 | 0.18555E-02 | 2.259 | 0.02389 | 15.61 |
| MNVL | 0.78895E-01 | 0.33423E-01 | 2.361 | 0.01825 | 1.730 |
| ACDT | 0.47750E-01 | 0.24344E-01 | 1.961 | 0.04982 | 0.3716 |
| TRDN | -0.35728E-02 | 0.19347E-02 | -1.847 | 0.06479 | 19.05 |
| DEXP | 0.45156E-03 | 0.96002E-03 | 0.470 | 0.63809 | 7.837 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 207 | 6 | 213 |
| 1 | 6 | 77 | 83 |
| TOTAL | 213 | 83 | 296 |

# Appendix G

## Details of the Models Calibrated For Special Cases

**G1: Details of the Models Calibrated For Cases Which Involved Driver Gap/Lag Rejection Decisions**

**G2: Details of the Models Calibrated For Cases in Which the Effect of an Ahead Driver Exists**

## Appendix G1

## Details of the Models Calibrated For Cases Which Involved Driver Gap/Lag Rejection Decisions

## G1.1: Modeling Cases Which Involved Driver Gap/Lag Rejection decisions in Maneuver 1

Drivers have rejected gaps in 135 cases out of the 337 observations collected for Maneuver 1. Starting with traffic and delay attributes and performing the due correlation and modeling analyses, it was found that the gap size (GSEC), speed on major road (MJSD), volume on minor road (MNVL), and total delay (TLDL) are significant at 5% or better levels. It should be mentioned that the number of rejected gaps (NREJ), and queue size (QSIZ) were found to be significant in this model. However, these measures are highly correlated to the total delay (TLDL). In conclusion it was found that the model with TLDL gives ,however, a better fit. Out of the driver, vehicle, and trip attributes the Vehicle Occupancy (OCUP) showed to be significant at 2.6% level as shown in Table G1-1 which represents a summary of the calibrated model. The detailed model is given in Table G1-2. Among the attributes relevant to cases which involve gap rejection actions, the difference between the accepted and the maximum rejected gaps (DAMR) showed to be significant at 4.2% level. Table G1-1 shows that (DAMR) has a negative coefficient of (-0.875). This variable is originally defined to measure driver consistency in accepting gaps with the inconsistency level increases as DAMR increases. This definition along with the obtained negative coefficient of DAMR indicate that the more the driver is inconsistent, the more he will be hesitant to accept gaps. Coefficient signs of traffic and delay attributes in the Model presented in Table G1-1 are according to the expected driver gap acceptance behavior.

**Table G1.1: Summarized Model For Cases Which Involved Driver Gap/Lag Rejection Decisions in Maneuver 1**

| Variable/ Statistic | Coefficient | Significant Level | Marginal Effects |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | -7.677 | 0.0885 | - 0.5501 |
| GSEC (Gap Size in Seconds) | 2.833 | 0.0003 | 0.2030 |
| MJSD (Speed at Major Road in Km/hr) | -0.263 | 0.0026 | - 0.0188 |
| TLDL (Total Delay Imposed on Driver) | 0.154 | 0.0353 | 0.0111 |
| MNVL (Traffic Volume at Minor Road) | 2.335 | 0.0171 | 0.1674 |
| OCUP (Vehicle Occupancy) | -0.579 | 0.0259 | - 0.0415 |
| DAMR (Diff. between accepted & max. rejected gap) | -0.875 | 0.0420 | 0.0627 |
| n (Number of observations) | 135 | | |
| L (â) (Loglikelihood value at maximum) | 14.04 | | |
| L (C) (restricted Loglikelihood value) | -91.93 | | |
| $\chi^2$ (Loglikelihood Ratio) | 155.80 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 6 | | |
| Sig. Level for $\chi^2$ Test | 0.00 | | |
| $\rho^2$ (Goodness of fit Index) | 0.847 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.782 | | |
| PCP (% correctly predicted observations) observations | 96.30% | | |

Table G1.2: Details of the Model Calibrated for Cases Which Involved Driver Gap/Lag Rejection Decisions in Maneuver 1.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.27345 | 0.14555 | 1.879 | 0.06028 | |
| GSEC | 0.12069 | 0.12001E-01 | 10.056 | 0.00000 | 5.587 |
| MJSD | -0.17807E-01 | 0.27555E-02 | -6.463 | 0.00000 | 34.49 |
| TLDL | 0.73135E-02 | 0.40429E-02 | 1.809 | 0.07045 | 10.58 |
| MNVL | 0.16464 | 0.34808E-01 | 4.730 | 0.00000 | 1.970 |
| OCUP | -0.36895E-01 | 0.12554E-01 | -2.939 | 0.00329 | 2.556 |
| DAMR | -0.40456E-01 | 0.16346E-01 | -2.475 | 0.01332 | 1.564 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                     RESP
Number of observations                  135
Iterations completed                      9
Log likelihood function           -14.03686
Restricted log likelihood         -91.93488
Chi-squared                        155.7960
Degrees of freedom                        6
Significance level                0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -7.6765 | 4.5071 | -1.703 | 0.08853 | |
| GSEC | 2.8326 | 0.78100 | 3.627 | 0.00029 | 5.587 |
| MJSD | -0.26274 | 0.87217E-01 | -3.012 | 0.00259 | 34.49 |
| TLDL | 0.15435 | 0.73332E-01 | 2.105 | 0.03530 | 10.58 |
| MNVL | 2.3354 | 0.97949 | 2.384 | 0.01711 | 1.970 |
| OCUP | -0.57906 | 0.25989 | -2.228 | 0.02587 | 2.556 |
| DAMR | -0.87462 | 0.43010 | -2.034 | 0.04200 | 1.564 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.55014 | 0.42648 | -1.290 | 0.19707 | |
| GSEC | 0.20300 | 0.11263 | 1.802 | 0.07149 | 5.587 |
| MJSD | -0.18829E-01 | 0.11839E-01 | -1.590 | 0.11174 | 34.49 |
| TLDL | 0.11062E-01 | 0.84846E-02 | 1.304 | 0.19231 | 10.58 |
| MNVL | 0.16737 | 0.11310 | 1.480 | 0.13894 | 1.970 |
| OCUP | -0.41499E-01 | 0.30717E-01 | -1.351 | 0.17669 | 2.556 |
| DAMR | -0.62680E-01 | 0.46906E-01 | -1.336 | 0.18146 | 1.564 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 55 | 2 | 57 |
| 1 | 3 | 75 | 78 |
| TOTAL | 58 | 77 | 135 |

## G1.2: Modeling Cases Which Involved Driver Gap/Lag Rejection Actions in Maneuver 2

The modeling procedure detailed in Section 6.2 was followed to study the variables which only apply for the cases in which the concerned driver has rejected a gap or more. These cases account for 126 observations. The final model calibrated for these observations is summarized in Table G1-3. The detailed model is given in Table G1-4.

As shown in Table G1-3, gap size (GSEC) and total delay are the only significant variables among traffic and delay attributes. The overall model is significant at 0.0000000%. Among driver , vehicle, and trip attributes, only driver familiarity to the site (DFAM) (measured in number of times the driver passes the site per week) and vehicle occupancy are significant at 5% or better levels. Among the variables relevant to the cases in which drivers have rejected gaps the size of the gap succeeding the current gap "Succeeding gap in seconds, (SSEC) is significant at 2.41%. Signs of the coefficients of gap size (GSEC) , total delay (TLDL), vehicle occupancy (OCUP), and driver familiarly to the site (DFAM) are according to the expected driver behavior. The negative sign of (OCUP) indicates that drivers with higher vehicular occupancy tend to be more cautious in accepting gaps because they try to avoid any risk of accidents. The positive signs of the other three variables (GSEC, TLDL, DFAM) are readily explainable.

The positive sign taken by the variable which represents the size of the succeeding gap in seconds (SSEC) indicates that drivers do not tend to wait for the longer succeeding gap when the current gap is (in their estimation) adequate and/or that drivers concentrate only on evaluating the current gap with less attention paid to the coming gap. However, the sign of

**Table G1.3: Summarized Model for Cases Which Involved Driver Gap/Lag Rejection Decisions in Maneuver 2.**

| Variable / Statistic | Coefficient | Significance level | Marginal Effect |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | - 29.932 | 0.0029 | - 0.0844 |
| GSEC (Gap Size in Seconds) | 5.087 | 0.0027 | 0.0144 |
| TLDL (Total Delay Imposed on Driver) | 0.428 | 0.0142 | 0.0012 |
| OCUP (Vehicle Occupancy, persons) | - 1.348 | 0.0377 | - 0.0038 |
| DFAM (Driver Familiarity, visiting times per week) | 0.133 | 0.0480 | 0.0004 |
| SSEC (Succeeding Gap, seconds) | 1.197 | 0.0241 | 0.0034 |
| n (Number of observations) | 126 | | |
| L (â) (Loglikelihood value at maximum) | - 7.99 | | |
| L (C) (restricted Loglikelihood value) | - 84.63 | | |
| $\chi^2$ (Loglikelihood Ratio) | 153.29 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 5 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.906 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.847 | | |
| PCP (% correctly predicted observations) | 97.62% | | |

Table G1.4: Details of the Model Calibrated for Cases Which Involved Driver Gap/Lag Rejection Decisions in Maneuver 2.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 126 |
| Iterations completed | 10 |
| Log likelihood function | -7.991633 |
| Restricted log likelihood | -84.63464 |
| Chi-squared | 153.2860 |
| Degrees of freedom | 5 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -29.932 | 10.060 | -2.975 | 0.00293 | |
| GSEC | 5.0871 | 1.6984 | 2.995 | 0.00274 | 4.773 |
| TLDL | 0.42783 | 0.17455 | 2.451 | 0.01424 | 13.71 |
| OCUP | -1.3483 | 0.64876 | -2.078 | 0.03769 | 2.643 |
| DFAM | 0.13311 | 0.67325E-01 | 1.977 | 0.04803 | 22.75 |
| SSEC | 1.1966 | 0.53038 | 2.256 | 0.02406 | 5.171 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.84437E-01 | 0.15913 | -0.531 | 0.59569 | |
| GSEC | 0.14350E-01 | 0.26746E-01 | 0.537 | 0.59158 | 4.773 |
| TLDL | 0.12069E-02 | 0.22513E-02 | 0.536 | 0.59190 | 13.71 |
| OCUP | -0.38033E-02 | 0.67894E-02 | -0.560 | 0.57535 | 2.643 |
| DFAM | 0.37548E-03 | 0.70362E-03 | 0.534 | 0.59358 | 22.75 |
| SSEC | 0.33755E-02 | 0.63005E-02 | 0.536 | 0.59213 | 5.171 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 49 | 1 | 50 |
| 1 | 2 | 74 | 76 |
| TOTAL | 51 | 75 | 126 |

this variable does not match with the expected driver gap acceptance behavior. It was expected that the probability of accepting a current gap will decrease if the size of the coming gap (succeeding gap) is longer.

The high rho-squared and percent correctly predicted values for the model indicate the good capability of the model in explaining driver gap acceptance behavior in cases which involved gap/lag rejection actions. Among all the significant variables in the model given in Table G1-5, the size of gap (GSEC) has the highest effect on gap acceptance behavior followed by vehicle occupancy (OCUP) and the size of the succeeding gap (SSEC).

### G1.3: Modeling Cases Which Involved Driver Gap/Lag Rejection Actions in Maneuver 3

The difference between the accepted and the maximum rejected gaps (DAMR) and the size of the preceding gap/lag (PSEC, PMET) which was available to the driver are variables which are relevant to the cases in which the concerned driver has rejected a gap/lag or more. To study these variables and to check their significance in explaining driver behavior in these cases, the same modeling procedure discussed in Chapter 6 was followed to develop gap acceptance models using the relevant data observations. The final model is summarized in Table G1-5. The detailed model is presented in Table G1-6. As can be noted from the Table G1-5, the same basic traffic and delay attributes (GSEC, MJSD, TLDL) and accident and driving experience (ACDT, DEXP) which were found to be significant in the FULL model calibrated for Maneuver 3 are also significant in this model. The new variables which are significant in this model are the vehicle occupancy (OCUP) and the variable representing the difference between the accepted and the maximum rejected gaps (DAMR). These two variables are, however, significant at 5.1% and 5.9% levels, respectively.

The signs taken by the variable coefficients agree with the expected driver gap acceptance behavior. The negative sign taken by DAMR means that the probability of accepting a gap decrease as the difference between accepted and maximum rejected gaps increases. The variable (DAMR) was originally defined as a measure for driver consistency in gap accept/reject behavior. The driver inconsistency increases as DAMR increases. Taking this into account along with the negative sign of (DAMR) it can be stated that, " inconsistent drivers have higher tendency to reject gaps/lags". Regarding vehicle occupancy, it is expected that drivers of highly occupied vehicles avoid accepting gaps/lags which involve any potential accident risks. This could explain the negative sign taken by OCUP.

Investigating variable's marginal effects given in table F1-5, it can be seen that the absolute marginal effects of OCUP and DAMR are higher than the marginal effects other important factors like total delay (TLDL) and the speed of the oncoming vehicle at major road (MJSD). This again confirms the previously stated note about the importance of OCUP and DAMR in explaining driver gap acceptance behavior for cases which include gap/lag rejection decisions. The marginal effect of gap size GSEC is, however, still the highest among all variables.

Table G1.5: Summarized Model for Cases Which Involved Driver Gaps / Lags Rejection Decisions in Maneuver 3.

| Variable/Item | Variable Coefficient | | Variable Marginal Effect | |
|---|---|---|---|---|
| | Value | Sig. Level | Value | Sig. Level |
| Constant (Accept-Choice Specific Constant) | -12.329 | 0.0000 | -0.2714 | 0.0427 |
| GSEC (Gap Size in Seconds) | 4.270 | 0.0000 | 0.0940 | 0.0573 |
| MJSD (Speed at Major Road in Km/hr) | -0.318 | 0.0000 | -0.0070 | 0.0818 |
| TLDL (Total Delay Imposed on Driver) | 0.066 | 0.0177 | 0.0015 | 0.1644 |
| MNVL (Traffic Volume at Minor Road) | 1.191 | 0.0029 | 0.0262 | 0.0983 |
| ACDT (Accident Experience in last 2 yr.) | 0.663 | 0.0469 | 0.0146 | 0.1644 |
| DEXP (Driving Experience in Yr.) | 0.124 | 0.0183 | 0.0027 | 0.1403 |
| OCUP (Vehicle Occupancy, in Persons) | -0.240 | 0.0505 | -0.0053 | 0.1665 |
| DAMR (Difference Between Accepted and max. Rejected Gap) | -0.390 | 0.0592 | -0.0086 | 0.1456 |
| n (Number of observations) | 460 | | | |
| L (â) (Loglikelihood value at maximum) | -34.37 | | | |
| L (C) (restricted Loglikelihood value) | -260.85 | | | |
| $\chi^2$ (Loglikelihood Ratio) | 452.96 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 8 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.868 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.838 | | | |
| PCP (% correctly predicted observations) | 97.17% | | | |

Table G1.6: Details of the Model Calibrated for Cases Which Involved Driver Gap/Lag Rejection Decisions in Maneuver 3.

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 460 |
| Iterations completed | 10 |
| Log likelihood function | -34.37062 |
| Restricted log likelihood | -260.8483 |
| Chi-squared | 452.9553 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -12.329 | 2.9343 | -4.202 | 0.00003 | |
| GSEC | 4.2698 | 0.76407 | 5.588 | 0.00000 | 4.115 |
| MJSD | -0.31783 | 0.53569E-01 | -5.933 | 0.00000 | 40.68 |
| TLDL | 0.66384E-01 | 0.27977E-01 | 2.373 | 0.01765 | 18.82 |
| MNVL | 1.1912 | 0.40041 | 2.975 | 0.00293 | 1.593 |
| ACDT | 0.66309 | 0.33369 | 1.987 | 0.04691 | 0.3261 |
| DEXP | 0.12414 | 0.52612E-01 | 2.360 | 0.01830 | 11.44 |
| OCUP | -0.24028 | 0.12287 | -1.956 | 0.05051 | 2.622 |
| DAMR | -0.39000 | 0.20668 | -1.887 | 0.05916 | 0.6087 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.27135 | 0.13390 | -2.027 | 0.04271 | |
| GSEC | 0.93976E-01 | 0.49440E-01 | 1.901 | 0.05733 | 4.115 |
| MJSD | -0.69953E-02 | 0.40198E-02 | -1.740 | 0.08182 | 40.68 |
| TLDL | 0.14611E-02 | 0.10507E-02 | 1.390 | 0.16438 | 18.82 |
| MNVL | 0.26217E-01 | 0.15858E-01 | 1.653 | 0.09829 | 1.593 |
| ACDT | 0.14594E-01 | 0.10497E-01 | 1.390 | 0.16442 | 0.3261 |
| DEXP | 0.27322E-02 | 0.18529E-02 | 1.475 | 0.14033 | 11.44 |
| OCUP | -0.52885E-02 | 0.38221E-02 | -1.384 | 0.16646 | 2.622 |
| DAMR | -0.85836E-02 | 0.58989E-02 | -1.455 | 0.14564 | 0.6087 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 337 | 6 | 343 |
| 1 | 7 | 110 | 117 |
| TOTAL | 344 | 116 | 460 |

**Table G2.5: Summarized Model for Cases in Which the Effect of an Ahead Driver Exists in Maneuver 3.**

| Variable / Statistic | Coefficients | | Marginal Effect | |
|---|---|---|---|---|
| | Value | Sig. Level | Value | Sig. Level |
| Constant (Accept-Choice Specific Constant) | -9.902 | 0.0167 | -1.2722 | 0.0316 |
| GSEC (Gap Size in Seconds) | 2.140 | 0.0021 | 0.2749 | 0.0657 |
| MJSD (Speed at Major Road in Km/hr) | -0.168 | 0.0186 | -0.0216 | 0.0973 |
| TLDL (Total Delay Imposed on Driver) | 0.078 | 0.0573 | 0.0100 | 0.0657 |
| AREJ (Number of Gaps Rejected by the Ahead Driver) | 0.596 | 0.0383 | 0.0766 | 0.0314 |
| n (Number of observations) | 73 | | | |
| L (β) (Loglikelihood value at maximum) | -9.63 | | | |
| L (C) (restricted Loglikelihood value) | -48.60 | | | |
| $\chi^2$ (Loglikelihood Ratio) | 77.94 | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | |
| $\rho^2$ (Goodness of fit Index) | 0.802 | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.720 | | | |
| PCP (% correctly predicted observations) | 94.52% | | | |

# Appendix G2

## Details of the Models Calibrated For Cases in Which the Effect of an Ahead Driver Exists

## G2.1: Modeling Cases in Which the Effect of an Ahead Driver Exists in Maneuver 1

Data set for maneuver 1 includes 66 observations in which the effect of an ahead driver exists when the concerned driver arrives at the intersection. Variables relevant to this case are the gap size accepted by the ahead driver (ASEC, AMET), number of rejected gaps by the ahead driver (AREJ) and the number of ahead entries in the accepted gap (AENT). It was found that the gap size in Seconds (GSEC) and speed at major road (MJSD) are significant at 0.013 and 0.005%, respectively while Total Delay (TLDL) is significant at 5.2% levels. Among the variables relevant to the studied case AREJ was found to be significant at 1.9% as shown in Table G2-1. The detailed Model is given in Table G2-2. The positive sign taken by the coefficient of AREJ is expected. As the ahead driver rejects more gaps, the delay imposed on the succeeding driver increases and his patience becomes less. Consequently the probability to accept a gap by him increases.

## G2.2: Modeling Cases in Which the Effect of an Ahead Driver Exists in Maneuver 2

Within the data sample collected for Maneuver 2, there are 156 observations in which the effect of an ahead driver exists in terms of having some kind of interaction or friction between the concerned driver and an ahead driver. Variables relevant to this case include size of the gap accepted (ASEC, AMET) and number of gaps rejected by the ahead driver.

A summary of the final model obtained using the 156 observations which represent cases in which the ahead driver influence exists is given in Table G2-3, while the detailed model is given in Table G2-4. The model has a total of five independent variables. The first three variables in the model (GSEC, TLDL, MNVL) belong to traffic and delay attributes and are significant at 2.5% or better levels. The fourth variable (ACTN) belongs to driver

**Table G2.1: Summarized Model for Cases in Which The Effect of an Ahead Driver Exists in Maneuver 1**

| Variable/ Statistic | Coefficient | Significant Level | Marginal Effect |
|---|---|---|---|
| Constant (Accept-Choice Specific Constant) | -1.577 | 0.6014 | -0.0115 |
| GSEC (Gap Size in Seconds) | 1.721 | 0.0128 | 0.0125 |
| MJSD (Speed at Major Road in Km/hr) | -0.277 | 0.0054 | -0.0020 |
| TLDL (Total Delay Imposed on Driver) | 0.233 | 0.0519 | 0.0017 |
| AREJ (Number of Rejected Gaps by Ahead Driver) | 1.578 | 0.0189 | 0.0115 |
| n (Number of observations) | 66 | | |
| L ($\beta$) (Loglikelihood value at maximum) | -10.15 | | |
| L (C) (restricted Loglikelihood value) | -44.65 | | |
| $\chi^2$ (Loglikelihood Ratio) | 68.99 | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | |
| Sig. Level for $\chi^2$ Test | 0.000 | | |
| $\rho^2$ (Goodness of fit Index) | 0.773 | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.683 | | |
| PCP (% correctly predicted observations) | 92.42 | | |

Table G2.2: Details of the Model Calibrated for Cases in Which the Effect of an Ahead Driver Exists in Maneuver I.

```
Multinomial logit model
There are 2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.77246 | 0.18256 | 4.231 | 0.00002 | |
| GSEC | 0.49266E-01 | 0.84086E-02 | 5.859 | 0.00000 | 7.491 |
| MJSD | -0.19900E-01 | 0.35552E-02 | -5.597 | 0.00000 | 37.62 |
| TLDL | 0.99312E-02 | 0.64522E-02 | 1.539 | 0.12376 | 7.347 |
| AREJ | 0.85097E-01 | 0.26807E-01 | 3.174 | 0.00150 | 1.470 |

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                  RESP
Number of observations                66
Iterations completed                   9
Log likelihood function        -10.15477
Restricted log likelihood      -44.65071
Chi-squared                     68.99189
Degrees of freedom                     4
Significance level             0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -1.5772 | 3.0188 | -0.522 | 0.60135 | |
| GSEC | 1.7207 | 0.69099 | 2.490 | 0.01277 | 7.491 |
| MJSD | -0.27744 | 0.99772E-01 | -2.781 | 0.00542 | 37.62 |
| TLDL | 0.23306 | 0.11989 | 1.944 | 0.05190 | 7.347 |
| AREJ | 1.5782 | 0.67243 | 2.347 | 0.01892 | 1.470 |

```
Partial derivatives of probabilities with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.11489E-01 | 0.22184E-01 | -0.518 | 0.60454 | |
| GSEC | 0.12534E-01 | 0.22009E-01 | 0.569 | 0.56902 | 7.491 |
| MJSD | -0.20209E-02 | 0.39201E-02 | -0.516 | 0.60619 | 37.62 |
| TLDL | 0.16976E-02 | 0.32076E-02 | 0.529 | 0.59664 | 7.347 |
| AREJ | 0.11496E-01 | 0.21721E-01 | 0.529 | 0.59663 | 1.470 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 25 | 2 | 27 |
| 1 | 3 | 36 | 39 |
| TOTAL | 28 | 38 | 66 |

**Table G2.3: Summarizsd Model for Cases in Which the Influence of an Ahead Driver Exists in Maneuver 2.**

| Variable / Statistic | Coefficient | Sig. Level | Marginal Effect | | | |
|---|---|---|---|---|---|---|
| | | | ACTN = Speed | ACTN = Distance | t-statistic | All observation |
| Constant (Accept-Choice Specific Constant) | - 22.674 | 0.0000 | - 5.3610 (1.3413)* | - 0.1587 (0.1701) | - 3.88 | - 0.9741 |
| GSEC (Gap Size in Seconds) | 2.844 | 0.0000 | 0.6725 (0.1561) | 0.0199 (0.0219) | 4.140 | 0.1222 |
| TLDL (Total Delay Imposed on Driver) | 0.247 | 0.0001 | 0.0584 (0.0163) | 0.0017 (0.0019) | 3.46 | 0.0106 |
| MNVL (Traffic Volume at Minor Road) | 1.145 | 0.0448 | 0.2707 (0.130) | 0.0080 (0.0084) | 2.02 | 0.0492 |
| ACTN (Gap Acceptance Criteria) | 1.603 | 0.0981 | 0.3789 (0.2563) | 0.0112 (0.0104) | 1.43 | 0.0689 |
| n (Number of observations) | 156 | | | | | |
| L ($\beta$) (Loglikelihood value at maximum) | - 21.44 | | | | | |
| L (C) (restricted Loglikelihood value) | - 99.97 | | | | | |
| $\chi^2$ (Loglikelihood Ratio) | 157.08 | | | | | |
| D.F * (Degrees of Freedom for $\chi^2$ Test) | 4 | | | | | |
| Sig. Level for $\chi^2$ Test | 0.0000 | | | | | |
| $\rho^2$ (Goodness of fit Index) | 0.786 | | | | | |
| $\rho^2$ - Adjusted (Adjusted goodness of fit Index) | 0.746 | | | | | |
| PCP (% correctly predicted observations) | 94.87% | | | | | |

* Between brackets is the standard error

Table G2.4: Details of the Model Calibrated for Cases in Which the Effect of an Ahead Driver Exists in Maneuver 2.

```
Multinomial logit model
There are  2 outcomes for LH variable RESP
These are the OLS start values based on the
binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.80679 | 0.10344 | -7.800 | 0.00000 | |
| GSEC | 0.17685 | 0.13429E-01 | 13.169 | 0.00000 | 5.358 |
| TLDL | 0.18281E-01 | 0.20729E-02 | 8.819 | 0.00000 | 21.30 |
| MNVL | 0.26179E-01 | 0.20692E-01 | 1.265 | 0.20581 | 3.756 |
| ACTN | 0.54949E-01 | 0.49390E-01 | 1.113 | 0.26591 | 0.5769 |

MODEL FOR AHEAD DRIVER CASES, ALL RELEVANT ATT., M2, ALL

```
Multinomial Logit Model
Maximum Likelihood Estimates
Dependent variable                  RESP
Number of observations               156
Iterations completed                   8
Log likelihood function        -21.43670
Restricted log likelihood      -99.97498
Chi-squared                     157.0766
Degrees of freedom                     4
Significance level             0.0000000
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -22.674 | 5.0828 | -4.461 | 0.00001 | |
| GSEC | 2.8442 | 0.59891 | 4.749 | 0.00000 | 5.358 |
| TLDL | 0.24710 | 0.61019E-01 | 4.050 | 0.00005 | 21.30 |
| MNVL | 1.1450 | 0.57048 | 2.007 | 0.04475 | 3.756 |
| ACTN | 1.6027 | 0.96879 | 1.654 | 0.09807 | 0.5769 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 49 | 4 | 53 |
| 1 | 4 | 99 | 103 |
| TOTAL | 53 | 103 | 156 |

Table G2.4 "Continued": The marginal Effects of the ACTN Strata in the Detailed Model Calibrated for Cases in Which the Effect of an Ahead Driver Exists.

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are SPEED

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -5.3610 | 1.3413 | -3.997 | 0.00006 | |
| GSEC | 0.67248 | 0.15608 | 4.309 | 0.00002 | 4.765 |
| TLDL | 0.58424E-01 | 0.16317E-01 | 3.581 | 0.00034 | 21.77 |
| MNVL | 0.27071 | 0.12996 | 2.083 | 0.03724 | 3.682 |
| ACTN | 0.37893 | 0.25632 | 1.478 | 0.13931 | 0.0000 |

MODEL FOR AHEAD DRIVER CASES, ALL RELEVANT ATT., M2, ALL

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are DISTANCE

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.15866 | 0.17013 | -0.933 | 0.35105 | |
| GSEC | 0.19903E-01 | 0.21892E-01 | 0.909 | 0.36329 | 5.793 |
| TLDL | 0.17291E-02 | 0.18852E-02 | 0.917 | 0.35905 | 20.96 |
| MNVL | 0.80119E-02 | 0.84365E-02 | 0.950 | 0.34228 | 3.811 |
| ACTN | 0.11215E-01 | 0.10394E-01 | 1.079 | 0.28059 | 1.000 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.97409 | 0.54872 | -1.775 | 0.07586 | |
| GSEC | 0.12219 | 0.71446E-01 | 1.710 | 0.08722 | 5.358 |
| TLDL | 0.10616E-01 | 0.62871E-02 | 1.688 | 0.09132 | 21.30 |
| MNVL | 0.49189E-01 | 0.28605E-01 | 1.720 | 0.08551 | 3.756 |
| ACTN | 0.68852E-01 | 0.45755E-01 | 1.505 | 0.13238 | 0.5769 |

Marginal Effects for MltLogit

| Variable | SPEED | DISTANCE | All Obs. |
|---|---|---|---|
| ONE | -5.3610 | -0.1587 | -0.9741 |
| GSEC | 0.6725 | 0.0199 | 0.1222 |
| TLDL | 0.0584 | 0.0017 | 0.0106 |
| MNVL | 0.2707 | 0.0080 | 0.0492 |
| ACTN | 0.3789 | 0.0112 | 0.0689 |

attributes. This variable describes the criteria on which drivers base their gap acceptance decision (distance or speed of the oncoming vehicle). The variable is significant at 9.8% level.

The positive signs taken by coefficients of gap size (GSEC), traffic volume at minor road (MNVL), and total delay (TLDL) attributes in the model are expected and readily explainable. The positive sign for the variable describing "gap acceptance criterion", (ACTN) indicates that the probability of accepting a gap increases when drivers base their acceptance decision on their estimate of the distance of the oncoming vehicle (distance gap) rather than their estimate of the speed of that vehicle since the variable is coded as a binary dummy variable which takes the value 0 when the driver bases his gap accepting decision on his estimate of the speed of the oncoming vehicle and the value 1 when he bases his decision on his estimate of the distance of the oncoming vehicle.

It should be mentioned in this context that drivers ability to estimate the distance of the oncoming vehicles exceeds their ability to estimate the speed of these vehicles. Each of the interviewed drivers was asked to estimate the speed and distance of the vehicle he interred in front of it. Driver estimates were later compared to the actual values of speed and distance as extracted from video records.

As can be seen from Table G2-3, the overall model is significant at 0.0000000% and it has high values of $\rho^2$ and the "percentage of correctly predicted cases" which indicates the good capability of the model in explaining driver gap acceptance behavior in the cases in which the influence of an ahead driver exists.

To further study the effect of the different independent variables included in the model on driver gap acceptance behavior, the marginal effects of these variables are thoroughly investigated. The main comments derived from this investigation:

a. The "accept specific constant" has the highest absolute marginal effect on driver gap acceptance behavior particularly when the driver base his decision to accepted a gap/lag on the speed of the oncoming vehicle. The high negative value of the marginal effect in this case indicates that drivers have much higher tendency to reject gaps/lags when they base their decision to accept/reject a gap on the speed of the oncoming vehicle. Results of the preliminary analyses showed that, in general, the speed of the oncoming vehicle as estimated by the driver exceeds the actual speed of these vehicles. This result can form one base for explaining the higher tendency to reject gaps/lags when drivers base their decision to accept/reject a gap on the speed rather than the distance of the oncoming vehicle;

b. Among the four independent variables included in the model. The gap size in seconds (GSEC), the gap acceptance criteria's (ACTN) and the traffic volume at minor road (MNVL) have the three highest marginal effects of around 0.12, 0.07 and 0.05 , respectively;

c. The marginal effects computed separately for the two strata of gap acceptance criterion (ACTN = speed, ACTN = distance) are given in Table 6.15. The t-test is used to check whether the marginal effect of certain variable in "ACTN = speed" strata is significantly different from its counterpart in "ACTN = distance" strata. The t-statistics computed for this test are also given in Table 6.15. These statistics indicate that the marginal effects for the model constant, GSEC, TLDL, and MNVL

in the first strata are significantly different from their counterparts in the second strata at 5% or better levels;

d. For "ACTN = speed" strata the marginal effects of the constant term, GSEC, TLDL, and MNVL are significantly different from zero at 0.00006%, 0.00002%, 0.00034%, and 0.0372%, respectively. For "ACTN = distance" stratum marginal effects of all of the variables are significant only at around 28% - 36%. In the overall model, the marginal effects of the constant term, GSEC, TLDL, MNVL, and ACTN are significant at around 7.5 to 9% while ACTN marginal effect is significant at around 13.24%.

### G2.3: Modeling Cases in Which the Effect of an Ahead Driver Exists in Maneuver 3

The variables relevant to cases in which the effect of an ahead driver exists include the size of gap acceptance (ASEC, AMET) and the number of gaps (AREJ) rejected by the ahead driver and the number of ahead entries (AENT) in the same gap accepted by the concerned driver. This case is represented by a total of 73 observations in the data set. The final model calibrated using these observations is given in Table G2-5. The detailed model is given in Table G2-6. In this model only the three basic traffic and delay attributes (GSEC, MJSD, TLDL) and a variable relevant to the studied case (AREJ) are significant at 5% or very close levels.

The coefficient taken by the variable describing the number of rejected gaps by the ahead driver (AREJ) is positive. This sign is expected since AREJ is another measure of the delay in queue imposed on the concerned driver. Hence as (AREJ) increases the "delay in queue" will increase and the driver will become less patient and will accept shorter gaps/lags. The absolute marginal effect of (AREJ) is higher than the marginal effect of both of the (MJSD) and (TLDL). This result along with the previously noted results about the significance of delay attributes in all of the calibrated models lead to the general conclusion that delay in its various forms is a basic significant factor in explaining driver gap acceptance behavior.

Table G2.6: Details of the Model Calibrated for Cases in Which the Effect of an Ahead Driver Exists in Maneuver 3.

Multinomial logit model
There are 2 outcomes for LH variable RESP
These are the OLS start values based on the binary variables for each outcome Y(i) = j.
Coefficients for LHS=0 outcome are set to 0.0

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.12218 | 0.13775 | -0.887 | 0.37509 | |
| GSEC | 0.12427 | 0.13527E-01 | 9.186 | 0.00000 | 5.300 |
| MJSD | -0.10383E-01 | 0.30468E-02 | -3.408 | 0.00065 | 43.37 |
| TLDL | 0.91584E-02 | 0.18128E-02 | 5.052 | 0.00000 | 24.66 |
| AREJ | 0.19287E-01 | 0.11220E-01 | 1.719 | 0.08560 | 3.712 |

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 73 |
| Iterations completed | 8 |
| Log likelihood function | -9.632115 |
| Restricted log likelihood | -48.60200 |
| Chi-squared | 77.93977 |
| Degrees of freedom | 4 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -9.9022 | 4.1390 | -2.392 | 0.01674 | |
| GSEC | 2.1400 | 0.69685 | 3.071 | 0.00213 | 5.300 |
| MJSD | -0.16811 | 0.71452E-01 | -2.353 | 0.01864 | 43.37 |
| TLDL | 0.77651E-01 | 0.40840E-01 | 1.901 | 0.05725 | 24.66 |
| AREJ | 0.59593 | 0.28761 | 2.072 | 0.03827 | 3.712 |

Partial derivatives of probabilities with respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -1.2722 | 0.59191 | -2.149 | 0.03161 | |
| GSEC | 0.27493 | 0.14939 | 1.840 | 0.06571 | 5.300 |
| MJSD | -0.21597E-01 | 0.13026E-01 | -1.658 | 0.09731 | 43.37 |
| TLDL | 0.99761E-02 | 0.54204E-02 | 1.840 | 0.06570 | 24.66 |
| AREJ | 0.76562E-01 | 0.35571E-01 | 2.152 | 0.03137 | 3.712 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 43 | 2 | 45 |
| 1 | 2 | 26 | 28 |
| TOTAL | 45 | 28 | 73 |

# Appendix H

## The FULL Models Calibrated For Sites 1 and 2 Separately

Table H .1: **Summary of the FULL models calibrated for Sites 1 and 2 separately along with the t-tests performed on their coefficients, Maneuver 1**

| Variable | Site 1 Model | | | Site 2 Model | | | t-Statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant | -7,2447 | 2,9171 | 0,0130 | -10,7280 | 4,0876 | 0,0087 | 0,6936 |
| GSEC (Gap size in sec.) | 1,9515 | 0,4130 | 0,0000 | 2,5271 | 0,6429 | 0,0001 | -0,7533 |
| MJSD (Speed at major road in kmph) | -0,1720 | 0,0496 | 0,0005 | -0,2926 | 0,0777 | 0,0002 | 1,3088 |
| TLDL (Total delay in sec.) | 0,2439 | 0,0800 | 0,0023 | 0,2339 | 0,0778 | 0,0027 | 0,0901 |
| MNVL (Traffic volume at minor road in veh/30 sec) | 1,1347 | 0,4484 | 0,0114 | 2,5532 | 0,9075 | 0,0049 | -1,4014 |
| ACDT (Accident experience in the last two years) | 0,0768 | 0,4975 | 0,8774 | 1,3649 | 0,5834 | 0,0193 | -1,6802 |
| VLTN (Traffic violations in the last year) | 0,6518 | 0,3812 | 0,0873 | 1,3453 | 0,7245 | 0,0633 | -0,8471 |
| DEXP (Driving experience in years) | 0,0493 | 0,0600 | 0,4112 | 0,1351 | 0,0892 | 0,1296 | -0,7992 |
| TRDN (Trip duration in minutes) | -0,1349 | 0,0502 | 0,0072 | -0,0456 | 0,0333 | 0,1705 | -1,4828 |
| n (Sample size) | 176 | | | 161 | | | |
| L(B) (Log likelihood at maximum) | -23,13 | | | -18,53 | | | |
| L(C) (Restricted log likelihood) | -117,41 | | | -109,65 | | | |
| Chi-squared | 188,56 | | | 182,24 | | | |
| D. F (Degrees of freedom) | 8 | | | 8 | | | |
| Significance Level | 0,0000 | | | 0,0000 | | | |
| Rho-squared | 0,803 | | | 0,831 | | | |
| Adjusted Rho-squared | 0,735 | | | 0,758 | | | |
| % correctly predicted observation. | 93,75% | | | 95,65% | | | |

Table H 2: FULL MODEL FOR MANEUVER 1 USING DATA COLLECTED AT SITE 1

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 176 |
| Iterations completed | 9 |
| Log likelihood function | -23.12908 |
| Restricted log likelihood | -117.4085 |
| Chi-squared | 188.5588 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -7.2447 | 2.9171 | -2.483 | 0.01301 | |
| GSEC | 1.9515 | 0.41295 | 4.726 | 0.00000 | 8.220 |
| MJSD | -0.17199 | 0.49607E-01 | -3.467 | 0.00053 | 37.92 |
| TLDL | 0.24391 | 0.80040E-01 | 3.047 | 0.00231 | 5.487 |
| MNVL | 1.1347 | 0.44838 | 2.531 | 0.01139 | 2.341 |
| ACDT | 0.76751E-01 | 0.49746 | 0.154 | 0.87739 | 0.3125 |
| VLTN | 0.65183 | 0.38124 | 1.710 | 0.08731 | 0.6818 |
| DEXP | 0.49270E-01 | 0.59950E-01 | 0.822 | 0.41116 | 9.932 |
| TRDN | -0.13493 | 0.50176E-01 | -2.689 | 0.00716 | 17.94 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.58282E-01 | 0.54069E-01 | -1.078 | 0.28106 | |
| GSEC | 0.15699E-01 | 0.13994E-01 | 1.122 | 0.26191 | 8.220 |
| MJSD | -0.13836E-02 | 0.13938E-02 | -0.993 | 0.32086 | 37.92 |
| TLDL | 0.19622E-02 | 0.17792E-02 | 1.103 | 0.27008 | 5.487 |
| MNVL | 0.91283E-02 | 0.94372E-02 | 0.967 | 0.33341 | 2.341 |
| ACDT | 0.61745E-03 | 0.40785E-02 | 0.151 | 0.87967 | 0.3125 |
| VLTN | 0.52439E-02 | 0.55316E-02 | 0.948 | 0.34314 | 0.6818 |
| DEXP | 0.39637E-03 | 0.60049E-03 | 0.660 | 0.50920 | 9.932 |
| TRDN | -0.10855E-02 | 0.10175E-02 | -1.067 | 0.28602 | 17.94 |

Frequencies of actual & predicted outcomes Pred. outcome has max. prob.

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 63 | 5 | 68 |
| 1 | 6 | 102 | 108 |
| TOTAL | 69 | 107 | 176 |

Table H.3: FULL MODEL FOR MANEUVER 1 USING DATA COLLECTED AT SITE 2

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 161 |
| Iterations completed | 9 |
| Log likelihood function | -18.53042 |
| Restricted log likelihood | -109.6478 |
| Chi-squared | 182.2348 |
| Degrees of freedom | 8 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -10.728 | 4.0876 | -2.625 | 0.00868 | |
| GSEC | 2.5271 | 0.64290 | 3.931 | 0.00008 | 7.090 |
| MJSD | -0.29264 | 0.77700E-01 | -3.766 | 0.00017 | 38.34 |
| TLDL | 0.23385 | 0.77813E-01 | 3.005 | 0.00265 | 6.144 |
| MNVL | 2.5532 | 0.90749 | 2.814 | 0.00490 | 1.981 |
| ACDT | 1.3649 | 0.58335 | 2.340 | 0.01929 | 0.4099 |
| VLTN | 1.3453 | 0.72446 | 1.857 | 0.06332 | 0.5217 |
| DEXP | 0.13514 | 0.89163E-01 | 1.516 | 0.12962 | 9.484 |
| TRDN | -0.45640E-01 | 0.33295E-01 | -1.371 | 0.17045 | 18.00 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.15822 | 0.15540 | -1.018 | 0.30860 | |
| GSEC | 0.37270E-01 | 0.35539E-01 | 1.049 | 0.29431 | 7.090 |
| MJSD | -0.43159E-02 | 0.44342E-02 | -0.973 | 0.33040 | 38.34 |
| TLDL | 0.34489E-02 | 0.35234E-02 | 0.979 | 0.32765 | 6.144 |
| MNVL | 0.37655E-01 | 0.39402E-01 | 0.956 | 0.33924 | 1.981 |
| ACDT | 0.20130E-01 | 0.21007E-01 | 0.958 | 0.33793 | 0.4099 |
| VLTN | 0.19841E-01 | 0.21700E-01 | 0.914 | 0.36056 | 0.5217 |
| DEXP | 0.19930E-02 | 0.23060E-02 | 0.864 | 0.38745 | 9.484 |
| TRDN | -0.67309E-03 | 0.84127E-03 | -0.800 | 0.42365 | 18.00 |

Frequencies of actual & predicted outcomes Pred. outcome has max. prob.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 66 | 2 | 68 |
| 1 | 5 | 88 | 93 |
| TOTAL | 71 | 90 | 161 |

Table H .4: **Summary of the FULL models calibrated for Sites 1 and 2 separately along with the t-tests performed on their coefficients, maneuver 2**

| Variable | Site 1 Model | | | Site 2 Model | | | t-statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant | -29,7790 | 7,5235 | 0,0001 | -22,2970 | 5,1620 | 0,0000 | -0,8200 |
| GSEC (Gap size in sec.) | 3,8014 | 0,8514 | 0,0000 | 2,9633 | 0,5662 | 0,0000 | 0,8197 |
| TLDL (Total delay in sec.) | 0,3221 | 0,0857 | 0,0002 | 0,2253 | 0,0529 | 0,0000 | 0,9612 |
| MNVL (Traffic volume at minor road in veh/30 sec) | 1,8920 | 0,7448 | 0,0111 | 0,7599 | 0,5208 | 0,1446 | 1,2457 |
| DSEX (Driver sex) | 3,5115 | 1,3189 | 0,0078 | 3,3516 | 1,2313 | 0,0065 | 0,0886 |
| DAGE (Driver age) | 0,0339 | 0,0349 | 0,3306 | 0,0360 | 0,0525 | 0,4922 | -0,0334 |
| TRDN (Trip duration in minutes) | -0,0280 | 0,0283 | 0,3224 | -0,0200 | 0,0246 | 0,4157 | -0,2144 |
| n (Number of observations) | 216 | | | 180 | | | |
| L(B) (Log likelihood at maximum) | -19,56 | | | -25,31 | | | |
| L(C) (Restricted Log likelihood) | -133,76 | | | -115,25 | | | |
| Chi-squared | 228,4 | | | 179,88 | | | |
| D. F (Degrees of freedom) | 6 | | | 6 | | | |
| Significance level | 0,0000 | | | 0,0000 | | | |
| Rho-squared | 0,85 | | | 0,78 | | | |
| Adjusted Rho-squared | 0,81 | | | 0,73 | | | |
| % correctly predicted | 98,15% | | | 93,33% | | | |

Table H .5: FULL MODEL FOR MANEUVER 2 USING DATA COLLECTED AT SITE 1

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 216 |
| Iterations completed | 10 |
| Log likelihood function | -19.55748 |
| Restricted log likelihood | -133.7577 |
| Chi-squared | 228.4005 |
| Degrees of freedom | 6 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -29.779 | 7.5235 | -3.958 | 0.00008 | |
| GSEC | 3.8014 | 0.85136 | 4.465 | 0.00001 | 7.263 |
| TLDL | 0.32207 | 0.85699E-01 | 3.758 | 0.00017 | 9.602 |
| MNVL | 1.8920 | 0.74478 | 2.540 | 0.01108 | 3.458 |
| DSEX | 3.5115 | 1.3189 | 2.662 | 0.00776 | 0.2593 |
| DAGE | 0.33924E-01 | 0.34869E-01 | 0.973 | 0.33061 | 38.01 |
| TRDN | -0.28044E-01 | 0.28342E-01 | -0.990 | 0.32241 | 20.51 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.33600E-02 | 0.63343E-02 | -0.530 | 0.59581 | |
| GSEC | 0.42892E-03 | 0.81082E-03 | 0.529 | 0.59681 | 7.263 |
| TLDL | 0.36340E-04 | 0.69005E-04 | 0.527 | 0.59845 | 9.602 |
| MNVL | 0.21347E-03 | 0.40381E-03 | 0.529 | 0.59705 | 3.458 |
| DSEX | 0.39620E-03 | 0.74617E-03 | 0.531 | 0.59543 | 0.2593 |
| DAGE | 0.38277E-05 | 0.76748E-05 | 0.499 | 0.61797 | 38.01 |
| TRDN | -0.31643E-05 | 0.68120E-05 | -0.465 | 0.64228 | 20.51 |

Frequencies of actual & predicted outcomes Pred. outcome has max. prob.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 65 | 2 | 67 |
| 1 | 2 | 147 | 149 |
| TOTAL | 67 | 149 | 216 |

Table H .6: FULL MODEL FOR MANEUVER 2 USING DATA COLLECTED AT SITE 2

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 180 |
| Iterations completed | 9 |
| Log likelihood function | -25.31375 |
| Restricted log likelihood | -115.2532 |
| Chi-squared | 179.8790 |
| Degrees of freedom | 6 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -22.297 | 5.1620 | -4.319 | 0.00002 | |
| GSEC | 2.9633 | 0.56618 | 5.234 | 0.00000 | 7.139 |
| TLDL | 0.22528 | 0.52876E-01 | 4.261 | 0.00002 | 11.11 |
| MNVL | 0.75987 | 0.52082 | 1.459 | 0.14457 | 3.478 |
| DSEX | 3.3516 | 1.2313 | 2.722 | 0.00649 | 0.2222 |
| DAGE | 0.36028E-01 | 0.52454E-01 | 0.687 | 0.49218 | 37.06 |
| TRDN | -0.19996E-01 | 0.24616E-01 | -0.812 | 0.41659 | 17.00 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.70913E-01 | 0.66050E-01 | -1.074 | 0.28300 | |
| GSEC | 0.94244E-02 | 0.87919E-02 | 1.072 | 0.28374 | 7.139 |
| TLDL | 0.71649E-03 | 0.68322E-03 | 1.049 | 0.29432 | 11.11 |
| MNVL | 0.24167E-02 | 0.26284E-02 | 0.919 | 0.35786 | 3.478 |
| DSEX | 0.10659E-01 | 0.10297E-01 | 1.035 | 0.30060 | 0.2222 |
| DAGE | 0.11458E-03 | 0.18398E-03 | 0.623 | 0.53342 | 37.06 |
| TRDN | -0.63596E-04 | 0.87712E-04 | -0.725 | 0.46842 | 17.00 |

Frequencies of actual & predicted outcomes Pred. outcome has max. prob.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 55 | 6 | 61 |
| 1 | 6 | 113 | 119 |
| TOTAL | 61 | 119 | 180 |

Table H .7: **Summary of the FULL models calibrated for Sites 1 and 2 separately along with the t-tests performed on their coefficients, maneuver 3**

| Variable | Site 1 Model | | | Site 2 Model | | | t-Statistic |
|---|---|---|---|---|---|---|---|
| | Coefficient | St. Error | Sig. Level | Coefficient | St. Error | Sig. Level | |
| Constant | -11.2450 | 3.9005 | 0.0039 | -8.4811 | 1.8450 | 0.0000 | -0.6406 |
| GSEC (Gap size in sec.) | 3.3958 | 0.8624 | 0.0001 | 2.8314 | 0.4429 | 0.0000 | 0.5822 |
| MJSD (Speed at major road in kmph) | -0.3262 | 0.0946 | 0.0006 | -0.2296 | 0.0400 | 0.0000 | -0.9400 |
| TLDL (Total delay in sec) | 0.1590 | 0.0595 | 0.0075 | 0.0600 | 0.0188 | 0.0014 | 1.5867 |
| MNVL (Volume at minor road in veh/30 sec) | 2.5353 | 0.8421 | 0.0026 | 1.1412 | 0.3486 | 0.0011 | 1.5297 |
| ACDT (Accident experience in the last two years) | 0.8542 | 0.5049 | 0.0907 | 0.5187 | 0.3286 | 0.1145 | 0.5571 |
| DEXP (Driving experience in years) | 0.1419 | 0.0775 | 0.0669 | 0.0106 | 0.0582 | 0.0686 | 1.3554 |
| TRDN (Trip duration in minutes) | -0.1095 | 0.0432 | 0.0112 | -0.0227 | 0.0251 | 0.3659 | -1.7380 |
| n (Number of observations) | 265 | | | 359 | | | |
| L(B) (Log likelihood at maximum) | -15.56 | | | -42.48 | | | |
| L(C) (Restricted log likelihood) | -159.7 | | | -198.8 | | | |
| Chi-squared | 288.28 | | | 312.64 | | | |
| D. F (Degrees of freedom) | 7 | | | 7 | | | |
| Significance Level | 0.0000 | | | 0.0000 | | | |
| Rho-squared | 0.903 | | | 0.786 | | | |
| Adjusted Rho-squared | 0.859 | | | 0.751 | | | |
| % correctly predicted | 98.11% | | | 95.54% | | | |

Table H .8: FULL MODEL FOR MANEUVER 3 USING DATA COLLECTED AT SITE 1

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 265 |
| Iterations completed | 10 |
| Log likelihood function | -15.56371 |
| Restricted log likelihood | -159.7043 |
| Chi-squared | 288.2812 |
| Degrees of freedom | 7 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -11.245 | 3.9005 | -2.883 | 0.00394 | |
| GSEC | 3.3958 | 0.86237 | 3.938 | 0.00008 | 4.858 |
| MJSD | -0.32618 | 0.94593E-01 | -3.448 | 0.00056 | 43.99 |
| TLDL | 0.15902 | 0.59489E-01 | 2.673 | 0.00751 | 16.26 |
| MNVL | 2.5353 | 0.84208 | 3.011 | 0.00261 | 1.585 |
| ACDT | 0.85424 | 0.50491 | 1.692 | 0.09067 | 0.3283 |
| TRDN | -0.10952 | 0.43158E-01 | -2.538 | 0.01116 | 19.50 |
| DEXP | 0.14193 | 0.77456E-01 | 1.832 | 0.06689 | 11.45 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.64997 | 0.40189 | -1.617 | 0.10582 | |
| GSEC | 0.19628 | 0.10936 | 1.795 | 0.07269 | 4.858 |
| MJSD | -0.18853E-01 | 0.99247E-02 | -1.900 | 0.05748 | 43.99 |
| TLDL | 0.91915E-02 | 0.49271E-02 | 1.866 | 0.06211 | 16.26 |
| MNVL | 0.14654 | 0.90171E-01 | 1.625 | 0.10413 | 1.585 |
| ACDT | 0.49375E-01 | 0.39782E-01 | 1.241 | 0.21455 | 0.3283 |
| TRDN | -0.63303E-02 | 0.37171E-02 | -1.703 | 0.08857 | 19.50 |
| DEXP | 0.82036E-02 | 0.56943E-02 | 1.441 | 0.14968 | 11.45 |

Frequencies of actual & predicted outcomes Pred. outcome has max. prob.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 186 | 2 | 188 |
| 1 | 3 | 74 | 77 |
| TOTAL | 189 | 76 | 265 |

Table H .9: FULL MODEL FOR MANEUVER 3 USING DATA COLLECTED AT SITE2

| | |
|---|---|
| Multinomial Logit Model | |
| Maximum Likelihood Estimates | |
| Dependent variable | RESP |
| Number of observations | 359 |
| Iterations completed | 8 |
| Log likelihood function | -42.47947 |
| Restricted log likelihood | -198.8006 |
| Chi-squared | 312.6422 |
| Degrees of freedom | 7 |
| Significance level | 0.0000000 |

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -8.4811 | 1.8450 | -4.597 | 0.00000 | |
| GSEC | 2.8314 | 0.44289 | 6.393 | 0.00000 | 4.263 |
| MJSD | -0.22964 | 0.40004E-01 | -5.740 | 0.00000 | 41.63 |
| TLDL | 0.60048E-01 | 0.18753E-01 | 3.202 | 0.00137 | 15.90 |
| MNVL | 1.1412 | 0.34855 | 3.274 | 0.00106 | 1.858 |
| ACDT | 0.51866 | 0.32860 | 1.578 | 0.11447 | 0.3203 |
| TRDN | -0.22722E-01 | 0.25131E-01 | -0.904 | 0.36591 | 17.54 |
| DEXP | 0.10602E-01 | 0.58211E-02 | 1.821 | 0.06856 | 8.467 |

Partial derivatives of probabilities with respect to the vector of characteristics. They are computed at the means of the Xs. Observations used for means are All Obs.

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.36962 | 0.11344 | -3.258 | 0.00112 | |
| GSEC | 0.12340 | 0.40773E-01 | 3.026 | 0.00247 | 4.263 |
| MJSD | -0.10008E-01 | 0.36830E-02 | -2.717 | 0.00658 | 41.63 |
| TLDL | 0.26170E-02 | 0.11485E-02 | 2.279 | 0.02269 | 15.90 |
| MNVL | 0.49735E-01 | 0.20448E-01 | 2.432 | 0.01500 | 1.858 |
| ACDT | 0.22604E-01 | 0.14950E-01 | 1.512 | 0.13053 | 0.3203 |
| TRDN | -0.99028E-03 | 0.11404E-02 | -0.868 | 0.38519 | 17.54 |
| DEXP | 0.46207E-03 | 0.27385E-03 | 1.687 | 0.09154 | 8.467 |

Frequencies of actual & predicted outcomes Pred. outcome has max. prob.

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 265 | 7 | 272 |
| 1 | 9 | 78 | 87 |
| TOTAL | 274 | 85 | 359 |

# Appendix I

## Binary Gap Acceptance Models Other Than The Binomial Logit Model

**I1: Basic Formulation of the Binary Probit and the Maximum Score Models**

**I2: Basic Formulation of the Maximum log likelihood Estimation Method**

**I3: Detailed Outputs of the Binary Probit and Maximum Score Models for Maneuver 1**

# Appendix I1

## Basic Formulation of the Binary Probit and the Maximum Score Models

## I1) Basic formulations of the Binary Probit and Maximum Score Models.

### *I1.1) Binary Probit Model*

In Binary probit model the error term (disturbances) is assumed to be normally distributed with zero mean and $\sigma^2$ variance. Under this assumption the choice probability ( the probability that choice is selected by individual n, ($P_n(i)$), can be expressed as ( Ben-Akiva and Lerman, 1985):

$P_n(i) = \text{Prob}\ (\varepsilon_{jn} - \varepsilon_{in} \leq V_{in} - V_{jn})$

which can be written in the form;

$P_n(i) = \phi\ (V_{in} - V_{jn})/\sigma = \phi\ \{(\beta(X_{in} - X_{jn}))/\sigma\}$ ,

where $V_{in}$ and $V_{jn}$ are the systematic parts of the utilities offered by choices i and j to individual n and $\phi$ is the standardized cumulative normal distribution, $X_{in}$ and $X_{jn}$ are the vectors of attributes affecting the choice of i and j alternatives by the $n^{th}$ individual.

The term $1/\sigma$ is the scale of the utility function which can be set to any arbitrary positive value, usually $\sigma = 1$. It should be noted that the difference between the binary Probit model and the Binomial Logit is that the disturbance term ($\varepsilon$) is assumed to be normally distributed in the former.

***II. 2) Maximum Score Model***

Maximum score estimation is one of the nonparametric estimation methods which do not make a specific distribution assumption on the disturbance term (ε) but rather hypothesize that the distribution of the disturbances belong to a class that has same very general properties. Maximum Score estimation was originally proposed by Manski in 1975, ( Ben-Akeva and Lerman, 1985). In this model parameters are selected so that the fraction of the sample who chose the alternative with greatest systematic component of the utility is maximized. More details on the mathematical formulation of this model can be found in Greene (1995, pp 439-440).

# Appendix I2

## Basic Formulation of the Maximum log likelihood Estimation Method

**Basic formulation for Maximum Likelihood Estimation of Binary Choice Models**

Given a sample of N observations drawn randomly from a population, the likelihood of the entire sample is the product of the likelihoods of the individual observations;

$L(\beta_1, \beta_2, \beta_3 ...... \beta_k) = \Pi\ [P_n(i)^{yin}\ P_n(j)^{yjn}$

where L is the likelihood function. T is usually more convenient to analyze the logarithm of L which is denoted by LL and expressed as;

$LL(\beta_1, \beta_2, \beta_3 ...... \beta_k) = \Sigma\ [y_{in} \log P_n(i) + y_{jn} \log P_n(j)],$

in binary choice cases $y_{jn} = 1 - y_i$ and $P_n(j),= 1 - P_n(i)$. Substituting these forms in the expression of LL we get

$LL(\beta_1, \beta_2, \beta_3 ...... \beta_k) = \Sigma\ [y_{in} \log P_n(i) + ( 1 - y_{jn}) \log( 1 - P_n(i)],$

to maximize LL, the partial derivatives with respect to β's are found and equated to zero.

# Appendix I3

## Detailed Outputs of the Binary Probit and Maximum Score Models for Maneuver 1

Table B.1: Details of the BASIC Binary probit Model Calibrated for Maneuver 1.

```
Dependent variable is binary, y=0 or y not equal 0
Ordinary    least squares regression    Weighting variable = ONE
Dependent variable is RESP       Mean =     0.59644, S.D. =       0.4913
Model size: Observations =     337, Parameters =   5, Deg.Fr. =   332
Residuals:  Sum of squares=    35.8717      Std.Dev. =          0.32871
Fit:        R-squared = 0.55777, Adjusted R-squared =          0.55244
Model test: F[  4,     332] =  104.69,     Prob value =         0.00000
Diagnostic: Log-L =    -100.7198, Restricted(β=0) Log-L =    -238.2036
            Amemiya Pr. Crt.=    0.110, Akaike Info. Crt.=        0.627
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.58723 | 0.94814E-01 | 6.193 | 0.00000 | |
| GSEC | 0.59266E-01 | 0.35895E-02 | 16.511 | 0.00000 | 7.680 |
| MJSD | -0.18834E-01 | 0.16832E-02 | -11.189 | 0.00000 | 38.12 |
| TLDL | 0.61482E-02 | 0.26357E-02 | 2.333 | 0.01967 | 5.801 |
| MNVL | 0.10941 | 0.19802E-01 | 5.525 | 0.00000 | 2.160 |

```
Binomial Probit Model
Maximum Likelihood Estimates
Dependent variable                      RESP
Number of observations                   337
Iterations completed                       7
Log likelihood function            -64.19407
Restricted log likelihood          -227.2826
Chi-squared                         326.1771
Degrees of freedom                         4
Significance level                 0.0000000
Results retained for SELECTION model.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -1.3951 | 0.76570 | -1.822 | 0.06846 | |
| GSEC | 0.73834 | 0.90813E-01 | 8.130 | 0.00000 | 7.680 |
| MJSD | -0.10616 | 0.15946E-01 | -6.658 | 0.00000 | 38.12 |
| TLDL | 0.54599E-01 | 0.15492E-01 | 3.524 | 0.00042 | 5.801 |
| MNVL | 0.49557 | 0.15510 | 3.195 | 0.00140 | 2.160 |

```
Partial derivatives of E[y] = Φ[*]   with
respect to the vector of characteristics.
They are computed at the means of the Xs.
Observations used for means are All Obs.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | -0.15088 | 0.86651E-01 | -1.741 | 0.08164 | |
| GSEC | 0.79853E-01 | 0.23856E-01 | 3.347 | 0.00082 | 7.680 |
| MJSD | -0.11482E-01 | 0.43774E-02 | -2.623 | 0.00872 | 38.12 |
| TLDL | 0.59051E-02 | 0.24319E-02 | 2.428 | 0.01517 | 5.801 |
| MNVL | 0.53597E-01 | 0.26040E-01 | 2.058 | 0.03957 | 2.160 |

Frequencies of actual & predicted outcomes (Pred. outcome has max. prob.)

| | Predicted | | |
|---|---|---|---|
| Actual | 0 | 1 | TOTAL |
| 0 | 119 | 17 | 136 |
| 1 | 18 | 183 | 201 |
| TOTAL | 137 | 200 | 337 |

Table 13.2: Details of the Maximum Score Model Calibrated for Maneuver I.

```
Maximum Score Estimates of Linear Quantile
Regression Model from Binary Response Data
Quantile                      0.500      Number of Parameters =      5
Observations input    =        337       Maximum Iterations    =     50
End Game Iterations   =         0        Bootstrap Estimates   =     20
Check Ties?                    No
Save bootstraps?               No
Start values from MSCORE (normalized)
Score functions:        Naive    At theta(0)       Maximum
            Raw       0.19288      0.19288         0.83383
    Normalized        0.59644      0.59644         0.91691
Estimated MSEs from  20 bootstrap samples
(Nonconvergence in   0 cases)
Angular deviation (radians) of bootstraps from estimate
Mean square =  0.980359              Mean absolute =  0.919158
Standard errors below are based on bootstrap mean squared
deviations.  These and the t-ratios are only approximations.
```

| Variable | Coefficient | Standard Error | z=b/s.e. | P[\|Z\|≥z] | Mean of X |
|---|---|---|---|---|---|
| Constant | 0.28436 | 0.65407 | 0.435 | 0.66374 | |
| GSEC | 0.75640 | 0.36111 | 2.095 | 0.03620 | 7.680 |
| MJSD | -0.16209 | 0.79983E-01 | -2.027 | 0.04271 | 38.12 |
| TLDL | 0.49121E-01 | 0.14522 | 0.338 | 0.73516 | 5.801 |
| MNVL | 0.56419 | 0.58235 | 0.969 | 0.33264 | 2.160 |

Frequencies of actual & predicted outcomes
Predicted outcome is the sign of x(i)*theta.

| Actual | Predicted 0 | 1 | TOTAL |
|---|---|---|---|
| 0 | 124 | 12 | 136 |
| 1 | 16 | 185 | 201 |
| TOTAL | 140 | 197 | 337 |

Table B.2 "Continued": Details of the Maximum Score Model Calibrated for Maneuver 1.

MAX. SCORE MODEL FOR MANEUVER1 (TRAFIIC AND DELAY ATTRIB. ONLY)

Predicted Values    äobservation was not in estimating sample.

| Observation | Observed Y | Predicted Y | Residual | x(i)Ä | Prob[y=1] |
|---|---|---|---|---|---|
| 1 | 1.0000 | 1.0000 | 0.0000 | 0.9450 | 0.8277 |
| 2 | 1.0000 | 1.0000 | 0.0000 | 0.5838 | 0.7203 |
| 3 | 1.0000 | 1.0000 | 0.0000 | 5.6563 | 1.0000 |
| 4 | 1.0000 | 1.0000 | 0.0000 | 6.4869 | 1.0000 |
| 5 | 0.00000 | 0.00000 | 0.0000 | -0.1909 | 0.4243 |
| 6 | 1.0000 | 1.0000 | 0.0000 | 3.1628 | 0.9992 |
| 7 | 1.0000 | 1.0000 | 0.0000 | 0.9820 | 0.8369 |
| 8 | 1.0000 | 1.0000 | 0.0000 | 2.7919 | 0.9974 |
| 9 | 0.00000 | 0.00000 | 0.0000 | -1.9641 | 0.0248 |
| 10 | 0.00000 | 0.00000 | 0.0000 | -1.8850 | 0.0297 |
| 11 | 1.0000 | 1.0000 | 0.0000 | 3.0798 | 0.9990 |
| 12 | 0.00000 | 0.00000 | 0.0000 | -2.3999 | 0.0082 |
| 13 | 1.0000 | 1.0000 | 0.0000 | 4.0907 | 1.0000 |
| 14 | 1.0000 | 1.0000 | 0.0000 | 6.9993 | 1.0000 |
| 15 | 1.0000 | 1.0000 | 0.0000 | 4.2439 | 1.0000 |
| 16 | 0.00000 | 0.00000 | 0.0000 | -0.8997 | 0.1841 |
| 17 | 1.0000 | 1.0000 | 0.0000 | 1.8455 | 0.9675 |
| 18 | 1.0000 | 1.0000 | 0.0000 | 2.9000 | 0.9981 |
| 19 | 1.0000 | 1.0000 | 0.0000 | 4.4506 | 1.0000 |
| 20 | 1.0000 | 1.0000 | 0.0000 | 5.1638 | 1.0000 |
| 21 | 1.0000 | 1.0000 | 0.0000 | 1.7816 | 0.9626 |
| 22 | 1.0000 | 1.0000 | 0.0000 | 4.8760 | 1.0000 |
| 23 | 1.0000 | 1.0000 | 0.0000 | 17.3976 | 1.0000 |
| 24 | 1.0000 | 1.0000 | 0.0000 | 1.6181 | 0.9472 |
| 25 | 1.0000 | 1.0000 | 0.0000 | 6.1164 | 1.0000 |
| 26 | 1.0000 | 1.0000 | 0.0000 | 6.1295 | 1.0000 |
| 27 | 0.00000 | 0.00000 | 0.0000 | -3.6498 | 0.0001 |
| 28 | 0.00000 | 0.00000 | 0.0000 | -2.0937 | 0.0181 |
| 29 | 1.0000 | 0.00000 | 1.0000 | -0.6855 | 0.2465 |
| 30 | 0.00000 | 0.00000 | 0.0000 | -3.6075 | 0.0002 |
| 31 | 0.00000 | 0.00000 | 0.0000 | -2.7710 | 0.0028 |
| 32 | 0.00000 | 0.00000 | 0.0000 | -1.7066 | 0.0439 |
| 33 | 1.0000 | 1.0000 | 0.0000 | 2.6152 | 0.9955 |
| 34 | 1.0000 | 1.0000 | 0.0000 | 9.7401 | 1.0000 |
| 35 | 1.0000 | 1.0000 | 0.0000 | 7.1722 | 1.0000 |
| 36 | 0.00000 | 0.00000 | 0.0000 | -2.0289 | 0.0212 |
| 37 | 1.0000 | 0.00000 | 1.0000 | -2.2745 | 0.0115 |
| 38 | 0.00000 | 0.00000 | 0.0000 | -1.6268 | 0.0519 |
| 39 | 1.0000 | 1.0000 | 0.0000 | 3.1268 | 0.9991 |
| 40 | 1.0000 | 1.0000 | 0.0000 | 1.2472 | 0.8938 |
| 41 | 0.00000 | 0.00000 | 0.0000 | -1.8881 | 0.0295 |
| 42 | 1.0000 | 1.0000 | 0.0000 | 2.6130 | 0.9955 |
| 43 | 0.00000 | 1.0000 | -1.0000 | 1.1318 | 0.8711 |
| 44 | 1.0000 | 1.0000 | 0.0000 | 8.2867 | 1.0000 |
| 45 | 1.0000 | 1.0000 | 0.0000 | 5.8067 | 1.0000 |
| 46 | 1.0000 | 1.0000 | 0.0000 | 0.7172 | 0.7634 |
| 47 | 1.0000 | 1.0000 | 0.0000 | 2.2988 | 0.9892 |
| 48 | 1.0000 | 1.0000 | 0.0000 | 4.5708 | 1.0000 |
| 49 | 0.00000 | 0.00000 | 0.0000 | -1.9424 | 0.0260 |

# Appendix J

# Curriculum Vitae

## Curriculum Vitae

Abdelmalek Abu Sheikh was born on the 12th of October in 1961 in the town of Rama in Jordan. He obtained his high school certificate from Madaba Secondary School for Boys in 1980. He graduated with a B.Sc. degree in Civil Engineering from Yarmouk University in the city of Irbid, Jordan in 1984. He obtained his M.Sc. degree in Civil Engineering, Urban Transportation and Planning branch from the same university in 1987. In 1991 Abu Sheikh joined King Fahd University of Petroleum and Minerals in Dhahran, Saudi Arabia as a lecturer and Ph.D. student and he obtained his Ph.D. degree in Civil Engineering, Transportation Engineering branch in 1997. During his enrollment in the M.Sc. and Ph.D. programs Abu Sheikh was involved in many of the traffic engineering and transportation planning projects in Saudi Arabia and in Jordan as well. He worked for two years as a traffic engineer in the Police Traffic Department in Amman, Jordan and as the traffic engineering expert for main transportation planning projects in Saudi Arabia which include the Preparation of the Execution Plans for the Central Parts of the Holly City of Makka, the Preparation of the Master Plan for Jazan Region which includes five main cities, the preparation of the Master Plan for Al-Hasa Area

which includes several cities and urban areas, and the Preparation of the Applicant's Guides and the Procedural Manuals for Traffic Access and Impact Studies for Ar-Riyadh Development Authority (ADA). In addition to the main above mentioned projects, Abu Sheikh was involved in several traffic engineering and highway geometric design consultations and studies. Since June 1995, Abu Sheikh is holding the position of the "Head of Traffic and Transportation Engineering Unit" in Dubai Municipality, Dubai, United Arab Emirates.