# Validation and improvement of rear-end traffic conflict model for safety evaluation of coordinated signal systems.

**Shoukat Iyaz**

Civil Engineering

March 1997

Abstract

This study validation of a previous study [5] undertaken to study the effect of signal coordination on intersection safety. It was aimed to validate two statistical models developed in the previous study for prediction of rear-end conflicts. These models were function of number of stops at signalized intersection approaches. It was also aimed to study the effect of other promising roadway and traffic variables which could affect rear-end conflicts at signalized intersection approaches. The stops reduction curve and platoon dispersion factor values in TRANSYT-7F package were calibrated for the Traffic conditions of Eastern Province of Saudi Arabia in two different previous studies [2, 5]. In this study it was also aimed to test whether these calibrated TRANSYT-7F parameters could be used to obtain equivalent number of field stops which is the requried input for the two statistical models developed previously for prediction of rear-end conflicts.

It was found from this study that the models developed previously for prediction of rear-end conflicts were valid for use in the Eastern Province of Saudi Arabia. It was also found that apart from number of stops, average approach speed is also a significant parameter affecting the rear-end conflicts. Thereby a new model was built with number of stops and average approach speed as independent variables. This newly built model when compared with the previously built models showed a better fit to an independent data set. It was also found from this study that the calibrated stops reduction curve and default platoon dispersion factor values in TRANSYT-7F were adequate in obtaining equivalent number of field stops.

# Validation and Improvement of Rear-End Traffic Conflict Model for Safety Evaluation of Coordinated Signal Systems

by

Shoukat Iyaz

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

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## COLLEGE OF GRADUATE STUDIES

This thesis, written by **SHOUKAT IYAZ** under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **CIVIL ENGINEERING**.

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*This Thesis is dedicated to my loving parents, brother and sister*

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## THESIS ABSTRACT

**Name:** SHOUKAT IYAZ

**Title:** Validation and Improvement of Rear-end Traffic Conflict Model for Safety Evaluation of Coordinated Signal Systems

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*This study involved validation of a previous study [5] undertaken to study the effect of signal coordination on intersection safety. It was aimed to validate two statistical models developed in the previous study for prediction of rear-end conflicts. These models were function of number of stops at signalized intersection approaches. It was also aimed to study the effect of other promising roadway and traffic variables which could affect rear-end conflicts at signalized intersection approaches. The stops reduction curve and platoon dispersion factor values in* TRANSYT-7F *package were calibrated for the Traffic conditions of Eastern province of Saudi Arabia in two different previous studies [2, 5]. In this study it was also aimed to test whether these calibrated* TRANSYT-7F *parameters could be used to obtain equivalent number of field stops which is the required input for the two statistical models developed previously for prediction of rear-end conflicts.*

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*Keywords: Traffic Conflicts, Rear-end Conflicts,* TRANSYT-7F*, Stops, Signal coordination.*

King Fahd University of Petroleum and Minerals, Dhahran.
April 1997

# ملخص الرسالة

**الإســم** : شوكت إياز

**العنوان** : اثبات وتطوير نموذج التعارض الخلفي لتقييم سلامة أنظمة الاشارات المتناسقة

**الدرجة** : ماجستير العلوم

**التخصص الرئيس** : هندسة مدنية ( شعبة نقل ومرور )

**تاريـخ الدرجــة** : ابريل ١٩٩٧م

تشمل هذه الدراسة اثبات الدراسة السابقة لتأثير تنسيق الاشارات المرورية على السلامة في التقاطعات كان الهدف هو اثبات نموذجين احصائيين في دراسة سابقة للتنبؤ بالتعارض الخلفي هذه النماذج هي دالة في عدد التوقفات في تقاطعات الاشارات ، كذلك كان الهدف دراسة تأثير الطريق ومتغيرات النقل التي يمكن أن تؤثر على التعارضات الخلفية . تمت معايرة منحنى اختصار الوقوف وقيم معامل التشتت في برنامج ( TRANSYT - 7F ) لظروف النقل في المنطقة الشرقية في السعودية في دراستين مختلفتين سابقتين . وفي هذه الدراسة كان الهدف أيضاً اختبار امكانية استخدام عوامل (TRANSYT - 7F) المغايرة للتنبؤ باعداد السيارات التي تتوقف عند الاشارة وهو المطلوب كمدخل في النموذجية الاحصائيين المطورين سابقاً للتنبؤ بالتعارضات الخلفية .

وجد من هذه الدراسة أن النماذج المطورة سابقاً للتنبؤ بالتعارض الخلفي مناسبة للاستخدام ام في المنطقة الشرقية في السعودية . وجد أيضاً أنه بجانب عدد التوقفات أن متوسط السرعة عامل هام ومؤثر على التعارضات الخلفية . بذلك تم بناء نموذج جديد به عدد التوقفات ومتوسط السرعة كعوامل مستقلة . هذا النموذج الجديد يظهر نتائج أفضل لبيانات مستقلة عند مقارنته بالنماذج السابقة . ظهر أيضاً من هذه الدراسة ان منحنى اختصار الوقوف المعاير وقيم معامل التشتت في برنامج (TRANSYT - 7F) مناسبة .

للتنبؤ بعدد السيارات التي تتوقف عند الاشارة

**الكلمات الدليلية** : تعارضات المرور ، التعارضات الخلفية ، ( TRANSYT - 7F ) التوقفات ، تنسيق الاشارات .



**جامعة الملك فهد للبترول والمعادن**


ابريل ١٩٩٧

# Chapter 1

# Introduction

## 1.1 General

Traffic signal coordination is one of the means by which traffic flow can be optimized [1]. Ratrout [2] defines signal coordination as "the act of developing an optimum signal timing plan (optimum signal offsets and splits), by which the signalized intersections in a given network or arterial are interconnected and operated to optimize a given objective function." The objective function could be to minimize some combination of delay and stops, maximize green bandwidth, minimize fuel consumption or minimize operating cost.

Thus, signal coordination provides significant improvement in service, usually measured in terms of stops and delay [3]. Also, previous studies [3, 4] have shown that all accidents decrease as a result of signal coordination which suggests that intersection safety is affected by signal coordination. Some studies have found that rear-end accidents increase as a result of signal installation at unsignalized intersections [3, 4]. The rear-end accidents at signalized intersections take place because

some drivers decide to decelerate; either to stop in response to a yellow or red signal indication, or decrease their speed to turn right or left when the others decide to continue at the same speed or decelerate at a slower rate than the leading drivers. This behaviour causes conflicts between vehicles that might lead to rear-end accidents [5]. It has been found from previous studies that around 50 percent of urban accidents occur at intersections [6]. Many studies have already been conducted in the past to identify the primary causes for accidents at intersections. Some studies [7, 8] have used the data of accidents itself to identify the causes for accidents while some studies [5, 9, 10]have used accident surrogates like Traffic Conflict Technique to identify and assess the accident potential.

## 1.2 Problem Statement

Intersection safety is primarily dependent on various factors like physical environment, traffic parameters and traffic control [5]. Some studies have already been conducted in the past to identify some of these significant factors which affect intersection safety in the Eastern province of Saudi Arabia [5, 9, 10]. Because of lack of accident data by location, the Traffic Conflict Technique was often employed to study the problems at intersections [5, 9, 10].

In one such study, Al-Ofi [5] investigated the effect of signal coordination on intersection safety. In his research it was hypothesized that signal coordination mainly affects stops which may be related to rear-end accidents. To obtain the relationship between the rear-end accidents and stops, first, the relationship between rear-end conflicts and stops was established using the data collected from 38 signalized intersection approaches in Dammam- Al-Khobar region. To establish the relationship

between rear-end conflicts and stops Al-Ofi [5] built two statistical models. These are as shown below.

$$Rear-end\ Conflicts(perhour) = 2.555 + .00001\ \times\ stops^2 \qquad (1.1)$$

$R^2$= 0.664

$$Rear-end\ Conflicts(perhour) = .01154 \times stops \qquad (1.2)$$

$R^2$ = 0.869

Although Model 1 was deduced as the best for prediction of rear-end conflicts, Model 2 showing linear relation (without intercept) between rear-end conflicts and stops was built as it was required in that study to incorporate safety into the *TRANSYT* model. In the second step, a relationship was developed between rear-end conflicts and rear-end accidents using the data of rear-end accidents and rear-end conflicts collected by Isa et.al [10]. The resulting equation was:

$$Rear-end\ Accidents(in\ two\ years) = 2.309(conflicts/hour) \qquad (1.3)$$

$R^2$ = 0.869

These two equations were then combined to give a relationship between the rear-end accidents per hour to stops per hour. The resulting equation was

$$Rear-end\ accidents\ per\ hour = 2.347 \times 10^{-6}\ stops/hour \qquad (1.4)$$

As the number of stops are required as input for prediction of rear-end conflicts using the model (aforementioned), the stops reduction curve in *TRANSYT* model was calibrated to simulate number of field stops. From the findings of this study it was concluded that rear-end accidents are mainly affected by number of stops at signalized intersections and hence could be used as exposure measure for rear-end accidents at signalized intersections.

The relationships developed for predicting rear-end conflicts were not validated in Al Ofi's study. This study mainly aims to test the validity of these rear-end conflict models using the data collected from the intersection approaches of Al-Khobar region. It is also aimed to improve the prediction capability of these rear-end conflict models by introducing other variables like volume/capacity, number of intersections within half a mile distance etc.; in the model.

In an other study Ratrout [2] calibrated platoon dispersion factor in *TRANSYT-7F* model for the study area of Dammam and Al-Khobar. He showed that the model simulates the real platoon dispersion behaviour; and suggested platoon dispersion factors for different kinds of links in the study area.

The study arterial chosen by Al-Ofi [5] for calibration of stops reduction curve was King Abdul Aziz street in Al-Khobar in the Eastern province of Saudi Arabia. The present study also aims at testing the adequacy of *TRANSYT* model along with the parameters ( stops reduction curve and platoon dispersion factor) suggested from the previous studies, aforementioned, in obtaining equivalent number of field stops on an arterial other than that used for calibration of stops reduction curve.

## 1.3 Need for the present study

As mentioned earlier the rear-end conflict models developed earlier are in need of validation as the calibrated models cannot be used unless they are validated using some other data set. From the relationships developed for prediction of rear-end accidents it is clearly evident that if rear-end conflicts are predicted correctly then a more accurate estimate of rear-end accidents could be obtained. Thus in this study an attempt to improve the prediction capability of the rear-end conflict model is aimed by introducing variables like volume/capacity, number of intersections within half a mile, clearance interval etc.;

As the number of stops can also be easily obtained from the simulation output of *TRANSYT-7F*, it was calibrated to obtain number of stops in agreement with those observed in field. The data needed for simulation in *TRANSYT-7F* is the same as that required for obtaining optimized signal timing plans. Thus the analyst, while obtaining the optimum signal timing plans using *TRANSYT-7F* may also assess safety at signalized intersection approaches using the number of stops obtained from simulation run and the models developed for prediction of rear-end conflicts and rear-end accidents. The Adequacy of this calibrated stops reduction curve in *TRANSYT-7F* model in obtaining number of stops in agreement with those observed in field on an arterial other than that used for its calibration needs to be tested.

## 1.4 Goals and Objectives

The main goal would be to validate rear-end traffic conflict model using the traffic data collected from Al-Khobar city of Saudi Arabia.

To achieve the above goal the following objectives are aimed at.

1. to review the past work done by researchers concerning safety at intersections;

2. to identify and collect data relevant for study;

3. to test the validity of the rear-end traffic conflict model;

4. to improve the prediction capability of the rear-end conflict model by introducing other variables like approach speed, volume/capacity, number of intersections within half a mile distance, clearance interval etc.;

5. to re-examine the adequacy of *TRANSYT* simulation model with the calibrated parameters determined from previous studies, in estimating the regressor variable (number of stops) of the rear-end conflict model.

# Chapter 2

# Literature Review

## 2.1 General

Although, considerable amount of research has already been done concerning the safety of urban intersections, they continue to receive primary attention from researchers and traffic engineers, which might be simply due to the fact that greater proportion of accidents take place at intersections. Initially the studies conducted to determine the factors affecting intersection safety and studies performed in the area of accident predictions are discussed. Secondly, the problem in using the accident data in predicting accidents and the surrogate measures for accident potential are summarized with emphasis on Traffic Conflict Technique and its applications in the area of traffic safety. Finally, an overview of some popular simulation software available in the market and some conflict simulation models developed are elucidated.

## 2.2 Mechanism of Rear-end Accidents

The distance from the stop line of the intersection is divided into two zones : the dilemma zone, and the option zone. In the dilemma zone. the driver has to make two dangerous decisions: either to stop at a high deceleration rate and take a chance of being involved in a rear-end accident, or continue driving and take a chance of being involved in a right angle accident. A proper design of intergreen interval will practically reduce the risk of involvement in a right angle accident (excluding accidents that involve red signal violation). The second zone is the option zone, in which the driver can either stop, or enter the intersection prior to the onset of the red light. The presence of two legitimate options will split the drivers decisions whether to stop or go and this may increase the risk of rear-end accidents [5].

The risk of involvement in a rear-end accident cannot be eliminated but it can be reduced. Figure 2.1 shows the dilemma zone and option zone for signalized intersections approaches as a function of approach speed and distance from stop line for two cases: an amber phase of 3 seconds and an amber phase of 6 seconds. Referring to Figure 2.1. if a driver doing 80 km/hr was at a distance of 80 m from the stopline, he would be in the dilemma zone if the amber phase was 3 seconds. That is, he couldn't stop at a reasonable deceleration and couldn't cross the stop line before the onset of red because his stopping distance would be greater than 80 m and his speed would not enable him to cross the stop line in 3 sec. On the other hand, if the amber was 6 seconds, he could cross the stopline before the onset of red phase. If he was doing only 60 km/hr, and was at distance of 80 m from the stopline, he would be in the option zone if the amber was 6 sec [5].

He could take one of two decisions: either to stop or two cross the stopline before

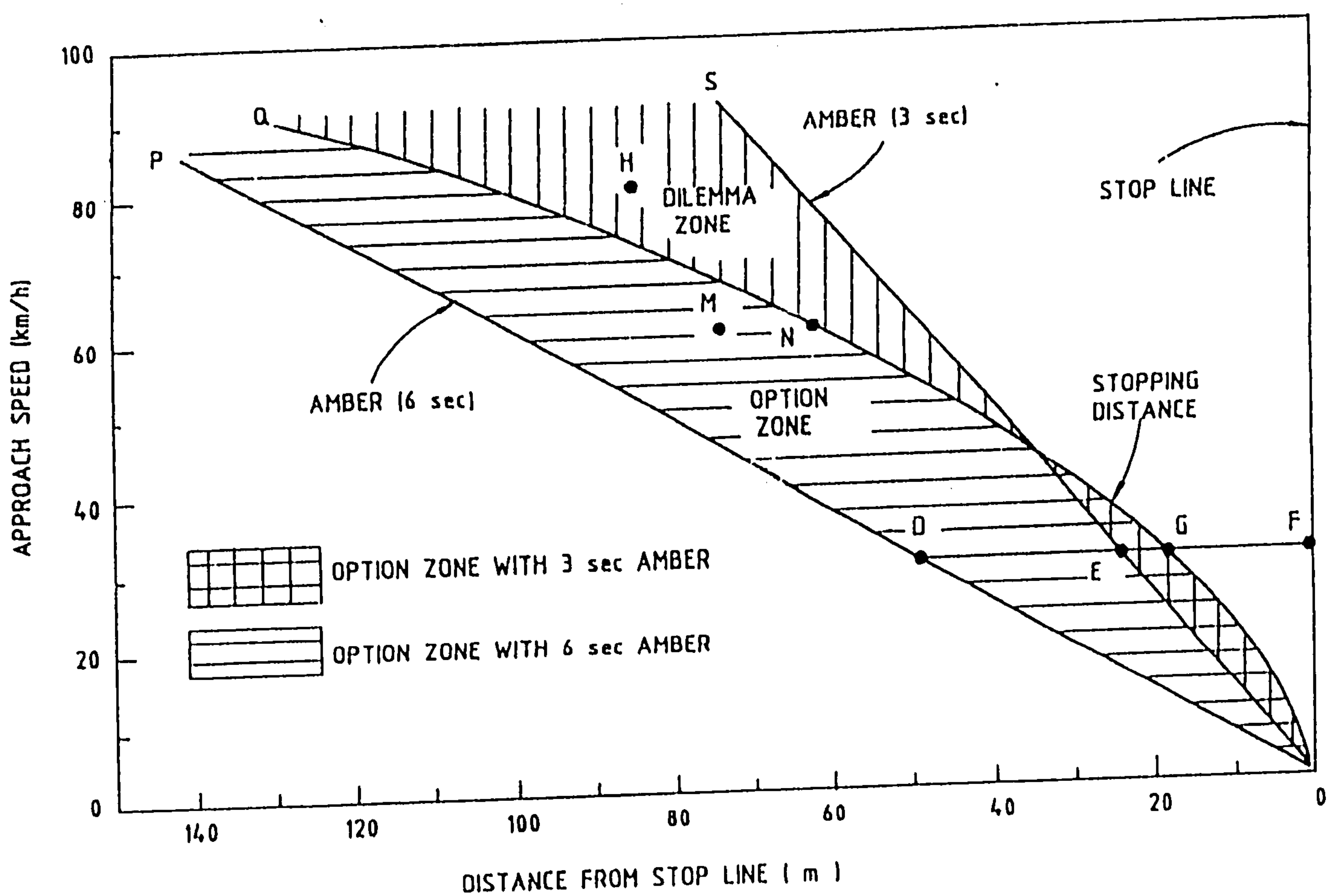



Figure 2.1: Dilemma and Option Zones Source [5]

the onset of the red phase. The dilemma zone is more dangerous than the option zone. The six second amber phase eliminates the dilemma zone, but creates a larger option zone, which is not totally safe itself. Figure 2.1 shows that the amber phase of 3 seconds will create a dilemma zone, for an approach speed greater than 50 km/hr. but the amber phase of 6 seconds will eliminate the dilemma zone. Inspection of Figure 2.1 also shows that no amber period can eliminate both dilemma zone and option zones simultaneously. So, the proper design of intergreen period could eliminate the option zone, which means that crossing accidents can be eliminated. but rear-end accidents cannot be minimized [5].

## 2.3 Factors Affecting Intersection Safety

Some of the studies performed to identify the factors affecting the intersection safety will be discussed in the following paragraphs.

Traffic volume affects the number of accidents at intersections. As more vehicles enter the intersection, more is the chance of being involved in an accident. At unsignalized intersections, conflicting movements are not separated with time. Hence, the number of accidents is sensitive to minor street volume as it increases the number of conflict chances than an equal increase in the major street volume [11].

Intersection geometry also affects intersection safety. With increasing number of legs, conflicting movements increase and hence the number of accidents experienced also increases. T and Y intersections usually have less accident rates than cross intersections [12]. Left turn channelization enhances the safety of intersections since it segregates different movements and different speeds [4, 13].

Speed and speed distributions are known to affect safety [1]. Speed affects driver response time and distance required to stop. As the speed increases stopping sight distance also increases and hence higher speed is an indication of higher accident potential. Speed variation increases interaction between vehicles which results in an increase of accidents. The severity of accidents increases with speed [5, 10].

Al-Isa[14] studied the speed distribution characteristics among other traffic performance measures as a possible surrogate measure for accident potential on the rural highways of Saudi Arabia. He found that skewness index of speed distribution could be a suitable surrogate measure for identifying hazardous locations on rural highways of Saudi Arabia[14].

In another study Resende [15] developed and validated volume/capacity based accident prediction models using regression analyses. These prediction models were generated based on four years of data analysis. Capacity was calculated using the procedures of HCM, and the daily V/C ratios thus obtained were used to develop accident prediction models for rural and urban interstate highways [15].

Signal coordination also was found to affect intersection safety. Comkin [3] presented some accident statistics relating to sections of arterial roads controlled by coordinated traffic signals. The accident statistics showed a significant decrease in accidents as a result of signal coordination and only rear-end type of accident did not show any significant decrease at 5 percent level. In actual practice, most of the programs that have been developed for signal coordination try to minimize delay and stops or maximize bandwidth. Furthermore, most of the evaluation studies investigate the success of the programs in optimizing these objectives in the field. Thus, very few studies have been conducted to evaluate traffic signal coordination

from the safety point of view.

Berg [4] investigated the effect of signal coordination on rear-end accidents. He hypothesized that rear-end accidents correlate with the number of stops. He used the accident data available about a high volume urban arterial. He used the *TRANSYT* model to develop optimized timing plans for a hypothetical time-of-day signal control system. Detailed performance data for both the existing conditions and proposed coordinated signal system were generated using the NETSIM (which is a macroscopic simulation model) because there were traffic actuated signals that cannot be simulated using *TRANSYT*.

Accident records were analyzed and correlated with the estimated frequency of vehicular stops under existing conditions. An accident prediction model was then used to estimate the safety impacts of the proposed signal coordination.

The output of the analysis showed that there was a small decrease in rear-end accidents due to a decrease in the number of stops. The prediction model showed significant relationship between number of stops predicted by the NETSIM, and the accident data. The correlation factor was 0.32, which the author thinks sufficient for such research. The small reduction in the number of stops (instead of a relatively large reduction) may be due to the large distances between the intersections in the study. The effect of coordination decreases due to huge dispersion of platoons, as the distance between intersections increases.

## 2.4 Use of Accident Records in Prediction of Accidents

The purpose of accident records is to have a knowledge of traffic accidents as a cause of mortality, morbidity and economic loss [16]. And also, to point out where, when and to whom traffic accidents are a critical problem, and to suggest lines of preventive action to be taken. They contribute a lot to traffic accident prevention efforts of agencies and traffic engineers.

First they point out high accident or hazardous locations for corrective action by traffic engineers. They indicate over-all deficiencies in streets and highways for traffic engineers and provide general guidelines for roadway designs that assist in elimination of traffic accidents. Secondly, they can also be used to measure the effect of accident prevention efforts and to determine negligence or fault. Thirdly, they identify problem drivers who are in need of corrective action. And last but not least they identify areas in which further research is needed about drivers, vehicles and traffic controls [17].

Pioneering efforts were made by various researchers and traffic engineers to relate traffic accidents with the various traffic and roadway characteristics. Some of the studies already conducted in this direction are summarized below.

In 1988, California State Dept of transportation, Sacremento, developed accident prediction models based on the Traffic Accident Surveillance and Analysis System (TASAS). A grouping and classifying technique called Classification and Regression Trees(CART) was used as a building block for developing prediction models. It includes an adjustment procedure to accomodate various accident reporting levels

of different police jurisdictions. Factors such as traffic intensity, proportion of cross street traffic, number of lanes and left turn arrangements were found to be significant. The models derived based on the above mentioned technique and TASAS provided more intuition and flexibility than other models derived from site observations and accident record systems [18].

In 1994, Utah Transportation Center, Logan, modelled the influence of the geometric design variables on traffic accidents on two lane highways. They also examined the spatial and temporal validity of these relationships between accidents and geometric variables [19].

Ahmad [8] in his study, developed accident prediction models using highway and traffic hazards as surrogate measures of safety. The independent variables developed for this study represented the hazards in terms of inadequate access control, deficient pavement shoulder width, deficient pavement markings, gaurd rail deficiencies, potential intersection conflict points, low pavement serviceability and road side obstructions. The ambient hazardousness was quantified using two procedures: use of design standard deficiencies as a measure of hazard; and use of an expert team for subjective rating of hazardousness. Multivariate linear regression analyses were performed to investigate the relationship between the hazards and accidents. The results showed the existence of statistical relationship between the hazard and accidents. The analyses indicated that inadequate control of access and operational friction are significantly correlated with accidents.

In 1995 Al-Assar[7] investigated the contribution of roadway and traffic control related defects and deficiencies towards traffic crashes and crash severity. Traffic signal timing design was considered as extremely critical to achieve safety. This

research indicated that the right angle, rear-end and total crash frequencies and rates were significantly reduced at signalized intersections due to the presence of an all-Red phase of at least 1.2 seconds along with the appropriate yellow interval. It also indicated that providing wider shoulders and wider travel lanes significantly decreased the frequency of the run-off-the road and total accidents on two lane rural highways.

## 2.5 Limitations of Using Accident Data

Inspite of the many utilities provided by the accident data there are some limitations associated with it especially in the area of accident predictions. Generally, only a fraction of total accidents that occur are recorded in accident files. Further. the criteria for reporting accidents vary from place to place. Some countries consider reporting only those accidents which have injury cost more than $400 [17]. Hence, because of such reporting criteria, estimates of traffic accidents actually occur reported range from 20 to 50 percent. Therefore, the number of reported accidents is a function of local reporting laws, accident severity, and damage costs of each accident.

Another problem in using accident data alone for identifying and evaluating accident sites is the random fluctuations in accident data. Many accidents might result from unrelated geometric deficiency such as, vehicle malfunction, an obvious driver error, or a weather related problem.

In 1973 a study conducted in Kentucky illustrated the effects of random accidents on the identification of hazardous sites. 99 of the 208 spot locations identified by accident data as hazardous, were wrongly identified because of random accident

occurrences. These 99 sites were found from field inspections to need no improvements, and accidents decreased to normally low levels the following year [17].

To test the reliability of accident data for predicting future accidents at a location, an analysis of 60 intersections in central Kentucky was made. The number of accidents for a given year compared with the number of accidents the following year resulted in a correlation coefficient (r-value)of only 0.64. The 95 % confidence level (twice the standard error) for this relationship was ±10.9 accidents per year, and the average number of accidents per year at the intersections was 11.1. This indicated that an error of almost 100 percent in either direction is possible when accident numbers from one year to the next were compared [17].

One more problem with accident data is the waiting time needed to obtain a significant data base. A previous study in Kentucky suggested that up to 2 years of accident data are necessary to ensure reliability when selecting high-accident locations. After an improvement is made, it often takes several more years to determine the effectiveness of the improvements based on accident data [17].

While accident data have many limitations, they can be quite useful when complemented by traffic conflict data. Accident histories can point out locations where conflict data is to be collected. Conflict counts at these sites can be used to help select appropriate improvements and later to determine whether the improvements were effective in reducing the hazard to motorists[17].

## 2.6 Traffic Conflict Technique for Highway Safety Analyses

The conventional way of determining whether a safety problem exists at a highway intersection is to review and analyze historical accident reports from the site . This method as discussed previously requires an average of three or more years of accident data to make an analysis. It also depends on the often biased, inconclusive, or incomplete information contained in accident reports and does not reflect the large number of accidents for which no reports are filed. To overcome these problems with accident data various agencies and organisations have employed Traffic Conflict Technique (TCT) for safety analysis.

This TCT was first developed by General Motors research Laboratories in 1968. Later on it was evaluated by Federal Highway Administration in cooperation with State Highway departments of Washington, Ohio, and Virginia. In this particular research, an attempt was made by FHA to determine whether any relation existed between traffic conflicts and traffic accidents. It was found that a significant relation indeed existed between conflicts and accidents. This was done by comparing the conflict counts with the actual accident data.

Research on TCT continues to be performed in basically two broad areas. In one area, researchers are trying to correlate accidents and conflicts. They have redefined conflicts and the techniques used to measure them to improve correlation. There has been some success. Other researchers believe that accident prediction may not be as important as identifying potential hazards and operational deficiencies. As a result of this thinking TCT has been used to justify and substantiate many types

of operational traffic engineering improvements at a variety of highway locations.

A traffic conflict occurs when one driver takes evasive action by braking or weaving to avoid what he believes to be an impending collision with another vehicle. the objective evidence of a traffic conflict is a brake-light indication or a lane change effected by the offended driver. By analyzing observers data on number and types of traffic conflicts at an intersection over a given period of time, the traffic engineer can determine whether a hazardous traffic situation exists and whether corrective action should be recommended. The traffic conflict survey has the advantage of using quantified, observable, timely data in place of accident reports as a basis for drawing conclusions about an intersection safety. It can be started and completed in a short period of time.Furthermore, it is also cost effective [20].

Although TCT was primarily developed as a tool for measuring traffic accident potential at intersections, it soon found its utility even at other locations of roadway sections.

In one such study Motoda [21], applied TCT to evaluate safety at curve sections of a two lane highway in a mountainous area. It was understood that the larger the number of vehicles strayed into the opposition lane, the greater were the chances of head-on collisions. Thereby, he suggested that the number of vehicles which enter the opposition lane can be used to assess the accident potential at curve sections, by considering it as an extension of traffic conflict definition of traffic conflict definition. Also, he recommended that this extended definition of Traffic Conflict can be applied at locations where traffic conflicts are seldom observed [21].

Joseph Fazio et.al [22] in their study proposed that conflict rates could be used as an alternative to crash rates for safety analyses of weaving sections of freeway. Also,

he developed and added computer subroutines to the Integrated Traffic Simulation package to count conflicts that may occur in freeway weaving sections. It was concluded from his study that conflict rates were good indicators of traffic safety as they are predictors of the probability of crash occurrence.

## 2.7 Critique of Existing Traffic Conflict Techniques

The General Motors Research procedures for observing traffic conflict suggests that evasive actions taken by the drivers may be identified by the brake lights or lane changes. This original definition of traffic conflicts was apparently well received and adopted by traffic engineers for use in numerous other studies. Later on some of the studies revealed the following weaknesses of TCT.

First, braking habits vary from driver to driver. Some drivers are very cautious and may apply brakes on entering an intersection regardless of hazard present, while others may not brake even when presented with a very hazardous situation. Consequently, it is possible that one could falsely identify such situations in terms of traffic conflict [23].

Secondly, braking does not indicate the severity of a conflict situation. An abrupt brake application to avoid an imminent collision and an unnecessary precautionary application will therefore receive the same rating unless and until a completely subjective rating scheme is introduced.

Third, deceleration evidence by brake application is not always a wise evasive action. In some conflict cases, acceleration rather than deceleration might be a

superior reaction to avoid a collision.

Fourth, the common procedure of observing brake application by only one of the vehicles involved in a conflict situation(by definition, the vehicle with the right of way), information describing the actions of the other vehicles involved is lost.

Fifth, Collisions are occasionally precipitated by the party with the right of way, such as a through vehicle that speeds toward an opposing left-turning vehicle but applies no brakes. In such cases the driver with the right-of-way may not apply his brakes, and the situation will not be considered as conflict by the present TCT method. Other weaknesses like brake lights may not be visible because of mechanical failures [23]. Thus, Traffic Conflict Technique has its own share of limitaions.

## 2.8 Prediction of Traffic Conflicts

Ghani [24] in his study investigated the possibility of predicting future conflicts by knowing the mix of driver characteristics at an urban intersection. He found that relationships between driver characteristics and conflicts were similar to relationships known to exist between driver characteristics and accidents. He concluded that traffic conflicts could be used to identify hazardous intersections when past accident records are not available.

Ergun and Tanvir [25] investigated the validity of Traffic Conflict Technique in the Kingdom of Saudi Arabia and they found that Traffic Conflict Technique is a more direct, easier method and can be used as a substitute for accidents.

*TRANSYT* [2](Traffic Network Study Tool) was written by Robertson in 1967 in the U.K and was developed substantially after that. *TRANSYT* is an Americanized version of the seventh British version *TRANSYT/7*. *TRANSYT-7F* has been

developed over the last decade and has been subjected to extensive validation and calibration in many countries including Saudi Arabia. The program is macroscopic and a deterministic model. It has two main modules: a traffic simulation module and an optimization procedure. The simulation process is based on simulating the dispersion of platoons of vehicles as they progress along network links [2]. This package will be used in this study for simulation purpose. The reasons for selecting this package is that it is one of the widely used simulation and optimization package and some of its features like Platoon dispersion factor [2] and stops reduction curve [5] have been calibrated to suit the local traffic cooditions. Furthermore it is not expensive and is easily available.

## 2.9 Conflict Simulation Models

In 1993, Tarek Sayed,[26] studied traffic conflicts as critical-event traffic situations and the effect of driver and traffic parameters on the occurrence of conflicts. He developed conflict simulation model for both T and 4-leg unsignalized intersections using discrete event simulation language, General Purpose Simulation System(GPSS/H). This microscopic simulation model has some features not normally part of GPSS/H and therefore was labelled as "TSC-Sim," for Traffic Systems Conflict Simulation. The model employs importance sampling to save characteristic information for only those conflicts that are predefined to be "significant" events. It was concluded from his studies that simulation models could be alternatives to direct observation of traffic conflicts which is expensive and requires trained people [26].

# Chapter 3

# Methodology

In this chapter, the methodology, design of experiment and the data collection procedures followed are explained.

## 3.1 Research Methodology

The whole study was divided into four stages.

- Stage 1: In the first stage the design of experiment required to achieve the goals and objectives of the study was dealt with. Data collection was carried out and a preliminary analyses of the data collected was performed.

- Stage 2: An null hypothesis was formulated for validation of previously built models and a Chi-Square test was performed to test this hypothesis.

- Stage 3: Promising new variables were selected for model improvement and the improved models were compared with the previously built models.

- Stage 4: Data required for simulation purpose was collected. The adequacy of *TRANSYT* model with the parameters determined from a previous study in obtaining equivalent number of field stops on some other arterial other than that used for their calibration was examined.

  These four stages are depicted pictorially in Figure 3.1 and explained in more detail in the following paragraphs.

### 3.1.1 Design of Experiment

This section is concerned with the selection of the type of intersections required for the study and determination of the sample size and the duration of the data collection period required for the present study.

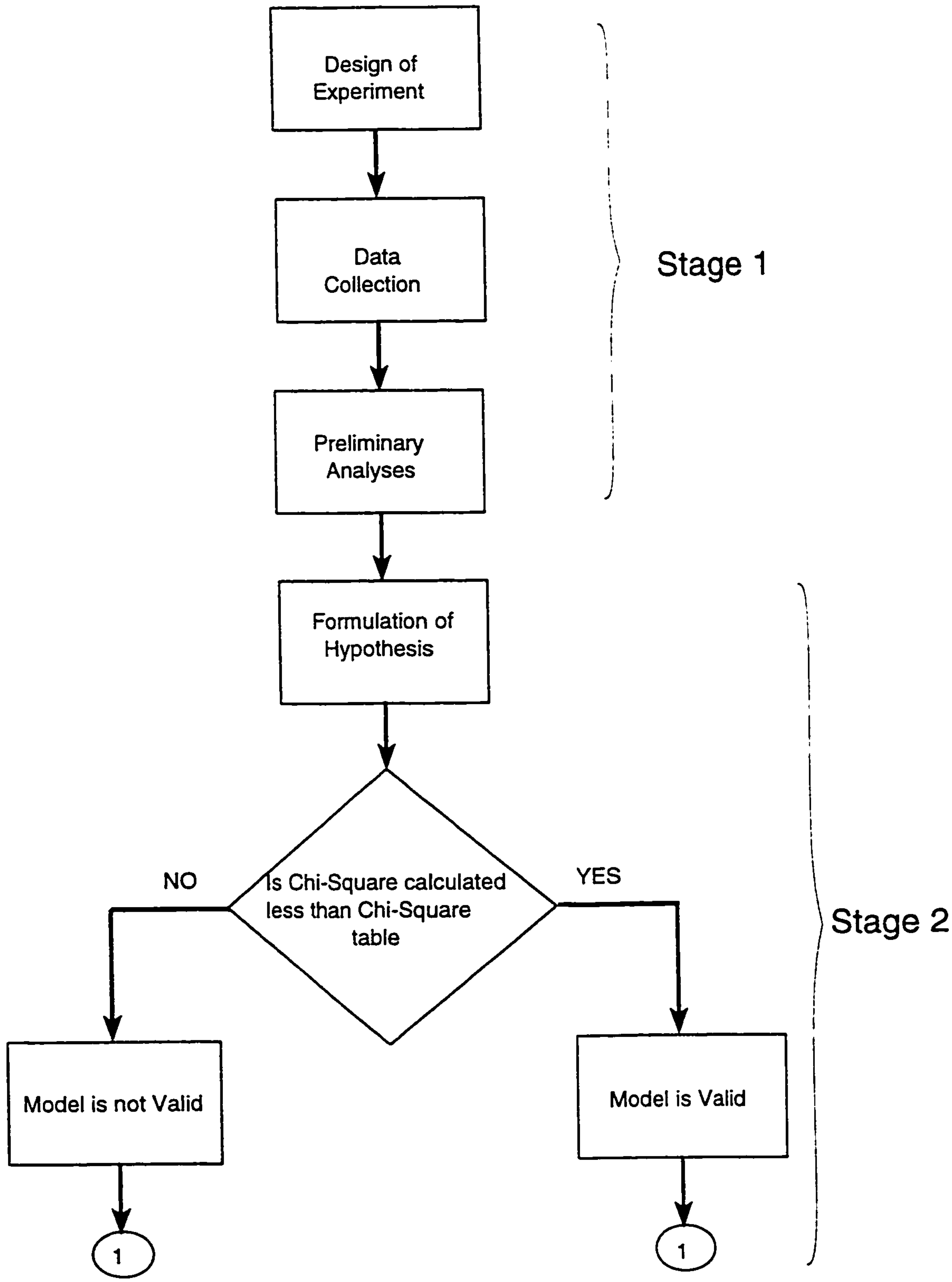
### 3.1.2 Selection of Intersection Type

The type of intersections required in the validation study should be similar to that used by Al-Ofi [5] for his Model building effort. Thus, the intersections having the following characteristics was selected.

1. The intersection should be a 4-legged intersection.

2. Each approach must be separated from the opposing flow approach with a raised median and must have at least two lanes.

3. Each approach must have left turn lanes and should possess ideal roadway geometry features.


Design of Experiment
Data Collection
Preliminary Analyses
Stage 1
Formulation of Hypothesis
Is Chi-Square calculated less than Chi-Square table
NO
YES
Stage 2
Model is not Valid
Model is Valid
1
1

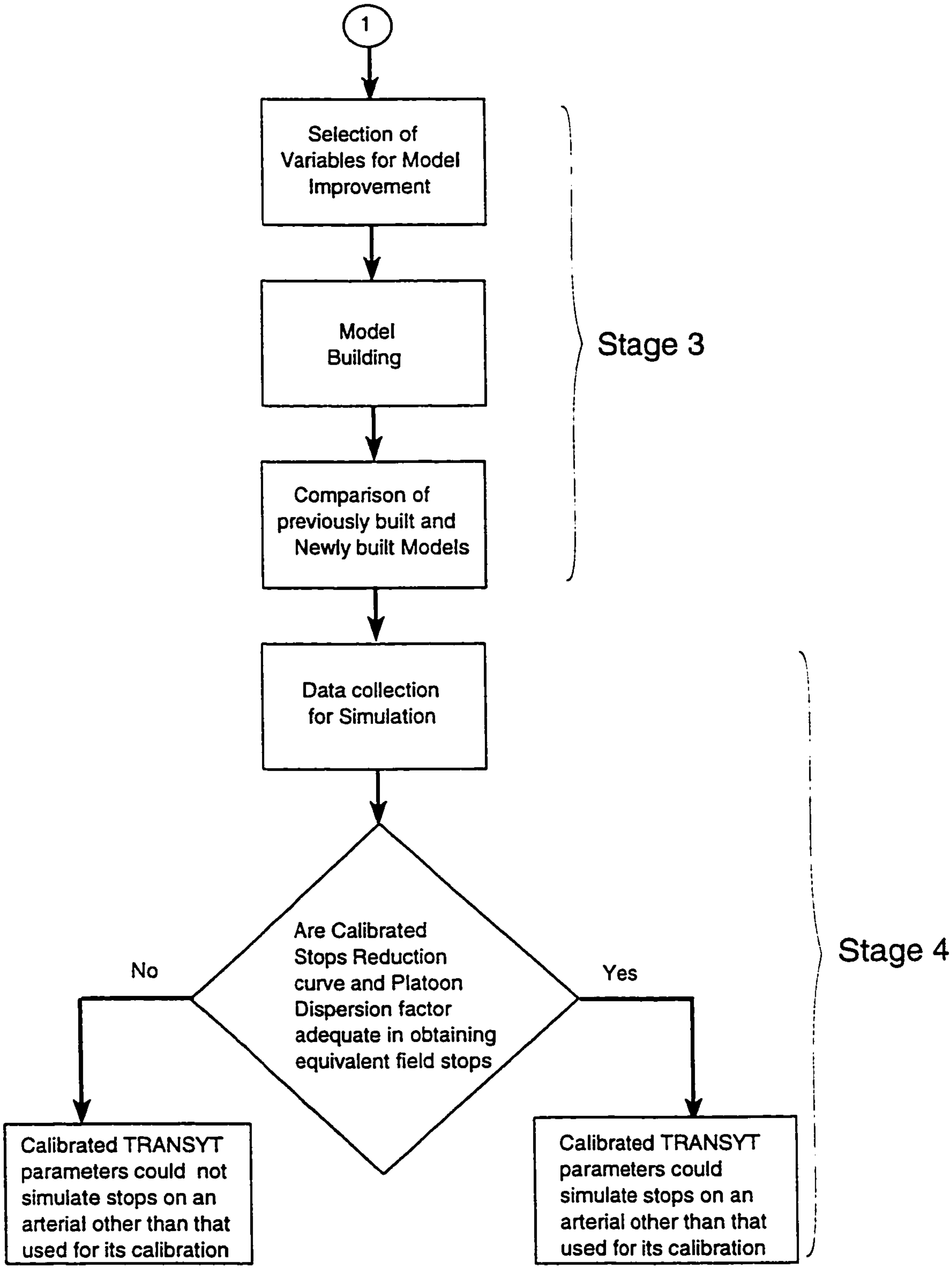



Figure 3.1: Methodology of Study

### 3.1.3 Determination of Sample Size

The sample size needed was determined using a statistical formula which is based on hourly variance of traffic conflicts. The hourly variance of conflicts obtained from Al-Ofi's study [5] was used for determination of sample size. The conflict data collected by Al-Ofi in his studies has a standard deviation of 4.19 conflicts per hour. Thus the size of the sample so that it gives a margin of error not greater than $\pm 1.75$ conflicts is found to be as shown below.

$$\begin{aligned} n &= \frac{Z_{\alpha/2}^2 \sigma^2}{E^2} \\ &= \frac{1.96^2 \times 4.19^2}{1.75^2} \\ &\approx 22 \; approaches \end{aligned}$$

where

| | | |
|---|---|---|
| E | = | error |
| $\sigma^2$ | = | variance of conflicts per hour |
| n | = | sample size |
| $Z_{\alpha/2}$ | = | normal random variable |
| | | at 95% confidence level. [13] |

Al-Ofi's model [5] is based on total hourly number of rear-end conflicts. Hence for validation of his rear-end conflict model, conflicts have to be observed for a one hour period. Thereby data was collected at each intersection approach for a one hour period.

### 3.1.4 Data Collection

An inventory survey of the selected type of signalized intersections was carried out to know the number of selected type of intersections available in the study area. A list of all available intersections which met the criteria, as mentioned previously was prepared. There were at least 45 such signalized intersection approaches in the Al-Khobar region of Eastern province. The required sample (22 approaches) of intersection approaches was selected randomly form this inventory list of intersection approaches. The selected intersection approaches are listed in Table 3.1. The following data were collected at each of the above mentioned list of intersection approaches.

1. Stops
2. Nonstops
3. Average Approach speed
4. Signal plan(signal splits,cycle length)
5. No of lanes
6. Width of intersection

This data was collected with the help of a few graduate students in Civil Engineering. They were given written information about definitions of traffic conflicts and stops and also trained in the field to collect such data. The definition of a stop adopted was: "Any vehicle that comes to a complete stop within the intersection area due to red signal or obstruction by a queue of vehicles still discharging at the beginning of a green signal." For observing the traffic conflicts, the General Motors

Table 3.1: Names of approaches where data was collected

| | |
|---|---|
| AbdulAziz/28th street North Bound | Makkah/15th street North Bound |
| Meqrin/28th street West Bound | AbdulAziz/28th street North Bound |
| Hmoud/28th street West Bound | Makkah/15th street West Bound |
| Riyadh/15th street South Bound | Makkah/20th street South Bound |
| Riyadh/20th street South Bound | AbdulAziz/22nd street North Bound |
| Hmoud/28th Street East Bound | AbdulAziz/10th street North Bound |
| AbdulAziz/10th street South Bound | Makkah/15th street South Bound |
| Meqrin/28th street East Bound | AbdulAziz/22nd street South Bound |
| Riyadh/15th street North Bound | Makkah/20th street North Bound |
| Riyadh/25th street West Bound | Makkah/25th street West Bound |
| Meqrin/22nd street North Bound | Riyadh/20th street East Bound |

definition [13] was adopted, which is as follows. "A Traffic Conflict is a traffic event involving two or more road users, in which one user performs atypical or unusual action, such as a change in direction or speed, that places another user in jeopardy of a collision unless an evasive maneuver is undertaken." Traffic conflicts were observed by only one person throughout the data collection process to have consistency.

Data was collected from morning 8:00 AM to around 11:30 AM on weekdays. Care was taken to avoid collecting data on approaches where the queue fails to discharge completely within the allocated green interval. Only two persons were required to collect data from the field. One person was counting stops and volume while the second person was observing rear-end conflicts according to its type for one hour period. The four type of rear-end traffic conflicts (For the operational definitions see Appendix A) that were observed are as follows.

1. Left turning same direction
2. Slow vehicle
3. Right turning same direction
4. Lane Change

The signal splits and the cycle length allocated for the approach being observed and for the other approaches connected to it were also recorded to help determine the All-Red period existing at the intersection. This data was collected immediately after volume and traffic conflict data collection. The number of lanes and the type of area surrounding the approach were also taken note of. After this part of data collection, approach speed was measured using the radar gun. The vehicle was parked in the parking lane so that the vehicle being targeted is not affected by the

presence of the stationary queue at the approach. Care was also taken to ensure that the driver in the vehicle being targeted doesn't see the radar. This is because the drivers usually slow down on seeing the radar gun. One person was measuring the speed of the oncoming vehicles and calling out the speed displayed on the radar gun for the other person to record them on the prescribed form according to the directional lane in which the vehicle traversed while clearing the observer. The minimum number of required speed measurements at each intersection approach was determined from the procedures explained in the Manual of Transportation Engineering Studies [27]. The minimum sample required was obtained as 30 vehicles.

### 3.1.5 Data Analyses

After the required data was collected, a preliminary analyses of the traffic data collected was performed. To ensure the quality of data collected, tests on reliability and repeatability of rear-end conflict observations were carried out.

The second stage which involved validation of previously built rear-end conflict models, a null hypothesis was formulated stating that the distributions of the observed and predicted number of conflicts are the same. This hypothesis was tested using a Chi-Square goodness of fit test.

The third stage consisted of selecting promising new variables which were likely to improve the model. The promising new variables selected were derived basically from four categories of data namely approach speed, number of intersections within some specific distance, signal timing plans and roadway features.

In the approach speed category average approach speed, coefficient of variance of approach speed, ratio of variance approach speed to average approach speed and

85th percentile approach speed were examined.

In the number of intersections within some specific distance category, number of intersections within half a mile and number of intersections within one kilometer were studied.

From the signal timing plan category, ratio of Field yellow plus Allred/ ITE yellow plus Allred was considered. In the category of roadway features Volume/Capacity and square of Volume/Capacity were examined.

A Pearson correlation analyses followed by regression analyses was performed using the SAS package to obtain the best model for prediction of rear-end conflicts. This newly built model was compared with the previously built models for prediction of rear-end conflicts in terms of goodness of fit. Also, this newly built model was validated using an independent data set. A Chi-Square test was conducted for this purpose.

### 3.1.6 Simulation Case Study

The last stage involved testing the adequacy of calibrated *TRANSYT-7F* parameters (Platoon Dispersion Factor and Stops Reduction Curve) in obtaining equivalent number of field stops through simulation runs. For this purpose, Stops and Volume data was collected simultaneously on the approaches of the arterial with three consecutive signalized intersections and having a common cycle length. Roadway features and signal timing plans at each of the three signalized intersections were also taken note of.

To test the adequacy of calibrated *TRANSYT-7F* parameters, the following four different runs were performed.

1. With the default stops reduction curve and default platoon dispersion factor

2. With the default stops reduction curve and the calibrated platoon dispersion factor found by Ratrout [2]

3. With the calibrated Stops reduction curve [5] and the default Platoon dispersion factor

4. With the calibrated Stops reduction curve and the calibrated Platoon dispersion factor

A paired t-test was performed between observed field percentage of stops and percentage of stops obtained from the best simulation run to test the hypothesis that there is no significant difference between observed percentage of stops and simulated percentage of stops obtained using the calibrated parameter values.

# Chapter 4

# Validation and Improvement of Rear-end Traffic Conflict Model

## 4.1 General

This chapter is concerned with the validation and improvement of Al-Ofi's rear-end traffic conflict model. Initially, a preliminary analysis of the traffic data collected is described and in the second part the statistical tests performed for validation of Al-Ofi's models is discussed. Finally, a comprehensive study made to improve the rear-end conflict model is described. The notations used to denote the variables under study are mentioned below which are used through out this manuscript to represent these variables.

1. ASPEED —Average Approach Speed in Km/Hr
2. V/C — Ratio of Volume to Capacity
3. CIRATIO — Ratio of Field Yellow plus All red to ITE Yellow plus All red

4. NINT — Number of intersections within half a mile

5. NINT1KM — Number of intersections within one kilometre

6. CVAR — Coefficient of Variance for Approach Speed observations

7. VARSPEED — Ratio of Variance in Approach Speed to Average Speed

8. VAR — Variance in Speed

9. STOPS — Number of Stops per hour

10. 85SPEED — 85th Percentile Average Speed in Km/Hr

11. VCSQ — Square of Volume over Capacity ratio

12. RCONF — Total Rear-end Conflicts per hour

## 4.2 Preliminary Analyses of Data

The data collected at each intersection approach comprised of observed number of stops, volume, signal splits, approach speed, along with the rear-end traffic conflicts. This data was statistically analyzed using the SAS statistical package [28]. Some of the descriptive statistics for each category of data collected are as shown in Table 4.1. It can be seen from the table that the mean and standard deviation for rear-end conflict observations is 4.5 and 2.595 respectively.

Figure 4.1 shows the bar chart indicating percentage contribution of each type of rear-end conflict to the total number of rear-end conflicts.

As can be seen from the Figure 4.1, the lane change conflict has the highest percentage of the total number of rear-end conflicts. The reason for this could be

Table 4.1 Summary of data utilized for study (continued on next page)

| APPROACH | RCONF | STOPS | ASPEED | CIRATIO | V/C | NINT | VAR | VARSPEED | 85SPEED | NINT1KM | CVAR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KAAziz/10 NB | 10 | 646 | 62 | 0.678 | 0.62 | 0 | 242.69 | 3.92 | 81 | 0 | 0.251 |
| KAAziz/10 SB | 5 | 466 | 58 | 0.672 | 0.64 | 1 | 171.44 | 2.93 | 76 | 2 | 0.225 |
| Makkah/15 NB | 2 | 339 | 41 | 0.607 | 0.44 | 2 | 73.97 | 1.82 | 54 | 2 | 0.209 |
| Makkah/15 SB | 2 | 305 | 37 | 0.579 | 0.35 | 0 | 79.28 | 2.11 | 47 | 0 | 0.2406 |
| Meqrin/28 WB | 6 | 479 | 53 | 0.66 | 0.63 | 1 | 78.63 | 1.49 | 64 | 1 | 0.167 |
| Meqrin/28 EB | 7 | 408 | 62 | 0.678 | 0.47 | 1 | 127.84 | 2.06 | 75 | 1 | 0.182 |
| KAAziz/28 NB | 7 | 1090 | 53 | 0.799 | 1 | 1 | 96.34 | 1.81 | 61 | 1 | 0.1851 |
| KAAziz/22 SB | 7 | 628 | 52 | 0.658 | 1.05 | 1 | 97.56 | 1.88 | 65 | 1 | 0.1899 |
| Hmoud/28 WB | 6 | 375 | 56 | 0.669 | 0.39 | 1 | 128.68 | 2.29 | 73 | 2 | 0.2025 |
| Makkah/15 WB | 2 | 237 | 38 | 0.588 | 0.38 | 2 | 26.73 | 0.699 | 43 | 2 | 0.136 |
| Riyadh/15 SB | 4 | 317 | 45 | 0.63 | 0.46 | 1 | 76.99 | 1.7 | 54 | 1 | 0.1949 |
| Makkah/20 EB | 7 | 694 | 44 | 0.625 | 0.98 | 1 | 38.77 | 0.88 | 51 | 2 | 0.1415 |
| Makkah/20 SB | 3 | 258 | 45 | 0.63 | 0.4 | 2 | 32.69 | 0.748 | 49 | 2 | 0.1207 |
| Hmoud/28 EB | 6 | 292 | 52 | 0.65 | 0.36 | 1 | 161.06 | 2.49 | 60 | 1 | 0.244 |

Table 4.1: Summary of data utilized for study (Table Continued from previous page)

| APPROACH | RCONF | STOPS | ASPEED | CIRATIO[1] | V/C | NINT | VAR | VARSPEED | 85SPEED | NINT1KM | CVAR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Riyadh/20 SB | 4 | 332 | 45 | 0.63 | 0.4 | 1 | 32.57 | 0.729 | 50 | 2 | 0.126 |
| Riyadh/15 NB | 3 | 279 | 44 | 0.625 | 0.34 | 1 | 93.31 | 2.12 | 56 | 1 | 0.219 |
| KAAziz/22 NB | 7 | 499 | 52 | 0.658 | 0.42 | 1 | 54.78 | 1.088 | 57 | 2 | 0.142 |
| Hmoud/28 EB | 6 | 292 | 64 | 0.68 | 0.32 | 0 | 161.01 | 2.495 | 83 | 0 | 0.198 |
| Riyadh/25 WB | 0 | 131 | 49 | 0.648 | 0.31 | 0 | 61.69 | 1.26 | 56 | 1 | 0.16 |
| Makkah/25 WB | 1 | 140 | 44 | 0.625 | 0.38 | 2 | 62.79 | 1.415 | 53 | 2 | 0.18 |
| Meqrin/22 NB | 1 | 89 | 45 | 0.63 | 0.13 | 1 | 89.12 | 1.977 | 56 | 2 | 0.209 |
| Riyadh/20 EB | 3 | 252 | 47 | 0.639 | 0.36 | 1 | 91.7 | 1.939 | 59 | 2 | 0.203 |
| Mean | 4.5 | 388.54 | 49.45 | 0.648 | 0.492 | 1 | 94.52 | 1.811 | 60.13 | 1.36 | 0.187 |
| Std.dev | 2.595 | 224.75 | 7.62 | 0.043 | 0.238 | 0.617 | 53.13 | 0.776 | 11.12 | 0.72 | 0.038 |
| Variance | 6.738 | 50513.5 | 58.069 | 0.0019 | 0.057 | 0.38 | 2823.34 | 0.602 | 123.83 | 0.528 | 0.0014 |

[1]See section 4.1 for the meaning of the notations and Appendix C for sample calculations

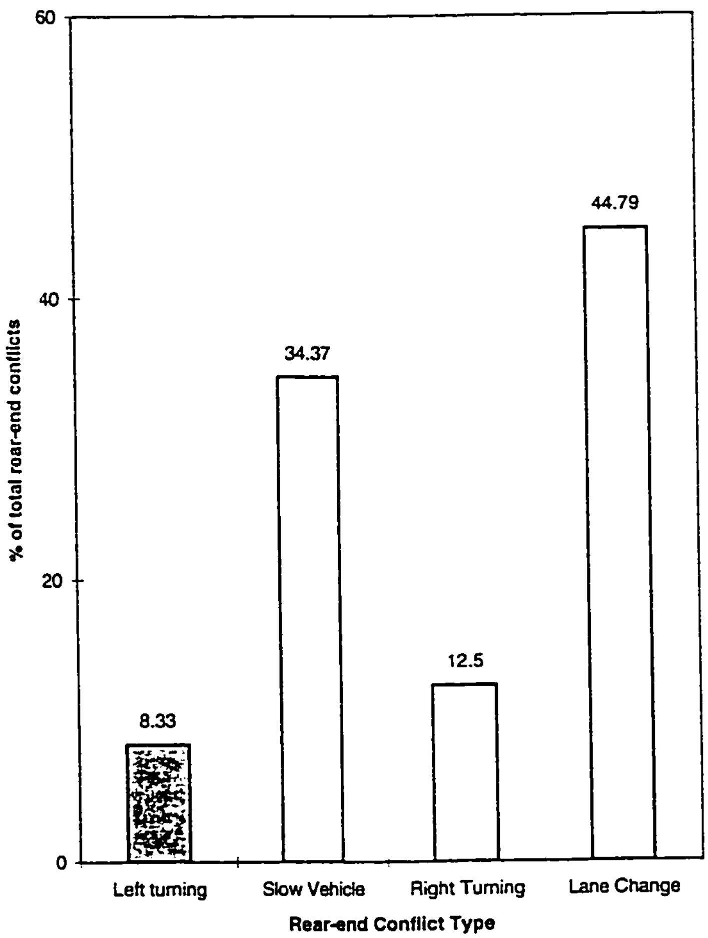



Figure 4.1: Percentage of total rear-end conflicts for each rear-end conflict type

the decision of the driver at the last moment to change lane to either turn left or right direction. A second reason could be the lane changing habit of the drivers without giving a signal. Another probable reason which might contribute to this phenomenon is the driver behaviour observed during this study. Commonly it was noticed that when drivers reach the crossing line of the intersection, they decide to change the lane in order to be nearer to the crossing line so that when the signal changes to green they will be discharged first.

The second highest occurring type of conflict is the slow vehicle type of conflict. The reason for the high occurrence of slow-vehicle type of conflicts could be inadequate clearance interval timing set on the field and lack of signal coordination. The signalized intersections of Al-Khobar region have a uniform yellow interval of 3 seconds which might not be adequate in fulfilling the demand of intergreen interval required to eliminate dilemma zone and as well as reduce the option zone.

The third highest occurring type of conflict is the right turning same direction conflict. This type of conflict did not contribute significantly to the total number of rear-end conflicts. The reason for this could be the low right turning volume. The left turning same direction conflict was the least of all the type of rear-end conflicts. The reason for this could be adequate design of left turning bays at most of the signalized intersection approaches.

Scatter Plots were obtained to study the behaviour of rear-end conflicts against number of stops, volume, approach speed, volume/capacity and clearance interval. Figures 4.2, 4.3, 4.4, 4.5, 4.6 show these plots. With increasing values of all these variables, rear-end conflicts show an increasing trend.

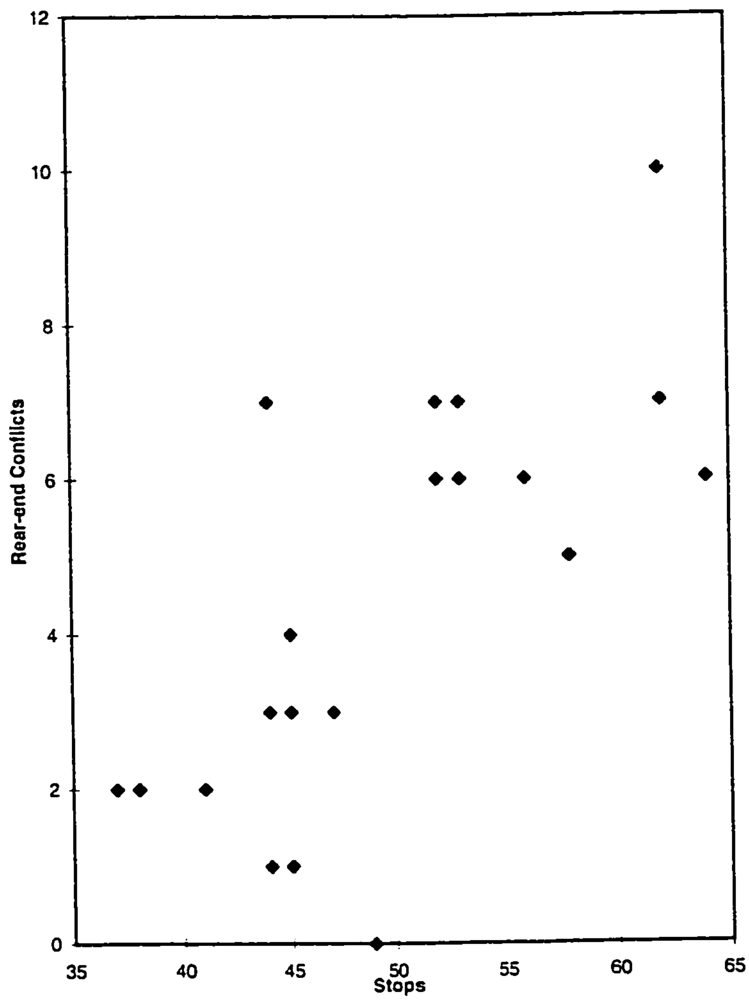



Figure 4.2: Variation of Rear-end Conflicts with stops

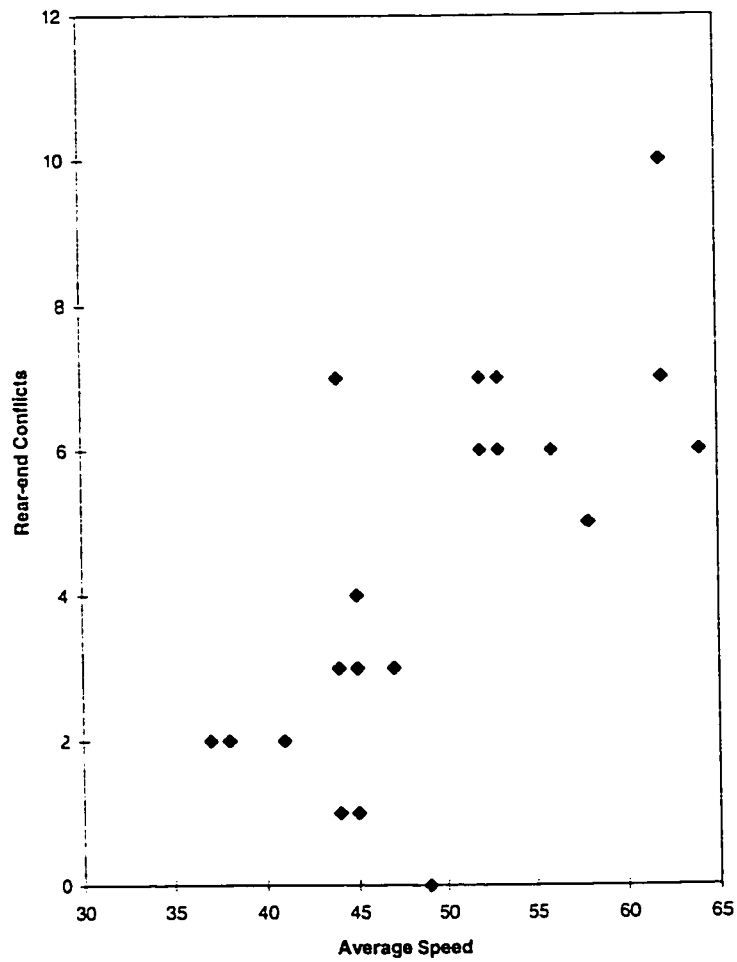



Figure 4.3: Variation of Rear-end Conflicts with Average approach Speed

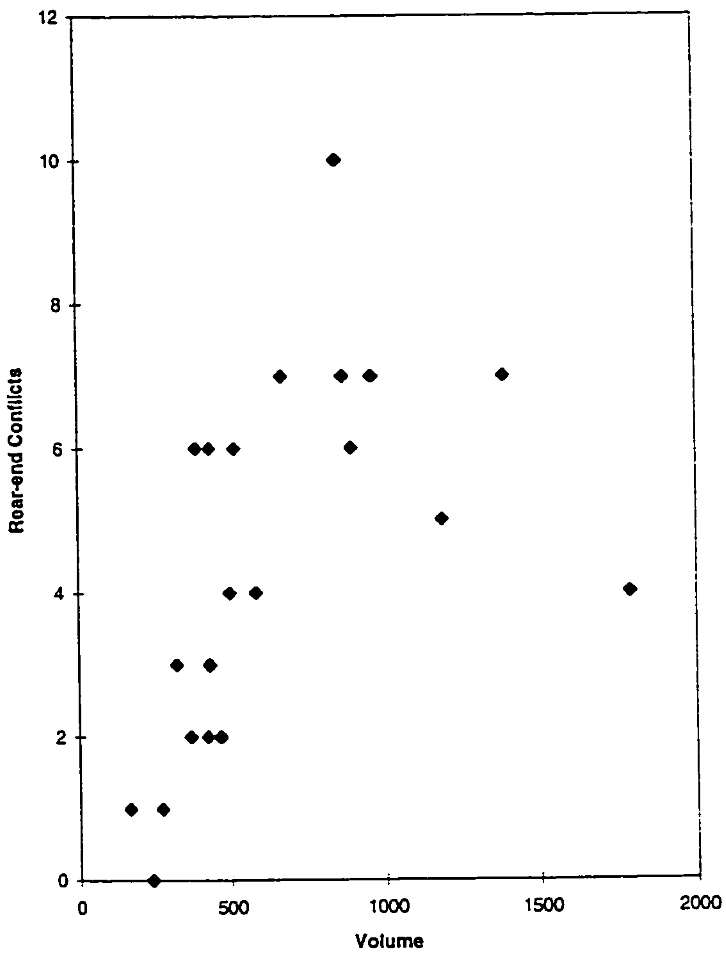



Figure 4.4: Variation of Rear-end Conflicts with Volume

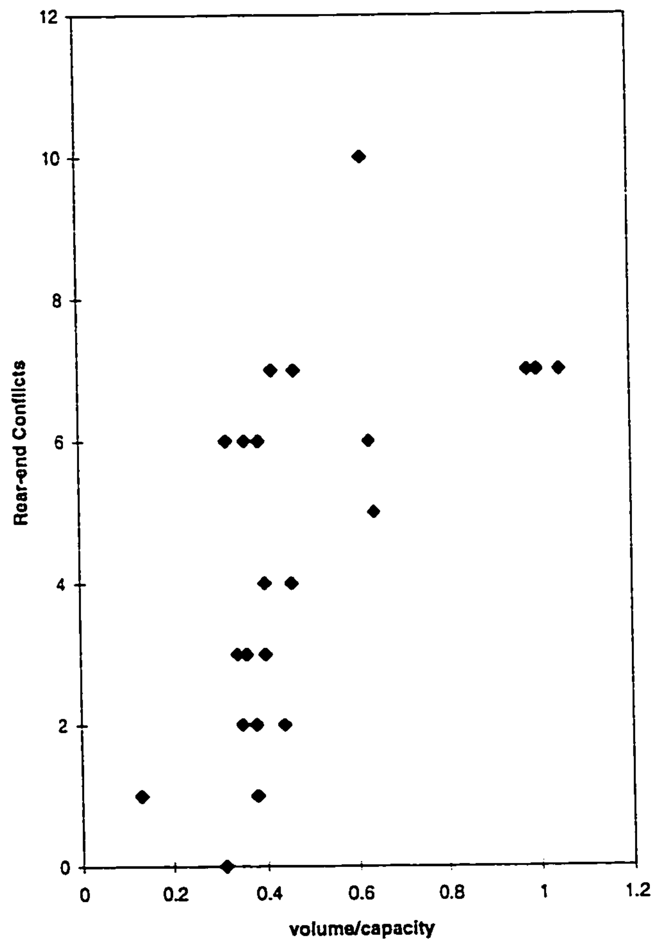



Figure 4.5: Variation of Rear-end Conflicts with Volume/Capacity

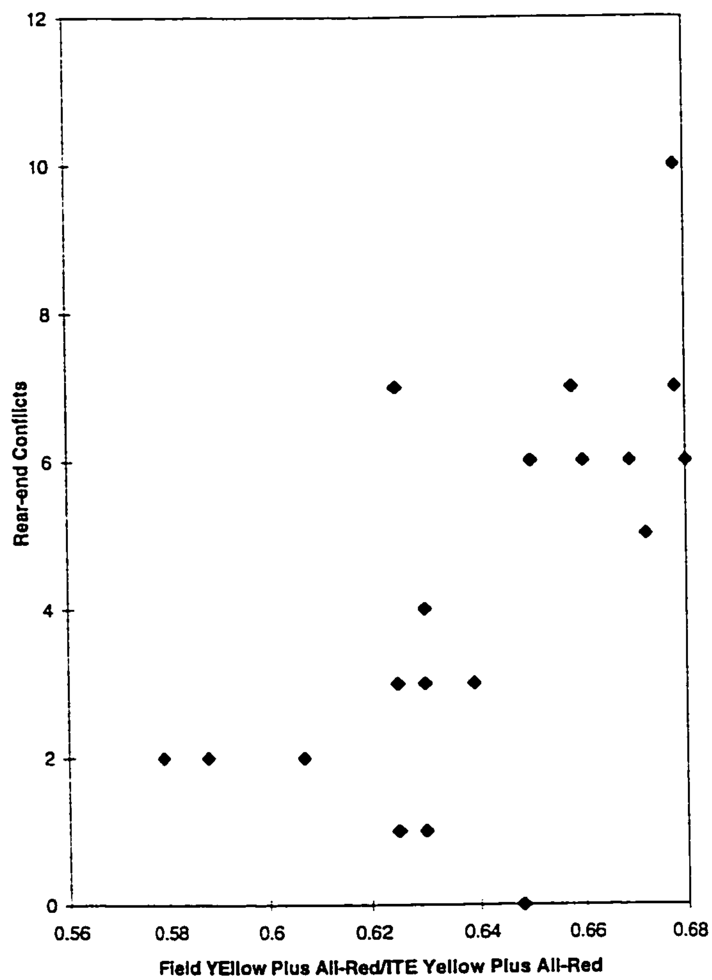



Figure 4.6: Variation of Rear-end Conflicts with Field Yellow Plus Allred/ITE Yellow Plus Allred

### 4.2.1 Check for Sample Size

To check whether the sample size used for collecting the data was adequate. the sample size required was recalculated based on the variance found in rear-end conflicts collected in this study. The standard deviation of rear-end conflicts in this study was obtained as 2.595. The calculations are as shown below.

$$\begin{aligned} n &= \frac{Z_{\alpha/2}^2 \sigma^2}{E^2} \\ &= \frac{1.96^2 \times 2.595^2}{1.75^2} \\ &\approx 9 \; approaches \end{aligned}$$

where

| | | |
|---|---|---|
| E | = | error |
| $\sigma^2$ | = | variance of conflicts per hour |
| n | = | sample size |
| $Z_{\alpha/2}$ | = | normal random variable |
| | | at 95% confidence level. [13] |

Thus the sample size so obtained as 9 intersection approaches is less than the sample size actually considered (22 approaches). This implied that the sample considered was adequate for this study.

### 4.2.2 Reliability and Repeatability

To ensure the quality of conflict data collected, recommendations of NCHRP 219 report [13] were followed and tests on reliability and repeatability of rear-end conflicts were conducted.

One measure of reliability is the degree to which different observers record identical results when observing the same traffic events [13]. The necessity of performing this formal test was eliminated since only one person was observing the rear-end conflicts through out the data collection phase of the study. Thereby this test was not performed.

Repeatability is the ability of an observer to achieve uniformity in the number of conflicts counted repetitively at a given site under "similar" conditions [13]. It is assumed that similar conditions could be obtained by collecting data at the same time of the week days. To check whether the same observer can record the same number of traffic conflicts under similar conditions, traffic conflicts were observed at eight approaches(constituting 36% of the original sample size) where conflict data was already observed previously. This data was collected considering the same starting time of the previously collected data at their respective approaches.

A paired t-test was conducted to test the null hypothesis that there is no significant difference between the initially observed and repeated number of conflicts. As shown in Table 4.2 the t-Statistic obtained was more than t-table value which resulted in null hypothesis being rejected at 5% significance level. This implied that there is a statistical difference between initially observed and repeated number of conflicts. Although it is assumed that similar traffic conditions could be obtained by collecting data at the same time on weekdays, in reality this might not be true.

Table 4.2: Paired T-tests to test repeatability of Rear-end Conflicts

| Stops(previous) | Stops(repeated) | Conflicts(previous) | Conflicts(repeated) | Conflicts/Stops(Previous) | Conflicts/stops(repeated) |
|---|---|---|---|---|---|
| 339 | 397 | 2 | 6 | 0.0058 | 0.0151 |
| 140 | 125 | 1 | 0 | 0.0071 | 0 |
| 694 | 552 | 7 | 8 | 0.01 | 0.014 |
| 646 | 710 | 10 | 12 | 0.0154 | 0.016 |
| 408 | 449 | 7 | 9 | 0.0171 | 0.02 |
| 479 | 470 | 6 | 7 | 0.0125 | 0.0148 |
| 1090 | 1056 | 4 | 6 | .0036 | 0.0056 |
| 279 | 312 | 3 | 3 | 0.0107 | 0.00961 |
| T-value | .0209 | T-value | 2.582 | T-value | 0.977 |
| | | | | T-table (0.05) | 1.895 |

The reason for this difference in conflict counts might be attributed to changing traffic characteristics and the random nature of traffic conflicts and not necessarily because of inconsistent procedure in collecting conflict data. To show that the changing number of stops affected the rear-end conflicts again a paired t-test was performed between ratio of conflicts to number of stops obtained from previous and repeated data sets to test the hypothesis that there is no difference between the initially observed and repeated ratio of conflicts to number of stops. As shown in Table 4.2 the t-statistic obtained was less than the t-table value which resulted in null hypothesis failing to get rejected at 5% significance level. This result implied that the changing number of stops affected rear-end conflicts rather than observer inconsistency.

To have a further insight into this repeatability of rear-end conflict counts two models were built for prediction of rear-end conflicts using number of stops as a representation of traffic characteristics. Only stops were considered due to the fact that it was found from the previous study to be the most important variable affecting the rear-end conflicts. One of these models was built using the previous data set and the other model was built using the repeated data set. These models are as shown in the Table 4.3. For comparison of these estimated model parameters hypotheses were

Table 4.3: Comparison of Model Coefficients to assess Repeatability of rear-end Conflicts

| Data Set | Dependent Variable | Intercept | slope |
|---|---|---|---|
| Repeated data set | Rear-end Conflicts | 2.6723 | 0.00727 |
| Original data set | Rear-end Conflicts | 1.1525 | 0.008615 |
| | T-statistic | 0.782 | 1.91 |
| | T-table 5 % significance level | 1.943 | |

formulated stating that the parameter estimates of these models are the same. The coefficients of stops were compared using t-test statistic which is as shown below.

$$t_0 = \frac{\hat{\beta}_1 - \beta_{1,0}}{\sqrt{\frac{MS_E}{S_{xx}}}}$$

where

| | | |
|---|---|---|
| $\hat{\beta}_1$ | = | Estimated slope in one of the regression model |
| $MS_E$ | = | Mean Square Error |
| $\beta_{1,0}$ | = | Estimated Slope in the other regression model |
| $S_{xx}$ | = | Corrected Sum of squares of x [29] |

For comparing the intercept estimates the following test statistic was used.

$$t_o = \frac{\hat{\beta}_0 - \beta_{0,0}}{\sqrt{MS_E[\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}]}}$$

Where

| | | |
|---|---|---|
| $\hat{\beta}_0$ | = | Estimated intercept in one of the regression model |
| $MS_E$ | = | Mean Square Error |
| $\beta_{0,0}$ | = | Estimated intercept in the other regression model |
| $S_{xx}$ | = | Corrected Sum of squares of x |
| n | = | Number of data points used for model building [29] |

In both the cases the value of the calculated t-statistic was found to be less than the t-table value at 5 % significance level. This implied that there was no evidence

for rejection of null hypothesis and the coefficients of these two models could be the same. Thus, from the results of comparison of model coefficients and intercept estimates, it was deduced that there is no significant difference between these two models. This means that there is no strong evidence to suspect that the observer was inconsistent in recording conflict counts and the difference between conflict counts at the same location could be attributed to change in the number of stops.

## 4.3 Validation of Rear-end Conflict Model

The models developed previously by Al-Ofi [5] for prediction of rear-end conflicts are functions of stops obtained at signalized intersection approaches. These models developed are as shown below.

MODEL 1:

$Rear - end\ conflicts(perhour) = 0.01154 \times Stops(perhour)$

$R^2 = 0.869$

MODEL 2:

$Rear - end\ conflicts(perhour) = 2.555 + .00001 \times Stops^2(perhour)$

$R^2 = 0.664$

Although Model 1 was deduced as the best for prediction of rear-end conflicts. Model 2 showing linear relation (without intercept) between rear-end conflicts and stops was built as it was required in that study to incorporate safety into the $TRANSYT$ model. It can be observed that the $R^2$ value for the model without intercept is higher than that for the other model with intercept. This is not because the model without intercept fits the data better than the model with intercept but because $R^2$ is calculated differently for without intercept model. For the model with intercept, $R^2$

is the variability measured by the sum of squares about the mean "$\bar{y}$" accounted by the regression, while for the model without intercept, $R^2$ measures the proportion of variability in "y" about the origin explained by regression. Hence these two models cannot be compared in terms of $R^2$. For validation of these two models, traffic data was collected from 22 intersection approaches of Al-Khobar region as described in chapter 3. The following subsections deal with the formulation of hypothesis for model validation and the test conducted to check such a hypothesis.

### 4.3.1 Formulation of Hypothesis

To validate Al-Ofi's rear-end traffic conflict models hypotheses about their distributions was formulated as shown below.

$H_0$: The distributions of observed and predicted number of conflicts are the same

$H_1$: They are not the same

### 4.3.2 Chi-square test

This hypothesis was tested by performing the Chi-square goodness of fit test. The calculations of this test for validation of each of these models is as shown in Table 4.4. The test statistic used for this purpose is as shown below.

$$\chi^2 = \frac{(observed - Predicted)^2}{Predicted}$$

This test-statistic is distributed a $\chi^2$ distribution with n degrees of freedom which is obtained as shown below.

Table 4.4: Chi-Square test for Model Validation

| OBSERVED VALUES | | PREDICTED CONFLICTS | | $\frac{(Observed-Predicted)^2}{Predicted}$ | |
|---|---|---|---|---|---|
| STOPS | CONFLICTS | MODEL1 | MODEL2 | MODEL1 | MODEL2 |
| 646 | 10 | 7.455 | 6.728 | 0.868 | 1.591 |
| 466 | 5 | 5.378 | 4.727 | 0.0265 | 0.015 |
| 339 | 2 | 3.912 | 3.704 | 0.9345 | 0.784 |
| 305 | 2 | 3.520 | 3.485 | 0.6561 | 0.632 |
| 479 | 6 | 5.528 | 4.849 | 0.0403 | 0.272 |
| 408 | 7 | 4.708 | 4.220 | 1.1154 | 1.832 |
| 1090 | 7 | 12.579 | 14.436 | 2.474 | 3.830 |
| 628 | 7 | 7.247 | 6.499 | 0.0084 | 0.0386 |
| 375 | 6 | 4.328 | 3.961 | 0.646 | 1.0492 |
| 237 | 2 | 2.735 | 3.117 | 0.197 | 0.4001 |
| 317 | 4 | 3.658 | 3.560 | 0.0319 | 0.0544 |
| 694 | 7 | 8.009 | 7.371 | 0.127 | 0.0187 |
| 258 | 3 | 2.977 | 3.221 | 0.00017 | 0.0151 |
| 292 | 6 | 3.370 | 3.408 | 2.0531 | 1.9721 |
| 332 | 4 | 3.831 | 3.657 | 0.0074 | 0.0321 |
| 279 | 3 | 3.220 | 3.333 | 0.0149 | 0.0333 |
| 499 | 7 | 5.758 | 5.045 | 0.2676 | 0.7575 |
| 292 | 6 | 3.370 | 3.408 | 2.0531 | 1.9721 |
| 89 | 1 | 1.027 | 2.634 | 0.00071 | 1.0138 |
| 252 | 3 | 2.908 | 3.190 | 0.0029 | 0.0113 |
| 131 | 2 | 1.512 | 2.727 | 0.1576 | 0.1936 |
| 140 | 2 | 1.616 | 2.751 | 0.0914 | 0.2050 |
| | | | CHI-VALUE | 11.776 | 16.726 |
| | | | Degrees of Freedom | 19 | 20 |
| | | | $\chi^2$-table value | 31.41 | 30.14 |

$n =$ *No. of observations - No. of parameters estimated in the model- 1*

In Table 4.4 the model without intercept is referred to as Model 1 and the model with intercept is referred to as Model 2. The Chi-square value for the model with intercept was obtained as 16.726 whereas for the model without intercept the Chi-square statistic was obtained as 11.77.

The critical Chi-Square value from table with 19 and 20 degrees of freedom is 30.14 and 31.41 respectively. This implied that there was no evidence to reject the null hypothesis and the distributions of the observed and predicted number of rear-end conflicts could be the same. Thus both the models were found to satisfactorily fit the validation data set. The Chi-square statistic for the model without intercept was less than Chi-square statistic for the model with intercept. This suggested that the model without intercept performed better than the model with intercept.

## 4.4 Improvement of Rear-end Conflict Model

After validating Al-Ofi's rear-end traffic conflict models the next step was to make an attempt to improve the model by incorporating some of the new variables which were not tested by Al-Ofi during his calibration effort. In the calibration process of the rear-end traffic conflict model, Al-Ofi [5] had used volume, number of lanes and overlapping phase as independent variables apart from stops in the regression analysis. All these variables were either insignificant or were highly correlated with stops. And finally, the model had only stops as the independent variable.

A number of independent variables were selected to investigate their significance in improving the prediction ability of the two models developed previously. The promising variables for model improvement were derived basically from four broad

categories namely, Roadway features. Signal timing plan, Approach Speed and Number of intersections within some specified distance. The hypothesis in selecting these variables and their expected relation with rear-end conflicts is explained in the following subsection.

### 4.4.1 Selection of Variables for Model Improvement

An increase in the the ratio of volume to capacity induces greater interaction between vehicles and thus increases the chance of conflicts. Hence this variable was selected to study its affect in inducing rear-end conflicts.

Clearance interval ratio which in this study has been defined as the ratio of actual yellow plus all-red observed on the field to the demand yellow plus all-red calculated as defined by ITE's formula [27] for clearance interval timing. This variable has been selected to test the proper design of intergreen interval phase, which is a major contributer to intersection safety because it eliminates, dilemma zone and reduces the option zone [5].

Approach speed is known to affect driver response and distance required to stop. As the speed increases stopping sight distance also increases and hence higher speed is an indication of higher accident potential. Further, the severity of accidents increases with speed. Thereby five versions of speed were selected namely, the average speed, 85th percentile speed, variance in speed observations at each approach, ratio of variance in speed observations at each approach to average speed and coefficient of variance for speed observations at each approach.

As the number of intersections within half a mile increase the number of rear-end conflicts are expected to decrease. This is because the platoon of vehicles moves in a

more compact form (rather than the dispersed form) if the intersections are closely spaced [30]. The distance specifically within half a mile was considered bearing the fact that the intersections spaced at less than half a mile distance usually make the platoon compact and the intersections spaced at more than this distance might allow the platoon to get dispersed. In the dispersed platoon, different vehicles travel with varying speeds [30]. This speed variance is a factor which could induce rear-end conflicts [24]. Consequently the number of intersections within half a mile, and the number of intersections within one km were examined to capture their contribution to rear-end conflicts.

### 4.4.2 Pearson-Correlation Analyses

In order to have an insight of relationships between the independent variables selected and the rear-end conflicts as well as between the independent variables themselves, a Pearson-correlation analyses was carried out using the SAS statistical package. The results are shown in Table 4.5.

As can be seen from the Table 4.5, stops has the highest correlation with the rear-end conflicts as expected with an r-value of 0.74. The next highly correlated variable is the approach speed with a r value of 0.70. The number of intersections within half a mile is negatively correlated with rear-end conflicts, indicating that as the number of intersections within half a mile increase, the number of rear-end conflicts decrease. This is explained in the previous section. Besides observing the correlation between the dependent and independent variables, the correlations between the independent variables were also noted.

High correlations between the independent variables can substantially affect the

Table 4.5: Correlation Coefficients (Significance)

| | Stops | Aspeed[2] | Var | VarSpeed | 85Speed | V/C | Ciratio | Nint | Nint1km | Cvar | Vcsq | Rconf |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stops | 1 (0.0) | 0.35 (0.1125) | 0.22 (0.3316) | 0.16 (0.4581) | 0.27 (0.2086) | 0.87 (0.0001) | 0.7 (0.0002) | -0.13 (0.5423) | -0.19 (0.3834) | 0.0009 (0.9968) | 0.84 (0.0001) | 0.74 (0.0001) |
| Aspeed | | 1 (0.0) | 0.75 (0.0001) | 0.6 (0.003) | 0.94 (0.0001) | 0.2 (0.358) | 0.69 (0.0004) | -0.44 (0.0377) | -0.37 (0.0853) | 0.25 (0.20) | 0.15 (0.4841) | 0.7 (0.0002) |
| Var | | | 1 (0.0) | 0.96 (0.0001) | 0.85 (0.0001) | 0.063 (0.7804) | 0.43 (0.0433) | -0.506 (0.0163) | -0.53 (0.0099) | 0.77 (0.0001) | 0.02 (0.926) | 0.55 (0.0072) |
| VarSpeed | | | | 1 (0.0) | 0.76 (0.0001) | 0.017 (0.9373) | 0.32 (0.1391) | -0.5 (0.0156) | -0.55 (0.008) | 0.89 (0.0001) | -0.012 (0.9555) | 0.42 (0.0496) |
| 85Speed | | | | | 1 (0.0) | 0.1613 (0.4734) | 0.575 (0.005) | -0.471 (0.0268) | -0.41 (0.0525) | 0.455 (0.0331) | 0.11 (0.608) | 0.633 (0.0015) |
| V/C | | | | | | 1 (0.0) | 0.48 (0.0225) | 0 (1.00) | -0.08 (0.7084) | -0.106 (0.6374) | 0.98 (0.0001) | 0.606 (0.0028) |
| Ciratio | | | | | | | 1 (0.0) | -0.238 (0.2854) | -0.22 (0.3088) | 0.097 (0.6646) | 0.48 (0.0236) | 0.586 (0.0041) |
| Nint | | | | | | | | 1 (0.0) | 0.74 (0.0001) | -0.405 (0.0609) | -0.01 (0.945) | -0.29 (0.179) |
| Nint1km | | | | | | | | | 1 (0.0) | -0.5 (0.0163) | -0.07 (0.754) | -0.32 (0.136) |
| Cvar | | | | | | | | | | 1 (0.0) | -0.106 (0.6368) | 0.135 (0.5467) |
| Vcsq | | | | | | | | | | | 1 (0.0) | 0.54 (0.0091) |
| Rconf | | | | | | | | | | | | 1 (0.0) |

[2]See section 4.1 for the meaning of the notations used

results of multiple regression analysis. As can be seen from Table 4.5, stops are highly correlated with the ratio of volume to capacity, square of volume to capacity ratio, and clearance interval, with an r-value of 0.87, 0.84 and 0.70 respectively. Also, clearance interval ratio is found to be highly correlated with approach speed, with an r-value of 0.69.

The high correlation between stops and ratio of volume to capacity is logical because the number of stops increase as the ratio of Volume to Capacity increases. Also, the high correlation between clearance interval and speed could be due to the fact that speed is used to find the demand yellow interval which is the denominator part of the clearance interval ratio variable. One variable (which is most significantly correlated with rear-end conflicts) was selected from each of the four broad categories of independent variables mentioned earlier to avoid the problem of multi-collinearity. This process of examination of the correlations between the independent variables and the dependent variable resulted in many of the independent variables getting dropped from further analyses. The independent variables left out were:

1. Stops
2. Average approach speed
3. Volume/capacity
4. Number of intersections within one Kilometer distance.
5. Clearance interval ratio

## 4.5 Model Building

To establish the relationship between the dependent and independent variables remaining after the correlation analyses, the SAS statistical package was utilized. Models were built with various combinations of the independent variables using stepwise regression; forward selection, backward elimination and maximum $R^2$ procedures were carried out to obtain the best regression model. To check the significance of coefficients a t-test was carried out for each individual coefficients of all the models built. The level of confidence was set as 95 %, which means that if the significance of the t-value calculated is less than 0.05 then the null hypothesis ($H_o : \beta_1 = \beta_2 = \beta_i = 0$) is rejected and it is concluded that the coefficient is significantly different from zero and that the variable is significantly related to the dependent variable. Table 4.6 summarizes the models built whose coefficient estimates were significant at 5% significance level.

Of all the models built Model 3 with Stops and Approach Speed as independent variables is found to be the best in terms of $R^2$ (in the category of models with intercept). Although, Model 5 which is built without intercept has a higher $R^2$ value than Model 3 it cannot be compared with Model 3 in terms of $R^2$ as the $R^2$ values are calculated differently for with and without intercept models. Model 5 was built to compare it with Al-Ofi's model (Model 1). It was observed that Model 1 and Model 5 have more or less the same $R^2$ values. The need to constrain Model 3 by removing the intercept was not required in this study. For Model 3 shown below normal probability plot (See Appendix D) was examined to check the assumption of normality in regression analyses and it was observed that this model satisfies the

Table 4.6: Summary of Models built

| MODEL # | COEFFICIENT ESTIMATES (SIGNIFICANCE) FOR VARIABLES | | | | SUMMARY STATISTICS | | |
|---|---|---|---|---|---|---|---|
| | INTERCEPT | STOPS | ASPEED [3] | STOPSQ | $R^2$ | $Adj.R^2$ | F-Statistic |
| MODEL 3 | -6.6413 (0.0017) | 0.006566 (0.0001) | 0.1737 (0.0002) | | 0.785 | 0.762 | 34.68 (0.0001) |
| MODEL 4 | 1.1525 (-0.1489) | 0.008615 (0.0001) | | | 0.556 | 0.534 | 25.09 (0.0001) |
| MODEL 5 | | 0.01086 (0.0001) | | | 0.881 | 0.8754 | 155.51 (0.0001) |
| MODEL 6 | -7.423 (0.0121) | | 0.241091 (0.0002) | | 0.5009 | 0.476 | 20.07 (0.0002) |
| MODEL 7 | 3.3275 (0.0001) | | | 5.886E-06 (0.0044) | 0.339 | 0.3065 | 10.28 (0.0044) |
| MODEL 8 | -6.387 (0.0111) | | 0.20283 (0.0003) | 4.29E-06 (0.0057) | 0.669 | 0.634 | 19.24 (0.0001) |

[3] See section 4.1 for the meaning of notations used

normality assumptions. Again for Model 3 the plot between the predicted value of rear-end conflicts versus the residuals were plotted (See Appendix D) to assess the fit of the model and to check whether any transformation was needed. It was observed that the points on the plot do not show any significant pattern and appear to be random. Thereby, it was deduced that Model 3 with stops and speed as independent variables satisfies the normality assumptions and no transformation is needed for this Model. Consequently Model 3 was inferred as the best of all the models built. This particular model from now on would be referred to as the newly built model. Model 3 is as shown below.

MODEL 3:

$REC = -6.641 + .00656 \times Stops + 0.173 \times Speed,$

$R^2 = 0.785$

Where

| | | |
|---|---|---|
| REC | = | Rear-end conflicts per hour |
| Stops | = | Number of stops per hour |
| Speed | = | Average Speed in km/hour |

## 4.6 Comparing the fit of Newly built and Previously built Models

An independent data set which was not used for the purpose of model building (data set used for repeatability check) was utilized to compare the goodness of fit of previously built models and the newly built model. A Chi-Square test was performed

for this purpose. Table 4.7 shows the calculations of this test. It was found that the calculated Chi-Square value for the newly built model was less than the calculated Chi-Square values of the previously built models. This suggested that using the newly built model smaller differences between observed and predicted values could be obtained than by using the previously built models. However because of the small sample size utilized for comparing the fit of models a strong statement cannot be made stating that the newly built model has better capability of predicting rear-end conflicts than the previously built models. Thereby it is recommended that the newly built model be used whenever average approach speed data is available and if not the previously built models could as well be used to predict rear-end conflicts.

## 4.7 Validation of Newly built Model

The Chi-Square test calculations in Table 4.7 also served the purpose of validation of newly built model. This Chi-Square test tested the following null hypothesis.

$H_0$: The distributions of observed and predicted number of conflicts obtained using the newly built model are the same

$H_1$: They are not the same

As can be seen from the Table 4.7 the Chi-Square calculated value for the newly built model (Model 3) was obtained as 9.3678 which is less than Chi-Square table value of 9.49 obtained with 4 degrees of freedom.

Thus, it was inferred that there was no statistical evidence to reject the null hypothesis and the distributions of the observed and predicted number of conflicts could be the same. Thereby the newly built model was validated.

Table 4.7: Chi-Square test for validation of Newly built Model

| Observed Values | | | $\frac{(Observed-Predicted)^2}{Predicted}$ | | |
|---|---|---|---|---|---|
| STOPS | ASPEED | RCONF. | MODEL 1[4] | MODEL 2[5] | MODEL 3[6] |
| 710 | 62 | 12 | 9.223 | 2.553 | 1.172 |
| 397 | 41 | 6 | 0.439 | 0.845 | 2.748 |
| 125 | 44 | 0 | 1.443 | 2.711 | 1.822 |
| 552 | 44 | 8 | 0.417 | 1.026 | 2.460 |
| 449 | 62 | 9 | 2.814 | 4.291 | 0.523 |
| 470 | 53 | 7 | 0.458 | 1.049 | 0.322 |
| 1056 | 55 | 6 | 3.14 | 4.333 | 1.502 |
| 312 | 44 | 3 | 0.100 | 0.079 | 0.00082 |
| | | Chi- Value | 18.034 | 16.887 | 9.3678 |

[4] MODEL1 Previously built model without intercept
[5] MODEL2 Previously built model with intercept
[6] MODEL3 Newly built model

# Chapter 5

# Adequacy of Calibrated TRANSYT Model

## 5.1 General

*TRANSYT-7F* is one of the most popular and widely used optimization package. It has been developed substantially over the last decade and has been subjected to extensive validation and calibration in many countries including Saudi Arabia. Ratrout [2] calibrated the platoon dispersion factor in *TRANSYT-7F* and Al-Ofi [5] calibrated stops reduction curve in *TRANSYT-7F* model for the traffic conditions of Eastern province of Saudi Arabia. The study site chosen by Al-Ofi was King Abdul Aziz street of Al-Khobar region in the Eastern province of Saudi Arabia. This chapter is mainly concerned to test whether this calibrated *TRANSYT-7F* simulation model can be used to obtain number of stops in agreement with those observed in the field, along arterials other than that used for the above two studies. If the *TRANSYT* model can simulate the number of stops, the prediction of rear-end

conflicts can be achieved (via model obtained in this study) without going through the difficult task of observing stops in field.

## 5.2 Previous Calibration Studies

Calibration is a technique by which analysts determine the appropriate parameter values required in the model to simulate the real world phenomenon as closely as possible.

### 5.2.1 Ratrout's Calibration Effort

Ratrout [2] calibrated platoon dispersion factor in *TRANSYT-7F* model for the study area of Dammam and Al-khobar. He showed that the model simulates the real platoon dispersion behaviour; and suggested the platoon dispersion factors for different kinds of links in the study area. During this study he also determined the driver performance characteristics data which include the saturation flow, start-up lost time, green extension time, average vehicle spacing and platoon dispersion factors. These data depend on the behaviour of drivers in the study area. They are as shown in Tables 5.1 and 5.2.

### 5.2.2 Al-Ofi's Calibration Effort

The number of stops were not checked against the field stops in Ratrouts study since it was not one of the objectives of his work.

Table 5.1: Data collected by Ratrout (2) in his study

| The Study Area | | |
|---|---|---|
| Extension of effective green | Average Vehicle Spacing (dm) | Platoon Dispersion Factors[1] |
| 3 | 70 | Low Friction 28 |
| | | Moderate Friction 40 |

[1] Platoon Dispersion Factor 40 used on all the links of the study arterial

Table 5.2: Driver performance characteristics collected by Ratrout(2)

| City of Dammam | | | City of Al-Khobar | | |
|---|---|---|---|---|---|
| Start-up | Saturation Flow rate | | Start-up | (c)Saturation Flow rate (vphg/lane) | |
| Lost time | (vphg/lane) | | Lost time | (vphg/lane) | |
| (sec) | Thru | Turn | (sec) | Thru | Turn |
| 2 | 1720 | 1690 | 2 | 1780 | 1650 |

Since Al-Ofi had obtained the number of stops as the most important measure of effectiveness (MOE) directly related to number of accidents, he compared the field stops with the number of stops obtained through simulation using *TRANSYT-7F*. He achieved the calibration of *TRANSYT* stops reduction curve by modifying the default stops reduction algorithm until a good simulation of stops was obtained. The study area chosen for his study was King Abdul Aziz street in Al-khobar city of Saudi Arabia. Table 5.3 shows the series of curves that were used in comparing the actual field values and the model percentage of stops using these curves. Curve 4 gave the best simulation of the number of stops. He performed a paired t-test to prove that there is no statistical difference between the observed number of stops and simulated number of stops and thus achieved the calibration of *TRANSYT* model.

## 5.3 Data Collection for Simulation

The process of simulation requires that all the signalized intersections considered in the study arterial must have a common cycle length or the cycle length should be a multiple of cycle length at other intersections on the arterial being considered. The volume on the arterial must neither be too low nor saturated. Keeping these facts in mind, Riyadh street in Al-Khobar region was selected as the study arterial. The data required for simulation can be grouped into four categories:

1. Physical Description of the Arterial
2. Volume Data at each Intersection
3. Signal timing plan
4. Driver Performance Characteristics data

Table 5.3: Stops reduction curves used by Al-Ofi Source [5]

| Delay (Seconds) | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | Default | 20 | 50 | 65 | 76 | 83 | 88 | 93 | 95 | 97 | 99 | 100 | 100 | 100 | 100 |
| | t | Curve 1 | 5 | 14 | 24 | 39 | 53 | 69 | 80 | 85 | 90 | 93 | 96 | 98 | 99 | 100 |
| % | o | Curve 2 | 2 | 5 | 14 | 20 | 33 | 45 | 60 | 72 | 81 | 89 | 94 | 98 | 99 | 100 |
| | p | Curve 3 | 1 | 2 | 5 | 10 | 19 | 28 | 40 | 55 | 73 | 87 | 95 | 98 | 99 | 100 |
| | s | Curve 4 | 1 | 3 | 7 | 15 | 24 | 35 | 58 | 63 | 78 | 88 | 93 | 97 | 99 | 100 |

### 5.3.1 Physical Description of the Arterial

This category of data includes the number of lanes and link lengths. Figure 5.1 shows the physical layout of the arterial links and intersections. It is a divided arterial with three lanes in each direction. All the signalized intersection approaches have left turn bays. The cross streets are the 15th street, 20th street and 25th street. The arterial is a mixed commercial and residential area, with parking allowed along the arterial except near the intersections, where the parking lanes change to right turn lanes. The intersections have adequate sight distances, where drivers can see the signal long before the intersection.

### 5.3.2 Volume and Speed Data

The volumes at each intersection classified by movement are needed for the model. This data was collected by three graduate students at each of the three signalized intersections. They were trained to use the manual tally boards and the volume count procedure was explained to them clearly. The time of the day chosen was from 9:15 to 10:15 on a weekday morning. During this time none of the intersections were neither saturated nor the volume was too low. The volume/capacity ratios were less than 0.95 and greater than 0.4. Over saturated periods were avoided intentionally because the *TRANSYT* model is not reliable when intersection approaches are near saturation. The link to link volumes were estimated using a procedure explained in the *TRANSYT* manual. This procedure is explained by the example, using the section of an arterial, where there is an upstream and downstream node. There are three links on the south bound approach between the two nodes: the south bound thru movement, the right turn movement at the downstream node and the left turn

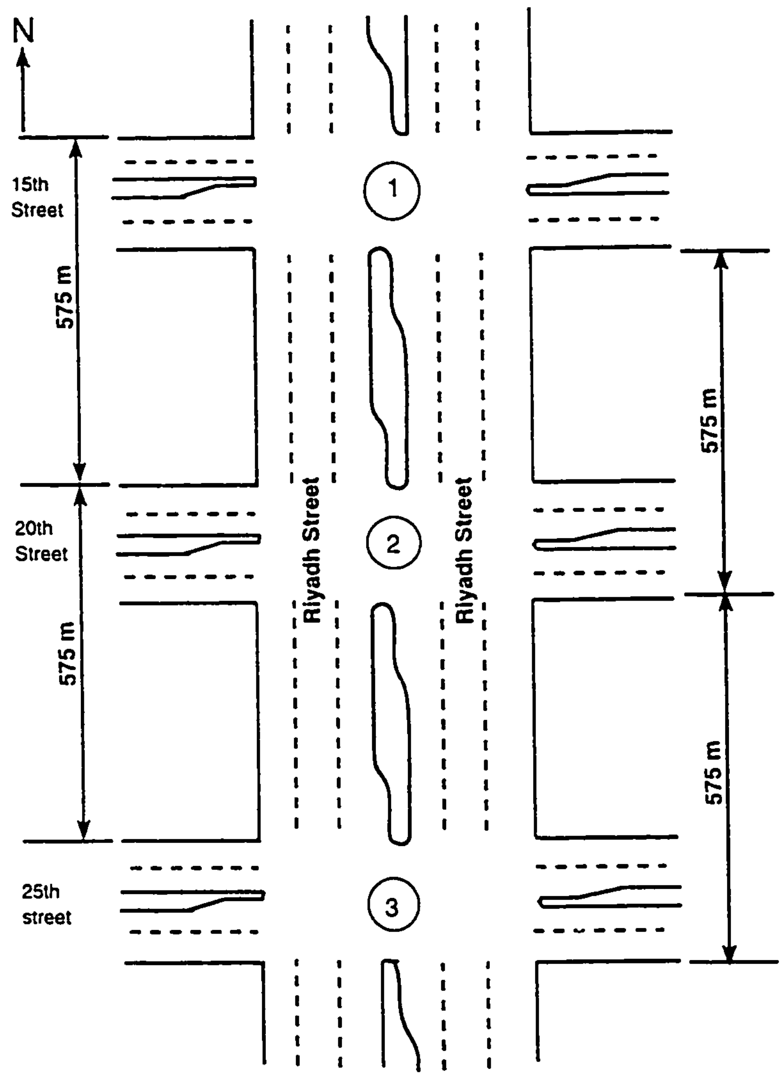



Figure 5.1: Physical Layout of the Arterial

at the downstream node. The link-to-link volumes denote the source of the volumes at the downstream movement from the upstream node. As suggested by the *TRANSYT* manual, the turning movement volumes at the downstream node are assumed to be from the upstream thru movement only, while the through movement at the downstream node are to be from the upstream turning and through movements. Figure 5.2 explains this idea graphically. The turning lanes on the main arterial are considered to be separate links while the through lane is considered to be one link. Figure 5.3 shows the coding scheme that was used in the *TRANSYT* model. Tables 5.4 and 5.5 show the volume data collected for one hour duration.

The sample size required for obtaining the speed along the links was obtained using the procedures explained in the manual of Traffic Engineering Studies [27]. The speed data was collected according to the procedures of floating car technique explained in the manual of Traffic Engineering studies [27]. Table 5.6 shows the average speed values obtained on each link of the arterial. The outside links which include every link connecting a node on the arterial to another node outside the arterial listed nodes were assumed to have a speed equal to the speed on the link following it on the arterial under study. The Stops data was also collected simultaneously along with the volume data.

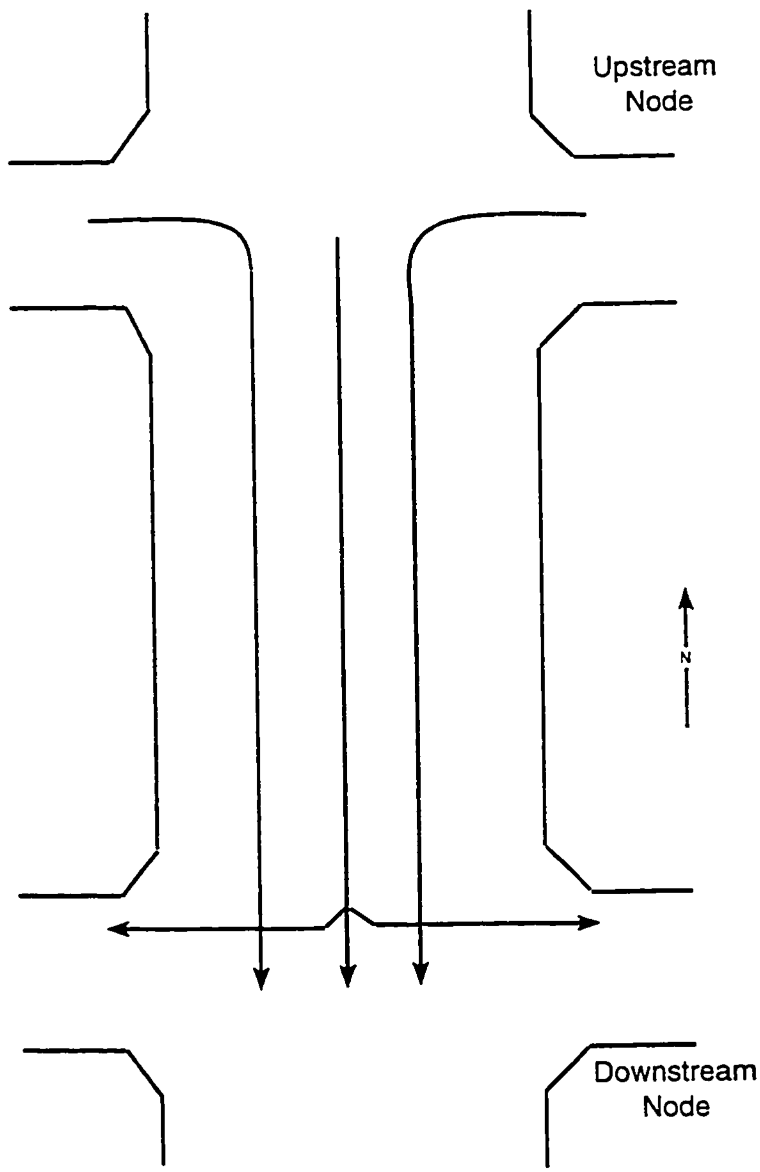



Figure 5.2: Assumptions about Link-Link Volume Estimation

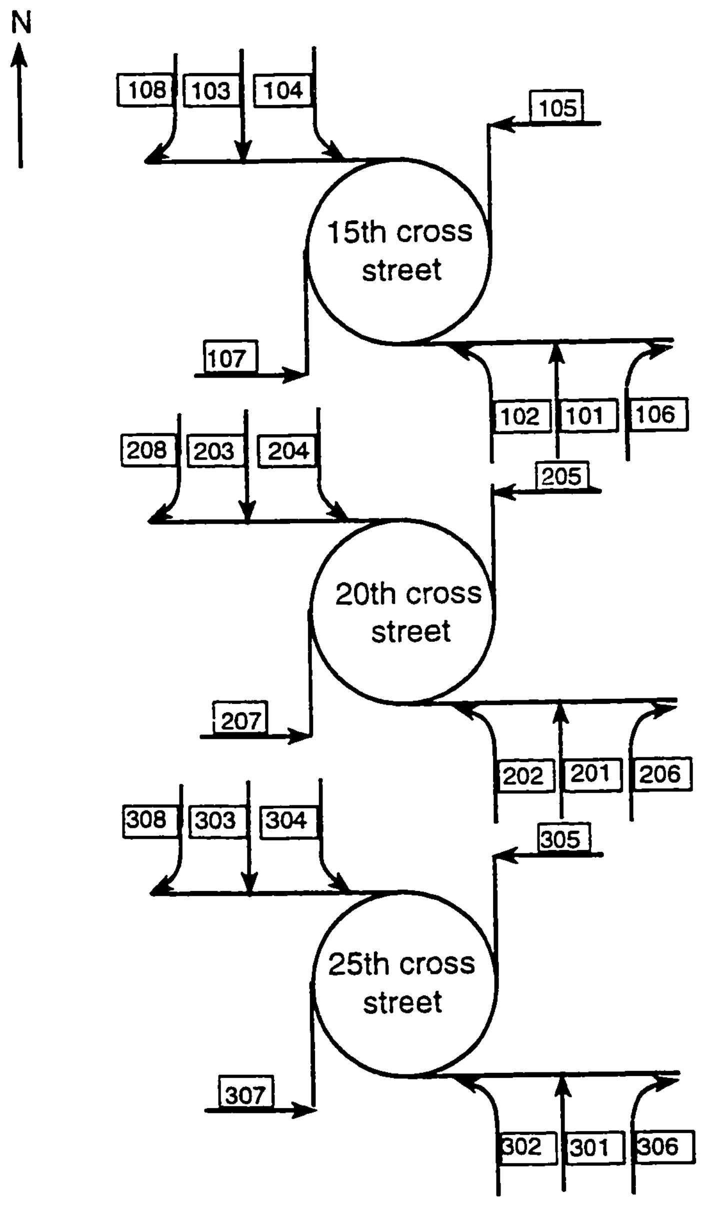



Figure 5.3: Coding Scheme Adopted for Simulation purpose

Table 5.4: Volume data for simulation

| Approach Name | Volumes(vehicles per hour) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | East Bound | | | | South Bound | | | |
| | Right | Thru | Left | Total | Right | Thru | Left | Total |
| Riy/15 | 26 | 182 | 69 | 277 | 69 | 281 | 37 | 387 |
| Riy/20 | 69 | 169 | 75 | 313 | 43 | 198 | 67 | 308 |
| Riy/25 | 71 | 70 | 49 | 190 | 75 | 118 | 143 | 336 |

Table 5.5: Volume data for simulation

| Approach Name | Volumes(vehicles per hour) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | North Bound | | | | West Bound | | | |
| | Right | Thru | Left | Total | Right | Thru | Left | Total |
| Riy/15 | 29 | 269 | 110 | 408 | 17 | 126 | 43 | 186 |
| Riy/20 | 28 | 205 | 109 | 242 | 63 | 161 | 50 | 274 |
| Riy/25 | 42 | 140 | 91 | 273 | 41 | 112 | 91 | 244 |

Three graduate students collected the stops and nonstops data at the intersection approaches. The external links were avoided. because the arrivals are assumed to be random along these links, which might not be true and therefore the simulation ability of the model could not be assessed. Table 5.7 shows the data of stops and non stops at these approaches.

### 5.3.3 Signal Timing Plan

The data about signal timing plan were collected immediately after the volume data collection. Each intersection has four unidirectional phases. That is, the green phase is given to one approach at a time. All intersections had a common cycle length of 100 seconds. After each phase there is a three second yellow phase and two second all-red period. At Riyadh/25th street and Riyadh/20th street junctions, the remaining 80 seconds, outside the yellow and all-red periods, are divided into four green phases; 25 seconds for each approach on the arterial and 15 seconds for each approach on cross streets. At Riyadh/15th junction, all the four approaches have an equal green phase length of 20 seconds. The offsets were observed using a electronic stop watch. The stop watch was started at the beginning of green at first intersection and while the stop watch is still ticking the second intersection was reached and the beginning time of green was recorded and similarly the third intersection was reached and begining time of green was recorded. The offsets between the start of green phases of the north bound approaches were 96 seconds and 56 seconds respectively. Figure 5.4 shows the time Space diagram.

Table 5.6: Average Speed (Km/hr) along the links on Riyadh Street

| Speed in Km/Hour | | | |
|---|---|---|---|
| North Bound | | South Bound | |
| 20th-15th | 25th-20th | 15th-20th | 20th-25th |
| 56 | 60 | 52 | 50 |

Table 5.7: Stops (per hour) and Nonstops (per hour) data observed on field

| Approach Name | Stops | Non Stops | % Stops |
|---|---|---|---|
| Riyadh/15 N.B | 300 | 107 | 74 |
| Riyadh/20 N.B | 305 | 79 | 79 |
| Riyadh/25 S.B | 251 | 90 | 73 |
| Riyadh/20 S.B | 153 | 294 | 34 |

### 5.3.4 Driver Performance Characteristics

The driver performance characteristics data include the saturation flow, start-up lost time, green extension time, average vehicle spacing and platoon dispersion factors (A suitable moderate friction, PDF value of 40 was used on all the links considered). These data depend on the behaviour of drivers in the study area. Ratrout [2] collected these data in 1988 in the same study area. In this study it is assumed that the driver's performance characteristics have not changed significantly during the last few years. Hence the data from Ratrout's study were used in this study. These data have already been shown in Tables 5.1, 5.2.

## 5.4 Simulation Results

The data collected for the one hour duration period was entered into the TRANSYT model. To assess the adequacy of the parameters in simulating the field stops, the following different runs were performed.

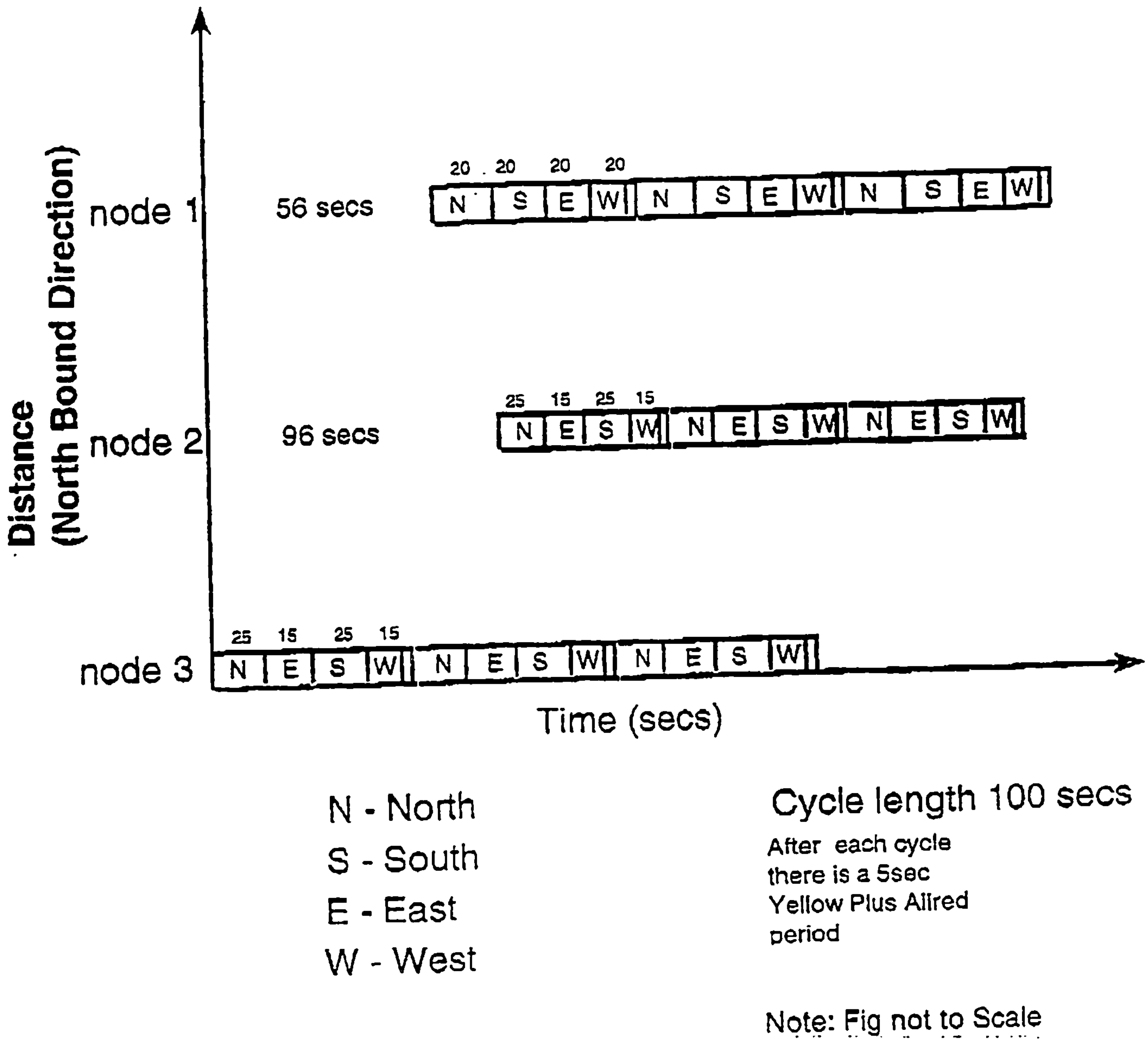



Figure 5.4: Time Space Diagram

1. With the default stops reduction curve and default platoon dispersion factor
2. With the default stops reduction curve and the calibrated platoon dispersion factor found by Ratrout [2]
3. With the calibrated Stops reduction curve [5] and the default Platoon dispersion factor
4. With the calibrated Stops reduction curve and the calibrated Platoon dispersion factor

In each of the above runs, the number and percentage of stops on each approach excluding the exterior links were observed. These results are as shown in Table 5.8.

It can be seen from Table 5.8 that the calibrated Stops reduction curve was effective in reducing the percentage of stops. The *TRANSYT* model over estimated the percentage of stops with the default stops reduction curve. It can also be seen from Table 5.8 that the calibrated platoon dispersion factor did not significantly change the percentage of stops. It was observed that on Riyadh/25th South Bound approach and Riyadh/20th North Bound approach the calibrated stops reduction curve did not change the percentage of stops. The arrrival of platoon on these approaches was observed to be at the beginning of red phase. Platoon arrival on red is associated with large delays and probably because of this reason the calibrated stops reduction curve did not decrease the percentage of stops at these approaches. From this phenomenon it was deduced that calibrated stops reduction curve is more effective in obtaining equivalent percentage of field stops when the signals are properly coordinated and for poorly coordinated signal systems the calibrated stops reduction

Table 5.8: Summary of simulation runs

| Source | Number (percent) of stops for approach | | | |
|---|---|---|---|---|
| | Riyadh/15th | Riyadh/20th | Riyadh/20th | Riyadh/ 25th |
| | North Bound | North Bound | South Bound | South Bound |
| Field Values | 300 (74%) | 305 (79%) | 153 (34%) | 251 (73%) |
| WD SR WD PDF | 328 (80%) | 278 (81%) | 125 (41%) | 286 (85%) |
| WD SR WC PDF | 325 (79%) | 278 (81%) | 128 (42%) | 287 (85%) |
| WC SR WD PDF | 297 (73%) | 276 (80%) | 99 (31%) | 284 (84%) |
| WC SR WC PDF | 294 (72%) | 277 (81%) | 101 (33%) | 286 (85%) |

**WD SR WD PDF** With the default stops reduction curve and default platoon dispersion factor
**WD SR WC PDF** With the default stops reduction curve and the calibrated platoon dispersion factor
**WC SR WD PDF** With the calibrated Stops reduction curve and the default Platoon dispersion factor
**WC SR WC PDF** With the calibrated Stops reduction curve and the calibrated Platoon dispersion factor

curve may not reduce the percentage of stops significantly.

The best run was obtained when the simulation run was performed with the calibrated value of stops reduction curve and default value of platoon dispersion factor (except on Riyadh/20th South Bound approach). In order to prove that the differences between the simulated percentage of stops using the results of best run (with the calibrated stops reduction curve and with the default platoon dispersion factor) and the field percentage of stops are not statistically different the following paired t-test was conducted using the results of the best simulation run and field observations.

$H_0$: $d_1$=0

$H_1$: $d_1 \neq$0

where $d_1$ is the mean of the differences between percent of stops observed on the field and simulated by the model. The test statistic used for testing this hypothesis is as shown below. $\sigma$ is the standard deviation in the differences of the percentages of stops.

$$t = \frac{\bar{d}_1 - 0}{\sigma/\sqrt{n}}$$

$$t = \frac{2 - 0}{6.218/\sqrt{4}}$$

$$t = 0.6437$$

Thus, the calculated t-value (0.6437)is less than t-table value (3.182) at 5% significance level. Thereby it was inferred that the difference is not statistically different than zero which in turn implied that the calibrated Stops reduction curve and the default platoon dispersion factor were adequate in obtaining equivalent number of

field stops. Consequently, it was inferred that the calibrated stops reduction curve and the default platoon dispersion factor could be used to simulate and obtain number of stops on signalized intersection approaches.

# Chapter 6

# Summary and Conclusions

## 6.1 Background of Study

Intersection Safety continues to receive primary attention from Researchers and Traffic Engineers which might be simply due to the fact that a greater proportion of accidents take place at intersections. For assessing whether a safety problem exists at a highway location, the conventional way for analysts has been to review and analyze historical accident data from site. Studies have shown that this procedure requires three or more years of accident data to make an analysis. It also depends on the often biased, inconclusive or incomplete information contained in the accident reports. Traffic Conflict Technique alleviates some of these problems associated with the accident data. Some of the previous studies have shown that there exists a correlation with traffic conflicts and accidents [5, 25].

In one of the studies conducted on assessment of accident potential at signalized intersection approaches in Saudi Arabia, an alternative method for assessing the accident potential was used [5]. In this particular study it was hypothesized that

rear-end accidents are directly correlated with the number of stops at intersection approaches, i.e., as the number of stops increase the number of rear-end accidents increase. With this hypothesis, a relationship between rear-end conflicts and number of stops at intersection approaches was developed. Rear-end conflicts data was used instead of rear-end accidents due to non-availability of accident data by location at the time of this study period. Two relationships were developed for prediction of rear-end conflicts using data from 38 intersection approaches. These models are as shown below.

$Rear - end\ conflicts = 2.555 + .00001 \times Stops^2,\ R^2 = 0.664$

$Rear - end\ conflicts(phr) = .01154 \times Stops(phr),\ R^2 = 0.869$

Prior to the study under discussion rear-end accident and rear-end conflict data that was collected by Isa et.al [14] was used to develop the following relationship between rear-end accidents and rear-end conflicts.

$Rear - end\ Accidents(\text{in two years}) = 2.309\ conflicts\ per\ hour,\ R^2 = 0.869$

From these models it is evident that, only number of stops at intersection approaches are required as input for assessment of accident potential. As number of stops could be easily obtained from simulation output of *TRANSYT-7F*, the stops reduction curve was modified to obtain the equivalent number of field stops. In an another study Ratrout [2] determined the appropriate platoon dispersion factors in *TRANSYT-7F* for the same study region. Thus these two *TRANSYT-7F* parameters (stops reduction curve and platoon dispersion factor) were calibrated for the local conditions.

In this study first it was aimed to validate the models developed earlier for prediction of rear-end conflicts. Secondly it was aimed to improve these previously built

models. Finally, it was aimed to test the adequacy of the calibrated stops reduction curve and platoon dispersion factors of *TRANSYT-7F* in obtaining equivalent number of field stops on some arterial other than those used in their calibration. Thus one could simulate and obtain stops(the main regressor variable in rear-end conflict model) rather than actually observing them in the field.

## 6.2 Data Collection

An inventory survey of signalized intersection approaches in Al-Khobar region having left turn bay and at least two lanes, was made before starting the data collection process. The sample size needed was determined using a statistical formula and it was found to be 22 intersection approaches. Two persons were required to collect the data for this study. Only one person was collecting data about rear-end conflicts through out the data collection phase. Apart from the number of stops and nonstops, approach speed, roadway characteristics and signal timing plans were also observed at each intersection approach. For observing the approach speed, a radar gun was used and the minimum number of speed observations required at each intersection approach was determined using the procedures explained in the manual of Transportation Engineering Studies [27]. To ensure the quality of traffic conflict data collected NCHRP [31] recommends tests on reliability and repeatability of rear-end conflicts. As only one observer was observing traffic conflicts through out the data collection phase a formal test on reliability was not performed. To test the repeatability of traffic conflicts, data was collected at eight locations where the traffic conflicts were observed previously. The results of statistical analyses showed that the observer was consistent in observing the traffic conflicts.

## 6.3 Model Validation

For the purpose of validation of the models developed in the previous study a hypothesis was formulated about the distributions of observed and predicted rear-end conflicts. The null hypothesis stated that the distributions of the observed and predicted number of conflicts are the same. This hypothesis was tested using a Chi-Square goodness of fit test. The Chi-Square value calculated was found to be less than the Chi-Square table value, for both models with and without intercept. Thus it was inferred that there was no statistical evidence to reject the null hypothesis and that the distributions of the observed and predicted number of conflicts could be the same. Thereby both the models developed were validated.

## 6.4 Model Improvement

To improve the prediction capability of the rear-end conflict model it was hypothesized that the inclusion of other traffic and roadway variables would improve its prediction capability. These variables were taken to be the following:volume/capacity approach speed, number of intersections within half a mile and Field yellow plus Allred/ITE yellow plus Allred, variance in speed, number of intersections within one kilometer and half a mile distance.

A correlation matrix was obtained using the SAS statistical package. To avoid the problem of multicollinearity the correlation matrix was thoroughly examined and the independent variables selected for regression analyses were Stops, approach speed, volume/capacity, and number of intersections within one km distance and clearance interval ratio.

Of all the models built for various combinations of the independent variables selected the model with stops and average approach speed as independent variables was found to be the best in terms of $R^2$. This model is as shown below.

$REC = -6.641 + .00656 \times Stops + 0.173 \times Speed$, $(R^2 = 0.785)$

Where,

REC= Rear-end conflicts per hour

Stops= Number of stops per hour

Speed= Average Speed in km/hour

All the remaining models have either lesser $R^2$ values than this model or their parameter estimates are not significant at 5% significance level. For the best model developed normal probability plot was examined to check the assumption of normality in regression analyses and it was found to be satisfied as shown in Appendix D. Also, the plot between the predicted value of rear-end conflicts versus the absolute error were plotted to assess the fit of the model and to check whether any transformation was needed. The plot given in Appendix D shows that the model with stops and speed as independent variables did not need any transformation.

## 6.5 Comparing the fit of Previously built and Newly built Model

The data set used to perform the repeatability test was used to compare the fit of the previously built and newly built model. A Chi-Square test was performed to compare the goodness of fit of the previously built and newly built model. It was

observed that the Chi-value for the newly built model was less than that obtained using previously built models which suggested that the newly built model is better than the previously built models in terms of goodness of fit. However as the sample size (8 intersection approaches) used for this purpose was small, a statement stating that the newly built model is better than the previously built could not be made. Consequently it was suggested that the newly built model can be used whenever average approach speed data is available. Otherwise the previously built models are also valid for prediction of rear-end conflicts and thus can be used.

## 6.6 Adequacy of Calibrated *TRANSYT*

Finally, the adequacy of calibrated *TRANSYT* parameters in obtaining equivalent number of field stops was examined. As the process of simulation requires that all the signalized intersections considered in the studied arterial must have a common cycle length and the volume on the arterial must be moderate, Riyadh street in Al-Khobar region was selected. The data concerning the Physical description of the arterial, volume data at each intersection, signal timing plan and driver performance characteristics were collected with the help of a few graduate students of the Civil Engineering Department. The offsets between the start of green phases of the approaches along the Riyadh street were also observed. The link to link volumes were estimated using a procedure explained in the *TRANSYT* manual. As suggested by the *TRANSYT* manual, the turning movement volumes at the downstream node are assumed to be from the upstream thru movement only, while the thru movement at the downstream node are to be from the upstream turning movements. The speed along the links was collected using average moving observer method as suggested

in the manual of Traffic Engineering Studies. The Stops data was also collected simultaneously along with the volume data. Two graduate students collected the stops and nonstops data at the intersection approaches. The driver performance characteristics data, which include the saturation flow, start-up lost time, green extension time, average vehicle spacing and platoon dispersion factors were collected by Ratrout [2] in 1988 in the same study area. In this study it was assumed that the driver's performance characteristics have not changed significantly during the last few years. Hence, the data from Ratrout's study were used in this study. The data collected for the one hour duration period was entered into the TRANSYT model. To assess the adequacy of the parameters in simulating the field stops, the following different runs were performed.

1. With the default stops reduction curve and default platoon dispersion factor

2. With the default stops reduction curve and the calibrated platoon dispersion factor found by Ratrout [2]

3. With the calibrated Stops reduction curve [5] and the default Platoon dispersion factor

4. With the calibrated Stops reduction curve and the calibrated Platoon dispersion factor

In each of the above runs the percentage of stops on each each approach were compared with the observed field percentage of stops. It was observed that the the simulation run with calibrated stops reduction curve and default platoon dispersion factor is the best in terms of agreement with the percentage of stops in the field. It was also observed that both the calibrated and the default platoon dispersion factor

did not significantly alter the simulated percentage of stops. In order to prove that the difference between the simulated percentage of stops (Using the results of the run–with calibrated stops reduction curve and default platoon dispersion factor) and percentage of field stops are not statistically different a paired t-test was conducted. It was found that the t calculated was less than t-table at 5% significance level. Thus it was inferred that the difference is not statistically different from zero and the calibrated Stops reduction curve and default platoon dispersion factor were adequate in simulating the equivalent number of field stops.

## 6.7 Conclusions

The objectives of this study were to validate and improve the rear-end traffic conflict model developed in a previous study as well as to test the adequacy of calibrated *TRANSYT* model in obtaining the number of stops in agreement with those observed in the field. The findings of the study are as mentioned below.

1. The models developed previously by Al-Ofi [5] for prediction of rear-end conflicts fitted the validation data set adequately. This meant that these models are valid and can be used for prediction of rear-end conflicts at locations similar to those studied in the Eastern Province of Saudi Arabia.

2. From the results of the Pearson correlation and regression analyses it was found that the number of stops was the most important variable affecting the number of rear-end conflicts. This strongly supported the hypothesis of Al-Ofi's [5] study that rear-end conflicts are mainly affected by the number of stops.

3. From the new model developed in this study it is evident that apart from stops. average approach speed is also an important variable affecting the number of rear-end conflicts.

4. The $R^2$ values for the newly built model is higher than that of previously built models which implied that the newly built models have better capability of explaining the variability in the data.

5. The newly built model with both stops and average approach speed as independent variables showed a better fit than the previously built models to an independent data set.

6. The calibrated stops reduction curve and the default platoon dispersion factor were adequate in obtaining equivalent number of field stops.

## 6.8 Recommendations for Further Study

The following areas mentioned below are in need of further study.

1. The possibility of using Traffic Conflict Technique at other locations such as curve sections of highways.

2. A study of weaving conflicts in the weaving sections of arterial could be made and a relationship could be established between Level of Service, roadway characteristics and Weaving conflicts.

3. A study on the applicability of rear-end conflict models on signalized intersection approaches without left turn bays could be undertaken.

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# Appendix A

## Traffic Conflict Technique

A traffic conflict is an event involving two or more road users in which the unusual action of one user, such as a change in direction or speed, places the other user in danger of collision unless an evasive maneuver is taken. Generally speaking, the road usrs are drivers, but the definition also includes pedestrians and cyclists. For a traffic conflict to occur, an actual impending collision is not necessary. An action or a maneuver that merely threatens another user with the possibility of a collision is sufficient. Also, some collisions occur without evasive maneuvers. They are included as extreme cases under this broad definition. An intersection traffic conflict is described as an event involving several stages as follows:

- Stage1 One vehicle makes some sort of unusual or unexpected maneuver.
- Stage2 A second vehicle is placed in danger of collision.
- Stage3 The second vehicle reacts by braking or swerving.
- Stage4 The second vehicle then continues to proceed through the intersections.

The last stage is necessary to convince one (the observer) that the second vehicle was actually responding to the maneuver of the first vehicle and not, for example, to a traffic control device. **Operational Definitions**

The definitions of rear-end conflicts used in this study are as mentioned below.

1. Left-Turn Same-Direction Conflict A left turn, same direction conflict occurs when the first vehicle slows to makea left turn, thus placing a second, following vehicle in danger of a rear-end collision. The second vehicle breakes or swerves, then continues through the intersection.

2. Right-Turn Same-Direction Conflict A right turn, same direction conflict occurs when the first vehicle slows to make a right turn, thus placing a second, following vehicle in danger of a rear-end collision. The second vehicle breakes or swerves, then continues through the intersection.

3. This situation occurs when an instigating vehicle changes fron one lane to another, thus placing a following, conflicted vehicle in the new lane in jeopardy of a rear-end or side swipe collision. The conflicted vehicle brakes or swerves, then continues through the intersection.

4. A slow vehicle, same direction conflict occurs when the first vehicle slows while approaching or passing through an intersection, thus placing a second,following vehicle in danger of a rear-end collision. The second vehicle brakes or swerves, then continues through the intersection.

# Appendix B

## Regression Analysis

For the building of regression equations for the yellow interval demand, multiple regression analysis will be used. Following is a short explanation of the regression technique.

1. Multiple Regression Analysis

Multiple regression is a general statistical technique through which one can analyze the relationship between a dependent or criterion variable and a set of independent or predictor variables. In general, multiple regression requires that variables are measured on interval or ratio scale and the relationships among the variables are linear and additive. These restrictions are not absolute, however nominal variables can be incorporated into regression through the use of dummies or indicator variables.

$$Y' = a + b_1x_1 + b_2x_2 ...... + b_kx_k \tag{6.1}$$

Where 'Y' represent the estimated value of Y. 'a' is the intercept and $b_i$'s are regression coefficients. The 'a' and $b_i$ coefficients are selected in such a way the sum of squared residuals $\sum(Y - Y')$ is minimized. The selection of optimum 'a' and '$b_i$' coefficients using the least-squares criterion implies that the correlation between the actual 'Y' values and 'Y' estimated values is maximized, while the correlation between the independent variables and the residual values (Y - Y') is reduced to zero. The actual calculation of 'a' and '$b_i$', requires a set of simaltaneous equations derived by differentiating $\sum(y - y')^2$ and equating the partial derivatives to zero. Regression coefficients Bi are tested statistically using F-test and T-test.

Heirarchial tests can be employed using stepwise regression, to examine the contribution of a subset of K variables to the explained variation. For example. assume that $x_1$ and $x_2$ are both prior to $x_3$ and $x_4$. If the null hypotheses is that variables $x_3$ and $x_4$ do not add significantly to variation in Y already explained by $x_1$ and $x_2$. the test will be

$$F = \frac{incremental SS due x_3 and x_4/M}{SS_{res}/(N-k-1)}$$

where SS is sum of squares, $SS_{res}$ is the unexplained or error sum of squares, 'M' is the number of variables in the subset $(x_3, x_4)$, 'N' is the number of observations, 'K' is the total number of variables. If calculated 'F' is greater then F-table value, the null hypotheses will be rejected i.e $x_3$ and $x_4$ add no significant explanation to 'Y'. $R^2$, the coefficient of determination, is more easily interpreted as the measure of association when one concerns with the strength ( goodness of fit ) of the relationship.

$$R^2 = \frac{\text{"}Explained\text{"} Sum of Squares}{\text{"}Total\text{"} Sum of Squares}$$

$$R^2 = \frac{Explained Variance}{Total Variance}$$

Variance is a measure of the variability or lack of homogeneity in a variable. When the cases cluster close to the mean, variance will be small; as the cases become spread out, variance increases. The total variance is the sum of squared distance of cases from the mean of the variable. The size of error is measured by the vertical distance from the actual point to the regression line. These distances are squared

and summed together over all cases and divided by the numberr of cases minus 2. Thus we have a statistic called residual variance i.e the amount of original (total) variance which can not be explained by using the regression line as a prediction device.

Statistical Analysis system (SAS) which have several in built methods to perform a regression analysis such as procedure Reg and procedure Stepwise etc. procedure Stepwise has five techniques for model selection.

1. Forward Selection
2. Backward Elimination
3. Stepwise
4. Max R
5. Min R

# Appendix C

**Sample Calculations**

**CIRATIO** Field yellow plus All red/ITE Yellow plus All red

ITE yellow plus All red **Y**= $t + \frac{V}{2\times a}+\frac{W+L}{V}$

$= 1+ \frac{56.4}{2\times 10} + \frac{180.4+20}{56.4}$

$= 7.37$

Field Yellow plus All red (KAAziz/10th NB)= 3+2= 5*secs*

**CIRATIO**= $\frac{7.37}{5}$= 0.678

t= Driver reaction time(1 sec)

V= Speed of vehicle in ft/sec

a= Acceleration vehicle in ft/$sec^2$ (10ft/$sec^2$)

W= Width of intersection in feet

L= Average length of vehicle (20ft)

**V/C** Volume/Capacity

Capacity of each lane = $(g/C) \times S$

g= Effective green in secs

C= Cycle Length in secs

S=Saturation flow rate=1780 vehicles per hour for through lane and 1650 vehicles per hour for turning lane [2]

Capacity on KAAziz/10th NB = $\frac{26}{130}\times[1650 \times 2 + 1780 \times 2]$=1372 Vehicles per hour

**V/C**=Volume on the approach per hour/Capacity of approach= $\frac{854}{1372}$=0.62

# Appendix D

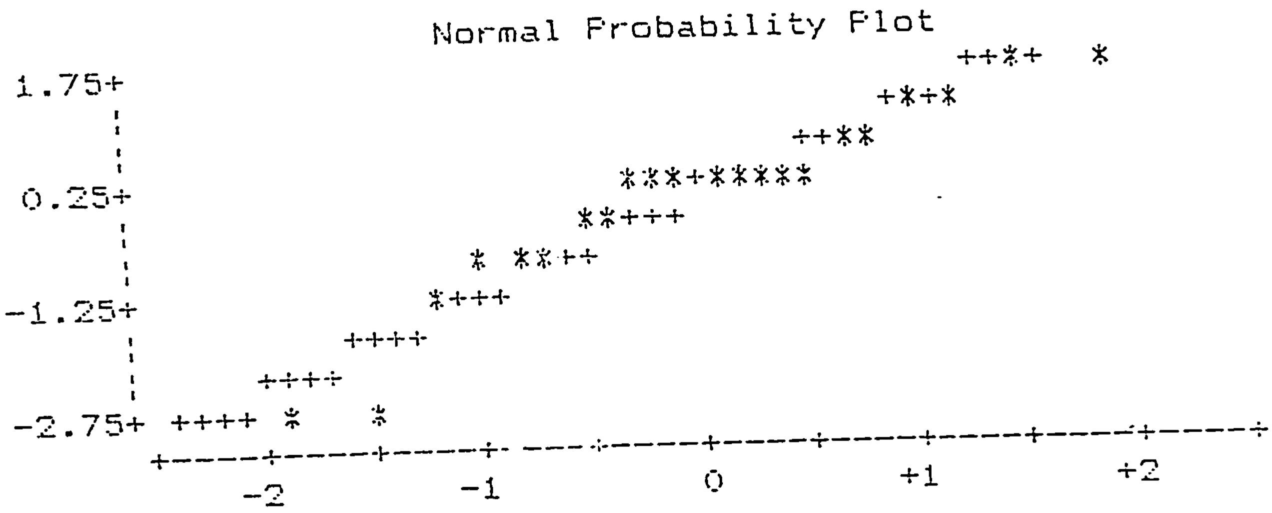



Figure 6.1: Normal Probability Plot for Model 3

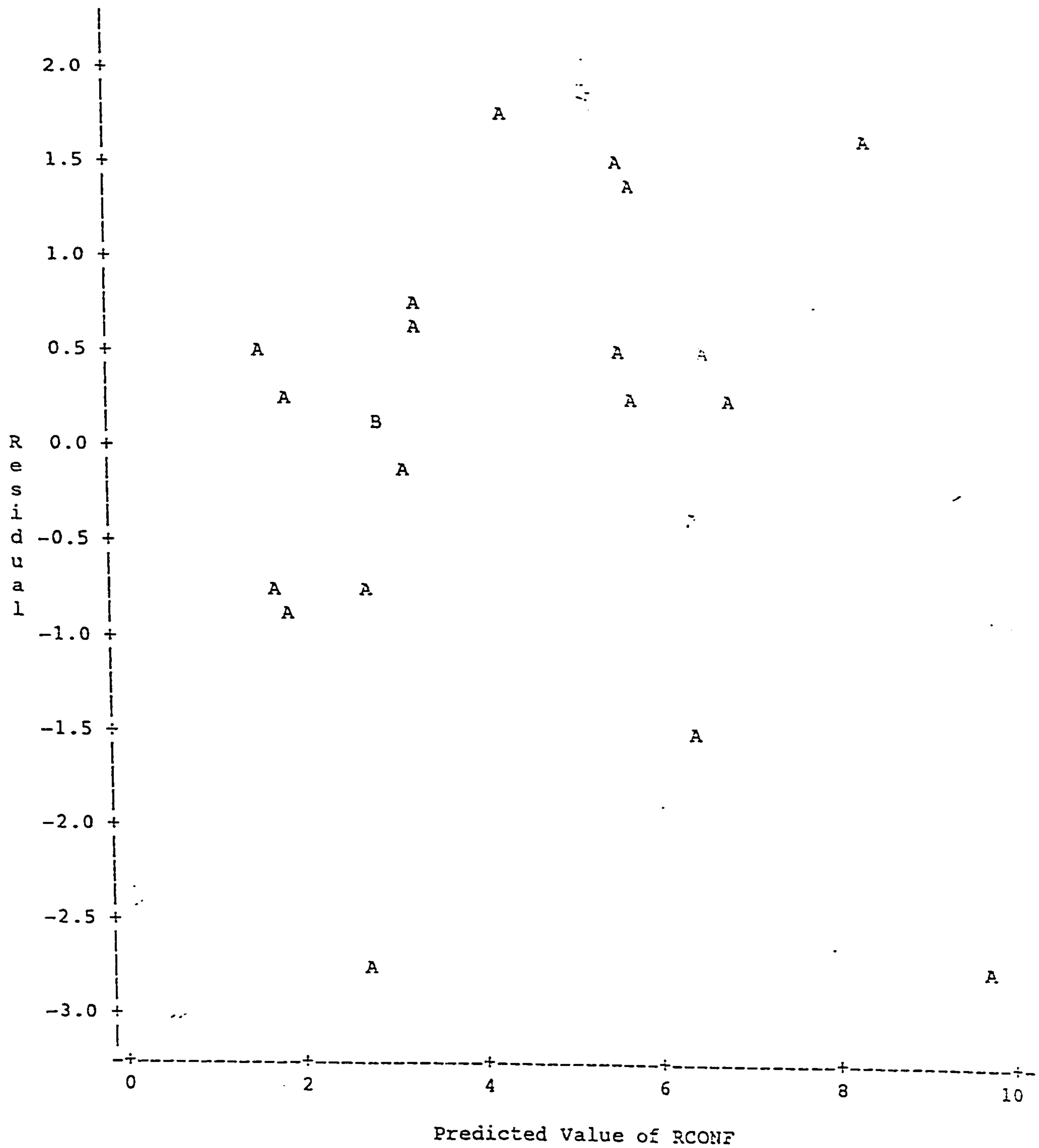
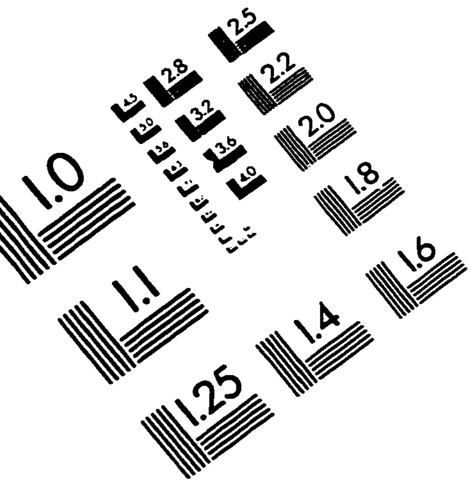
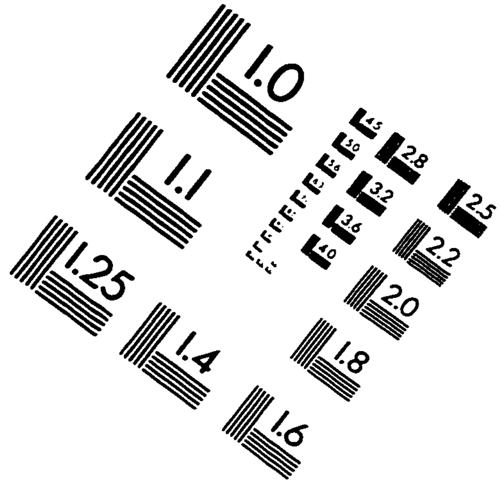
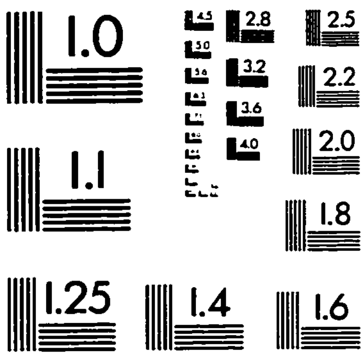


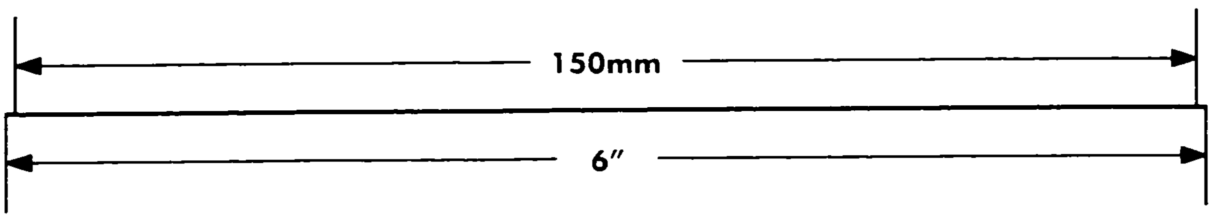

Figure 6.2: Residual Versus Predicted Y for Model 3

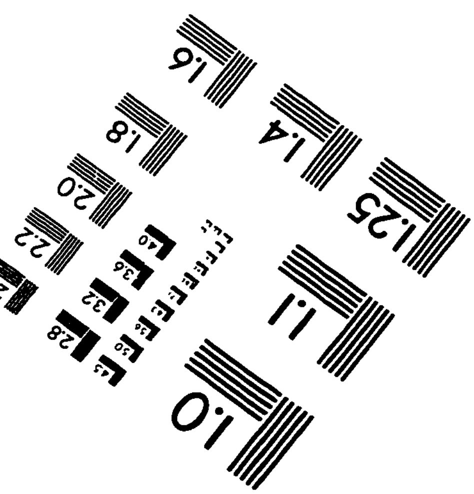
# IMAGE EVALUATION TEST TARGET (QA-3)

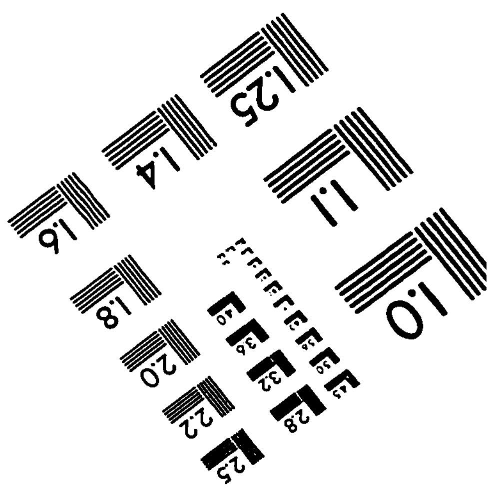










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