JOINT HIGHWAY RESEARCH PROJECT

FHWA/ISHC/JHRP-79/8

DEVELOPMENT AND USE OF A
COMPUTER SIMULATION MODEL FOR
THE EVALUATION OF DESIGN AND
CONTROL ALTERNATIVES FOR
INTERSECTIONS OF MINOR ROADS
WITH MULTI-LANE RURAL HIGHWAYS:
SELECTION OF THE SIMULATION MODEL

A. E. Radwan
K. C. Sinha
H. L. Michael

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Interim Report

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EVALUATION OF DESIGN AND CONTROL ALTERNATIVES FOR INTERSECTIONS
OF MINOR ROADS WITH MULTI-LANE RURAL HIGHWAYS:
SELECTION OF THE SIMULATION MODEL

TO: Harold L. Michael, Director
Joint Highway Research Project

July 11, 1979

Project: C-36-59X

FROM: Kumares C. Sinha, Research Engineer
Joint Highway Research Project

File: 8-5-24

Attached is the third Interim Report on the Indiana HPR Part II Study entitled "Evaluation of Design and Control Alternatives to Improve Safety of Intersections of Multi-Lane Rural Highways". The title of the present report is "Development and Use of a Computer Simulation Model for the Evaluation of Design and Control Alternatives for Intersections of Minor Roads with Multi-Lane Rural Highways: Selection of the Simulation Model". It has been authored by Ahmed Essam Radwan, Kumares C. Sinha and Harold L. Michael.

This part of the project (part of Task 10 of the approved Proposal) summarizes the results of a literature review involving driver gap acceptance at intersections on multi-lane highways, accident analysis and safety measurement techniques at such intersections, and a review of the available computer simulation models.

This report is forwarded for review, comment and acceptance as partial fulfillment of the objectives of the research.

Respectfully submitted,

Kumares C. Sinha
Research Engineer

KCS:ms

cc:	A. G. Altschaeffl	D. E. Hancher	C. F. Scholer
	W. L. Dolch	K. R. Hoover	M. B. Scott
	R. L. Eskew	J. F. McLaughlin	K. C. Sinha
	G. D. Gibson	R. F. Marsh	C. A. Venable
	W. H. Goetz	R. D. Miles	L. E. Wood
	M. J. Gutzwiller	P. L. Owens	E. J. Yoder
	G. K. Hallock	G. T. Satterly	S. R. Yoder

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by

A. E. Radwan, Graduate Instructor

K. C. Sinha, Research Engineer

H. L. Michael, Director

Joint Highway Research Project

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16. Abstract <p>The main objective of the simulation phase of this project was to analyze the safety aspects of intersections at multi-lane rural divided highways using a simulation approach, and to evaluate possible design and control alternatives in terms of accident reduction. The alternatives tested included some of the countermeasures suggested by the first two phases.</p> <p>This phase of the project involved three parts. The first activity was to conduct a literature review involving driver gap acceptance at intersections on multi-lane highways, accident analysis and safety measurement techniques at such intersections, and a review of the available computer simulation models.</p> <p>The second activity was composed of three steps: 1. A field study at rural Indiana intersections to investigate driver behavior, 2. Traffic conflict studies at signalized as well as at unsignalized intersections, to select the appropriate safety measurements, and 3. Selection and subsequent modification of a computer simulation model for the purpose of simulating traffic at intersections under study.</p> <p>The last part of this phase of the project was to apply the validated computer model in evaluating operation and safety of traffic under different design and control alternatives.</p> <p>The present report summarizes the results of a comprehensive literature survey conducted in the first part of the simulation phase of the project to select the computer model to be used in the study.</p>			
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INTRODUCTION

Intersections are considered one of the most critical elements of a highway system. This element greatly affects the efficiency, capacity and safety of highway links. However, perhaps the major problem at intersections is that of traffic safety; the existence of vehicle conflicts at intersections and the resultant probability of an accident is of critical concern.

Of the total number of reported two-vehicle accidents occurring every year in the United States, approximately 36 percent occur at intersections (1). In Indiana, approximately 37 percent of the total reported accidents occur at intersections (1). From investigations of accidents in Indiana, it has been found that approximately 48 percent of the intersection accidents can be identified as entering-at-angle accidents (2). These entering-at-angle accidents account for 80 percent of the fatalities, 56 percent of the personal injuries and 46 percent of the property damage of all two-vehicle intersection accidents.

Recent studies have been directed towards the general area of intersection safety, however very little effort has been placed on investigating the design, operation, and safety of intersections of a four-lane divided major highway with a lesser volume highway located in suburban or rural areas.

The main objective of this research was to analyze the safety aspects of intersections of multi-lane rural divided highways and to evaluate possible design and control alternatives to minimize accidents at such intersections. The analysis and evaluation scheme for such a problem can take many forms ranging from purely empirical data collection to development of complex theoretical models. This study included use of a validated traffic simulation computer model supplemented by field observations.

In the following paragraphs a summary is presented of the relevant information collected from the literature.

Driver Characteristics at Stop Controlled Rural Intersections

The topic of driver characteristics at intersections, in particular the decision process of a driver stopped at a stop sign on the minor street to cross or merge with the traffic on the major street, has been studied by numerous researchers. These studies can be grouped into two categories: gap and lag acceptance distributions, and distributions of gap acceptance and rejections.

Gap and Lag Acceptance Distributions

Considerable amount of research has been conducted to study the traffic characteristics of at-grade intersections. In these investigations various techniques were used to analyze intersectional flow patterns under different roadway and traffic conditions. In 1944, Greenshields (3) employed time motion pictures to study the time

intervals accepted by drivers when crossing another traffic stream. Both controlled and uncontrolled intersections were studied, and, in particular, stop sign controlled intersections were included in these investigations. The average minimum acceptable time gap was defined as that value which was accepted by 50 percent of the drivers.

A few years later a similar study was made with a 20-pen graphic recorder by Raff (4); the concept of time lag was introduced and evaluated. Instead of Greenshield's definition of an average minimum time gap, Raff developed the critical lag, which was defined as the median time lag; that is, the number of accepted lags shorter than the critical time lag is equal to the number of rejected lags longer than this specific value. In Raff's study, the critical lags were not constant but varied from intersection to intersection. Critical lags were influenced by sight obstructions, main street speed, main-street width, and the patterns of traffic flow on the side street. However, traffic volumes on the main street did not significantly modify the critical value. Turning movements, which probably affect the amount of delay to the side street vehicles, received little attention in that study. In comparing the critical lag with the critical gap, Raff noted that this gap averaged about 0.2 sec. greater than critical lag.'

Bissell (5) considered vehicular movements across the intersection as through, left turn and right turn. A 20-pen graphic recorder was used to obtain the necessary data for two intersections within similar urban areas. In the analysis of the data, it was determined that the acceptance of lags was not significantly different from the acceptance of gaps. This homogeneity of lags and gaps was demonstrated by the

overlapping of the confidence intervals determined for a confidence coefficient of 80 percent. A mathematical formula of the cumulative logarithmic normal distribution for pooled lags and gaps was devised to describe the human judgment for accepting or rejecting the main street traffic gaps offered to drivers stopped on a side street. Although the lane position (near or far) of the main street traffic did not influence the gap acceptance for the traffic entering from the side street, the type of entering maneuver produced different gap-acceptance distributions.

The studies by Greenshields (3) and Raff (4) were both conducted in New Haven Conn., and Bissell (5) investigated one intersection in Richmond, Calif. and another in Oakland, Calif. As a general comparison of the three studies, Greenshields, Raff, and Bissell reported, respectively, a mean gap acceptance of 6.1 sec., a mean lag acceptance of 5.9 sec., and a mean lag-and-gap acceptance of 5.8 sec.

Solberg (6) used the time motion pictures to study the lag and gap acceptance at right-angle intersections formed by two-way, two-lane, urban streets. Four sites, selected in Lafayette and Indianapolis, IN., were as identical as possible regarding geometry and adjacent land use. The data were collected at these sites by means of a motion picture camera. This study showed that the acceptance distributions were well described by a linear relationship between the probit of acceptance and the logarithm of acceptance time. It was found that there was no significant difference between the median lag-acceptance and the median gap-acceptance values at the four intersections studied. However, significant variations were found between right- and left-turning drivers and between drivers proceeding through the intersection and

those making left turns. Right-turning drivers and those crossing the intersection had statistically equal median acceptance times. Community size apparently had some influence on driver performance at intersection approaches controlled by stop signs. The overall median acceptance times for right turn, left turn, and through movements were 7.36, 7.82 and 7.18 sec., respectively.

Wagner (7) conducted a gap acceptance study at the intersection of a four-lane, undivided, intermediate speed state highway with a two-lane, low-speed city street controlled by stop signs. A specially devised survey apparatus consisting of 10 pushbutton microswitches electrically connected to a multiple-pen event recorder was used for collecting data. The results of this study gave rather strong verification of earlier findings that the relationship between lag or gap size and percent acceptance has a log-normal form. It was concluded also that the acceptance of gaps and the acceptance of lags should be treated separately. A gap of 8 sec. was acceptable to 60 percent of the waiting drivers for example, but a lag of the same size was acceptable to only 50 percent.

In addition, Wagner (7) found that there was no evidence that truck driver behavior and car driver behavior were significantly different. The analysis of lags and gaps during peak and off peak showed that drivers accept smaller lags and gaps during peak periods. As for the effect of direction of traffic movement, it was found that during peak period, it is necessary to segregate right turners from the other maneuvers, however, no significant difference was observed during off peak period between the left, straight, and right gap acceptance samples.

The reaction of side street drivers was studied in terms of starting delay time and it was found that starting delay time for succeeding vehicles was smaller and less disperse than for the first vehicle in the queue.

Tsongos and Wiener (8) have developed acceptance and rejection distributions for day and night conditions and they found a significant difference between the two conditions only for the very short and very long gaps 2-3 and 10-12 seconds.

Sinha and Tomiak (9) studied the gap acceptance phenomenon at stop-controlled intersections in which they concluded that the manual or stop watch method developed and utilized in their study was an adequate substitute for the camera technique in measuring section-gap acceptance times at an intersection. It was also found that major street speed significantly affected the size of a section-gap acceptable to a minor street driver and that left-turning vehicles required larger time gaps than those for through-moving vehicles. In addition they observed that the presence of opposing traffic on the other side of the intersection affected the minor street driver's decision to accept or reject a gap.

The Swedish Highway Capacity Manual (10) recommended a set of critical gaps developed from previous studies for Swedish conditions. These values are dependent on the type of maneuver, the speed limit, and the type of priority control (stop or yield sign), the effects of which are shown in Table 2. Correction values are added or subtracted to the base critical gaps of Table 2 to represent:

1. Width of main road.
2. The existence of a median on main road.
3. Radius for right-turning vehicles.
4. Angle between major and minor road.
5. One way major road.
6. Percentage of heavy vehicles.
7. Size of urban area.

The German Highway Capacity Manual (11) recommended values which are generally 0.5-1.50 seconds above those given in Table 1.

Distributions of Gap Acceptance and Rejections

Several methods were developed to analyze systematically the gap acceptance data. One of the main purposes of these methods was to eliminate the bias in the collection and measurement of data. This bias arises from the fact that each driver has an acceptance threshold different than the other. For example, the drivers with the low acceptance threshold are more likely to accept the first gap offered to them. On the other hand, drivers with high acceptance threshold will probably reject several short and medium-size gaps before finding an acceptable one. This fact was realized by Raff and Hart (4) when they introduced the concept of critical lag acceptance.

A further difficulty arises from the fact that since only one acceptance/rejection decision is included for each minor road vehicle, a much larger sample is required to give the same statistical accuracy as that obtained by using both lag and gap acceptance data. For these reasons, several investigators decided to use the combined lag and gap acceptance data in their analysis.

Table 1. Size of Critical Gaps (seconds): Swedish Highway Capacity Manual

(Source: Ref. 10)

Vehicle Stream		Speed on Primary Road				90 Km/h (56 mph) Stop
		50 Km/h (31 mph)		70 Km/h (44 mph)		
		Yield	Stop	Yield	Stop	
Primary Approach	Left Turn	5.0		5.8		6.5
	Right Turn	4.8	5.5	6.0	6.5	7.2
Secondary Approach	Straight	5.2	5.8	6.0	6.5	7.0
	Left Turn	5.3	6.0	6.2	6.8	7.5

Blunden et. al. (12) proposed combining lag and gap acceptance into one probability distribution. The number of rejections of each gap size was reduced in proportion so that the total number of acceptances would be equal to the total number of rejections. Further "smoothing" of the gap acceptance curve was obtained by assuming that any driver accepting a particular size gap can be added to the number accepting each gap size in excess of his value and conversely for rejections. The resulting gap acceptance curve was then claimed to give an unbiased estimate of the critical acceptance gap distribution.

An alternative method of eliminating gap acceptance bias was suggested by Drew (13). This method takes into account only vehicles that reject the initial lag and uses only one rejected gap, the largest, per vehicle. A histogram can be constructed by summation of the ranges, of the largest rejected gap or lag and the final gap accepted, for all drivers to give the distribution of critical acceptance gap.

Several other researchers attempted to develop critical gap distribution and its parameters. One of these efforts was that of Moran (14). In his study only one accepted or rejected gap was recorded for each minor road vehicle and the problem arising from the inclusion of multiple rejections was not considered. McNeil and Morgan's work (15) on the other hand, did consider the question of multiple rejections and alternative methods of estimating the critical gap distribution and its moment were developed according to whether the major road headway distribution is known or unknown.

Another method of eliminating acceptance curve bias was proposed by Ashworth (16). Using a theoretical approach to the problem, it showed that with a normal distribution of critical acceptance gaps and a random flow of traffic on the major road the resulting gap acceptance curve obtained by considering all accepted and rejected gaps and lags was displaced by an amount " s^2q " from its original position, where " s^2 " is the variance of the critical gap distribution and " q " is the major road volume measured in vehicles per second.

In an analysis of the efficiency of urban intersections Surti (17) observed that there were some indications that the driver on the minor street tends to accept a shorter gap under the pressure of a queue of 2 or more vehicles formed behind him than the gap he would accept under normal conditions.

SAFETY MEASUREMENTS AT INTERSECTIONS

To evaluate the effectiveness of countermeasures that can be taken to enhance safety at intersections it is necessary to choose a procedure to measure safety at such intersections. Previous studies included the following measurements:

1. Traditional accident analysis
2. Intersection exposure measure
3. Traffic conflict technique

Traditional Accident Analysis

Accidents on highways is one of the most complicated subjects a traffic engineer encounters. The occurrence of an accident is explained by the interaction of a group of unexpected events faced by a driver. These unexpected events occur simultaneously or in a sequential order within a short time interval such that the driver has inadequate time for a decision. Accidents are more likely to occur where there are a number of things the driver must observe and where simultaneous reactions are required. A highway intersection is a prime example of this situation. The major factors that contribute to the occurrence of an accident are: the driver, the vehicle, the roadway, the traffic control system, and the environment.

The Driver

In 1968 approximately 90.6 percent of the nationwide total of accidents were attributed to improper driving (18). The principal kinds of improper driving were: fatal accidents - excessive speed, failure to yield right-of-way, and driving left of centerline; non-

and following too closely; total accidents (predominately property damage) - failure to yield right-of-way, excessive speed, and following too closely.

A detailed analysis, by the Bureau of Public Roads (19) showed that although approximately 59 percent of the drivers in 1968 were males, they constituted about 75 percent of all drivers involved in accidents. It was also found that the total accident involvement rate, based on vehicle-miles of travel, indicated a male rate about 1.3 times that of a female rate.

The Vehicle

Vehicle defects were found to contribute approximately 2 to 3 percent of the accidents at both rural highways and intersections (18). Recently, the federal government has specified design changes to vehicles. Organizations are studying the need, for example, of additional lights on vehicles. There is some indication that vehicle "running lights" can reduce accident occurrence (20).

The Roadway

An important design element affecting accidents was found in one study to involve provision for vehicles to make left turns off major routes. After left-turn channelization was installed at 40 unsignalized urban and rural intersections along California highways, accidents were found to be reduced significantly (21). Another research group (22) concluded that the presence of the geometric elements (curves, grades, intersection, and structures) increased the accident rate on highways. The dominant element was intersections, which often gave accident rates three times as high as the rates on sections with none of the elements.

General experience with various kinds of improvements has been studied and summarized (23). The summary of this study is given in Table 2. The fractional reductions apply to all accidents, not just to those that might be affected by the improvement. Negative improvements are possible and are indicated by a minus sign in the table. The type and width of intersection median and their effects on the overall safety was investigated earlier and it was concluded that a median should be at least 40 feet wide (24).

The Traffic Control System

Street signs and other devices for the control and regulation of speeds and other traffic flow characteristics constitute a class of factors affecting intersection safety. One study was directed to show the importance of design elements in traffic safety by using accident rates as a measure (25). A before-and-after study to involve provisions for vehicles to make left turns off major routes by means of installing left-turn channelization was conducted at 40 unsignalized urban and rural intersections along California highways. Accidents were found to be reduced significantly after the installation.

Syrek (26) considered a number of rural intersections controlled by two-and-four stops and traffic signals and determined the accident rates (accidents per million vehicles) for the various intersections when grouped by volume ranges. Solomon (27) studied a number of intersections where red/amber flashers and traffic control signals had been installed. He found that intersection accident rates (accidents per million vehicles) generally went down when flashers were installed, but that the rates went up when traffic control signals were installed. The effect of flashers was most pronounced at low volume intersections while

Table 2. Forecast of Accident Reduction for Rural Junctions

(Source: Ref. 23)

<u>Improvement Project</u>	<u>Number of Lanes</u>	<u>Fractional Reduction in</u>		
		<u>All Accidents</u>	<u>Fatal, Injury</u>	<u>Damage Only</u>
Install or improve sign, direction, warning	2 More than 2	.37 .09	.19 -.07	
Stop ahead sign	2	.47	.96	
Install warning signals	2	.56*	.29*	
Warning signals, T-junction	More than 2	.21**		
Improve signals	More than 2	.42*	.45**	
Left-turn lane without signal	More than 2	-.06	-.01**	
Left-turn lane with signal	More than 2	.43*	.58*	
Rumble strips	2	.27**	.26**	.24**

Note: * Moderate sample size limits confidence in this figure.

** Small sample size limits confidence in this figure.

traffic control signals resulted in increased accident rates at low volume, uncomplicated, intersections, but in reduced rates at complex or high volume intersections.

McMonagle (28) examined a number of intersections in rural and suburban areas where either red/amber flashers or traffic control signals had been installed while only the types of accidents and the number of injuries and fatalities from one year before and for one year after the installation of the various devices have been reported. With no attempt at rate evaluation, effects similar to those found by Soloman were indicated.

A recent study was conducted by Van Maren (29) on sixty-one rural multi-lane intersections throughout Indiana to correlate design and control characteristics with accidents. Based on the correlation matrix of accident rates and different variables, it was concluded that at non-signalized divided intersections, the increase in the danger distance (the distance between the two stop lines on the minor approach) resulted in increase in the accident rates. Median barriers were found to increase the accident rates. It was also concluded that as the size of stop sign on the minor road increased the accident rate decreased.

As for high accident signalized intersections, it was found that the presence of stop line pavement markings decreased the accident rate, route markers and/or signal ahead advance warning signs on the minor road reduced the right angle accident rates, and a horizontal curve on the major road and/or a skew of the two roadways were found to increase the accident rate considerably.

A study was conducted in Oregon at an intersection where a semi-actuated controller was replaced with a volume density control. Over a five-year period with semi-actuated control, the intersection had experienced about 17 rear-end accidents per year. It was suspected that these accidents were due largely to the fact that the controller removed the green indication from the main highway on call from a vehicle on the side street, even though a whole platoon of traffic might be approaching the intersection on the main highway.

The volume-density controller was installed to hold the green indication on the highway for such platoons before giving the side street a green. The result was a reduction in the total number of stops and a reduction of 60 percent in the annual number of accidents. Use of semi-actuated controllers at locations such as just beyond a hill crest, where main highway vision is restricted, is especially accident provoking.

Accidents sometimes occur when a driver fails to stop for a signal. On the assumption that the driver was without malicious intent and honestly failed to see the signal, experiments have tried both larger signal lenses and additional signal locations. While the evidence is not conclusive, the results suggest that adding a second or third signal is more effective than increasing the size of the red lens.

The approach distance within which a driver has to make a decision regarding the entry to a signalized high speed isolated intersection during the amber phase is known as "dilemma zone". A comfortable level of deceleration on a wet street was reported to be 15 feet/sec^2 by many authorities (30, 31, 32). Olson and Rothery (33) reported in 1972 that very few motorists are willing to stop for a yellow signal that re-

quires deceleration beyond 12 ft per second per second. Williams (34) investigated driver behavior during the yellow interval at a low-speed intersection, and reported that only 12 percent of drivers were willing to accept a deceleration rate of 15 ft/sec^2 or more.

The Environment

Environmental factors also have an influence on accidents. These factors include such things as weather conditions and land use. Adverse weather conditions can cause slippery road surfaces and reduce driver visibility. Unrestricted land usage often results in decreasing the driver's sight distance at intersections and thereby effectively reduces his safe approach speed.

Intersection Exposure Measure

Measures of exposure at intersections were exhaustively analyzed by previous researchers. One researcher suggested using mileage, another used flow rates entering the intersection, and a third counted the number of times vehicles from different directions want to occupy the same area of the road space simultaneously. Arguments against using mileage as a variable in measures of exposures at intersections were due to Mathewson and Brenner (35) and Breuning and Bone (36). All researchers agreed that the amount of traffic and the paths it takes are more meaningful than distance at intersections. Grossman (37) calculated the number of conflict zones in an intersection, added together the flows which pass each zone and summed over all zones; this sum was his measure of exposure.

McDonald (38) reported a study of 1811 accidents at 150 divided intersections. He obtained the relation:

$$A = 0.000783 v_d^{0.455} v_c^{0.633}$$

where: A: Number of accidents per year.

V_d : Average daily traffic entering from the divided highway.

V_c : Average daily traffic entering from the crossroad.

Traffic Conflict Technique

The traffic conflict technique (TCT) was developed by Perkins and Harris of General Motors Corporation and is commonly referred to as the GM technique. A conflict occurs when a driver violates a rule of the road or makes an aggressive movement. The GM technique identifies five major classes of traffic conflicts: left-turn, weave, cross-traffic, red-light, and rear-end conflicts. Perkins (39) applied the traffic conflict technique to a group of intersections and he found that the installation of traffic signals at intersections caused increase in rear-end conflicts and decrease in right-angle conflicts.

Campbell and King (40) were of the opinion that the traffic conflict technique does detect accident potential prior to development of an accident history. Baker (41) applied the traffic conflict technique on 392 intersections before improvements were made and 173 intersections after the improvements. Baker felt that those characteristics of intersections that contribute to accident causation could be more readily exposed by using conflicts than by using conventional accident analysis techniques. Figure 1 shows the number of conflicts per 1,000 vehicles by hourly approach volumes as developed by Baker for the cases of one lane, two lanes, and three or more lanes per approach.

Paddock (42) developed a series of regression models in an attempt to find a reliable accident prediction model. In addition, substantial insight into the workings of the conflicts technique has been obtained.

A rural study by the Road Research Laboratory (43) showed that conflicts do not correlate well with reported injury accidents, however serious conflicts, which is defined to be a last second evasive movement

FIGURE 1. CONFLICTS FOR 106, 4-LEGGED
NONSIGNALIZED INTERSECTIONS

(Source Ref. 41)

or stop to avoid collision, correlate well with reported injury accidents both in location and time of day. Spicer (44) applied the conflict technique at six rural divided intersections. Positive correlation was found between serious conflicts and injury accidents. A graph showing the number of serious conflicts over a 10 hour day plotted against the number of injury accidents over 3 years, for each site is shown in Figure 2.

In order to evaluate the performance of the traffic conflict technique video tape sequence of collisions and conflict events were recorded and were analyzed in details by Allen, et. al. (45). Preliminary investigations revealed that the common traffic conflict technique method of brake application is considerably deficient as a descriptive tool. Consequently, seven methods of defining a conflict situation were introduced and evaluated. In another study Zegeer and Deen (46) conducted conflict counts at five intersections in central Kentucky to determine characteristics of conflict data. Good reliability was found between observers in simultaneous counts of conflicts and weaves with r-values as high as 0.93, and conflict counts were recommended during routine inspections of suspected hazardous locations.

FIGURE 2. NUMBER OF INJURY ACCIDENTS AND
SERIOUS CONFLICTS AT SIX INTERSECTIONS

(Source Ref. 44)

TRAFFIC SIMULATION MODELS

Computer simulation has become an important tool for traffic engineers and transportation planners. Field traffic data is expensive to obtain and it takes many hours of work to collect relevant information. On the other hand, a well-calibrated simulation model can yield an enormous amount of data quickly and inexpensively. For example, several months of real traffic observation are necessary to evaluate the effects of even simple changes in signal systems. But traffic simulation experiments are comparatively cheap and quick and they can be employed without liability associated with "playing around" with traffic signals.

To evaluate the effects of design and control alternatives on traffic safety and operation, it is necessary to select an effective computer model that simulates traffic through the intersection of interest. In general, there are three classes of traffic simulation models: single road, single intersection, and network models. Single intersection models have been built for a specific purpose. Lewis (47) developed a digital simulation computer program to study the traffic flow through single urban intersections. The type of intersection studied was the four-legged right-angled intersection of a high-volume major arterial street with a lower-volume minor arterial street.

Two types of intersection controls were studied; traffic-actuated signal and the two-way stop sign. A set of graphs which showed delay

under both control strategies were developed for various traffic volume combinations. Using the criteria of the minimization of average delay for all vehicles, volume warrants were developed for this particular intersection. Another example of single intersection simulation model was developed by Scraggs (48) to simulate traffic through uncontrolled T-junctions. A gap acceptance traffic model was used to determine the capacity of the minor road at this particular unsignalized T-junction. Webster (49) utilized a computer simulation model to provide an excellent study of isolated intersection operation. He developed an equation to calculate average delay per vehicle at intersections from flow rates, saturation flow, and cycle length. A recent study (50) was directed to simulate traffic at uncontrolled intersections. The purpose of the study was to evaluate signing policies for intersections of low volume roads. A new microscopic traffic simulation package for intersection traffic called the TEXAS MODEL has been developed at the University of Texas (51). This package can be used to aid in evaluating the operational effects of various traffic demands, types of traffic control, and/or geometric configurations at single intersections.

Selection of a Simulation Model

One of the work elements of this project was to adopt an existing simulation model, or develop one if necessary, and use as a tool to evaluate traffic characteristics and safety aspects at the intersection of four-lane major divided highway and two-lane minor road. A detailed evaluation of the existing simulation programs indicated that the best choice would be to adapt the simulation package developed under the

auspices of the Federal Highway Administration as part of the Urban Traffic Control System implemented in Washington, D. C. (10,11). The model UTCS-1S, smaller version of the program UTCS-1 (known now as NETSIM), has a demonstrated flexible, modular format permitting its efficient application to a wide variety of traffic system problems.

CONCLUSIONS

Most of the previous studies involved gap acceptance characteristics and distributions at intersections of two-way, two-lane urban streets, and at intersections of four-lane undivided highways with two-lane, city streets. However not much attention has been paid to examine driver characteristics at an intersection of a four-lane, divided, uncontrolled high speed highway with a two-lane stop controlled, intermediate speed road. High speed traffic on the major highway together with the existence of a median can be expected to be the main factors for the variation in gap acceptance distributions for the minor road drivers.

The review studies involving safety measurements at intersections indicated that the traffic conflict technique is probably the best available procedure to measure accident potential, because traffic conflicts can be measured reliably and they occur more frequently than traffic accidents. The literature review also indicated that a modified version of the simulation package NETSIM (UTCS-1S) would be the desirable tool for the purpose of this study.

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