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INVESTIGATION OF THE IMPACT OF MEDIANS ON ROAD USERS
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16. Abstract

The purpose of this study is to determine the safety impacts of raised curb medians, two way left turn lane (TWLT) medians and undivided cross-sections on vehicular and pedestrian traffic. The study concentrated on medians located on unlimited access arterials in central business district (CBD) and suburban environments.

A total of 32,894 vehicle and 1,012 pedestrian accidents were analyzed from 145.9 mi (234.8 km) of unlimited access arterials located in three large metropolitan areas. Operational data in the form of vehicle-pedestrian conflicts, pedestrian walking speed, and pedestrian use of medians for refuge were obtained and analyzed as part of the study. The accident data were used to develop nonlinear predictive models for estimating the effect of cross-section type on vehicular and pedestrian accidents. The predictive equations were used to develop a computer program that can be used by design engineers to determine the relative safety and delay benefits obtained from the installation of raised, TWLT and undivided medians.

Raised median pedestrian accident rates are significantly less than pedestrian accident rates on undivided arterials in suburban areas, and less than both TWLT and undivided arterial pedestrian rates in CBD areas. No significant differences were identified between the pedestrian accident rates of raised curb and TWLT medians in suburban areas. The CBD vehicle accident rates of raised medians, for both midblock and signalized intersections, are higher than that of TWLT medians and undivided cross-sections. A greater percentage of raised median vehicle accidents, however, are of lower severity (property damage only) than that of TWLT and undivided cross-sections for both CBD and suburban locations.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Pedestrian accidents annually account for approximately 16 percent of total traffic fatalities in the United States with 6,552 pedestrian fatalities occurring during 1989.[1] The pedestrian safety problem is largely an urban one. Each year approximately 85 percent of all pedestrian fatalities occur in urban areas. In some large urban areas 40 to 50 percent of those killed in traffic accidents are pedestrians.[2]

Approximately 17 percent of the 1989 pedestrian fatalities consisted of children under age 15 and 20.4 percent were pedestrians over the age of 64.[1] The pedestrian problem has often been characterized as a problem "of the young, the old, and the drunk." This characterization is misleading when considered in terms of pedestrian fatalities or involvement per 100,000 population. Since 1979, for example, pedestrian fatalities per 100,000 for those under age 14 have been lower than for pedestrians aged 14 to 64 and less than half the rate of adults 65 and older. While the characterization may be misleading in some respects, it serves to demonstrate that certain segments of the pedestrian population are perceived as being over-involved in accidents. This perception is based on the diverse physical and attitudinal characteristics of the pedestrian population.

One of the primary differences in pedestrian characteristics is walking speed. There is considerable variation in the walking speed of pedestrians depending upon their age and trip purpose. A study of free-flow walking speeds for 967 persons observed in two transportation terminals in New York City indicated that although 4.5 ft/s (1.4 m/s) was the observed average, 78 percent of the pedestrians normally walked slower than this.[3] The median speed, considered to be more representative than the average, was 4.0 ft/s (1.2 m/s). The New York study stated that the normal average walking speed of 3.6 ft/s (1.1 m/s), observed in a laboratory study of healthy older men, was in the 25th percentile of the distribution. Studies of street crossing speeds display slightly different results due to oncoming vehicles and impending signal change prompting nondisabled pedestrians to move faster. A time-lapse photography study of pedestrians in dense platoons crossing New York City streets indicated an average crosswalk walking speed of 3.3 ft/s (1.0 m/s).[4]

The Manual on Uniform Traffic Control Devices (MUTCD) indicates that normal walking speed can be assumed to be 4 ft/s (1.2 m/s).[5] The results of the New York study, however, indicate that if a walking speed of 4 ft/s (1.2 m/s) is used to determine the pedestrian clearance interval, 50 percent of pedestrians will have to walk faster than their normal walking speed to cross safely within the allocated green time. The Institute of Transportation Engineers (ITE) handbook suggests that a normal walking speed of 4 ft/s (1.2 m/s) is acceptable but speeds of 3.0 to 3.25 ft/s (0.9 to 1 m/s) may be more appropriate for slow walkers.[6] The 1965 edition of the ITE handbook estimated that 35 percent of the pedestrians did not attain the 4 ft/s (1.2 m/s) rate.[7] A recent study conducted in Florida at a location with a large number of elderly pedestrians determined that a walking speed of 2.5 f/s (0.8 m/s) was appropriate for 87 percent of those pedestrians.[8] In another study pedestrians aged 70 years or older were instructed to cross an intersection at fast, very fast and normal speed. The results indicated that 60 percent of the older pedestrians considered a speed lower than 4 ft/s (1.2 m/s) as fast. Approximately 90 percent crossed at a speed lower than 4 ft/s (1.2 m/s) with 15 percent of the elderly sample walking at a rate less than 2.3 ft/s (0.7 m/s).[9]

The diversity of walking speeds presents a problem to traffic engineers in determining the minimum green time and appropriate clearance interval at signalized intersections. The Traffic

Control Devices Handbook, which provides interpretation of the MUTCD states that "Those having slower walking speeds have the moral and legal right to complete their crossing once they have lawfully entered the crossing".[10] The traffic engineer, therefore, has the task of selecting an appropriate walking speed and, hence, minimum green time while simultaneously providing the cycle splits required for progressive and efficient movement of vehicular traffic. The signal timing task involves decisions about the duration of the signal cycle, its phases and the clearance interval with the goal of minimizing delay to vehicles. Pedestrian needs and vehicular needs, however, often conflict during the selection of optimal signal timing plans.

Many agencies tend to use long cycle times (120 to 180 s) for intersections with vehicle flows that are near capacity. For a coordinated signal system the longest cycle length of the group will be used at all the intersections. Long cycle lengths necessitate long pedestrian waiting times which increase the possibility of a pedestrian attempting to walk on a red signal phase.

The duration of the green phase must provide sufficient time for pedestrians to cross and simultaneously satisfy vehicular needs. The needs of pedestrians and vehicular traffic can be opposed to each other especially at the intersection of a high volume roadway with a relatively low volume minor roadway. In this instance the major street is often wide and the proportionate green time to the minor street movement is small. The pedestrians are, however, crossing the wide major roadway with the minor street green indications. The selection of minimum green time based on slower walking speeds in these instances can result in increased delay to the major roadway traffic. For example, at a walk speed of 3 ft/s (0.9 m/s) a pedestrian crosses a 60-ft (18.3-m) wide road in 20 s while using 4 ft/s (1.2 m/s) requires 15 s. Using 3 ft/s (0.9 m/s) results in providing an additional 5 s of green to the minor approach, where it may not be needed to accommodate vehicles, and takes away 5 s from the major approach, which may already be congested.

Problems at signalized intersections are complicated by geometric design and vehicle movement paths. Consider the situation of vehicle left turn movements at an intersection as presented in figure 1. The majority of vehicular left turn movements often takes place at the end of the green phase. At this time slower moving pedestrians may still be in the roadway, partially fatigued, and concerned with arriving at the far curb line. The left turning vehicle is concerned with oncoming traffic and may not be aware of pedestrians in the crosswalk into which the turn is being made. The result is an increased potential for pedestrian vehicle conflicts and subsequent accidents.

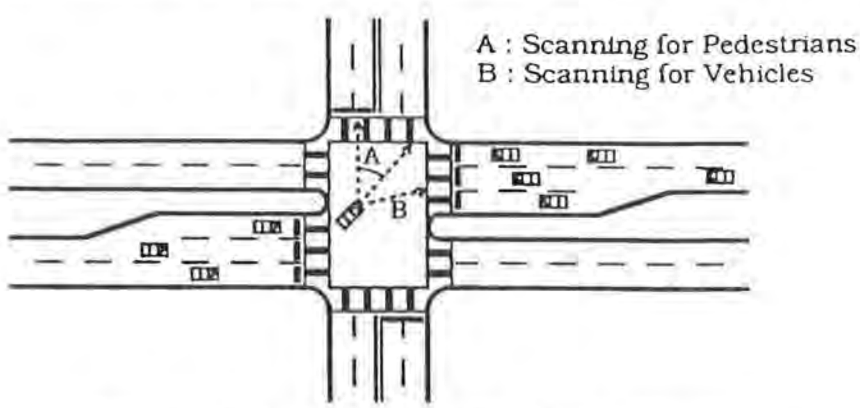

Figure 1. Attention conflicts for left-turn maneuvers.

Pedestrians crossing unsignalized intersections or at midblock locations are faced with the dilemma of judging the speed and closing distance of oncoming vehicles, relative to their own walking speed, in order select a gap in traffic that will allow them to cross safely. Judging the speed of an oncoming vehicle is often difficult for younger pedestrians who lack the experience to estimate approaching vehicle speeds, closing distances, and their own crossing times. It is even more difficult for elderly pedestrians with visual impairments and relatively slow reaction-perception time. The time required to cross a 4-lane, 48-ft (14.6 m) wide roadway is 12 s at the typical average walking speed of 4 ft/s (1.2 m/s), and 16 s at a walking speed of 3.0 ft/s (0.9 m/s). An approaching vehicle moving at 30 mi/h (48 km/h) travels 528 ft (160.9 m) in 12 s and 704 ft (214.6 m) in 16 s. Increasing the street width to 6, 12-ft (6, 3.7 m) lanes and the vehicle speed to 50 mi/h (80 km/h) increases the vehicle distance traveled during the pedestrian crossing at rates of 4 and 3 ft/s (1.2 and 0.9 m/s) to 1,320 and 1,760 ft (402.3 and 536.4 m), respectively. This relatively large distance increases the potential for vehicle-pedestrian conflicts and accidents.

The difference in pedestrian walking speeds, vehicular travel distances and vehicular signal timing needs are among the difficulties encountered by pedestrians in crossing roadways and by traffic engineers in producing optimal intersection signal timing plans. The magnitude of these problems increases as the vehicular volumes and roadway widths increase. Solutions to the problems include separating the paths of pedestrians and vehicles, narrowing the roadway cross section at intersections, and providing medians and refuge islands.

Path separation can be accomplished by pedestrian over and underpasses. These countermeasures are costly to both install and maintain and are infeasible in many instances due to the restrictive geometrics of the site. In addition, they often pose personal security risks to pedestrians and, because they require additional walking effort and distance, are often underutilized.

Narrowing of the roadway cross section can be performed at intersections and midblock pedestrian crossings where vehicular capacity is not an overriding concern. Examples of this technique, often called a sidewalk flare, are presented in figure 2. Sidewalk flares essentially provide an extension of the sidewalk at selected locations, which reduces the time of pedestrian exposure to traffic, increases their visibility to motorists, and elevates the pedestrian above the parking lanes by the height of the curb. Advantages of this technique are that it reduces the curb to curb pedestrian crossing distance, elevates the pedestrian above the pavement surface thereby providing better visibility, and slows traffic. This design has been used in central business district (CBD) and suburban areas that have 24-h curb parking. The design is not appropriate for high-speed arterial and collector streets or where the right lane is important for vehicular capacity. Adequate delineation of the flares is required to prevent vehicles from straying into the parking lane at night.

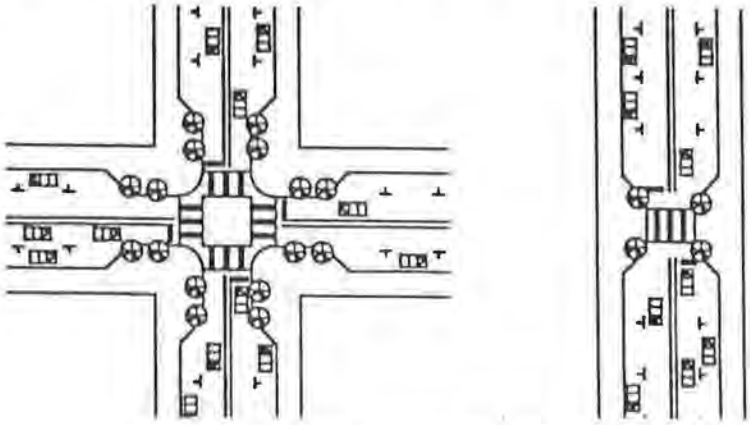

Figure 2. Examples of sidewalk flares.

Medians and refuge islands are classifications of traffic control islands defined as areas between traffic lanes for control of vehicle movements or for pedestrian refuge. Medians can be designed to serve more than one purpose, including controlling or protecting vehicle crossover or other turning movements, providing a landscape area, channelizing traffic and providing pedestrian protection. Pedestrian refuge islands are specifically designed to provide a place of safety for pedestrians who cannot safely cross the entire roadway width at one time because of changing traffic signals or oncoming traffic.

Refuge islands are particularly useful at locations where heavy volumes of vehicular traffic make it difficult and dangerous for pedestrians to cross the roadway.(11) The MUTCD states that refuge islands are particularly useful: (1) on multilane roadways, (2) in large or irregularly shaped intersections, and (3) at signalized intersections to provide a place of safety between different traffic streams.(10)

It has long been recognized that medians are an effective method of increasing vehicular safety and capacity on urban and suburban arterials. Medians can provide an additional lane for through traffic by removing left turning vehicles from the traffic stream. Medians are generally considered to be beneficial to pedestrian safety and operations, but their actual effect is unknown.

STUDY OBJECTIVE AND GENERAL RESEARCH APPROACH

This project, sponsored by the Federal Highway Administration (FHWA), had the primary objectives of: 1) determining the safety and operational effects of medians on all roadway users including pedestrians, 2) determining the data needed to develop quantitative installation criteria, and 3) developing installation criteria if determined as feasible. The research approval of the study included the following primary tasks:

- Conduct a literature review of median impacts concentrating on those studies where pedestrian safety was an issue. The focus was on studies performed in urban and suburban locations. It was not within the scope of this study to view or quantify the effect of medians on unlimited access arterials or rural locations that do not have a significant amount of pedestrian traffic.
- Use the literature reviewed to: (1) summarize existing studies that address the safety and operational impacts of medians on pedestrians and vehicles, (2) identify the predominant types of medians, (3) identify any existing guidelines that could be used to determine when medians should be installed, and (4) to identify the data variables and data collection techniques required to quantify the safety and operational impacts of medians.
- Conduct a state-of-the-practice survey of State, county and city agencies, concentrating on responses from large cities to maximize the experience of agencies with large pedestrian volumes.
- Conduct an accident based study of the impact of median installations on the safety of both vehicles and pedestrians.

CHAPTER 2. LITERATURE REVIEW RESULTS

The majority of the reviewed literature on medians and refuge islands was concerned with median treatments for limited access arterials or for rural roadways. These articles were primarily concerned with performing safety analyses on the effects of different median widths, types of median barriers, and various median designs, such as, raised and flush. Since the efforts of this project concentrated on the safety and operations of both pedestrians and vehicles, the literature review was conducted by concentrating on research articles that pertained to the analysis of medians in an urban or suburban environment. These articles were further stratified in order to focus on those median elements which were applicable to both pedestrian and vehicular operations and safety.

This does not imply that the only articles inspected were those that concurrently discussed pedestrian and vehicle operations and safety. Rather, articles were chosen to: (1) include all those encountered articles which did concurrently discuss pedestrian and vehicle safety, and (2) select those topics that had relevance to the location and design of medians in an urban or suburban environment. Median factors considered as relevant were those that would impact pedestrian crossing behavior, median design elements pertaining to pedestrian and vehicle needs, data elements required to evaluate the impact of medians on pedestrian behavior and safety, and recommendations in regard to installation guidelines or warranting criteria.

MEDIAN AND ISLAND TYPES

Traffic engineers have long recognized the important role of median treatments in alleviating the operational and safety deficiencies of arterial roadways. In suburban areas, medians have been used to reduce the accident potential and delay to through traffic resulting from left turning vehicles. Effective median design removes left turning vehicles from the through lanes and stores these vehicles in a median area until an acceptable gap in the opposing traffic is available. This permits reductions in both the frequency and severity of accidents. The frequency of accidents is reduced by removing stopped or slower left-turning vehicles from the through lanes. Severity is reduced by allowing additional perception-reaction time, thereby reducing left-turn conflicts. Delay to through vehicles is also reduced because left-turning vehicles and queues do not block the through lanes. These benefits can be achieved by medians that are installed at nonintersection locations as well as at major intersections. Urban and suburban arterials are experiencing deficiencies that are the result of high and steadily growing traffic volumes in conjunction with high driveway densities. A lack of effective access control to and from these driveways along the arterial segment results in safety and operational deficiencies. In addition to vehicular benefits medians have the potential for providing a resting place for pedestrians and in enabling them to concentrate all their attention on crossing one direction of traffic at a time.

There are many possible median types depending upon whether they are raised or flush, barrier free or barriered, and how they are delineated from through traffic lanes. Barrier type medians are not considered in this report since they essentially prohibit pedestrian movement. The principal types of barrier free medians appropriate for urban and suburban areas are summarized below.

Raised Medians

Raised medians promote safety and through traffic service by preventing left turns and U-turns across the medians, except at designated crossover points. In addition to preventing left turns, raised medians reduce friction in the traffic stream by separating opposing traffic. The effectiveness and utility of the median increases with increased width. If the raised median is at least 4 ft (1.2 m) wide it may be used by pedestrians as a rest area enabling them to cross only one direction of traffic at a time. If the median width is at least 12 ft (3.7 m) it can serve as a deceleration lane and storage area for left-turning vehicles at planned crossover points and as a pedestrian rest area.

Flush Medians

Flush medians use delineation treatments that do not physically restrict the movement of traffic across the median. The typical type of delineation treatment is painted traffic lanes but some jurisdictions also use raised pavement markers or mushroom buttons. The four principal types of flush medians are narrow divider strips, continuous and alternating left turn lanes and, two-way-left turn-lanes.

The standard design for two-way left turn lanes (TWLT) is specified by the Manual on Uniform Traffic Control Devices as presented in figure 3. The major design requirement of this technique is the median width which should be at least 12 ft (3.7 m). The intent of a TWLT lane is to remove left turning vehicles from through lanes and to provide storage in the median area until an acceptable gap in opposing traffic occurs.

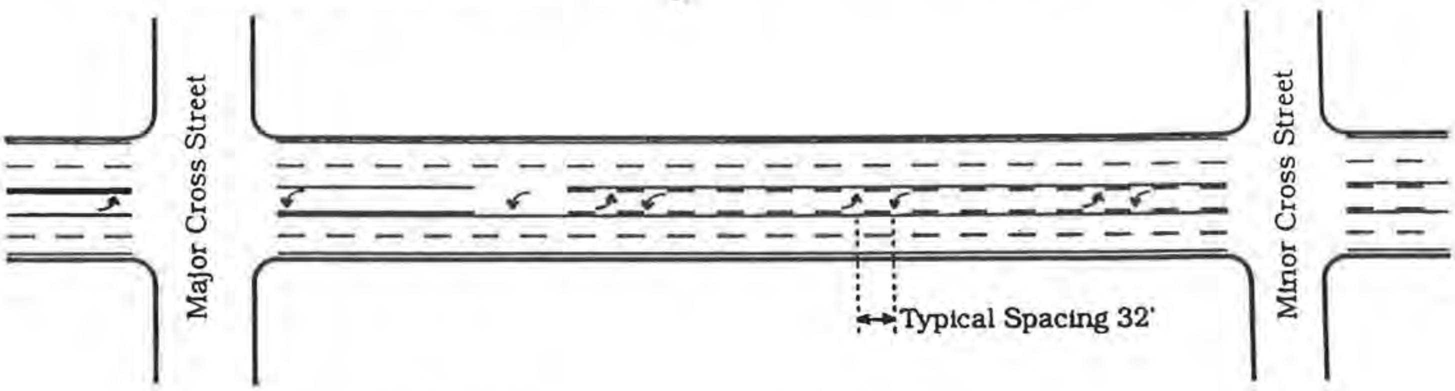

Figure 3. Typical configuration of TWLT median lanes.

The standard design in the continuous left-turn lane is shown in figure 4. This median is similar to the TWLT lane except that it provides individual left turn lanes for each direction of traffic. This technique requires a 24-ft (7.3-m) wide paved median and is not currently in frequent use.

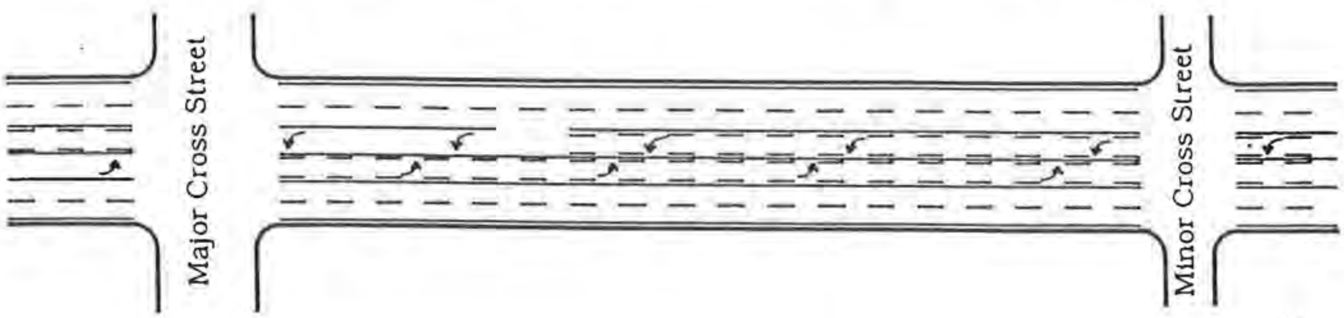

Figure 4. Typical configuration of continuous left-turn lanes for each direction of traffic.

The design of an alternating left-turn lane is presented in figure 5. The alternating left turn lane provides left turn opportunity for only one direction of traffic at a time. Both directions of traffic therefore have left turn capabilities over a limited section of roadway.

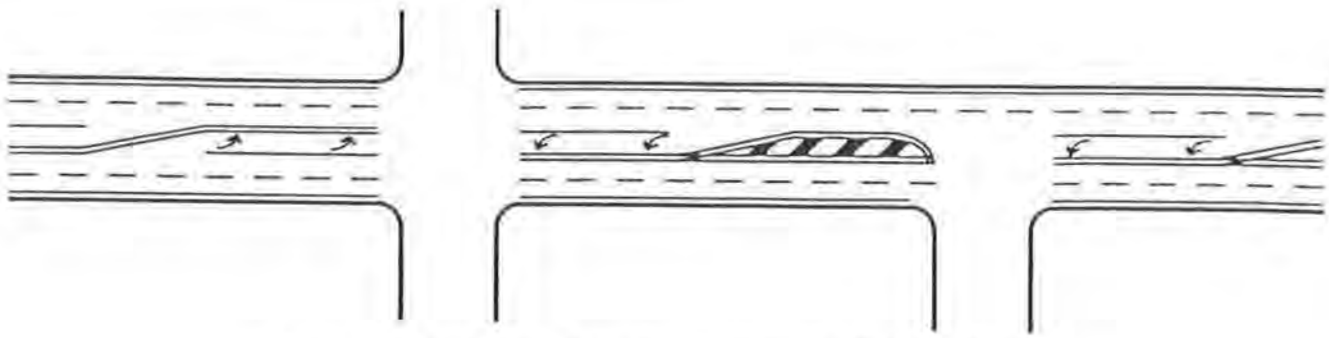

Figure 5. Typical configuration of alternating left-turn lane.

Previous research sponsored by the National Cooperative Highway Research Program (NCHRP) identified medians and refuge islands as techniques to increase the safety of pedestrians crossing major arterial streets.[12] The authors contend, however, that while the potential for increasing safety was present, the actual effect on pedestrian safety was unclear. To emphasize their concern they mention a previous study that claimed to reduce pedestrian accidents by the installation of refuge islands, which on close inspection exhibited problems of regression to the mean.[13] The literature search performed for this current project supports the NCHRP study conclusion that there is a substantial lack of definitive information on the effect of medians and refuge islands on pedestrian safety. Those articles that discussed or evaluated medians on urban and suburban locations were primarily concerned with their impact on vehicle safety and operations.

The NCHRP study developed a general finding that multilane highways with medians are substantially more convenient for pedestrians to cross than highways without medians. The authors concluded that medians should be divided as a standard feature of multilane suburban highways.[12] They cited a study of an arterial street in suburban Virginia which found that almost 90 percent of pedestrian crossings occurred at midblock. It can be expected that when pedestrians are faced with long distances between intersections, they will cross at midblock locations to reduce the total walking distance. The presence of medians at these locations can provide a significant benefit to both pedestrian convenience and potential safety on multilane roadways. This is particularly true at those midblock locations with relatively high volumes or unsignalized intersections since medians greatly simplify the pedestrian's task of crossing the roadway.

Effectiveness of Raised Medians

A limited amount of literature was identified that concerned the safety and operational impacts of raised medians on unlimited access urban roadways. Billion and Parsons performed a study to investigate the effect of median design on accident rates for divided roadways in Long Island, New York.[14] They studied 82 mi (132 km) of urban, divided, multilane, unlimited access roadways with traffic volumes up to 44,000 vehicles per day. Five years of accident data were analyzed which consisted of 1,552 accidents between intersections and 6,628 accidents at 650 intersections. Comparisons were performed between flush grass and raised medians with curbs. The results indicated that the curbed median had a higher overall, as well as a higher between intersection, accident rate than the flush median type. The rate for accidents between intersections was more than twice as large for curbed as for flush medians. The study also determined that the night accident rate for curbed median sections was twice that of the day rate when no illumination was present. For curbed median sections with illumination the night and day rates were the same.

A study performed in Los Angeles County, by Stover, et al., during the late 1960's on 12 pairs of roadways with raised and painted medians over 6 ft (1.8 m) wide determined that raised medians had a lower accident rate than painted medians.[25] Comparisons were performed on pairs of raised and painted medians with similar lengths, traffic volume, and adjacent land use. The roadway segments with raised medians had a rate of 1.00 accident per million vehicle mi (0.62 accidents per million vehicle km) while that for painted was 1.81 (1.12 per million vehicle km). The magnitude of the difference in the two median types of this study was almost the opposite of those determined from the Long Island study.

Harwood reported the results from the benefit-cost method that was used to determine which of five alternative median treatments was optimal.[16] Benefits were estimated by determining expected savings in accidents and delay based on regression equations developed by Mulinazzi and Michael.[17] Variables considered in the accident analysis included level of development, roadway type, number of driveways and crossroad ADT. The analysis considered three construction scenarios with option 1 assuming that the existing roadway was sufficiently wide to permit median installation without widening; option 2 required widening within the existing right-of-way; and option 3 required that both pavement widening and right-of-way acquisition be performed. The flush median two-way left-turn lane (TWLTL) was found to have a higher benefit-cost ratio under all construction options and levels of development than raised medians. Harwood did not separately perform an incremental benefit cost analysis and did not separately consider pedestrian accidents in his analysis.

Wooten, et al., in 1964 studied the impact of raised medians resulting from improvement projects in small, medium, and large size cities in Texas.[18] Improvement projects consisted of developing existing two-lane roadways into four-lane facilities with raised curbed medians. The before and after analysis indicated that the median eliminated the head-on collisions and significantly reduced rear-end collisions. Improper lane change and fixed object accidents were, however, increased. Operational studies indicated that the raised medians resulted in a large number of U-turns at adjacent crossovers with the median design too narrow for most vehicles to easily make the U-turn. The improvements were effective in attracting new businesses immediately after construction but there was a 10 percent reduction in the customer traffic in the after period. The high number of U-turns and the reduction of business traffic, in those median sections with commercial activity, resulted in the researcher recommending that "very careful consideration be given to a transversal type median which would permit midblock turns and thus eliminate the need for U-turns."

Providing for adequate median crossover opportunity was also discussed by Weinberg and Tharp in a 1969 NCHRP publication.[19] The authors state that medians are effective in reducing headlight glare, providing space for turning movements, providing a haven during emergencies and in serving as a pedestrian refuge. They further state that median openings serve a specific vehicle need and should, therefore, be designed properly. The opening should be of sufficient length and radius to allow the permitted movement to be accomplished without difficulty.

A study performed by Cribbins, et al., attempted to quantitatively determine the optimal spacing of median openings on multilane, divided highways when safety, level of service, and roadside access requirements were examined simultaneously.[20] Data were collected for 92 North Carolina study sites. Data of over 6,000 accidents that occurred on these sites during a 21-month period in 1963 and 1964 were related by distance measurements to median openings. Data were stratified by accident type and location type and analyzed by multiple regression techniques. The study indicated that wide median openings were not necessarily accident prone under conditions of low volume and light roadside development. The frequency of median opening did, however, have a significant effect on accident potential when traffic volume and roadside development increased. In addition, the study found that the signalization of median openings did not necessarily reduce the hazard of median opening use under high volume conditions. The use of signalization merely tended to make the traffic flow more orderly by offering a more equitable distribution of time for movements by each driver. The study recommended that the spacing of median openings be determined with consideration of the desired operating speed, facility type and the anticipated roadside egress and ingress needs. It further recommended that no additional spacings be permitted at locations other than those satisfying the predetermined spacing criteria.

Another article published by Cribbins, et al., based on the 1963 North Carolina data, discussed the effect of median storage lanes on accidents.[(21)] Cribbins reported that, at nonintersection locations, the accident rate increased, as the number of median openings increased, for median designs without storage lanes. For medians designed with storage lanes, the accident rate was not significantly affected by the number of openings, median width, speed levels or ADT.

Leong examined the immediate and long-range effects of narrow median strips on accidents in a 1970 study.[(22)] The study concentrated on raised concrete medians varying in width from 3 to 15 ft (0.9 to 4.6 m) from 21 segments of urban arterial roadway. The analysis indicated that there was a significant decrease in accident rate at signalized intersections but noted an increase in fixed object and sideswipe accidents at midblock locations.

The accident histories of different median types on rural roadways in Kentucky were studied by Garner in 1970.[(23)] The study indicated that raised medians provide an insufficient recovery area for vehicles on rural roadways. Garner suggested that the use of curbed raised medians in urban areas should be examined to determine if the same deficiencies exist.

Frick examined the differences in accident rates between four-lane roadways with raised curbed medians and four-lane roadways with a painted median lane.[(24)] The different median types had similar traffic volumes and speed limits but the painted median lanes had more legal access points than the curbed median section. The analysis of 2 years of accident data indicated that the painted median lane had an accident rate 2.65 times greater than the raised median. The results of the study prompted the authors to recommend the installation of curbed medians in lieu of painted median lanes. The study was, however, limited in scope since only two sections of roadway, one with painted medians and one with raised medians, were used in the analysis.

Sullivan and Gordon conducted a public opinion survey, in 1974, with residents of Knox County, Tennessee.[(25)] The purpose of the survey was to ascertain the perceptions of the general public on the safety and operational characteristics of raised versus TWLT median lanes. The survey was administered to users, customers, business proprietors and neighborhood residents of a local arterial scheduled for reconstruction. The results of the survey indicated that the majority of the respondents preferred the raised median. Those respondents with a vested interest in the right-of-way property such as business owners and operators, however, preferred the TWLT median lane.

A vehicle-object simulation model was used by Olsen, in 1974, to examine the effects of 4- and 6-in (102 and 152 mm) concrete curbs on vehicle crash test behavior.[(26)] The research indicated that 6-in (152 mm) concrete curbs do not redirect vehicles at speeds above 45 mi/h (73 km/h) when encroachment angles are greater than 5°. The use of curbed medians are not effective, therefore, in physically preventing vehicles from crossing the median and may cause the driver to lose control of the vehicle after striking the curb.

Reish and Lalani conducted a literature search and surveyed transportation and traffic engineers to assist in determining whether to control left turns by installing raised medians or to provide a TWLT median lane on a major arterial.[27] Their efforts resulted in the recommendation to implement raised medians throughout the length of the project. They based their decision on the high volume (over 25,000 ADT) and high midblock accident rates being experienced at the project site. In addition, raised medians were selected as a means of improving the design aesthetics.

Van Winkle, in a 1988 article, reported that experience with flush medians in Peoria, Illinois demonstrates them as being advantageous over raised medians.[28] He states that raised medians are fixed objects that can cause vehicles to go out of control, do not prevent head-on accidents, are difficult to delineate, cost more than flush medians and are not effective in controlling access. The author states that the ultimate key to improved safety is access management which is more likely to occur with flush medians.

TRAVERSABLE MEDIANS

For many years the American Association of State Highway and Transportation Officials (AASHTO) through its geometric design policy, commonly referred to as the Green Book, suggested the use of medians on all major roadways consisting of four or more lanes.[29] Early editions of the Green Book suggested that raised medians are generally more suitable for arterial streets. The current design policy recognizes the widely accepted practice of using a flush two-way left-turn lane (TWLT) median.[30] TWLT median lanes have received increased attention as an economical method for increasing the capacity and safety of existing transportation facilities.

The number of highway agencies using the TWLT median lane has increased since the concept was pioneered by a few States. Parker conducted a survey in 1977 of city and State design engineers and determined that raised medians were used on approximately 1/2 of the four-lane divided mileage, and that flush medians were used on 1/4 of the urban, divided, roadways.[31] A 1982 survey conducted by Committee 5B-4 of the Institute of Transportation Engineers determined that 72 percent of the contacted agencies were using TWLT median lanes.[32] In a 1990 report, Harwood determined TWLT median lanes were being used by 86 percent of the agencies responding to the survey.[33] The current widespread use of TWLT median lanes has been accompanied by a relatively large number of studies conducted to determine the safety, operational, and economic impact of continuous two-way left-turn median lanes.

Traffic accident operational and geometric data were collected for urban highways by Walton, et al., in 1978.[34] Their research indicated that the accident frequency on roadways with TWLT median lanes was significantly affected by the number of traffic signals per mile, the number of driveways per mile, the city population, and the average daily traffic. The results of their study were used to develop a regression equation to predict the annual number of accidents per mile for urban four-lane arterials with TWLT median lanes.

Sawhill and Neuzil conducted a study in 1963 at three TWLT median sites in Seattle.[35] The analysis of 7 years of accident data revealed that only 9.4 percent of the total number of accidents were related to the use of the continuous median lanes. Head-on accidents, a prime concern of the researchers, were determined to be negligible. Property damage and injury accidents were determined to be less severe for the continuous than for noncontinuous lane accidents. In addition, the continuous lanes were determined to reduce accidents by 26 percent, with the majority of accident reductions attributable to rear-end collisions.

Hoffman, in a 1974 study of TWLT lanes in Michigan, reported a 33 percent reduction in all types of accidents.(36) His study consisted of a before-after analysis of four projects where the four-lane, undivided highway was widened to five lanes to accommodate a center lane for left turns. The four projects were located on major roadways on the outskirts of large cities. In addition to the 33 percent reduction in total accidents, the study disclosed reductions of 45 percent in head-on left turn accidents and 62 percent in rear-end accidents. The continuous lanes were also effective in reducing injury accidents by 41 percent.

A comprehensive study on continuous TWLT median lanes was conducted by Nemeth in 1976.(37) The research approach included administering a nationwide expert opinion survey, a literature review, and before-after field studies in Ohio. The pertinent findings of the literature review are summarized below:

- TWLT median lanes are most applicable in areas of relatively dense roadside development where numerous crossover points are required for access.
- TWLT median lanes are used on urban arterials with volumes ranging from 8,000 to 31,000 vehicles per day.
- The posted speed limits found on roadways with TWLT median lanes range from 25 to 50 mi/h (40 to 81 km/h).
- TWLT median lanes should not be carried through major intersections.
- TWLT median lanes require less right-of-way than raised medians and can often be constructed within the existing right-of-way.
- Early studies of driver use of TWLT median lanes indicated that a large percentage of motorists use the lanes improperly.
- Most researchers reported a significant reduction in rear-end, sideswipe, midblock and left-turn accidents as a result of installing TWLT median lanes.
- Every study determined that head-on collisions due to the use of the median left-turn lane by opposing traffic was an uncommon occurrence.
- TWLT median lanes have been successfully used as reversible lanes during peak periods and as exclusive lanes for public transit.
- TWLT median lanes provide an alternative path for emergency vehicles during periods of heavy congestion.

The operational data obtained as part of the Nemeth study included analysis of traffic speeds, volumes and traffic conflict data during both the before-and-after time periods.(37) Analysis of sites that involved the restriping of a two-lane roadway to provide two through lanes and a median left-turn lane disclosed a reduction in travel time and delay and an increase in average running speed. There was a 37 percent reduction in traffic conflicts but this may be less than the actual reduction due to increases in through, side street and left-turn volumes during the after period. The restriping of a four-lane facility to obtain four through lanes and a left-turn median lane resulted in a slight increase in running speeds and a reduction in traffic conflicts.

The impacts of installing TWLT median lanes at seven sites in Arizona were studied by Burritt and Coppola.[38] Their analysis, consisting of 2 years before and 2 years after accident data, indicated that total accidents were reduced by 35.9 percent with a benefit cost ratio of 8.6 for the median treatment.

A 1978 study by Babcock and Foyle at 14 urban roadway sections located in 2 North Carolina cities analyzed accident and operational data.[39] Their analysis indicated the accident rates on five- and seven-lane continuous TWLT median sites were similar to the accident rates for four- and six-lane divided roadways. The TWLT median lanes were determined to be effective in accommodating large traffic volumes.

McCoy, et al., developed a simulation model in 1982 to quantify the effects of TWLT median lanes on traffic flow efficiency.[40,41] They validated their model by collecting stop and delay data on Nebraska roadways where TWLT median lanes were installed. The results of their simulation indicated that TWLT median lanes increased the efficiency of traffic operations over a wide range of traffic volumes, left-turn volumes and roadway densities. TWLT median lanes were determined to be partially effective at traffic volumes above 700 vehicles per hour, in each direction, with more than 70 midblock left turns per 1000 ft (305 m) from each direction.

In 1984 Thakkar reported the results of a study that had the objectives of determining the safety and cost effectiveness of TWLT median lanes.[42] Data collected for 2 years before and 2 years after the installation of TWLT median lanes were analyzed for 15 five-lane and 16 three-lane roadway sections. Statistically significant reductions in both frequency and rate of accidents were observed for total, left-turn, rear-end and sideswipe collisions after the installation of TWLT median lanes. The TWLT median lane installations were cost effective on both roadway types considering only the accident reduction benefits.

The Institute of Transportation Engineers formed Committee 5B-4 to summarize current practices and experiences with median acceleration, deceleration and storage lanes.[43] The committee performed a literature review and surveyed traffic engineering agencies and professionals to identify the safety, operational and cost effective impacts of median lanes. The 1984 summary of these activities indicated that TWLT median lanes were useful for handling midblock left turns, resulting in an average accident reduction of 35 percent, and reductions in congestion and delay. They further stated the TWLT median lanes had been successfully used on roadways with speeds of 25 to 55 mi/h (40 to 89 km/h), and with volumes up to 43,000 vehicles per day, with 5,000 in the peak hour.

McCoy and Ballard, et al., applied a simulation model to urban four-lane roadways to determine operational effects and to develop guidelines for the cost-effective use of TWLT median lanes.[44,45,46] The authors determined that average daily traffic (ADT) at which TWLT median lanes became cost effective depended upon the left-turn percentage and driveway density for the roadway. Their analysis indicated that TWLT median lanes were not appropriate when there was little conflict between left-turn and through movements, low driveway density, short intersection spacing and high pedestrian volumes.

Harwood reported the results of research conducted for the National Cooperative Highway Research Program in a 1986 report.[47] The purpose of the research was to investigate and compare the safety, operational and cost characteristics of selected multilane design alternatives for use in suburban areas. Information was developed on the advantages and disadvantages of each alternative to assist in the selection of the most appropriate design for a given condition. The principal variables used in the assessment were the prediction of accidents and motorist delay. The research indicated that the three lane TWLT median design had substantial traffic operational and safety advantages over a two-lane undivided roadway; requiring only a minimal increase in roadway width. The four-lane undivided was determined as being most appropriate for residential and light commercial areas on suburban roadways classified as collectors and minor arterials. The four-lane undivided alternative was best suited for use on major arterials with high volumes of through traffic and less than 45 driveways per mile (28 driveways per km). The five-lane TWLT median lane alternative was determined as the most appropriate for suburban roadways with commercial development, driveway densities greater than 45/mi (28/km), high left-turn volumes and high rate of rear-end and angle accidents.

MEDIANS AND PEDESTRIANS

The majority of reviewed publications did not discuss the safety nor operational impacts of medians on pedestrians. The study by Billion and Parsons, reported in a 1962 publication, was one of the few studies that retained pedestrian accidents as a separate category, not grouping them into the "other" category.[14] The raised median type had a rate of 5 pedestrian accidents per million vehicle mi (3.1 pedestrian accidents per million vehicle km). This was higher than the flush median types analyzed in the study. It was not possible to determine from the study, however, if the higher rate was due to increased pedestrian activity at curbed raised median sites.

Lalani, in 1977, reported the results of a study conducted in London, England, on the safety effectiveness of pedestrian refuge islands.[48] Accident data for 1 year of before and 1 year after were analyzed for 120 refuge island sites of 5 different configurations. The study indicated that refuge islands reduced vehicle accidents but increased pedestrian accidents. The author concluded that refuge islands, often installed to increase pedestrian convenience and safety, may actually increase pedestrian accidents. A review of the study, however, discloses problems with the experimental design. The study only used 1 year each for the before and after time periods resulting in possible regression to the mean validity threats and did not use accident rate analysis to control for changes in vehicle or pedestrian volumes.

Fegan, in a 1978 publication, reported that 20 percent of the rural and suburban pedestrian accidents were attributable to pedestrians making a midblock or intersection dash.[49] While median barriers were provided as a possible countermeasure for freeway pedestrian accidents, no mention was made of their possible effect on urban, rural or suburban pedestrian accidents. Fegan's paper was based on a number of studies conducted for the FHWA and the National Highway Traffic Safety Administration.

Parker analyzed accidents occurring at 19 raised median sections in Virginia.[31] A report of his study, published in 1983, indicated that only 17 of the 1809 (0.94 percent) accidents occurring during a 3-year period involved pedestrians. Eight of the 17 accidents involved pedestrians who were struck in the median area. During the same 3-year period, 29 of 1,757 (1.65 percent) accidents involved pedestrians at 17 sections with TWLT median lanes. Of these 29 accidents, 10 involved pedestrians who were struck in the median area.

A 1980 publication by Templer described the requirements and procedures for establishing a system of routes which are accessible to the handicapped and elderly.[50] This report recommends that refuge islands are warranted where pedestrians cannot safely cross the entire roadway at one time. The report stated that consideration to refuge island installation should be made when the total roadway exceeds 75 ft (23 m) or the geometrics result in large or irregularly shaped intersections.

A 1987 publication by Knoblauch discusses the apparent advantages of what the authors termed as safety islands.[51] A safety island was considered as a level or raised median or transit vehicle-loading area that provided a place for pedestrian refuge within the roadway. The author states that some pedestrians cannot cross a wide roadway before the traffic signal changes. The results of the study led to the conclusion that many accidents are caused by pedestrians running across the intersection in an attempt to cross before the end of the traffic signal phase. Safety islands would provide the opportunity to cross the roadway in stages, reduce pedestrian exposure, and require pedestrians to look for oncoming traffic in only one direction at a time. Some stated disadvantages to safety islands were that they could possibly create an illusion of safety, present maintenance problems and be a source of vehicle accidents. In a companion publication, the author states that safety islands can be used to reduce dart out, midblock dash, intersection dash and trapped pedestrian accident types.[52]

In 1987, Grayson published the results of paired comparison analyses between a 1962 and a 1983 pedestrian safety study conducted at 75 crossings in London, England.[53] The pedestrian crossing facilities used in 1983 were the same as those of the 1962 study but changes in the composition of many crossings had occurred. One of the principal changes consisted of the number of crossings with refuge islands increasing from under 1/2 in 1962 to over 2/3 in 1983. The study indicated an overall reduction in the pedestrian accident rate but it was not possible to attribute this reduction to the increased use of pedestrian refuge islands.

A 1989 article by Dunn discusses the background and safety considerations that led to a technical recommendation which sets standards for the installation and upgrading of pedestrian crossings in New Zealand.[54] Research indicated that pedestrians begin to reject crossing opportunities at vehicle headways of about 4 s. The 4 s headway and a typical walking speed of 4 ft/s (1.2 m/s) were used to determine that a typical pedestrian could safely cross a roadway of about 16 ft (5 m). This is equivalent to a total width of about 33 ft (10 m) for a two-lane roadway. The result was a technical recommendation specifying the maximum desirable length of crossing as 33 ft (10 m). For roadway widths exceeding 33 ft (10 m), the technical recommendation specifies that roadway narrowing or central refuge islands should be implemented.

SUMMARY OF LITERATURE REVIEW

The literature review is summarized to present the principal findings with regard to the predominant median types, their safety effectiveness, operational effectiveness and installation criteria.

Currently Predominant Median Types

Raised medians were the predominant type of median first used on urban and suburban roadways. Roadway designers considered them effective in controlling left turn movements, providing a storage space for left turning vehicles, separating opposing traffic flows, providing an opportunity for aesthetic enhancements and for providing areas for pedestrian refuge. Increased congestion, limited right-of-way, high cost of construction, maintenance costs of raised medians, safety analyses and the need for increased left turn opportunities have resulted in a large number of agencies using flush TWLT median lanes. The literature review indicates that TWLT median lanes have been successfully used on urban and suburban roadways having one or more of the following characteristics:

- Where traffic volumes are not exceedingly high. There is no firm consensus on the upper volume threshold level at which the advantages of TWLT median lanes dissipate. The ITE Survey of practice indicated that the upper level was an ADT of 43,000 while other researchers indicated 25,000.[27,32]

- On roadways having a relatively large number of left turns, commonly in areas having commercial development and frequent driveways. TWLT median lanes have also been successfully implemented in residential areas, combined commercial-residential areas, industrial areas and, in some States, rural areas.[36,37]

- In areas where the predominant accident patterns are related to left-turn maneuvers and indirect left turn access cannot be provided with a raised median.[47]

The advantages and disadvantages of raised and flush medians are summarized in tables 1 and 2, respectively. These tables were compiled from a 1990 report by Parker in conjunction with a 1990 report by Squires and Parsonson and are based on a consensus of the literature.[55,56] The increased installation rate of TWLT median lanes and the historic use of raised medians have resulted in their selection as the predominant median types for the purposes of this study.

Safety Effectiveness of Predominant Median Types

The majority of the reviewed literature described before and after accident studies of TWLT median lanes. Studies which compared the safety effectiveness of raised and flush median types provided mixed results. An inspection of these studies provides an insight into why some of these mixed results occurred.

- Frisk compared accident rates for two sites, during 1968, in Springfield, Illinois.[24] The results of the study indicated that the site with the flush median lane had an accident rate that was 2.65 times greater than the raised median section. Because only two sites were used, the study conclusions are questionable due to small sample sizes.

- Squires and Parsonson compared accident occurrence between raised medians and TWLT median lanes in Georgia.[56] They determined that there was no difference in accident rates between the two median types but determined that there was a significant difference in accidents per mile. Parker, in a comparison of 19 raised and 17 flush median sites in Virginia, also determined that there was no significant difference in accident rates between the two median types.[31] This 1983 study determined that the accident rate for raised medians was 442 accidents per hundred million vehicle mi (275 accidents per hundred million vehicle km) and that the rate for flush medians was 611 (380 per hundred million vehicle km). Parker also determined that the accident frequency per mile was not significantly different. In a 1990 update to his study, Parker again determined that neither the accident rates nor the accidents per mile were significantly different.[55]

Table 1. Advantages and disadvantages of raised medians.[55,56]

Advantages:

- Discourages new strip development and encourages large planned development.
- Allows better control of land use by local government.
- Reduced number of conflicting vehicle maneuvers at driveways.
- Safer on major arterials with high (>60) number of driveways per mile (>37 driveways per km).
- Increases traffic flow.
- Desirable for large pedestrian volumes.
- Permits circuitous flow of traffic in grid patterns.
- Allows greater speed limits on through road.
- Safer than TWLTL in four-lane sections.
- Safer than TWLTL in six-lane sections but depends on number of signals/mile, driveways/mile, ADT, and approaches/mile.
- Encourages access roads and parallel street development.
- Reduces accidents in mid-block areas.
- Reduces total driveway maneuvers on the major roadway.
- Low maintenance cost of raised medians, depending on final design.
- Studies have shown that delay per left- turning vehicle does not increase, up to the studied volume of 3700 vehicles per hour (vph).
- Curbs discourage arbitrary and deliberate crossings of the median.
- Reduces number of possible median conflict points.
- Provides separation between opposing traffic flows.
- Provides a median refuge area for pedestrians.
- With raised grass medians, an open space is provided for aesthetics.

Disadvantages

- Reduces operational flexibility for emergency vehicles and others.
- Increases left-turn volume at major intersections and median openings.
- Increases travel time for vehicles desiring to turn left where median openings are not provided.
- Reduces capacity at signalized intersections.
- Possible increase of accidents at intersections and median openings.
- Usually increases fixed object accidents.
- Requires motorists to organize their trip making to minimize the need for U-turns and use the arterial only for relatively long through movements.
- To minimize delay requires interparcel access, which may not be under government control or would be expensive to purchase and construct.
- Restricts direct access to adjoining property.
- Installation costs are higher.
- Can create an over concentration of turns at median openings.
- Indirect routing may be required for some vehicles.
- When accidently struck, curb may cause driver to lose control of the vehicle.
- A median width of 25 ft (7.6 m) is needed to accommodate U-turns.

Table 2. Advantages and disadvantages of two-way left-turn (TWLT) median lanes.[55,56]
Advantages:
• Left-turning vehicles are removed from through traffic while maximum left-turning access to side streets and driveways is still provided. • Delay to left turning vehicles and others is often reduced. • Operational flexibility for emergency vehicles and others is enhanced. • When less than 60 commercial driveways per mile (37 driveways per km) are permitted to be constructed two-way left-turn lanes appear to be safer. • Roads with two-way left turn lanes are operationally safer than roadways with no separate left-turn lanes in the median. • Detours can be easily implemented when required by maintenance in adjacent lanes. • Provides spatial separation between opposing traffic flows. • Eliminates the median island fixed object. • Provides temporary refuge for disabled vehicles. • Can be used as a reversible lane during peak hours. • Permits direct access to adjoining properties.
Disadvantages:
• There are conflicting vehicle maneuvers at driveways. • Poor operation of roadway if stopping sight distance is less than AASHTO minimum design. • No pedestrian refuge areas for pedestrians free from moving vehicles. • Operate poorly under high volume of through traffic. • Should not be used when access is required on only one side of the street. • Visibility problem of painted median especially with snow and rain or when pavement markers outlive their design life. • A safety problem when they are used as a passing lane. • High maintenance cost of keeping the pavement striped and raised pavement markers in proper operating condition. • Must continually instruct the public on proper use and operation. • Delays to left-turning vehicles increase dramatically when two way through volume reaches 2800 vph. • Limits operating speed to a maximum rate 45 mi/h (73 km/h). • Does not guarantee unidirectional use at high-volume intersections. • Are not aesthetically pleasing for some people. • Allows numerous potential traffic conflict points.

The studies by Parker and Squires and Parsonson were, however, too small to experimentally control for differences in traffic volumes, intersections per mile and driveways per mile between the median types.

- In 1986, Harwood analyzed accident data at sites in California and Michigan and found that accident rates at TWLT median lanes were 21 to 24 percent lower than accident rates for raised median sections.(47) Harwood used a good experimental approach, but only used sites in California and Michigan with a total raised median length of 21.8 mi (35 km) with 16.2 of these miles (26 km) in commercial areas.

While there are problems in many of the studies that compared the safety effectiveness of raised and flush median types there are a number of studies that determined the safety effectiveness of raised medians and TWLT median lanes without comparison. A summary of the raised median safety effectiveness results are summarized below.

- A study of three raised median installations by Wooten in 1964 determined significant accident reductions; one site as high as 69 percent.(18)

- Harwood and Glennon, using data obtained by Mulinazzi and Michael, estimated that raised medians would reduce accidents by 50 percent at major intersections and 60 percent of the left turn accidents at low volume driveways.(16,17)

- Harwood, in his 1986 study, determined that accident rates on raised medians and four-lane undivided sections were nearly identical after adjustment for type of development and driveways per mile.(47)

A summary of the safety effectiveness of TWLT median lanes is presented below:

- Sawhill and Neuzil, in 1963, reported a 25.8-percent decrease in accidents, with only one head-on accident, after a TWLT median lane was installed.(35)

- A 1-year before and 1-year after study conducted by Hoffman at four TWLT median lane sites in Michigan determined that total accidents decreased by 33 percent.(36) The study sites were initially four-lane undivided facilities widened to accommodate the median left-turn lane. Prior to the installation of the TWLT median lane there were 14 head-on accidents in which 18 people were injured. After the TWLT median lane installation there were eight head-on accidents in which one person was injured.

- A 2-year before and 2-year after study were conducted by Thakkar on a four-lane roadway on which a TWLT median lane was installed.(42) His study indicated that total accidents were reduced by 22.6 percent and the accident rate was decreased by 27.7 percent.

- Seven sites in Arizona were studied in a 2-year before and 2-year after experimental design by Burritt and Coppola.(38) They determined that total accidents were reduced by 35.9 percent and head-on accidents by 66.7 percent after flush median lanes were installed.

- Babcock and Foyle examined over 1000 accident reports for TWLT median lanes in North Carolina and did not identify any head-on accidents attributed to the median lane.[39]

- Parker, in a Virginia study, determined that 1.05 percent of the raised median accidents were head-on collisions, occurring primarily at the median openings.[31] Parker also determined that 0.98 percent of the accidents on TWLT median sections were head-on collisions with no fatalities involved.

A summary of the safety effectiveness of raised and TWLT median lanes on pedestrians is presented below:

- Billion and Parsons reported in a 1962 publication that raised medians had a higher accident rate than flush medians.[14] It was not possible to determine from the study, however, if the higher rate for raised medians was due to increased pedestrian activity.

- A 1977 study conducted in London, England, determined that pedestrian refuge islands increased the number of pedestrian accidents.[48] Problems with the experimental design and the failure to consider changes in traffic and pedestrian volumes result in questionable validity of the study conclusions.

- Grayson performed a paired comparison between 1962 and 1983 studies performed at 75 crossings in London, England.[53] This comparison determined a reduction in the pedestrian accident rate between the 1962 and 1983 study. Due to geometric and traffic control changes that took place between the study periods it is not possible to ascertain if the decrease in pedestrian accidents was due to the increase in refuge islands.

- In a 1983 study, performed in Virginia, Parker determined that 17 of the 1809 accidents (0.94 percent) occurring during a 3-year period involved pedestrians at raised median roadway sections.[31] For the TWLT median lane roadway sections there were 29 pedestrian accidents.

Summary of Operational Effectiveness

The majority of reviewed studies concentrated on the safety effect of medians on vehicular traffic. Where operational studies were conducted, the measures of effectiveness were speed, travel time, and delay measures. These measures of effectiveness are site specific and heavily influenced by the number of lanes, type of development, number of driveways, number of intersections, etc. The summary presented below groups those studies that had similar results.

- Delay to through vehicles has been determined to be considerably reduced by both raised and flush medians.[31,34,37,43] Both of these median types remove left-turning vehicles from the through lanes and separate opposing traffic flows.

- Left-turn operations on raised and flush medians have been determined to have different impacts on operations. Raised medians concentrate left-turn operations at median openings, requiring the driver to select an alternate route or make a U-turn to reach the destination. Harwood used a simulation model developed by McCoy, et al., to compare the operational effectiveness of raised and flush medians.[40,47] Harwood determined that raised medians resulted in greater travel time and delay than flush medians.

- Traffic volumes were considered by some researchers as being a warrant for median installation. Stover recommended that raised medians be used on all arterial roadways with two or more lanes and traffic volumes of at least 20,000 vehicles per day.[15] TWLT median lanes were suggested for use when the volume ranged from 10,000 to 25,000 vehicles per day by some researchers.[57,58] Volume warrants were opposed by Nemeth, and others because successful applications of flush medians were found for volume ranges between 5,000 and 50,000 vehicles per day.[34,37,43] This volume range is typical of the full range of volumes on facilities having four through lanes.

- Research conducted by Parker, in Virginia, and that conducted in other States indicates that TWLT median lanes have been successfully used for speed limits posted between 25 and 55 mi/h (40 and 89 km/h).[31,34,37,39] TWLT median lanes have been successfully used on some median sections with speeds posted at 60 mi/h (97 km/h).[37,43]

- Raised medians have resulted in observed wrong way movements when used in highly developed areas.[28,31]

- Driver confusion and operational efficiency were observed at the openings of raised medians when more than one vehicle occupied the opening at the same time.[31,39] These occurrences typically happened at unsignalized intersections in heavily developed areas.

- Improperly designed raised median openings result in U-turn problems.[15,31,39] The improper design can result in the operators of large vehicles starting their U-turn from the inside through lane instead of the left turn lane. Some drivers, to avoid running over the curb, must perform a backing maneuver to complete their U-turn.

Summary of Installation Criteria

Raised and Flush Medians

- A median of some sort should be used to provide left-turn channelization at all at-grade intersections on high-speed, high volume roadways.[30]

- Bretherton reported that a raised median is always safer than a TWLT median lane on any four- or six-lane road, regardless of traffic volumes, number of signals per mile or driveway frequency, or cross street frequency.[59]

- Squires agreed that a raised median is safer than a TWLT median lane on four-lane sections, but claimed that on six-lane roadways with a driveway density greater than 75 per mi (1.61 km), with two or fewer signals per mile, and a maximum of five or six approaches per mile, a TWLT median lane is preferable.[56]

- A raised median works best when there is adequate provision for access between neighboring businesses, such as interconnecting parking lots.[59]

- Reish recommended the installation of a raised median where volumes exceed 25,000 vehicles per day.[27]

- The use of some sort of median was recommended by Stover on all primary arterials and on secondary arterial roadways with two or more lanes in each direction, average speeds greater than 35 mi/h (56 km/h) and traffic volumes of at least 20,000 vehicles per day.[15] If an existing arterial with a TWLT median lane has a volume of 24,000 to 28,000 vehicles per day, the reconstruction of the arterial to utilize a raised median should be considered, according to Bretherton.[59]

- Harwood found that a four-lane divided facility was more appropriate than an undivided facility for major arterials where the peak hour flow rate is greater than 1000 vehicles per hour in one direction and which have a driveway density less than 45 per mi (1.61 km).[47]

- Most agencies prefer to utilize raised or grass flush medians on six-lane arterials.[27]

- Where major driveways or intersections are spaced more than 1 mi (1.61 km) apart, Harwood suggested that a median barrier be used.[16]

- Parker presented a method to select between a raised or a painted median.[61]

- Parker claimed that there is no evidence to limit the use of painted medians to a particular volume range or to roadways with a speed limit under 45 mi/h (73 km/h).[31,55]

- Cribbins attempted to use multiple regression to derive an equation for the optimum spacing of median openings, but was unable to do so.[20]

- An FHWA Implementation Package reported that traffic-serving businesses appear to be affected by their accessibility to a median crossing. Minimum spacings between median openings were also given.[13]

- Minimum spacings between median openings were also presented by Bretherton.[59]

- In urban areas, Bretherton concluded that median openings could be constructed where the minimum left-turn volume is 500 vehicles per day or 100 vehicles per hour during the peak hour on streets where the speed limit is less than 40 mi/h (64 km/h). Where the speed limit is over 40 mi/h (64 km/h), median openings can be constructed where the minimum left-turn volume is 350 vehicles per day or 70 vehicles per hour during the peak hour.[59]

Two-Way Left-Turn Median Lanes

- The addition of a TWLT median lane to an existing two-way four-lane street reduced stops and delays for every combination of volume, average running speed and left-turn percentage when estimated on a computer model developed by Ballard and McCoy. Stop and delay reduction isograms are presented which, when used within the context of a cost-effectiveness analysis, can help identify when an installation is justified.[41]

- Ballard and McCoy also tested 54 combinations of traffic volume, left-turn percentage and driveway density. In every case, the number of stops and the amount of delay were reduced. Those reductions in stops and delay were then used to develop equations to compute the operational benefits of adding a TWLT median lane. One set of equations was for volumes under 800 vehicles per hour, the other for volumes greater than this.[46]

- In a similar study conducted by McCoy, the addition of a TWLT median lane to a two-way two-lane roadway decreased stops and delays for all combinations of volumes and driveway density with one exception. In this one case, there was no change. Under balanced flow conditions, the addition of a TWLT median lane was particularly effective at volumes greater than 700 vehicles per hour in each direction and with more than 70 left turns per 1000 ft (305 m) from each direction. Isograms were presented to use within the context of a cost-effectiveness analysis to determine when an installation is justified.[40]

- ITE Committee 5B-4 concluded that TWLTL's are best suited for use on roadways with 25 to 55 mi/h (40 to 89 km/h) speed limits in areas of strip development.[43]

- Harwood reported, for a roadway with four through lanes, TWLT median lanes are most appropriate for suburban highways with commercial development, a driveway density higher than 45 per mi (1.61 km), low to moderate volumes of through traffic, high left-turn volumes and/or a high rate of rear-end or angle accidents associated with left-turn movements.[47]

- The use of a TWLTL is warranted on arterial highways with an ADT greater than 10,000 vehicles per day, average traffic speeds above 30 mi/h (48 km/h), a driveway density of more than 60 per mi (37 per km), fewer than 10 high-volume driveways per mile (6 per km) and a left turn percentage of at least 20 percent of through volume during peak periods, according to Harwood.[16]

- Bretherton reported that TWLT median lanes are definitely warranted at volumes above 28,000 vehicles per day because of the inability of turning vehicles to find acceptable gaps.[59]

- On roadways with four through lanes, TWLT median lanes are cost effective, based on operational savings alone, at an ADT of 16,200 vehicles per day, according to McCoy. If accident cost savings are also considered, an installation is justified at volumes above 7100 vehicles per day.[44]

- Thakkar also found that TWLT median lanes are safe and cost effective on roadways with four through-lanes, as well as on roadways with two through-lanes.[42]

- Nemeth stated that the use of TWLT median lanes is suitable for roadways with closely spaced driveways and high left-turn volumes, but not where the block lengths are short.[37]

- Stover also concluded that TWLT median lanes were suitable for use on roadways with closely spaced driveways, but asserted that they could only be effective if the turning volumes into individual driveways were relatively low from roadways with a speed limit of 45 mi/h (73 km/h) or less.[15]

- Walton made claims similar to those of Nemeth, but felt that TWLT median lanes could operate efficiently only under moderate left turn demands.[34]

- A literature review conducted by Walton revealed that a TWLT median lane is preferable to a one-way left-turn lane on four through-lane roads with ADT between 10,000 and 20,000 vehicles per day and on two through-lane roads with ADT from 4,000 to 12,000 vehicles per day. He also presented tables and equations to be used as guidelines for left-turn lane improvements or installations.[58]

- The use of TWLT median lanes is not appropriate where there are high pedestrian volumes, the roadway is a major arterial, the block lengths are short, or there are unusual driveway configurations, according to McCoy.[45]

Summary of Refuge Islands

- Dunn concluded that refuge islands should be provided if the roadway width exceeds 33 ft (10 m), based on evidence that pedestrians reject headways less than 4 s using an average walking speed of 4 ft/s (1.2 m/s).[54]

- A 1980 FHWA Implementation Package recommended the consideration of refuge islands on roadways greater than 75 ft (22.9 m) in width.[50]

- A later FHWA Implementation Package, published in 1987, stated that a refuge island should be considered where the entire roadway width cannot be crossed within the signal phase at a 3.5 ft/s (1.1 m/s) walking speed and the signal timing cannot be lengthened or an alternate crossing cannot be designated.[61]

- Smith recommended the use of refuge islands at locations where medians cannot be provided, traffic speeds are less than 45 mi/h (73 km/h) and pedestrian volumes are greater than 100 persons per day. They should not be used for midblock pedestrian crossings across high volume streets where speeds are above 45 mi/h (73 km/h). Refuge islands should be located every 300 to 500 ft (92 to 153 m).[12]

- Zegeer stated that refuge islands are necessary on wide, two-way streets with high vehicular volumes, high speeds, and high pedestrian crossing volumes. They should not be used on narrow streets, where there is a high turning volume of large trucks, where roadway alignment obscures the island, or in areas where snowplowing would be hampered.[62]

CONCLUSION OF LITERATURE REVIEW

While the results of the safety analyses on medians and refuge islands are mixed, it appears that both raised and TWLT medians significantly reduce the number and severity of vehicular accidents. The literature review made it apparent that both raised and TWLT medians offer significant vehicular accident reductions and vehicular benefits over comparable roadways without medians. Typical reductions in total vehicular accidents for both median types are in the 25 to 35 percent range.

The literature review did not provide a conclusive indication that medians improved pedestrian safety. This was due to the small number of pedestrian accidents encountered during the studies. Most researchers categorized pedestrian accidents as "other" and did not attempt to analyze them separately. The few studies which did address pedestrian safety admitted that the number of pedestrian accidents was too small to develop valid conclusions from their analyses.

Both raised and TWLT medians result in a reduction in accident severity. The results were mixed with regard to whether raised or TWLT medians decreased accident severity by the same amount. Some researchers concluded that raised medians reduced vehicular accident severity slightly more than TWLT median lanes. Another researcher found that there was no discernable difference in the accident severity between the raised medians and TWLT median lanes.

Rear-end and head-on accidents decreased with both raised median and TWLT median lane installation. Raised medians result in more fixed object and U-turn accidents than TWLT median lanes. TWLT median lanes result in a significantly higher number of midblock left turn accidents than raised medians. The initial concern of researchers that TWLT median lanes would result in a larger number of head-on accidents was not determined as being true. Raised medians and TWLT median lanes have similar head-on accident experience. The head-on accidents for raised medians occur at the median crossover points.

The current literature suggests that both raised and TWLT median lanes can be used over posted speed ranges of 25 to 55 mi/h (40 to 89 km/h) and all volume ranges typically encountered on urban and suburban arterials. Raised medians result in more delay and travel time due to the need for U-turns to reach destination points. TWLT median lanes are appropriate for suburban roadways with commercial development and driveway densities higher than 45 per mi (1.61 km).

CHAPTER 3. RESULTS OF THE STATE OF THE PRACTICE SURVEY

A state-of-the-practice survey was mailed to 150 State and local highway agencies, of which 57 were returned, representing a 38 percent response. The method of analysis followed was to group State and county agencies together, and to break cities down by population. The population categories used were: 0 to 100,000, 100,000 to 150,000, 150,000 to 500,000, and 500,000 and over. The upper and lower boundaries of each category were chosen to give an approximately equal number of responses in each category. A summary of the survey responses is presented in this chapter. An example of the blank survey instrument and a detailed summary of the responses is presented in appendix A.

Regarding the type of warrants or guidelines the agencies used to determine whether or not medians or refuge islands should be installed, the following responses were received. Twenty percent of the States use their own design criteria and 5 percent use the AASHTO "Green Book" criteria. Factors that States consider include accident history (20 percent), traffic volumes (15 percent), cost (10 percent), number and location of driveways (10 percent), and type of access control (10 percent). Ten percent of the State agencies do not regularly use any guidelines, and 30 percent did not respond to the question.

Criteria used by cities with populations under 100,000 include accident history (18 percent), AASHTO and MUTCD criteria (36 percent), State design criteria (9 percent), and availability of right-of-way (18 percent). Thirty-six percent did not respond to this question.

Cities with populations between 100,000 and 150,000 consider the following criteria: classification of street (20 percent), available safe gaps (10 percent), AASHTO criteria (10 percent), and the city's own standard plans (10 percent). Thirty percent use no guidelines and 10 percent did not respond. Cities with populations ranging from 150,000 to 500,000 generally use medians to provide an orderly flow of traffic (20 percent) or install medians with newly constructed arterials (20 percent). Twenty percent do not use any guidelines; 30 percent did not respond.

Large cities (over 1/2 million population) consider traffic volumes (14 percent), pedestrian volumes (14 percent), available right-of-way (29 percent), and arterial classification of street (72 percent) as their criteria. Fourteen percent use their own guidelines.

Pedestrian refuge islands do not receive much attention from roadway agencies. Some agencies do not intend to use medians as pedestrian refuge areas. One agency stated that it does not specifically design medians to be used by pedestrians, although pedestrians do use them. Other agencies have low pedestrian volumes and do not account for pedestrians in roadway design or time traffic signal phases to allow pedestrians to cross the entire roadway.

In some agencies, however, the needs of the elderly and handicapped are currently, or will soon be, included in their specifications for median design. There was mixed response on the questions concerning acceptable widths for pedestrian refuge islands. Fifty-five percent of the States feel that 4 ft (1.2 m) is an acceptable minimum width for a pedestrian refuge. City results, however, do not concur. The majority of cities in both the 100,000 to 150,000 population range, and the 500,000 and over range feel that 4 ft (1.2 m) is an acceptable minimum width. However, only 36 percent of the cities with populations less than 100,000 feel that 4 ft (1.2 m) is acceptable. Seventy percent of the cities in the 150,000 to 500,000 population range feel that 4 ft (1.2 m) is unacceptable for pedestrian refuge. All agencies, in general, feel that pedestrian refuge widths of 6 to 16 ft. (1.8 to 4.9 m) are desirable.

Many different criteria are used to prioritize median and refuge island installations. States typically use accident history (35 percent), traffic volumes (30 percent), or a case-by-case basis (15 percent). Twenty-five percent of the States do not prioritize median installation. City agencies, especially the smaller cities, typically do not prioritize median or refuge island installation. Those that do generally use political considerations, street classification, and traffic and pedestrian volumes. Most agencies do not have any difficulty in using their prioritization procedures. A few agencies commented that installation of a raised median can be a problem if it eliminates left-turn access.

In deciding what factors should be considered in developing new warrants or guidelines for the installation of medians and refuge islands, State officials feel that traffic volumes (65 percent), pedestrian volumes (55 percent), speed (30 percent), accident control (20 percent), number of lanes (10 percent), adjacent land use (10 percent), and the functional classification of the street (10 percent), should be considered. The response from cities were similar to those from States. Officials in cities under 100,000 consider traffic volumes (63 percent), pedestrian volumes (36 percent), street width (36 percent), available gaps (27 percent) and accident history (27 percent). Twenty-seven percent did not respond. Forty percent of cities in the 100,000 to 150,000 population range feel that traffic and pedestrian volumes should be considered; 30 percent did not respond. Cities in the 150,000 to 500,000 range feel that pedestrian crossing time (20 percent) and roadway geometrics (20 percent) should be included, in addition to accident history (20 percent) and traffic volumes (20 percent). Traffic volumes were suggested by 57 percent of the large cities and pedestrian volumes were recommended by 43 percent.

Most States have their own design specifications for medians. Cities generally use State or AASHTO and ITE guidelines, although some of the larger cities have their own specifications. Some State and city agencies sent copies of their specifications for median construction.

States were almost evenly split on the question of installing different types of medians based on pedestrian use: 45 percent install different types of medians based on pedestrian use; while 55 percent, do not. Most cities (at least 60 percent in each population category) do not install different types of medians based on pedestrian use.

Only 10 percent of the States use warrants to determine what type of median should be installed. Nine percent of cities under 100,000 use such warrants. None of the other cities use warrants.

Funding for median improvements usually comes from capital improvement funds, special tax districts; Federal, State, and local funds; and/or private development funds. This is true for all States and cities.

Most agencies have not conducted operational studies on medians and refuge islands except for very informal before-and-after studies. A study by the Florida DOT, however, found that safety for both vehicles and pedestrians was greatly improved when four-lane undivided roads were converted to five-lane roads (4 lanes plus a two-way left-turn lane).

In almost all classes of jurisdictions, a majority of the agencies feel that flat medians increase pedestrian and vehicle safety. In the class of cities under 100,000 people, however, 45 percent feel that flat medians do not increase safety and 36 percent feel that flat medians do increase safety. Many agencies commented that flat medians increase vehicle safety, but not pedestrian safety since they offer no physical protection from vehicular traffic (unlike raised medians).

CHAPTER 4 - DATA NEEDS AND ANALYSIS METHODS

Determining the benefits to be obtained from the installation of different median types requires the ability to predict the reduction in accidents and differences in operational characteristics. The basic premise necessary for these predictions is that accidents will occur at a certain level if the median had not been installed. Estimating this level requires the investigation of accident history and operational characteristics at locations with similar geometric design, traffic and environmental conditions. This has been done by a number of researchers to develop models that predict the vehicle accident and operational effects of median installation.

Mulinazzi and Michael were one of the first researchers to develop an accident prediction model for urban roadways.[17] Analyzing accident, roadway geometrics, traffic volume and other data revealed that accidents on their study section were significantly affected by the average daily traffic, the number of traffic signals per mile and the number of high-volume intersections per mile. Harwood and Glennon used these prediction models, in addition to other variables, to evaluate the effectiveness of median installation.[16]

Parker, in his 1983 Virginia study, determined that the number of traffic signals per mile had a significant impact on accidents for raised median sections.[31] Parker included the number of driveways per mile and area population into his final regression equation to retain consistency with equations developed for flush median sections. In a 1990 update, Parker again determined that average daily traffic and traffic signals per mile were the only variables that had a significant impact on accidents for raised median sections.[55]

An accident prediction model for raised median sections in Georgia was developed by Squires and Parsonson.[56] Similar to the results of Parker, they determined that the average daily traffic and number of traffic signals per mile were related to accident frequency.

A regression equation to predict accidents at TWLT median lanes in Texas was developed by Walton, et al.[34] Their results indicated that average daily traffic, traffic signals per mile, number of driveways per mile and area population were significant variables.

Parker's 1983 accident prediction equation for flush medians included average daily traffic, area population and number of traffic signals per mile.[31] The Squires and Parsonson prediction equation for flush medians on four-lane arterials included average daily traffic, traffic signals per mile and number of unsignalized approaches per mile.[56]

The vehicular accident prediction equations developed in prior studies are in agreement that average daily traffic, traffic signals per mile, number of driveways per mile, and the number of intersecting and nonsignalized roadways were the prime variables contributing to accident experience. Area population was included in some of the models but was used by Parker for comparison purposes only. While similar variables were used in the various models the equation coefficients of the variables differed between models. The result is a variation in the accident prediction levels. For example, the prediction equations developed by Parker on the Virginia data underestimate the actual number of accidents reported at selected sites in Texas and Georgia. Similarly, the Texas and Georgia based models overestimate the Virginia accident experience. One possible explanation for this discrepancy is that the accident reporting thresholds and practices are different between the States. While the predictions of the actual number of accidents vary between models, they display compatibility in their results. Parker performed a comparison of the models and determined that a high accident location predicted by one model was also correctly identified by the other models.[55]

The models developed in the prior studies did not identify a sufficiently large pedestrian accident data base to provide reliable results on the safety impact of medians on pedestrians. It was envisioned that the same problems with pedestrian accident magnitude in the prior studies would be prevalent in the current study.

DATA NEEDS

The literature review and the state-of-the-practice survey indicated that raised curb medians and TWLT median lanes are the predominant median types currently being installed. The survey indicated that refuge islands, designed primarily for pedestrian use, were not frequently installed. When present these islands often have the primary purpose of channelization of traffic with pedestrian needs as an additional or subsequent concern. Survey respondents indicated that adjusting traffic signal timing was a countermeasure used instead of refuge island installation to allow pedestrians to cross the roadway. The efforts of this project were, therefore, concentrated on arterials with raised curb medians, TWLT medians, and undivided arterials. The undivided arterials were included to provide the base or control data by which to measure the safety effects of the median sites. The results of prior research and the survey led to the decision to obtain data on the variables presented in table 3.

Prime concerns of the project were to: 1) obtain data which were representative of national driver and pedestrian characteristics and, 2) obtain sufficient pedestrian accident data to provide statistical reliability. To satisfy the requirement of the national representation, data were obtained from three regions of the country. Providing a sufficient pedestrian accident data base for statistical reliability necessitated a number of considerations.

The magnitude of pedestrian accidents can be increased by selecting high accident sites, selecting high pedestrian activity sites, increasing the years of accident analysis and by increasing the number of analysis sites. Selecting only those sites that have a high occurrence of pedestrian accidents would have required the inspection of accident data prior to site selection. This would have resulted in a nonrandom site selection process that would have biased the study. The ultimate result would have been the development of a predictive model that would overestimate the expected number of pedestrian accidents.

It was recognized that picking only those sites with high pedestrian activity would also pose reliability and site selection problems. It was considered as unlikely that a sufficient number of raised median, TWLT median lanes and undivided sites would have been identified in high pedestrian traffic areas. If sufficient sites of each roadway category were identifiable in high pedestrian traffic areas then the resulting data would have been very restrictive in its general applicability. Developing installation criteria on the high pedestrian traffic sites would have rendered the criteria as unsuitable for suburban and outlying CBD areas. This was undesirable since it limited the scope of the installation criteria and endangered its validity.

Increasing the years of pedestrian accident data analysis from the typical 3 years to 5 or more and increasing the number of sites were considered as viable alternatives. Of concern with this method, however, was to ensure that the geometrics and traffic control features of the analysis sites were not altered during the historic accident period. A number of sites that were initially selected at random were dropped from the study due to geometric changes that altered the median type and the number of lanes. While similar actions were exerted on changes to traffic control, such as speed limit and traffic signal changes, they were not as evident as geometric changes and may have gone unnoticed.

Table 3. Identified project data needs.

Data Needs	Median Type		
	Raised	TWLTL	Undivided
ADT	X	X	X
Segment Length	X	X	X
Accident Report Threshold	X	X	X
Land use	X	X	X
Area (CBD/Suburban)	X	X	X
Roadside Parking	X	X	X
Number of lanes (excluding twltl)	X	X	X
Median width	X	X	
Number of Cross roads	X	X	X
Number of Driveways	X	X	X
Number of Crossovers	X		
Posted Speed	X	X	X
# Signalized Intersections	X	X	X
Left-Turn Prohibition	X	X	X
Left-Turn Phase	X	X	X
Pedestrian Signal	X	X	X
Number of Lanes on Major Route	X	X	X
Number of Exclusive Left-Turn lanes	X	X	X
Number of Exclusive Right-Turn lanes	X	X	X
Median Type on Cross Street	X	X	X
Number of Lanes on Cross Street	X	X	X

Arterial miles of each median type and the number of pedestrian accidents, identified from the prior studies, were used to provide an initial estimate of the miles of each median type required. The actual selection of sites was performed by a stratified random process. The stratification occurred by ensuring an adequate representation of area (CBD and suburban) of each median type.

The selection of analysis cities was conducted by contacting officials in large metropolitan areas. These discussions explained the project purpose, data needs, and requested their cooperation. From the positive responses received the cities of Atlanta, Georgia; Phoenix, Arizona; and Los Angeles/Pasadena, California were selected. The specific data needs and assistance requested included:

- The presence of at least 15 arterial roadways for each of raised, TWLT and undivided types that were no less than 0.2 mi (0.3 km) in length located in CBD and suburban locales.
- Assistance in identifying appropriate analysis sites and input with the construction and traffic control history of each site.
- Ability to obtain at least 3 years of vehicular and pedestrian accident data for the analyses segments, and accident data within a 150-ft (46 m) radius of signalized intersections.
- Provide ADT for each year of the accident analysis period.

DATA COLLECTION METHODOLOGY

Fifteen arterial sites each with either raised or TWLT medians or an undivided cross-section were randomly selected from the candidate list. The individual sites and the local roadway authority were visited by the project team. The site visits were used to drive through each selected arterial to verify a homogeneous roadway and median design and to establish, with the local officials, that significant changes had not occurred to the location over the accident analysis time period. These determinations resulted in final site selections and the requests for accident data.

Each selected arterial was videotaped over its entire length. Multiple trips were made over each arterial using a video camera in a passenger van with a subsequent trip to physically measure median and roadway widths. On successive trips the camera was orientated to videotape the roadside, and when appropriate, the median, in both directions of travel. The video camera had the ability to impose alpha-numeric characters as well as actual time on the tape. This ability was used to put the arterial name on each tape. The distance from the starting point to each major cross road was verbally recorded on the tape. Recording the arterials on videotape provided a permanent record of roadway and roadside features that permitted accurate data extraction with the ability to double check the data.

The videotapes for each arterial were reviewed and those variables, identified as being relevant from prior studies; and as potentially relevant for this study, were extracted. Each median type arterial was divided into midblock segments with a segment defined as a roadway link subtended by signalized intersections. If this process resulted in segments that were shorter than 0.1 mi (0.16 km) in length then they were excluded from the midblock analysis. The variables were identified and extracted separately for midblock segments and signalized intersections. This method of extraction permitted the flexibility of modeling midblock segments, signalized intersections and the entire length of arterial (i.e., segments and signalized intersections) separately. The data items extracted for midblock segments and signalized intersections are presented in table 4. The total number of miles, segments and signalized intersections included in the study are summarized in table 5. The sites were selected, surveyed and included in the study prior to the collection and analysis of accident data.

Accident Data

The number of accidents and the years of accident data obtained from each study area are presented in table 6. A detailed printout of each pedestrian accident occurring on the major road and within a 150 ft (46 m) of the major road curb line was requested. All pedestrian accidents within 150 ft (46 m) of the major roadway were requested to help ensure that all relevant accidents were included. Without this type of request, accidents involving a pedestrian crossing the minor roadway (i.e., traveling along the arterial being analyzed) and being struck by a vehicle turning off of the major roadway may have been lost. Copies of the original pedestrian accident reports were obtained and the verbal description and diagram were reviewed to determine if project criteria were satisfied. The data layout and description codes used in the accident data bases varied between the three analysis cities. This necessitated the recoding of each data base into a common format for analysis. The scenario used in the extraction and coding of the accident data bases is summarized below:

- Pedestrian accidents occurring on the arterial and within 100 ft (30 m) of the arterial centerline curb line and involving a major arterial vehicle were included in the analysis.
- Vehicle accidents on the arterial segments (i.e., arterials subtended by signalized intersections 0.1 mi (0.2 km) or longer), and for signalized intersections, include only accidents occurring on the arterial. Vehicle accidents on the minor roadway were not included.

Average Daily Traffic

Traffic volume counts were obtained for each arterial. When available these counts were summarized for each analysis year. In many instances annual counts were not available necessitating the use of growth factors to increase or decrease the traffic volumes as appropriate. The growth factors were either obtained from the local representative or determined from the ADT trends of data which was provided. No pedestrian volume data were available for the arterials from any of the agencies. Pedestrian volumes were not, therefore, directly included in the study. The intensity of pedestrian presence is inherently assumed to be represented by the area (i.e., CBD or suburban) and the type of land use.

Table 4. Data variables extracted for analysis of midblock segments and signalized intersections.

Midblock Segments	Signalized Intersection
Tape I.D.	Tape I.D.
City I.D.	City I.D.
Major Road Name	Major Road Name
Area	Area
CBD	Minor Road Name
Suburban	Major Road Variables
Land Use	Far Median Type
single residential	Near Median Type
multiple residential	Far Median Width
single office	Near Median Width
multiple office	Number of Lanes
general business	Number of Exclusive LT lanes
shopping center	Number of Exclusive RT lanes
industrial	Left-turn provision
Segment length	Speed limit
Median type	ADT
Number of lanes	Pedestrian signals
Width of road	Minor Road Variables
Width of median	Number of lanes
Number of minor roads	Median type
ADT	Pedestrian signals
Speed limit	ADT

Table 5. Summary of data collection effort.

Roadway Portion	Median Type		
	Raised	TWLT	Undivided
arterial miles	51.9	55.1	38.9
number of segments	150	178	152
number of signalized intersections	121	136	227

1 mi = 1.6 km

Table 6. Summary of total accidents and analysis years.

Accident type	Atlanta	Phoenix	LA/Pasadena
vehicular	19222	9723	4194
(years of data)	3	5	4
pedestrian	313	363	652
(years of data)	3	5	4

CHAPTER 5 - DATA ANALYSIS

PHYSICAL DATA

The data collection sheets completed during the field review of each site, the videotapes and city maps were used to extract the physical data for each site. The data was organized into a database which contained a city and segment identifier that permitted a merge with the accident database. The number of two-way miles of each median type, by area, analyzed from each city is presented in table 7.

Table 7. Summary of two way miles of median type by city and area.

City	Miles of Median Type						TOTAL
	Raised		TWLT		Undivided		
	CBD	Suburb	CBD	Suburb	CBD	Suburb	
Atlanta	2.3	25.7	--	34.4	1.7	10.0	74.1
Phoenix	2.9	10.8	1.8	12.9	--	19.1	47.5
LA/Pasadena	0.9	9.3	6.0	--	6.7	1.4	24.3
Total	6.1	45.8	7.8	47.3	8.4	30.5	145.9

1 mi = 1.6 km

The majority of arterial miles (84.7%) included in the study were found in suburban areas. This disparity is due to the relatively limited number of miles available in CBD areas compared to the large number of suburban miles. Within the CBD of each city, the limited size, development intensity and city traffic engineering practices resulted in the inability of identifying each median type, of sufficient length for study purposes. Control over site selection was exercised to ensure that the combined arterial miles for each median type were sufficient for CBD and suburban data reliability. The largest number of arterial miles were obtained from the Atlanta area. A total of 145.9 (234.8 km) arterial miles were analyzed for the project.

Land use was classified as residential, office and business. The original land use classifications included subcategories on land use type such as single dwelling residential, high rise residential, shopping center and strip commercial. This subdivision of land use, however, resulted in large data stratifications that provided little useful data. Residential, therefore, indicates land use that varies from single dwellings to multistory apartment structures. Office refers to use that does not entail large movements of customers during the business day that have employees as the primary trip maker. The commercial designation includes business activity that depends upon customer visitation to the establishment. An inspection of table 8 indicates that the predominant land use in the vicinity of the suburban arterials was residential while only 0.3 mi (0.5 km) of CBD area was residential. It should be noted that the land use varied drastically not only along the arterial length but also on each side of the roadway. To compensate for this variation the predominant land use was coded for each segment of the arterial (i.e., between signalized intersections). There were many instances, however, where residential use would occupy one side of the arterial and another use such as commercial would occupy the opposite side. In these instances the land use was assigned based on judgement related to the observed activity at the time of the field survey.

Table 8. Summary of two-way miles of median type by land use.

Area and Land Use	Miles of Median Type			
	Raised	TWLT	Undivided	Total
CBD				
residential	--	0.3	--	0.3
office	3.1	3.3	1.6	8.0
commercial	3.0	4.2	6.8	14.0
SUBURBAN				
residential	26.7	19.0	25.2	70.9
office	4.4	6.1	0.7	11.2
commercial	14.7	22.2	4.6	41.5
Total	51.9	55.1	38.9	145.9

1 mi = 1.6 km

Table 9 presents the range of volumes present on the arterials. These volumes should be considered as representative since minor variations in volumes were experienced at some sites due to annual volume counts and growth factors. The volumes for the majority of sites remained relatively consistent during the analysis period. Since the project concentrated on CBD and suburban sites the volumes of all the studied arterials were relatively high. Only a limited number of arterials had volumes less than 15,000 vehicles per day.

Table 10 presents the number of arterial miles by traffic lane for each median type. All of the raised and TWLT sites consist of four to six lanes. The flush center lane for TWLT arterials is not counted as a traffic lane. The three and five lane facilities were located in Phoenix and Los Angeles/Pasadena where an unbalanced number of lanes is used to facilitate traffic movement during the peak hours.

Table 11 summarizes the minimum, maximum and average number of selected variables occurring on each type of arterial. CBD areas, with their higher development intensity, have higher average signalized intersection rate than suburban areas. Instances of zero public street and median crossovers per mile occur when the distance between signalized intersections is short.

ACCIDENT DATA

The accident data provided for each arterial was coded into a uniform format and merged with the physical features data base. Separate data bases were maintained for vehicular and pedestrian accidents. A list of the variables contained in both the data bases is presented in appendix B. Vehicle accidents include only those accidents that were coded as occurring on the arterial. The pedestrian data base included accidents coded as occurring on the arterial and on the minor roadway, within 100 ft (30 m) of the arterial centerline, that involved a arterial vehicle.

Table 9. Distribution of two-way median miles by average daily traffic volume.

Area and Median Type	Miles of Arterials by Average Daily Traffic (x 1000)					
	<10	10 - 15	15 - 20	20 - 30	30 - 40	>40
CBD						
raised	--	0.3	--	3.0	0.5	2.3
TWLT	--	1.0	--	2.4	1.9	2.5
Undivided	--	0.8	1.0	4.5	2.1	--
SUBURBAN						
raised	3.0	4.3	5.6	8.2	10.7	14.0
TWLT	--	--	4.8	15.3	11.0	16.2
Undivided	1.7	4.1	12.1	2.9	9.3	0.4
Total	4.7	10.5	23.5	36.3	35.5	35.4

1 mi = 1.6 km

Table 10. Summary of arterial miles by number of traffic lanes.

Thru Lanes	Miles of Arterials by Number of Through Lanes and Median Type										
	Raised			TWLT			Undivided				
	4	5[1]	6	4	5[1]	6	2	3[1]	4	5[1]	6
CBD	0.3	--	29.7	5.7	1.2	0.9	--	0.6	6.1	--	1.7
Suburban	13.0	3.1	5.8	26.9	11.6	8.8	2.9	--	22.1	4.5	1.0

1 mi = 1.6 km
[1]Unbalanced number of lanes to facilitate peak hour traffic flow

Summary rates for the arterials were determined by summing the accident frequency and dividing that number by the sum of the annual volume (ADT_i) and median length (L_i)product for each median segment. The equation can be written as (i.e., ($\sum_{i=1}^{n}$ Annual accident frequency for segment i) $\div$ (365 $\sum_{i=1}^{n} ADT_i \, L_i$) where n = number of segments. This provides a weighted average estimate which is better for comparing rates of arterials than that obtained by averaging the rates of each individual section. The rates were multiplied by 100 million vehicles to obtain a sufficient number of significant figures for analysis of pedestrian accidents.

Table 11. Summary of the frequency per mile of signalized intersections, public streets, driveways and raised median crossovers.

Area and Variable	Raised			TWLT			Undivided		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
CBD									
signalized intersections/mi	1.5	14.0	7.0	2.0	18.7	8.6	7.7	17.3	11.2
public streets/mi	7.0	20.0	12.9	0	18.0	9.2	0	17.1	5.6
driveways/mi	5.9	55.0	38.8	12.0	66.7	41.7	10.0	55.5	29.7
median crossovers/mi	0	10.8	7.5	--	--	--	--	--	--
SUBURBAN									
signalized intersections/mi	0.9	12.0	5.2	1.8	6.7	3.6	1.9	20.0	6.4
public streets/mi	0	20.0	7.7	2.3	18.0	9.4	0	20.0	10.5
driveways/mi	4.3	90.0	32.6	12.3	87.0	52.9	5.0	78.0	40.6
median crossovers/mi	0	11.0	4.4	--	--	--	--	--	--

1 mi = 1.6 km

The accident data were tested to determine if there were significant differences between the accident rates of selected data sets. Statistical tests were performed by using each categorized site and its respective accident rate in the data base. Since the data had been converted to rates, and a large number of observations existed for each data set, the data were considered as being normally distributed between analysis groups. The student's t-test was used to determine if a statistical difference existed between two data sets. The procedure was applied by using the SAS computer statistical analysis package.[73] The first step in the application of the t-test was to develop an F statistic to test for equality of the variances. This was necessary since the SAS procedure computes two t statistics: one based on the assumption that the variances of the two sets are equal and the other based on unequal variances.

Comparisons between more than two groups at a time were performed by simultaneously comparing the variability of group means about the overall mean (between estimate) relative to the variability of each observation to its respective group mean (within estimate). This procedure, known as analysis of variance (ANOVA), established where sufficiently large differences existed between the groups to determine that a significant difference existed. The Scheffé multiple comparison test was then used to establish simultaneous confidence intervals between all possible combinations of group pairs. The means of the paired groups were considered as being unequal, and therefore significantly different, when the confidence interval did not contain zero. All statistical tests were conducted as two-tailed 95 percent confidence interval tests.

An initial premise of the study was that pedestrian activity and intensity in CBD areas were different than that in suburban areas. If this premise were true then different models for each area, or the inclusion of area as an independent variable, would provide enhanced accident prediction capabilities. Table 12 contains the result of the t-test performed to determine if there is a significant difference in the accident rate between CBD and suburban areas for the different median types. Pedestrian accidents display a significantly higher accident rate in CBD areas for all of the median types. Vehicle accidents do not exhibit as large an influence by area as do pedestrian accidents. The impact of raised medians on vehicle accidents is significantly different between CBD and suburban areas with the average rate of vehicle accidents higher in CBD areas.

Table 12. Significant difference and mean accident rates between CBD and suburban area.

Ho: CBD accident rate = suburban accident rate. Significance level (of t - test) = 0.05.									
	Raised			TWLT			Undivided		
		Mean Rate[1]			Mean Rate[1]			Mean Rate[1]	
Accident Category	∝	CBD	Sub	∝	CBD	Sub	∝	CBD	Sub
vehicle	0.2463	471.64	384.02	0.0320*	475.17	611.27	0.0798	835.85	627.68
pedestrian	0.0608	26.30	9.23	0.0027*	31.55	13.11	0.000*	95.42	28.28

*Denotes significant difference.
[1]Summary - accident rates expressed in accidents per 10^8 vehicle miles
1 mi = 1.6 km

The frequency of vehicle and pedestrian accidents occurring on the arterials, and the associated summary rates, are provided in table 13. In the CBD, the accident rate for undivided arterials is higher for both vehicles and pedestrians than that of raised and TWLT medians in the same type of area. While this is not unexpected, it is also interesting to note that the vehicle accident rates, in CBD areas, is higher for raised curb medians than that of TWLT medians. In both CBD and suburban areas raised curb medians displayed a lower pedestrian accident rate than the arterials with either a TWLT lane or where no median exists on the street.

The accident rates for the different median types within CBD or suburban areas were analyzed to determine if the differences in the rates exhibited by table 13 were sufficiently large to be significant. Statistical significance was determined by performing ANOVA on the accident rate of each categorized site for the arterials. The statistical test, presented in table 14, indicates that there were significant differences in the accident rates between raised and TWLT median types and undivided cross-sections in both the CBD and suburban areas. Where differences existed, they were determined to be significant or not, by performing the Scheffé multiple comparison test as presented in table 15. For vehicular accidents there is a significant difference between the TWLT median and undivided cross-section in CBD areas, and in suburban areas between the raised - TWLT and raised median - undivided cross-section in suburban areas.

Table 13. Accident frequency and associated rate for arterials.

Area	Accident Category	Raised	TWLT	Undivided
CBD	Veh	1663	2019	2509
	Rate[1]	623.06	513.79	905.21
	Ped	51	162	242
	Rate[1]	19.11	41.11	87.31
SUB	Veh	7535	14828	4340
	Rate[1]	373.00	676.29	409.22
	Ped	128	282	147
	Rate[1]	6.31	12.89	13.91

[1]Arterial accident rates in 10^8 vehicle miles
1 mi = 1.6 km

Therefore, in CBD areas, undivided cross-sections have a significantly higher vehicle accident rate than TWLT medians. In suburban areas raised medians have a significantly lower vehicle accident rate than TWLT medians and undivided cross-sections. In addition, pedestrian accidents where raised medians exist are significantly less than those on undivided arterials in suburban areas and are less in CBD areas for both TWLT medians and for undivided cross-sections.

Due to the different operational characteristics and median effects on safety, the data of table 13 have been divided into midblock segment and signalized intersection accidents and are presented in table 16. The arterial accidents shown in table 13 are less than the total number of accidents of table 16 due to data verification and editing. In a limited number of cases, the median type changed for a short length of roadway between signalized arterials or sufficient data could not be reliably extracted from the video tapes due to vehicles blocking the visual field, or due to land uses that were too small for statistical reliability (e.g., industrial). In these instances, the median segments were dropped from the analysis but the intersection data was retained for use in the analysis of isolated intersections. The arterial accident data of table 13 includes the midblock and signalized intersection accidents that are appropriate for analyzing arterial lengths of specific median types. The midblock segment accidents of table 16 include all accidents not occurring within 100 feet (30 m) of the crossroad intersection centerline. The rates for midblock segments are based on the ADT of the arterial. The rates for the signalized intersections are based on the total number of entering vehicles.

Table 14. Statistical difference between arterial accident rates[1] of raised or TWLT medians and undivided cross-sections for CBD and suburban areas.

Ho: accident rate of raised = accident rate of TWLT = accident rate of undivided Significance level (critical ∝) = 0.05						
	Source[2]	DF	Mean Square	F	Prob. > F	Significant
CBD						
vehicle	Between	2	1928888	6.56	0.0020	yes
	Within	115	293918			
pedestrian	Between	2	63141	14.01	0.0001	yes
	Within	115	4508			
SUBURBAN						
vehicle	Between	2	2162291	10.58	0.0001	yes
	Within	323	204462			
pedestrian	Between	2	9990	4.85	0.0084	yes
	Within	323	2062			

[1]Accident rates expressed in accidents per 10^8 vehicle miles
[2]Between is the variability of vehicle and pedestrian group means to overall mean.
Within is the variability of vehicle and pedestrian observations to their group mean.
1 mi = 1.6 km

The CBD vehicle accident rates, presented in table 16, for raised medians, both midblock and signalized intersection locations, are higher than that of TWLT medians and undivided cross-sections. This difference is very pronounced at CBD signalized intersections with raised curb medians. The rate is more than three times greater than undivided cross-sections and almost 13 times greater than TWLT design. This disparity can be explained by considering that curbed medians concentrate left turn maneuvers at median cross-over points and at major intersections. Therefore, on short median segments, as would occur within CBD areas, vehicle turning movements would be concentrated at the signalized intersections. The pedestrian accident rate for CBD areas is lower at midblock locations with raised medians than that of TWLT medians or undivided cross sections.

Table 15. Scheffé multiple comparison test between median types for vehicle and pedestrian accident rates on arterials.

VEHICLE ACCIDENTS			
	95% Simultaneous Confidence Interval		Significant[1]
CBD			
raised, TWLT	-388.7	381.6	no
raised, undivided	-735.0	6.6	no
TWLT, undivided	-631.2	-901.0	yes
SUBURBAN			
raised, TWLT	-371.8	-82.7	yes
raised, undivided	-397.5	-89.9	yes
TWLT, undivided	-176.6	143.8	no
PEDESTRIAN ACCIDENTS			
CBD			
raised, TWLT	-52.9	42.5	no
raised, undivided	-115.0	-23.2	yes
TWLT, undivided	-97.4	-30.4	yes
SUBURBAN			
raised, TWLT	-18.4	10.6	no
raised, undivided	-34.5	-3.6	yes
TWLT, undivided	-31.3	0.9	no

[1]Pairs are significantly different if confidence interval does not contain zero.

Table 17 presents the predominant vehicle accident types for CBD and suburban areas that are occurring with raised or TWLT medians and undivided roadways. The vehicle rates exhibited were unexpected and at first they were believed to be erroneous. This resulted in a re-verification of the database. For example, the rear end accident rate with raised medians in CBD areas is higher than that for TWLT median and undivided cross-sections. The reason for this is not known with certainty since the total miles of arterials with raised, TWLT medians and undivided cross-section included in the analysis with the CBD areas were approximately equal. One possible explanation is that left turns are often prohibited from undivided roadways at midblock locations, within the CBD thereby, reducing the potential for rear-end accidents. In the majority of cases, the accident rates in CBD areas are less than suburban areas.

The determination of statistical significance of vehicle accident types between midblock median types, for both CBD and suburban areas, is presented in table 18. A significant difference in rear-end, right angle, and left turn vehicle accident rates between the different median types was exhibited in suburban areas. This significant difference was also exhibited with right angle type accidents in CBD areas. The median types that exhibited the difference, as determined by the Scheffe multiple comparison test are summarized in table 19. Raised medians have a significantly lower midblock accident rate when comparing raised to TWLT for rear-end, right angle and left turn accident types, and also when comparing raised to undivided for right angle type accidents in suburban areas. TWLT medians have significantly higher rear end and left turn accident rates than undivided arterials at suburban midblock segments. There were 29 CBD and suburban head-on type accidents at raised median midblock segments. These accidents were analyzed to determine what driver actions contributed to the accidents and the associated severity. Ten of the 29 head-on accidents (34.5%) were the result of motorists traveling the wrong way and 3 (10.3%) occurred in the median crossover resulting from a left turning maneuver. The majority of the raised medians where head-on accidents occurred (82.8%) had a width of 8 feet (2.4 m) or more. The severity rates for head-on accidents are summarized in table 10 and indicate that midblock, head-on type accidents at raised medians are less severe than TWLT and arterials.

A summary of vehicle accident severity by median type for midblock segments is presented in table 21. A greater percentage of accidents occurred at raised medians but were of lower severity (property damage only) than the percentage of TWLT median and undivided cross-section accidents. The severity of TWLT accidents is greater in CBD areas but is less in suburban areas when comparing to undivided arterials. Tests on the accident severity rates presented as table 22, indicate a statistical difference between the median types, for both the CBD and suburban areas, in property damage and personal injury accidents. The lack of significant differences in the fatality rates is due to relatively small sample sizes. The multiple comparison tests, summarized in table 23, indicate that raised medians have a significantly lower personal injury rate, and hence less severity, than TWLT and undivided cross-sections in both CBD and suburban areas.

Table 16. Accident frequency and associated rate for midblock median segments and signalized intersections.

Area	Location	Accident Category	Raised	TWLT	Undivided	Freq Totals
CBD	midblock	vehicle				
		freq	558	626	564	1748
		rate[1]	209.06	159.34	203.48	--
		pedestrian				
		freq	26	46	60	132
		rate[1]	9.74	11.71	21.65	--
	signalized inter	vehicle				
		freq[1]	1105	137	34.7	4659
		rate[2]	144.96	11.23	45.91	--
		pedestrian				
		freq	25	16	299	340
		rate[2]	3.28	1.31	4.02	--
Suburban	midblock	vehicle				
		freq	3823	6827	2241	12891
		rate[1]	189.23	311.37	211.31	--
		pedestrian				
		freq[1]	78	146	71	295
		rate	3.86	6.66	6.69	--
	signalized inter	vehicle				
		freq	4229	7507	2105	13841
		rate[2]	87.43	136.36	68.79	--
		pedestrian				
		freq[2]	47	137	71	255
		rate	0.97	2.49	2.32	--
Frequency			9,715	15,097	8,327	33,139
TOTAL vehicles, pedestrians			176	345	501	1,022

[1]Midblock accident rate per 10^8 vehicle miles
[2]Intersection accident rate per 10^8 entering vehicles
1 mi = 1.6 km

Table 17. Summary of predominant midblock vehicle to vehicle accident types.

Accident Type	Raised		TWLT		Undivided		Freq TOTAL
	CBD	Suburb	CBD	Suburb	CBD	Sub	
Rear End							
freq	269	1636	172	3061	179	1007	6324
rate[1]	100.78	80.98	43.78	139.61	64.58	94.95	--
Right Angle							
freq	70	708	73	1387	94	405	2737
rate[1]	26.23	35.05	18.58	63.26	33.91	38.19	--
Head-On							
freq	2	27	14	56	9	22	130
rate[1]	0.75	1.34	3.56	2.55	3.25	2.07	--
Left Turn							
freq	57	492	86	1151	53	232	2071
rate[1]	21.36	24.35	21.89	52.50	19.12	21.88	--
Other							
freq	160	960	281	1172	229	575	3377
rate[1]	59.95	47.52	71.53	53.45	82.62	54.22	--
FREQ TOTAL	558	3823	626	6827	564	2241	14639

[1]Accident rates expressed as accidents per 10^8 vehicle miles
1 mi = 1.6 km

Table 18. Statistical difference of midblock vehicle accident types between median types for CBD and suburban areas.[1]

Ho: accident type rate of raised = accident type rate of TWLT = accident type rate of undivided Significance level (critical α) = 0.05						
	Source	DF	Mean Square	F	Prob. > F	Significant
REAR END						
CBD	Between	2	12218	1.00	0.3681	no
	Within	578	12205			
SUBURBAN	Between	2	503609	28.39	0.0001	yes
	Within	1222	17739			
RIGHT ANGLE						
CBD	Between	2	13544	3.33	0.0365	yes
	Within	578	4067			
SUBURBAN	Between	2	104307	12.20	0.0001	yes
	Within	1222	8548			
HEAD ON						
CBD	Between	2	195	1.57	0.2084	no
	Within	578	124			
SUBURBAN	Between	2	46	0.42	0.6548	no
	Within	1222	109			
LEFT TURN						
CBD	Between	2	759	0.20	0.8168	no
	Within	578	3753			
SUBURBAN	Between	2	144226	33.24	0.0001	yes
	Within	1222	4339			

[1]Accident rates expressed as accidents per 10^8 vehicle miles
1 mi = 1.6 km
[2]Between is the variability of CBD and suburban group means to overall mean
Within is the variability of CBD and suburban observations to their group mean

Table 19. Scheffé multiple comparison tests of midblock vehicle accident type between median types in CBD and suburban areas.

		95% Simultaneous Confidence	Interval	Significant[1]
REAR END				
SUBURBAN	raised,TWLT	-81.6	-38.1	yes
	raised, undivided	-24.2	23.3	no
	TWLT, undivided	35.4	83.2	yes
RIGHT ANGLE				
CBD	raised, TWLT	-16.54	21.83	no
	raised, undivided	-30.00	6.43	no
	TWLT, undivided	-28.92	0.06	no
SUBURBAN	raised, TWLT	-44.3	-14.2	yes
	raised, undivided	-39.0	-6.1	yes
	TWLT, undivided	-9.9	23.3	no
LEFT TURN				
SUBURBAN	raised, TWLT	-41.8	-20.3	yes
	raised, undivided	-9.8	13.7	no
	TWLT, undivided	21.2	44.8	yes

[1]Pairs are significantly different if confidence interval does not contain zero.

Table 20. Summary of head-on vehicle accident rates for midblock segments by median type and area.

Severity	Raised		TWLT		Undivided	
	CBD	Suburban	CBD	Suburban	CBD	Suburban
PDO[2]						
frequency	2	12	4	26	0	5
rate[1]	0.75	0.59	1.02	1.19	0	0.47
Injury						
frequency	0	15	10	28	9	16
rate[1]	0	0.74	2.55	1.28	3.25	1.51
Fatal						
frequency	0	0	0	2	0	1
rate[1]	0	0	0	0.09	0	0.09

[1]Midblock segment rates in accidents per 10^8 vehicle miles.
1 mi = 1.6 km

Table 21. Summary of midblock vehicle accident severity by median type.[1]

Severity	Raised		TWLT		Undivided	
	CBD	Suburban	CBD	Suburban	CBD	Suburban
PDO						
frequency	401	2649	266	4855	3.42	1451
rate	150.24	131.12	67.71	221.43	123.39	136.82
percent	71.9	69.3	42.5	71.1	60.6	64.8
Injury						
frequency	156	1169	360	1962	222	783
rate	58.45	57.86	91.63	89.48	80.09	78.83
percent	28.0	30.6	57.5	28.7	39.4	34.9
Fatal						
frequency	1	5	0	10	0	7
rate	0.37	0.25	0	0.46	0	0.66
percent	0.1	0.1		0.2	0	0.3

[1]Midblock segment accident rate in accidents per 10^8 vehicle miles.

Table 22. Statistical difference of midblock vehicle accident severity rates between median types for CBD and suburban areas.[1]

Ho: accident severity of raised = accident severity of TWLT = accident severity rate of undivided Significance level = 0.05						
	Source	DF	Mean Square	F	Prob. > F	Significant[2]
PROPERTY DAMAGE ONLY						
CBD	Between	2	125344	4.08	0.0174	yes
	Within	578	30743			
SUBURBAN	Between	2	1146617	24.79	0.0001	yes
	Within	1222	46260			
PERSONAL INJURY						
CBD	Between	2	73224	4.47	0.0119	yes
	Within	578	16399			
SUBURBAN	Between	2	85213	9.66	0.0001	yes
	Within	1222	8817			
FATAL						
CBD	Between	2	2.04	2.42	0.0901	no
	Within	578	0.84			
SUBURBAN	Between	2	1.51	0.11	0.8968	no
	Within	1222	13.83			

[1]Accident rates in accidents per 10^8 vehicle miles
[2]Between is the variability of CBD and suburban group means to overall mean
Within is the variability of CBD and suburban observations to their group mean
1 mi = 1.6 km

Table 23. Scheffé multiple comparison test of accident severity between median types for midblock locations.

VEHICLE ACCIDENTS				
		95% Simultaneous Confidence	Interval	Significant[1]
PROPERTY DAMAGE ONLY				
CBD	raised, TWLT	-16.5	88.9	no
	raised, undivided	-59.5	40.6	no
	TWLT, undivided	-85.5	-5.8	yes
SUBURBAN	raised, TWLT	-134.6	-64.4	yes
	raised, undivided	-71.8	4.9	no
	TWLT, undivided	27.5	104.7	yes
PERSONAL INJURY				
CBD	raised, TWLT	-85.3	-8.3	yes
	raised, undivided	-65.8	7.3	no
	TWLT, undivided	-11.5	46.7	no
SUBURBAN	raised, TWLT	-39.7	-9.1	yes
	raised, undivided	-41.1	-7.7	yes
	TWLT, undivided	-16.9	16.8	no

[1]Pairs are significantly different if confidence interval does not contain zero.

PEDESTRIAN OPERATION ANALYSIS

Walking Speeds

Pedestrian crossing behavior was obtained using video cameras that had time imaging capabilities, to a hundredth of a second, at selected intersections and midblock segments. The crossing times were extracted from the tapes, entered into a database and merged with the geometric database. The width of the roadway from the geometric file and the crossing time were used to develop pedestrian walking speeds. Pedestrian age was estimated from the videotapes and grouped into the following categories:

- Less than 17 years old.
- 18 to 60 years old.
- More than 60 years old.

The majority of pedestrian observations occurred in CBD or commercially developed suburban areas where pedestrian activity was high. Due to the site collection criteria the majority of observations were of pedestrians older than 17 years. Table 24 presents the number of pedestrian observations obtained by age group, crossing location and median type. Efforts were concentrated on obtaining the walking speeds of pedestrians crossing TWLT and undivided arterials since raised medians provide the opportunity for refuge.

Table 24. Pedestrian observations by age group, crossing location and median type.

Age Group	Midblock		Signalized Intersection		Total
	TWLT	Undivided	TWLT	Undivided	
18 to 60	179	46	175	141	541
>60	20	3	24	20	67

Table 25 presents the mean walking speed, by age group, and t test results to determine if there are statistically significant differences in pedestrian walking speeds by type of median and location. Pedestrians aged 18 to 60 years exhibit a significantly higher walking speed at TWLT medians for both signalized intersections and midblock locations. Elderly pedestrians also exhibited higher walking speeds at TWLT signalized intersection locations but the sample size of elderly pedestrian observations is too small for reliability. The increased walking speed for TWLT lanes may be due to the pedestrian perception of increased walking distance resulting from the presence of the TWLT.

Table 25. Test for significance of median type on pedestrian walking speed.[1]

Ho: Walking speed at midblock = walking speed at midblock Significance level of t-test = 0.05						
	Midblock			Signalized Intersection		
	Mean Speed**		Prob > t	Mean Speed**		Prob > t
Age	TWLT	Undivided		TWLT	Undivided	
18 to 60	4.81	3.84	0.001*	4.79	3.90	0.001*
>60	3.88	--	--	4.25	2.08	0.001*

* Indicates significant difference in mean walking speeds.
** Speeds in ft/s.
1 ft/sec = 0.3 m/s.

Table 26 presents the mean walking speed by age group and t test results to determine if there are significant differences in age group means by crossing location. The walking speed for the 18 to 60 age group is significantly higher than that of the over 60 age group for both signalized intersections and midblock locations. An analysis of the difference in walking speed between locations is presented as table 27. Both age groups have a significantly higher walking speeds at midblock locations than at signalized intersections. This may indicate that pedestrians feel protected at signalized intersections and do not exercise the same urgency to cross as at midblock locations.

Table 26. Test for significance of crossing location on the walking speed of each age group.

Ho: Walking speeds of (18-60) age group = walking speed of (>60) age group Significance level of t-test = 0.05			
Location	Age		
	Mean Speed		Prob > |t|
	18-60	>60	
Midblock	4.61	3.89	0.002*
Signalized Intersection	4.43	3.37	0.001*

* Indicates significant difference in mean walking speeds
[1] Speed in ft/sec
1 ft/sec = 0.3 m/sec

Table 27. Test for significance of age on pedestrian crossing speeds at each crossing location.[1]

Ho: Walking speed of midblock = walking speed of intersection Significance level of t-test = 0.05			
Age	Location		
	Mean Speed**		Prob > t
	Midblock	Signalized Intersection	
18 to 60	4.61	4.39	0.0176*
>60	3.89	3.26	0.0122*

* Indicates significant difference in mean walking speeds.
** Speeds in ft/s.
1 ft/sec = 0.3 m/s.

A summary of the pedestrians using raised and TWLT medians as refuge during the crossing maneuver is presented as table 28. Over 18 percent of the observed pedestrains used the raised medians for refuge while only 5 percent gained refuge from TWLT medians. A number of pedestrains were observed standing on the dividing pavement marking during crossing undivided roadways. These observations were not, however, sufficiently large for meaningful analysis.

Table 28. Summary of pedestrian use of medians for refuge during the crossing maneuver.

MIDBLOCK	Raised	TWLT
observations	164	591
refuge	30	31
percent	18.29	5.25

PEDESTRIAN CONFLICTS

Pedestrian conflict data were obtained by placing video cameras at high pedestrian activity areas. Conflicts were taped for pedestrian crosswalks at signalized intersections and at midblock locations. The primary purposes of the conflict observations were to: 1) determine if certain types of conflicts were indigenous to, or predominant at, particular median types; and 2) investigate if conflicts could be related with ADT to accident type.

The second primary purpose was addressed in an effort to determine if use of the traffic conflict technique could be increased as a measure of safety by associating it with realistic data collection techniques. Due to a number of factors, including the time required for data collection and its correlation to accident occurrence, traffic conflicts are not widely used. Obtaining accurate pedestrian conflicts and exposure is especially difficult since both pedestrian and vehicle counts are required. In addition, the conflicts are site specific and are not applicable to another location unless pedestrian and vehicle volumes are also available at the second location. The current technology in obtaining accurate pedestrian volume counts requires manual collection which is time consuming and is generally not performed by local agencies.

Pedestrian conflict data were obtained at 25 signalized intersections and midblock locations in both CBD and suburban areas as summarized in table 29. The majority of CBD observations were conducted at TWLT and undivided arterials due to the insufficient availability of raised medians in CBD areas.

Table 29. Summary of pedestrian conflict data collection activity.

Area	Signalized Intersection			Midblock		
CBD	Raised	TWLT	Undivided	Raised	TWLT	Undivided
Conflicts	2	61	362	0	119	16
Hours	2.5	8.15	32.61	0	4	1.41
Locations	1	2	10	0	2	1
Suburban						
Conflicts	113	51	77	9	54	0
Hours	10	9.02	11.32	1.22	5.19	0
Locations	4	3	4	1	3	0

Pedestrian-vehicle conflicts were categorized by the type of vehicle maneuver taking place at the time of the conflict. For example, a pedestrian stepping off the curb at the start of the green interval and incurring a conflict with a right-turning vehicle was classified as a right-turn conflict. Similarly a pedestrian within the roadway at the start of the red interval and incurring a conflict with a through vehicle was categorized as a through conflict. This broad classification scheme has a number of advantages. First of all, it simplified the data collection task and removed judgement error prevalent with a large number of traffic conflict categories. Secondly, the scheme permitted comparisons of pedestrian conflict types with vehicle maneuvers from the accident data base on a site specific basis. The conflict observations for signalized intersections are normalized by the total number of entering vehicles since conflicts were obtained from the four approaches simultaneously. Conflict observations for midblock locations are normalized by the ADT and the length of the effective visual field of the camera. Field measurements combined with the ability to view in both directions resulted in the use of a 1/10 mi (161 m) as the effective visual field.

Conflict rates at intersections were determined by assuming that the ADT of entering vehicle volumes were equally distributed throughout the 24 hour period. It is realized that the ADT is not equally distributed throughout the day and that it does not approximate the actual vehicles present during the conflict observations. The purpose in its use, as previously discussed is to investigate the possible use of ADT as the base for conflict measures. Conflict rates for midblock observations were obtained in a similar manner with the exception that the effective visual field of the camera was used to obtain an estimate of miles. The equations used to obtain the conflict rates are presented below.

$$\text{Intersection Conflict Rate} = \frac{\text{Observed conflicts}}{\left(\frac{\text{ADT}}{24}\right)(\text{observation time})} \tag{1}$$

$$\text{Midblock Conflict Rate} = \frac{\text{Observed conflicts}}{\left(\frac{\text{ADT}}{24}\right)(\text{observation time})(\text{visual field})} \tag{2}$$

Table 30 presents the results of the statistical analysis to determine if differences existed in midblock and signalized intersection conflict rates between CBD and suburban areas. The purpose of this test was to determine if the increased pedestrian activity, typically found in CBD areas, could be used as a surrogate measure of pedestrian volume. The results of the test indicate that there were no significant differences between the conflict rates at CBD and suburban areas. The absence of a difference is probably more due to the project site selection criteria (i.e., high pedestrian activity at both CBD and suburban locations) than due to actual differences which may have existed by a random site selection process.

Table 30. Statistical difference in pedestrian conflict rates between CBD and suburban areas.

Ho: conflict rate at CBD = conflict rate at suburban Significance level of t-test = 0.05				
	Mean Rate[2]			
Location	CBD	Suburban	∝	Significant Difference
Midblock[1]	0.3090	0.0875	0.3118	no
Intersection[2]	0.0096	0.0068	0.5246	no

[1]Conflict rates for midblock locations in conflicts per vehicle-mile.
[2]Conflict rates for intersection in conflicts per vehicle.
1 mi = 1.6 km

Since there is no difference in the conflict rates between CBD and suburban locations the conflicts were combined, retaining intersection and midblock stratification, for further analysis. Table 31 summarizes the analysis to determine if there were significant differences in the type of conflict observed between median types at signalized intersections and midblock locations. Inspection of table 31 indicates that there are no significant differences in the type of conflict observed between the different median types.

Table 31. Significant difference in type of conflict between median types.

Ho: Conflict type raised = conflict type TWLT = conflict type undivided Significance level = 0.05						
Conflict Type	Mean Rate					
	Raised	TWLT	Undiv	F	Prob > F	Significant
INTERSECTIONS[1]						
Right turn	0.0037	0.0026	0.0063	0.68	0.5153	no
Through	0.0014	0.0004	0.0010	0.0010	0.6676	no
Left turn	0.0021	0.0014	0.0014	0.0007	0.8417	no
MIDBLOCK[2]						
Through	0.0390	0.2247	0.6337	0.23	0.8038	no

[1]Intersection conflict rate in conflicts per vehicle.
[2]Midblock conflict rate in conflicts per vehicle-mile.
1 mi = 1.6 km

Pedestrian conflicts and pedestrian accidents at signalized intersections were analyzed to determine if there were statistically significant differences in vehicle maneuvers contributing to the conflict and accident rates between the median types. Only those pedestrian accidents that occurred at the same sites from which pedestrian conflict data were obtained were used in the analyses. Since the results of table 31 indicated no statistical difference in conflict types between the different median types an analysis was performed to determine if there were differences in vehicle maneuvers, prior to vehicle-pedestrian accidents, at the same locations used for the conflict analysis. The results of this analysis, presented as table 32, indicate no significant difference in vehicle maneuvers between the different median types. The results of the vehicle-pedestrian conflict and accident analysis indicate, therefore, that the type of conflict and accident is not influenced by the type of median present.

The final step in the analysis of conflict data was to determine if there was a relationship between types of conflicts and types of accidents. A study by Migletz determined that a relationship did exist and developed a model to predict accidents based on conflict observations. The relationship between conflict types and accident types, for this project, were determined by applying a paired-t analysis to the data of table 32. Table 33 contains the site specific rates for conflict and accident types observed at intersections. The analysis was not performed for midblock locations due to the difficulty in accurately locating the positions of accident occurrences. The results of the paired-t test, presented as table 34, indicates that a significant difference only exists, at the 0.05 level of significance, between vehicle-pedestrian left turn conflicts and vehicle-pedestrian accidents involving left turning vehicles. The data does, therefore, indicate a relationship between pedestrian conflicts and accidents for through and right turn types.

The analysis of conflicts and accidents indicates that there is no difference in the type of conflict observed between raised, TWLT and undivided cross-sections for either intersection or midblock locations. There is also no difference in the conflict rates observed between CBD and suburban environments. The absence of the difference between CBD and suburban may, however, have been due more to the selection of high pedestrian volume locations than due to the environment. The data did indicate that there is a relationship between conflicts and accidents for through and right-turn types. This relationship should be verified by a larger study. If a definite relationship can be established then the use of ADT as a normalizing agent for conflicts and the use of conflict types to estimate accidents and develop countermeasures can be established.

Table 32. Statistical difference in intersection accident maneuvers between median types.

Ho: Accident maneuver raised = accident maneuver TWLT = accident maneuver undivided
Significance level = 0.05

Conflict type	Mean Rate[1]			F	Prob > F	Significance
	Raised	TWLT	Undivided			
Right turn	0	1.200	2.7115	0.67	0.5372	no
Through	5.2491	0	3.1608	0.86	0.4543	no
Left turn	0.5176	2.4002	9.1324	0.35	0.7134	no

[1]Accident rate per 100 million entering vehicles.

Table 33. Summary of conflict rates and accident rates by vehicle maneuver.

Location No	Conflict Rate (per 10^8 vehicles)			Accident Rate (Per 10^8 vehicles)		
	LT	TH	RT	LT	TH	RT
1	1.4826	0.3955	0.9489	0	0	0
2	0.3053	0	0	0	8.4279	0
3	0	0.3053	0	0	8.4279	0
4	0	0.0435	0	0	4.1406	2.0703
5	0.2523	0.0505	0.1262	2.4002	0	4.8005
6	0.4634	0.0211	0.0211	0	0	0
7	2.6674	0.0363	1.4734	12.0142	0	0
8	1.9200	0.7200	0.2400	0	13.6986	54.7945
9	0.5031	0	0.0479	0	0	0
10	0.7682	0.1035	0.0205	0	0	0
11	0.8780	0	0.1244	4.2546	1.4182	0
12	0.0809	0	0	0	3.8479	0

Table 34. Paired comparisons t-test for different vehicle maneuvers.

Ho: (mean of conflict type) - (mean of accident type) = 0 Significance level = 0.05			
Maneuver type	t	Prob > |t|	Significant
Right	-1.85	0.0912	no
Through	2.13	0.0563	no
Left	-3.06	0.0108	yes

CHAPTER 6 - DEVELOPMENT OF PREDICTIVE MODELS

Predictive equations were developed to model vehicle and pedestrian accident data for each median type. The goal of the modelling process was to develop statistically valid models that would have practical applications for use by design engineers. The following considerations were addressed during model development.

- Ease of Use - The developed model must be as accurate as possible while reducing the number and complexity of input variables required. Requiring a large quantity of data or extensive data collection and manipulation for model use would result in design engineers deciding not to use the models. Efforts were expended, therefore, on including those variables that had a statistically significant, and logical, impact on model results yet would be readily available to design engineers.

- Pedestrian Safety - Predicting safety consequences requires estimates of exposure. Pedestrian traffic accidents involve the presence of both a vehicle and a pedestrian in the same place at the same time. Estimates of vehicular presence is available to most agencies in the form of ADT counts. Pedestrian volumes are not readily available to most agencies resulting in the need to develop surrogate measures of pedestrian activity. This was accomplished during the model building process by including the area designation of CBD and suburban as independent variables, and by considering the type of land use. Pedestrian activity in CBD areas is more intense and concentrated than can be expected in suburban areas. Similarly suburban areas with residential land use can be expected to have different levels and types of pedestrian activity than areas with commercial development. This premise was supported by the statistical difference exhibited in pedestrian accidents between CBD and suburban areas as presented in table 12.

- Median Effect - The effect of different median types on vehicular and pedestrian safety varied by the intensity, type of development, and by location along the median segment. Advantages of TWLT lanes over undivided highways include removing the left-turning vehicles from possible interactions with through traffic. These possible interactions increase with the intensity of development resulting in an increased number of residential and commercial driveways per mile. The higher the development intensity, therefore, the greater the potential vehicle benefit from TWLT installations. Raised medians provide the same potential benefit for removing left-turning vehicles from interactions with through traffic. Raised medians, however, concentrate left-turn maneuvers at crossover points. The result is an increase in other conflicts due to the indirect left-turn maneuvers when vehicles gain access to driveways. Raised medians have an advantage over TWLT lanes in that they provide a relatively safe refuge area for pedestrians. The differences in the safety effects, between the various median types, change at signalized intersections due to the assignment of right-of-way.

The preceding concerns resulted in developing vehicular and pedestrian accident prediction models for entire lengths of arterials, and midblock segments. The inclusion of CBD or suburban areas, as well as land use for pedestrian accidents, was accomplished by including them as independent variables in each model. The following 12 models were developed:

- Models AV1, AV2, and AV3 estimate arterial vehicle accidents for raised, TWLT and undivided arterials, respectively. These models estimate the vehicle accidents that occur over the entire length of the arterial, including midblock and signalized intersection accidents. The models estimate vehicle accidents for the arterial and do not consider accidents occurring on the cross roads.

- Models MV1, MV2, and MV3 estimate vehicle accidents for midblock segments for raised, TWLT and undivided arterials, respectively. A midblock segment is defined as a section of arterial subtended by signalized intersections. The model estimates only vehicle accidents that occur on the arterial and 100 ft (30.5 m) from the centerline of each signalized intersection.

- Models AP1, AP2, and AP3 estimate pedestrian accidents for raised, TWLT and undivided arterials, respectively. They include all pedestrian accidents that occur on the arterial and within 100 ft (30.5 m) of the arterial centerline that can be attributed to a arterial vehicle. A pedestrian accident, for example, involving a vehicle turning right from the arterial and striking a pedestrian on the cross road would be included in the estimate.

- Models MP1, MP2, and MP3 estimate midblock pedestrian accidents for raised, TWLT and undivided arterial segments. The same definition of midblock as used for MV models and the same inclusion of pedestrian accidents as used for the AP models apply.

MODEL DEVELOPMENT

The use of statistical models to describe and predict the occurrence of accidents, based on traffic volumes and geometric roadway characteristics, has become standard practice. The majority of these predictive equations are based on additive and on multiplicative models that are developed by conventional linear regression approaches. While these models often provide adequate estimates of accident behavior they contain inherent errors that limit their application and accuracy.[(64)] The limitations of the linear regression models have resulted in the investigation of Poisson and negative binomial models.[(65,66)]

Engineers and statisticians generally agree that accidents occur at a particular site, during a specific period of time, by a Poisson distribution. The Poisson distribution is applicable since: 1) only two outcomes are possible for each vehicle passing through the analysis section (i.e., either an accident occurs or does not), 2) the probability of an individual vehicle being involved in an accident while passing through the segment is small; and 3) the number of opportunities for an accident to occur is large due to the relatively large traffic volumes. The Poisson distribution is frequently the distribution used to determine the statistical effectiveness of implemented countermeasures for individual projects.[(67,68)]

The development of statistical models is usually based on the accident experience of a number of sites: each with their own accident experience, traffic volumes, and geometrics. The very simple models will group sites by similar geometrics and then predict accidents (dependent variable) by changes in traffic volume and environmental characteristics (independent variables). The more complex models recognize that accidents are complex events and may include the interactions of the road, vehicle, human factors, speed, congestion and environment into the model. The use of linear regression in many past studies to develop prediction models was based on the assumption that the distribution of the dependent variable values, between similar sites, followed a normal distribution. This assumption is, however, flawed.

Consider a case where locations to be analyzed have been grouped by similar characteristics. The estimate of safety for each group of sites is obtained by determining the mean accident occurrence E(A). The mean is necessary since each site, while similar with respect to the categorizing variable, has different drivers and locational characteristics resulting in site specific accident occurrences. Associated with the mean, therefore, will be variability V(A) between the means of analysis sites.

Determining a model requires obtaining estimates of E(A) (dependent variable) as a function of the independent variables. What is essentially occurring is the attempt to predict accident occurrence from locations that do not actually exist since a number of the independent variables were created from mean values. If the prediction of accident occurrence (A) is required for a specific location, and V(A) is very large, knowledge of E(A) provides little reliable information on what can actually be expected to occur. Increased reliability on (A), therefore, requires a better estimate of V(A) than that obtained by using the variance of the individual analysis sites about the grouped mean.

Since the occurrence of accidents at an individual location is a Poisson process then the accident count must be considered as a Poisson random variable. However, differences between sites, and differences between years and ADT at one site, result in the sample accident frequencies not following a Poisson distribution. Once again, the cause of this is the variance, which for a Poisson distribution is equal to the mean. When a Poisson distribution is used to model accident occurrences the result can be over dispersed (i.e., the ratio of the variance to the mean will by greater than unity). Recent studies have applied the negative binomial model to overcome the problems of linear approximation and Poisson over dispersion.[(69,70,71)] This model is often referred to as an over-dispersed or compound Poisson model. It is the result of: 1) the number of accidents at a site being Poisson distributed, and 2) a gamma distribution for the group of Poisson means due to differences between locations and/or years of analysis.[(72)] As a result of compounding the distribution of accident occurrence about the group mean is negative binomial.

MODEL CONSTRUCTION

The number of accidents for a given location is Poisson distributed with mean (A). This mean is itself a random variable described by the gamma distribution with mean $E[A] = \bar{A}$ and a variance $V[x] = \bar{A}^2/k$, where the shape parameter k assumes positive values. This combination results in a negative binomial distribution that still has the mean $E[A] = \bar{A}$ but with a variance $V[A] = \bar{A} + \bar{A}^2/k$. Note how the negative binomial distribution addresses the over dispersion problem. For the standard Poisson distribution the variance to mean ratio is unity while for the negative binomial the ratio is greater than one.

The nonlinear regression procedure (NLIN) in the SAS statistical package was used to estimate the model coefficients.[(73)] This procedure permits modifications that enable the use of error structures that are not normally distributed. By specifying the negative value of the log-likelihood function as the loss function which is minimized, the NLIN procedure provided maximum likelihood estimates of parameters as a generalized linear model. When the sample is large the maximum likelihood estimator of a parameter is unbiased and has a variance that is nearly as small as can be achieved. The process determines the value of the parameter that maximizes the likelihood function.

The SAS NLIN procedure relates the predictive model to the expected value of the dependent variable by a link function. After an appropriate link function and error distribution has been chosen the model parameters are estimated. The dependent variable estimated by the model parameters was accident rate. The rate was related to the independent covariates (i.e., geometric and operational variables) by the following multiple linear form:

$$AR_i = \frac{Ai}{Vi} = x_i'\beta + \epsilon_i \qquad (i = 1,2..n) \tag{3}$$

where:

i	=	location
AR_i	=	accident rate for a specified time period
A_i	=	accident frequency for a specified time period
V_i	=	traffic volume for a specified time period
x_i'	=	transpose of the vector of independent variables (covariates) x_i
β	=	vector of regression parameters
ϵ_i	=	residual (error term)
n	=	number of locations

This was log transformed to provide an exponential relationship ensure that accident rate is always positive. This functional relationship, presented below, has been widely employed in statistical literature and found to be very flexible in fitting different types of data.[8]

$$AR_i = \frac{Ai}{Vi} = e^{x_i'\beta + \epsilon_i} \qquad (i = 1,2..n) \tag{4}$$

MODEL DEVELOPMENT RESULTS

The selection of independent variables for the predictive model was conducted with the intent of reducing the number of variables as much as possible while maintaining predictive accuracy. A backward stepwise procedure was used where all of the covariates were first included and ineffective covariates eliminated one by one until all remaining covariates were effective. The decision on which covariates to drop was made by using the t-distribution at a 10-percent significance level. Reducing the significance level to 5 percent would have reduced the number of covariates and also the accuracy of the models. The parameters with the smallest t value were eliminated at each step and the process was repeated until an best fit model was achieved.

Development of each of the models occurred in three primary steps. The first step was to use conventional multiple linear regression to develop a best fit predictive equation. In all of the cases the conventional linear regression provided low coefficient of determination (R^2) values indicating an absence of a linear relationship. The type of results typically obtained from the conventional linear model is presented in figure 6. Figure 6 is a plot of the standardized residuals versus the predicted average annual accident values. The distance of the residual from zero increases as the predicted value becomes larger. This indicates that as the predicted value increases the variance also increases. The assumption of a common variance used in the conventional regression is, therefore, violated.

Results similar to figure 6 for all of the attempted models resulted in modeling with a Poisson error structure. The appropriateness of the Poisson model was evaluated by inspecting the dispersion parameter, plotting the prediction ratio versus the predicted values and inspecting the Pearson χ^2 statistic for unity. The Pearson χ^2 statistic was not, however, afforded much weight in the analysis since nonlinear modeling was being performed. One disadvantage of the Pearson residual test is that its distribution for non-normal distributions will often be skewed.[74] In all cases the Poisson model did not provide an acceptable fit to the data. An example of the standardized residual versus predicted value plots for the Poisson models is provided in figure 7. This figure indicates large residual distances from zero for both low and high predicted values.

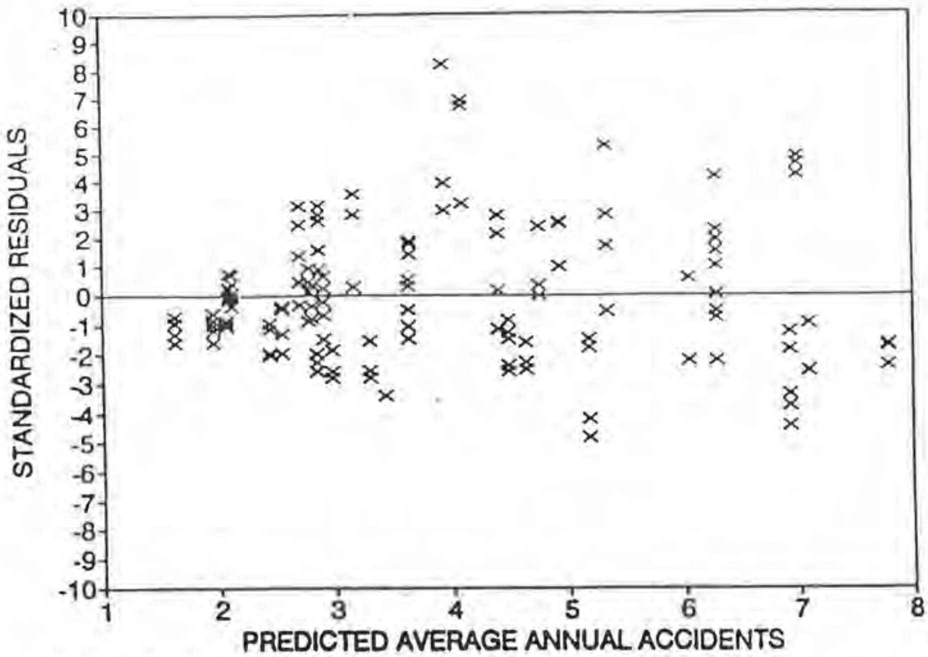

Figure 6. Standardized residual plot of conventional multiple linear regression model for vehicle arterial accidents (model AV1)

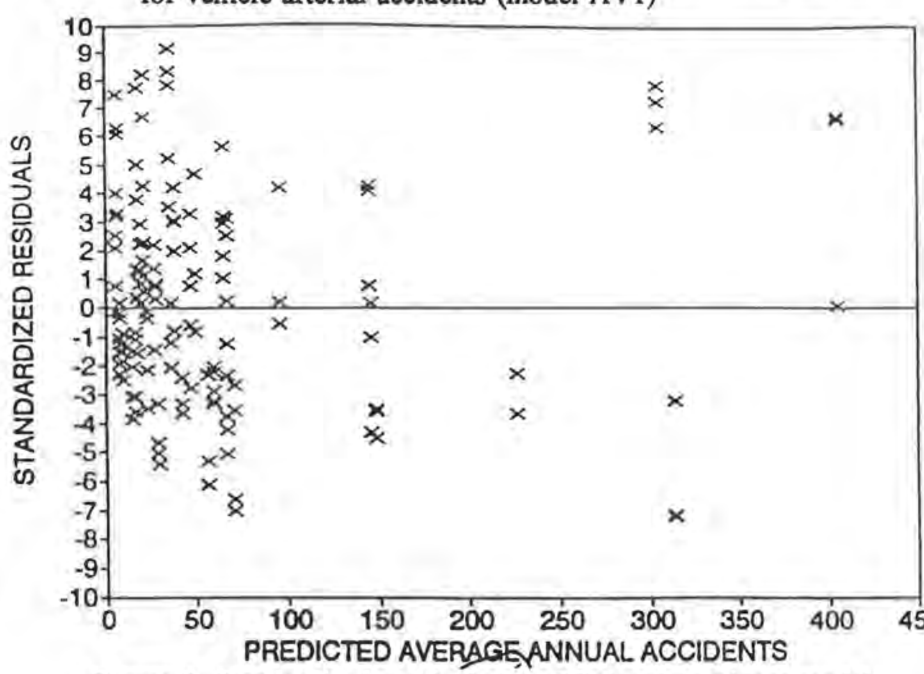

Figure 7. Standardized residual plot of Poisson nonlinear model for vehicle arterial accidents (model AV1).

The poor fit of the Poisson model resulted in applying the negative binomial model to the data. The k factor for the negative binomial model was estimated from the following variance equation for the negative binomial:

$$V[NB] = \overline{A} + \frac{\overline{A}^2}{k} \tag{5}$$

V[NB] = variance of negative binomial distribution

$\overline{A}$ = mean accident occurrence

k = constant

The constant (k) was determined by an iterative process using the result of the Poisson distribution as the starting point. The squared residuals from the Poisson distribution was used to estimate V[NB] and, in conjunction with the Poisson mean $\overline{A}$, was used to obtain the first estimate of k. The negative binomial model was obtained and the dispersion parameter and the significance for the k factor were inspected. If the dispersion parameter was over unity and the k factor was statistically significant, then a new k factor was estimated, using the negative binomial statistics, and the process repeated. This was continued until a value of k was converged upon. Use of the squared residuals to estimate the variance, and, hence, k has been performed by previous researchers including Hauer et al.[66] Figure 8 presents the standardized residual plot of the negative binomial model for the same data set used for the conventional and Poisson plots. The residuals for the negative binomial are considerably less than the residuals exhibited by the conventional and Poisson models. A flow chart of the model building process is provided in figure 9.

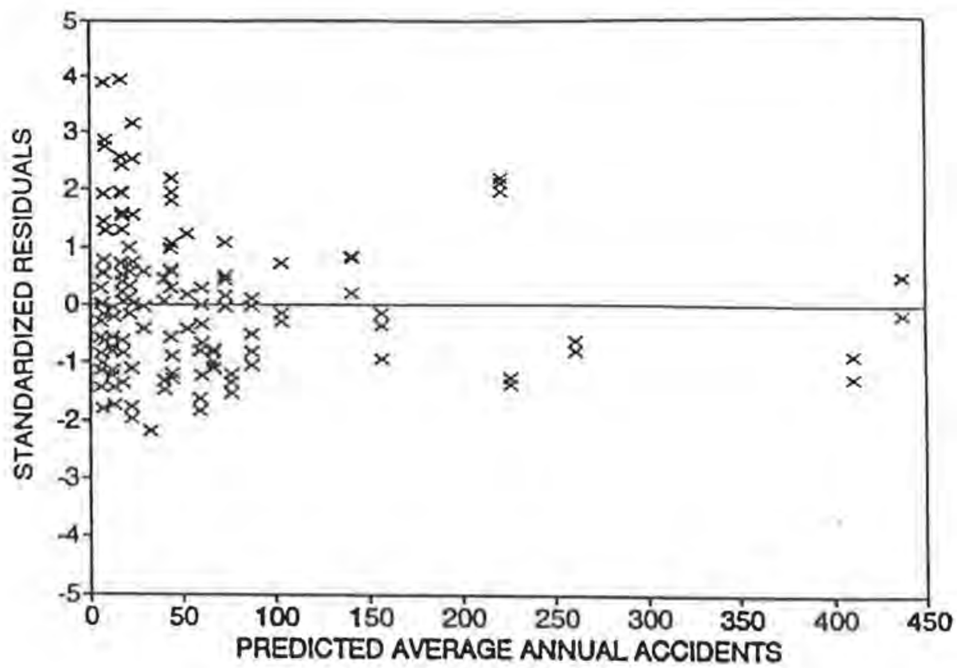

Figure 8. Standardized residual plot of negative binomial nonlinear model for vehicle arterial accidents (model AVI).

The model building statistics for vehicle and pedestrian accidents on arterials are presented as table 35 and for midblock accidents as table 36. The Pearson χ^2 statistic was nonsignificant for the pedestrian arterial model for all median types with the negative binomial model. The results of the pedestrian midblock models also indicate a nonsignificant Pearson χ^2 statistic for all median types. The degree of dispersion for the Poisson midblock models, however, was not as large as that exhibited by the arterial models. Pearson χ^2 value nonsignificance indicates that the model provides a good estimate of the model data. The Pearson χ^2 was significant for all of the vehicle arterial models. Significant Pearson χ^2 values is not, however, a definite indication of incompatibility for nonlinear models.

The independent variables (covariates) that were tested by the arterial and midblock models are presented as table 37. The variables that were determined as significant and, hence, retained in the negative binomial model, their associated coefficients and standard errors, are presented in table 38 for arterials and table 39 for midblock segments.

Table 35. Nonlinear predictive Model statistics for vehicle and pedestrian accidents on arterials.

		Vehicle			Pedestrian		
Model	Statistic	Raised	TWLT	Undiv	Raised	TWLT	Undiv
Poisson	dispersion parameter	13.43	12.94	13.10	1.16	2.23	3.96
	Pearson χ^2	1825.83	1812.28	1768.31	158.73*	314.50	538.31
	$\chi^2_{.05}$	164.22	168.61	163.12	165.32	169.71	164.22
Negative Binomial	initial k from Poisson	24.00	28.00	13.00	10000.00	3.30	2.80
	final k	5.70	15.00	10.00	1000.00	3.40	2.20
	Pearson χ^2	218.13	216.70	313.81	139.35*	134.67*	77.69*
	degrees of freedom	138	132	125	136	120	104
	$\chi^2_{.05}$	166.45	159.81	152.09	164.22	146.57	128.80

* denotes significance at 95 percent confidence level

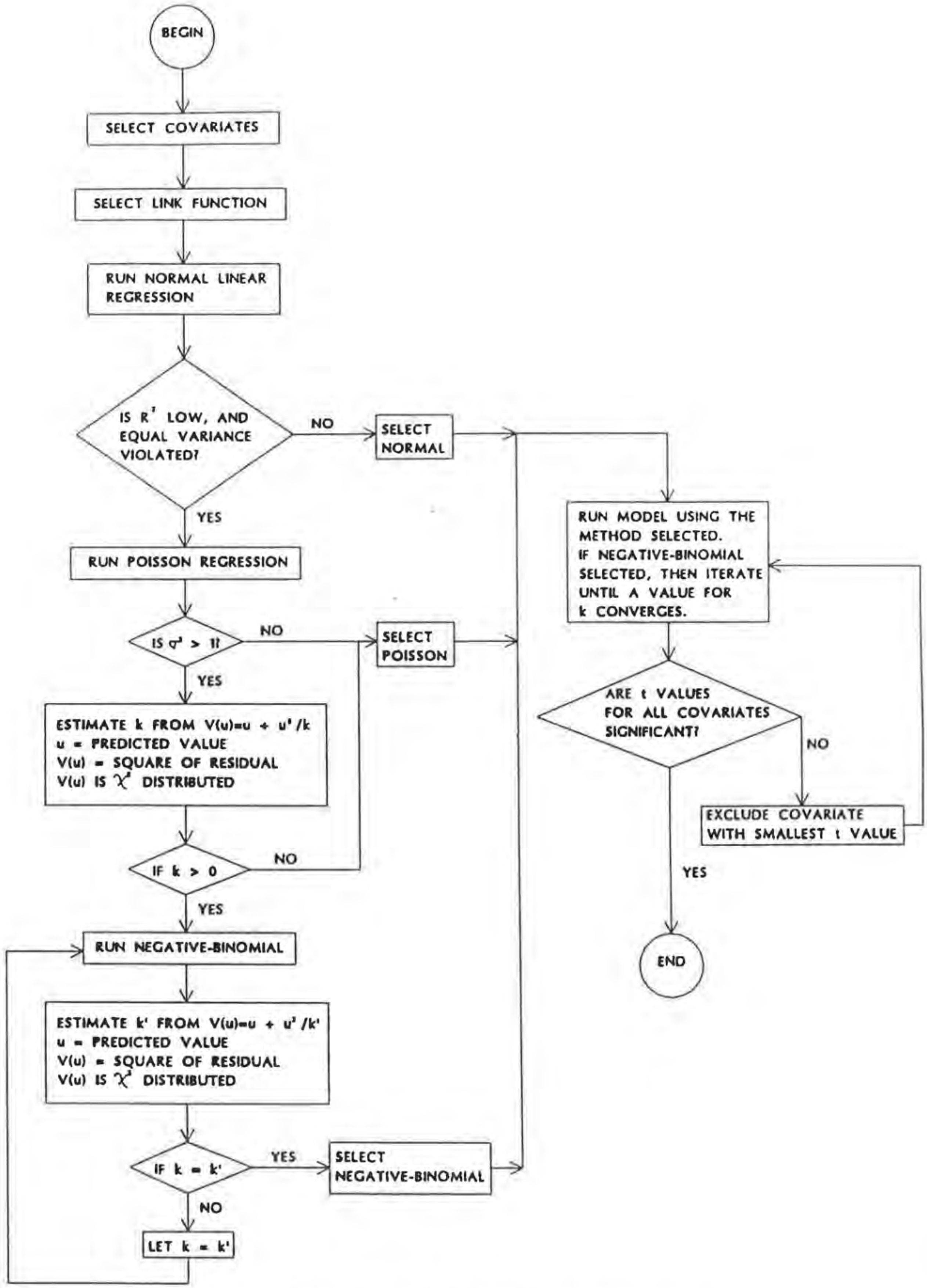

Figure 9. Flow chart of the model building process.

An inspection of tables 37 to 39 yields some interesting results. One result is that the number of signalized intersections is not included in the vehicle or pedestrian arterial models. This caused some concern resulting in a check of the data and in forcing signalized intersections to stay in the model. The data proved to be correct and forcing signalized intersections resulted in a change in the model constant and decreased model accuracy. The effect of signalized intersections is not as important in prediction accident frequency, therefore, as the other independent varibles retained by the model. It is also interesting to note than an increase in speed results in a reduction of accidents. At first this may appear as erroneous. Higher speeds, however, usually occur where development intensity, and hence vehicle interactions, are less, thereby, resulting in lower accident frequency.

Figures 10 through 15 present a fit of the models to the data in terms of prediction ratios. The vertical axis of each table is divided into two parts with unity as the boundary line. Instances where the model accurately predicts the average annual accident frequency will have a ratio of 1. The upper part of the axis indicates instances where the model prediction is greater than the actual and is determined by dividing the predicted value by the actual value (predicted/actual). The lower half indicates under prediction and is determined by dividing the actual value by the predicted value (actual/predicted). The inverse relationship is used to prevent ratios from becoming less than 1. The actual and predicted values contained in these tables are the average annual accident frequencies for each median type. The upper and lower bounds represented on each graph contain 90 percent of the observations.

Table 36. Nonlinear predictive model statistics for vehicle and pedestrian accidents on midblock segments.

Model	Statistics	Vehicle			Pedestrian		
		Raised	TWLT	Undiv	Raised	TWLT	Undiv
Poisson	dispersion parameter	4.65	6.13	4.21	1.14	1.34	1.37
	Pearson χ^2	2362.91	3511.37	2360.79	579.34	763.34	770.64
	$\chi^2.05$	561.54	629.80	617.21	562.59	625.60	618.26
Negative Binomial	initial k from Poisson	3.8	2.9	2.7	1.6	1.6	1.2
	final k	3.3	2.4	2.3	10	1.4	0.83
	Pearson χ^2	549.97	624.55	585.72	568.90*	630.85*	620.36*
	degrees of freedom	497	568	531	515	574	564
	$\chi^2.05$	779.09	696.78	714.50	564.68	610.68	594.35

*denotes significance at 95 percent confidence level.

Table 37. Covariates tested for inclusion in nonlinear regression models.

Models for Segment Accident: AV1, AV2, AV3, AP1, AP2, AP3
x_1 = Accident report threshold in \$, for vehicle accident only; x_2 = Dummy variable for landuse (residence/office/business); is 1 for office; x_3 = Dummy variable for landuse (residence/office/business); is 1 for business; x_4 = Dummy variable for area (CBD/suburban), is 1 for CBD; x_5 = Number of lanes excluding TWLTL; x_6 = Median width in feet, for raised median and TWLTL only; x_7 = Number of minor cross roads (two way total) per mile; x_8 = Number of driveways per mile; x_9 = Number of crossovers per mile, for raised median only; x_{10} = Posted speed limit in mi/h; x_{11} = Number of signals per mile, including signals at two ends.
Models for Midblock Accident: MV1, MV2, MV3, MP1, MP2, MP3
x_1 = Accident report threshold in \$, for vehicle accident only; x_2 = Dummy variable for landuse (residence/office/business); is 1 for office; x_3 = Dummy variable for landuse (residence/office/business); is 1 for business; x_4 = Dummy variable for area (CBD/suburban), is 1 for CBD; x_5 = Dummy variable for parking, is 1 if parking allowed; x_6 = Number of lanes excluding TWLTL; x_7 = Median width in feet, for raised median and TWLTL only; x_8 = Number of minor cross roads (two way total) per mile; x_9 = Number of driveways per mile; x_{10} = Number of crossovers per mile, for raised median only; x_{11} = Posted speed limit in mph.

Table 38. Negative binomial error structure prediction model, coefficients and standard error for arterials[1].

A = Vexp (βo + βi xi)						
A = Annual accident frequency V = Annual traffic volume in 10^6 vehicle-miles						
	Vehicles			Pedestrians		
	Raised (AV1)	TWLT (AV2)	Undiv (AV3)	Raised (AP1)	TWLT (AP2)	Undiv (AP3)
Constant	7.20515 (0.65)	3.70539 (0.48)	1.88309 (0.30)	-0.88369 (0.92)	-0.97281 (0.38)	-1.10911 (0.42)
x_1	-0.00788 (0.0008)	-0.00278 (0.0004)	-0.003031 (0.0005)	--	--	--
x_2	-0.44812 (0.14)	0.07227 (0.09)	1.06414 (0.23)	-1.65869 (0.31)	--	0.55689 (0.36)
x_3	--	--	0.65731 (0.15	--	--	0.73696 (0.27)
x_4	--	--	0.45652 (0.16)	1.03664 (0.23)	0.95036 (0.17)	1.43794 (0.25)
x_5	--	--	--	--	--	-0.25583 (0.10)
x_6	-0.02755 (0.007)	0.03544 (0.01)	--	-0.07866 (0.02)	-0.077121 (0.03)	--
x_7	--	-0.06057 (0.01)	--	--	--	--
x_8	--	0.01294 (0.0024)	0.01324 (0.0033)	0.02163 (0.005)	--	--
x_9	0.09615 (0.018)	--	--	--	--	--
x_{10}	-0.07002 (0.01)	-0.03389 (0.009)	--	-0.03922 (0.02)	--	--

[1]Asymptotic standard error is in parenthesis.

Table 39. Negative binomial error structure predictive model, coefficients and standard error for midblock segments.

Parameter	Vehicles			Pedestrians		
	Raised MV1	TWLT MV2	Undivided MV3	Raised MV4	TWLT MV5	Undivided MV6
Constant	1.56879 (0.18)	3.15501 (0.67)	1.64415 (0.19)	-3.24045 (0.32)	-3.89788 (0.64)	-4.03765 (1.06)
x_1	-0.00156 (0.0005)	-0.00359 (0.0004)	-0.00329 (0.0005)	--	--	--
x_2	-0.27075 (0.11)	-0.24483 (0.10)	1.13144 (0.23)	-1.19196 (0.40)	-0.62826 (0.26)	1.36700 (0.49)
x_3	--	--	0.72867 (0.13)	--	--	1.37281 (0.34)
x_4	--	--	--	1.08109 (0.29)	--	0.84182 (0.31)
x_5	-0.66038 (0.14)	-0.24979 (0.15)	-0.61007 (0.16)	--	0.81804 (0.25)	--
x_6	--	--	--	--	0.21729 (0.13)	-0.45389 (0.17)
x_7	-0.038716 (0.008)	0.05986 (0.01)	--	-0.03776 (0.024)	--	--
x_8	0.02916 (0.007)	--	0.03470 (0.006)	--	0.028883 (0.014)	--
x_9	0.004988 (0.001)	--	--	0.014379 (0.003)	--	0.0125005 (0.005)
x_{10}	-0.04840 (0.01)	--	--	--	--	--
x_{11}	--	-0.035797 (0.01)	--	--	--	0.057634 (0.03)

The most favorable result from graphs of the prediction ratio is to obtain ratios that are equal to one. Since this is usually not possible for real-world data the next best result is to obtain ratios that are relatively equally dispersed about unity. This indicates that the model does not have the tendency to predominately over- or under-estimate the dependent variable. In addition prediction ratios that display the absence of increasing error with increased prediction values are also desirable.

Figures 10 through 12 display a relatively equal distribution of predicted arterial vehicle accidents above and below unity. The vehicle accident prediction models which display the largest deviation from unity (± 2.12) are raised and undivided arterial models. The TWLT arterial model displays the smallest deviation from unity with 90 percent of the observations occurring within ±1.50 of unity. Inspection of figures 13 through 15 indicates that the arterial pedestrian models do not predict pedestrian accidents as accurately as the vehicle accident models predict vehicle accidents. The pedestrian model tends to underestimate accidents; especially for TWLT arterials. Ninety percent of the pedestrian prediction ratios are within ± 2.5 of unity.

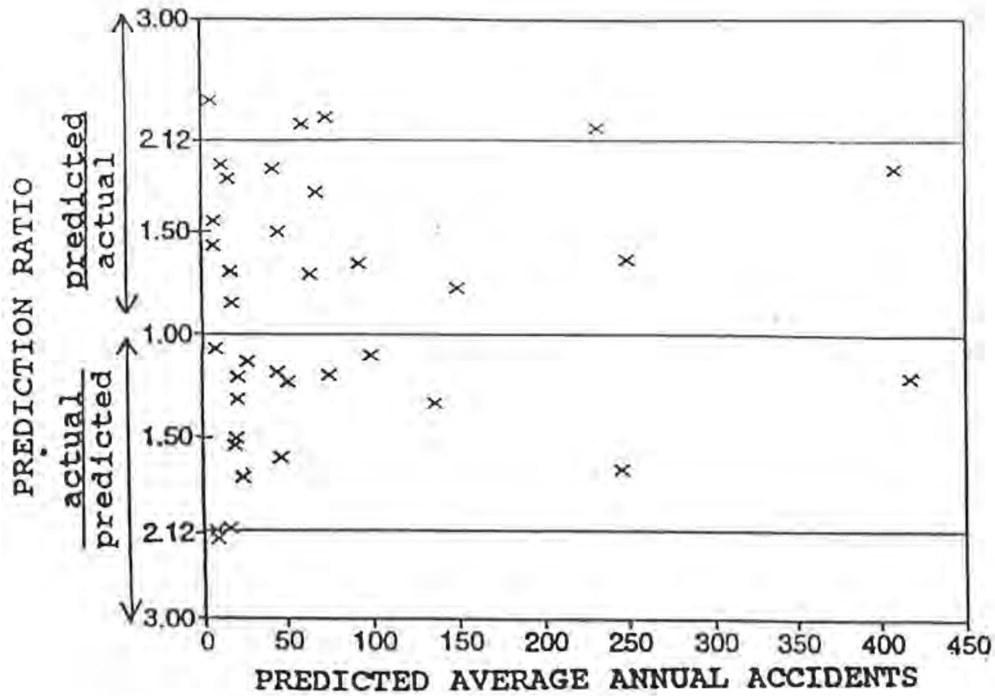

Figure 10. Plot of prediction ratio for vehicle accidents on raised median segments.

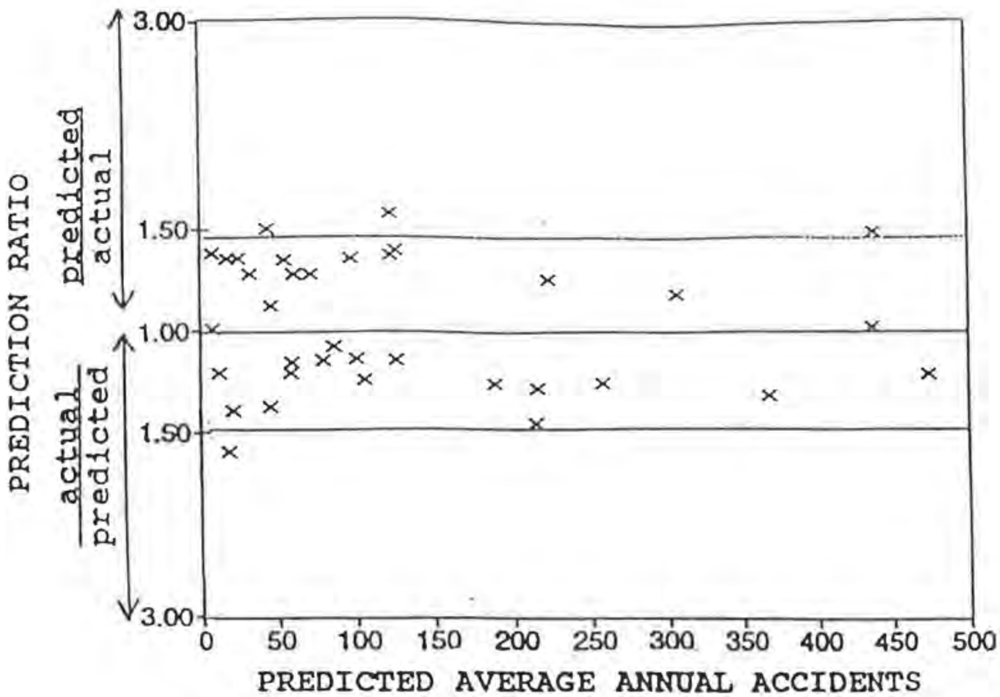

Figure 11. Plot of prediction ratio for vehicle accidents on TWLT median segments.

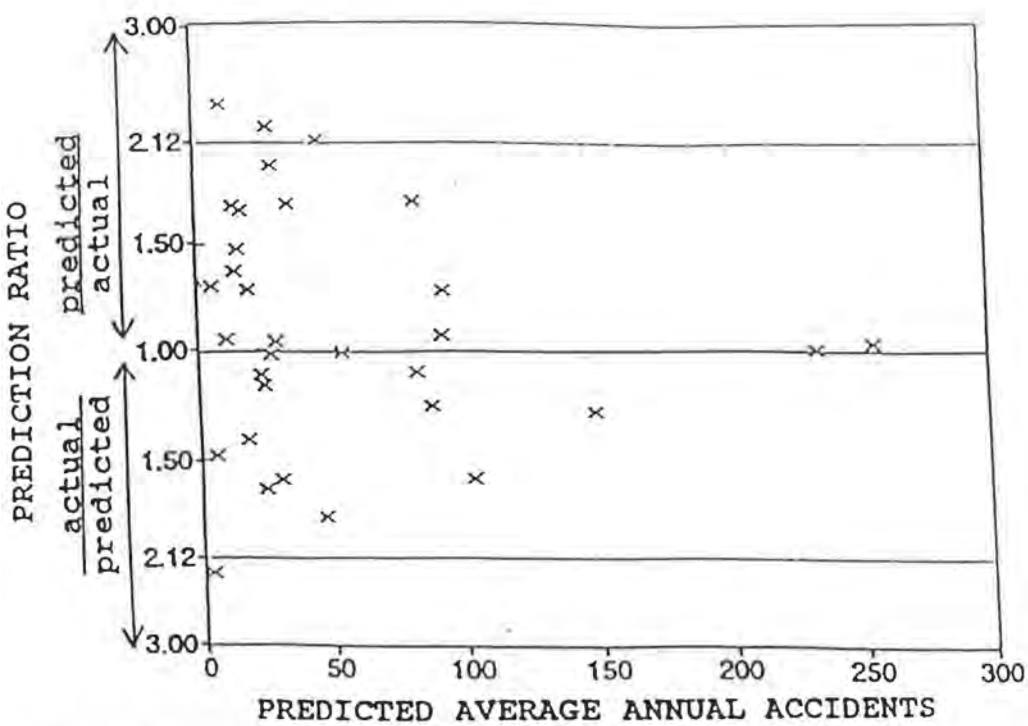

Figure 12. Plot of prediction ratio for vehicle accidents on undivided segments.

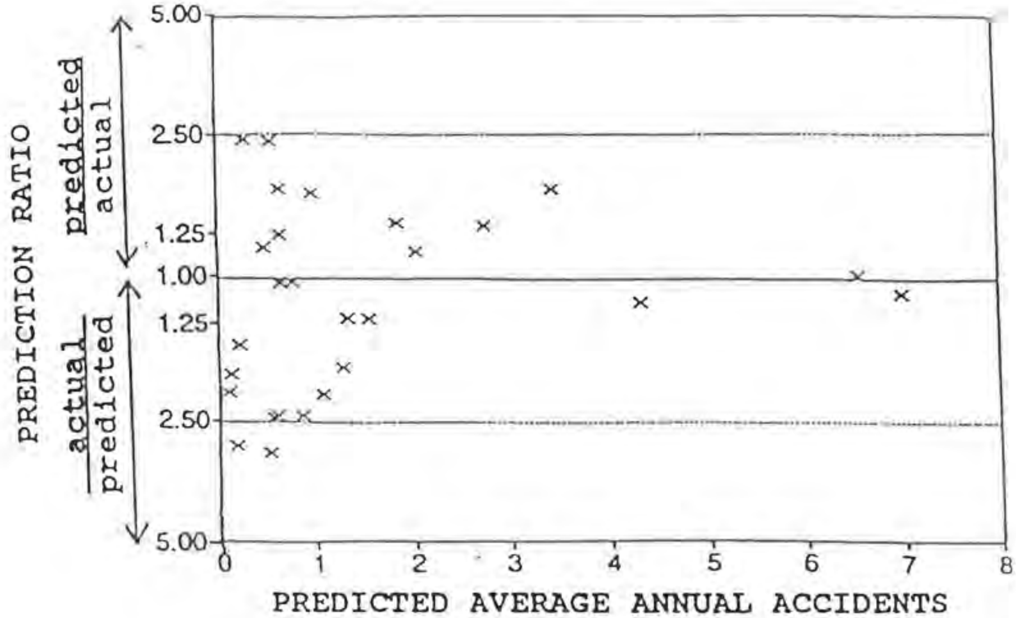

Figure 13. Plot of prediction ratio for pedestrian accidents on raised median segments.

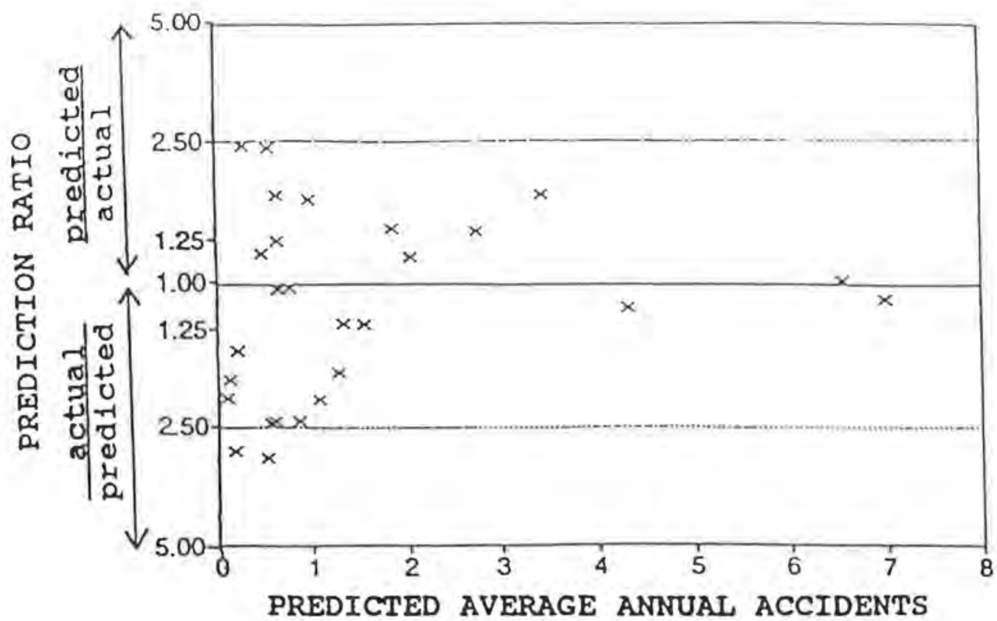

Figure 14. Plot of prediction ratio for pedestrian accidents on TWLT median segments.

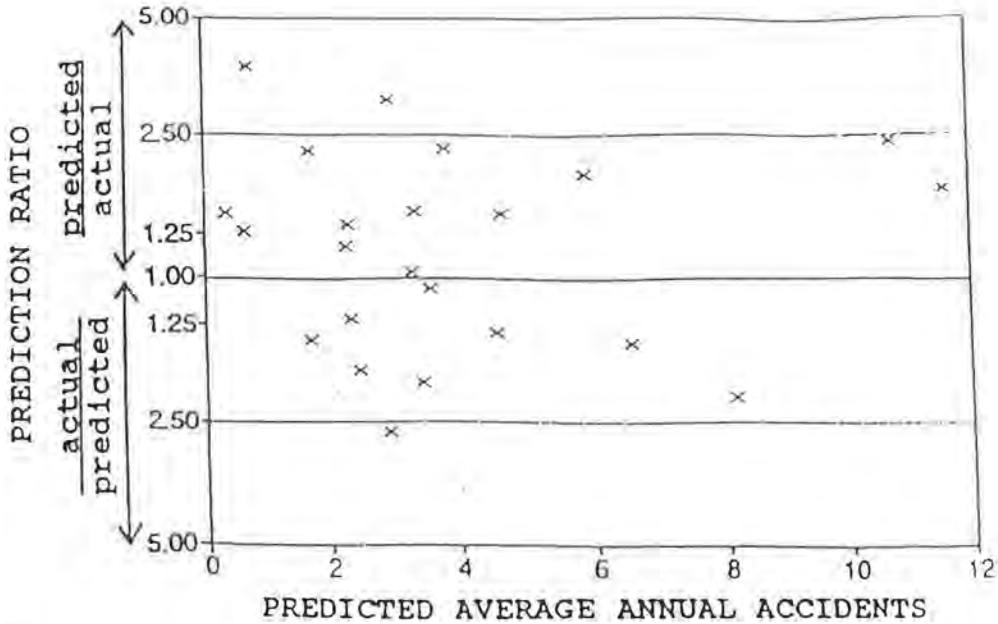

Figure 15. Plot of prediction ratio for pedestrian accidents on undivided segments.

COMPARISON WITH PREVIOUS MODELS

Comparisons were performed on the accident prediction accuracy between the project median models and models developed by Parker and Parsonson.[55,56] The comparison was performed on those sites from the following project data base that were within the model constraints of Parker and Parsonson.

- Parker's Virgina model was designed for urban or suburban, unlimited access roadways.[55] The model was intended for four-lane roadways with more than 30 residential and commercial driveways per mile. It is applicable to raised, TWLT and undivided roadways.
- Parsonson's Georgia model was designed for 4- and 6-lane urban or suburban unlimited access roadways.[56] The model is intended to perform a comparison between raised and TWLT median types.

The results of the comparison analysis between the project model and both Parker's and Parsonson's model are contained in appendix C. The comparisons were performed on only those sites which satisfied, as closely as possible, the requirements of each model. For this reason there is no comparison with undivided roadways for the Parsonson model since undivided arterials were not included in the Parsonson study. Table 40 summarizes the number of instances in which the predicted to actual ratio was closer to unity. In the majority of cases the project model provides a better estimate of expected annual accident frequency than either the Parker or Parsonson models. The magnitude of the differences in actual and predicted annual accident frequency was analyzed by the paired t-test. The results of these tests, presented as tables 41 and 42, indicate that there is no significant difference between the actual frequencies and the frequencies predicted by the project model for all median types. There are signficant differences in the actual and predicted frequencies in all cases with the Parker and Parsonson models except for the Parker undivided model. Even in the Parker undivided model the mean difference of the Parker model was greater than that of the project model. The project model, therefore, provides a better estimate of vehicle accident frequency than both the Parker and Parsonson models.

Table 40. Comparison of predicted to actual ratio of average annual accident frequency for different median types.

Instances of Ratios Closer to Unity						
Median Type	Project vs. Parker			Project vs. Parsonson		
	Number of Sites	Project	Parker	Number of Sites	Project	Parsonson
Raised	17	14	3	32	28	4
TWLT	17	14	3	25	21	4
Undivided	27	18	9	--	--	--

Table 41. Test for significance of the difference between actual and predicted annual accident frequency for project and Parker models.

Ho: There is no difference ($\bar{d}$) between actual and predicted annual accident frequency Significance level of paired t-test = 0.05						
Median Type	Actual vs. Project			Actual vs. Parker		
	$\bar{d}$	t	P>|t|	$\bar{d}$	t	P>|t|
Raised	23.9	1.74	0.1017	-52.9	-2.80	0.0129*
TWLT	-1.9	-0.26	0.7999	-56.9	-2.91	0.0103*
Undivided	-1.7	-0.48	0.6319	-3.3	-0.44	0.6625

*Denotes significant difference.

Table 42. Test for significance of the difference between actual and predicted annual accident frequency for project and Parsonson models.

Ho: There is no difference ($\bar{d}$) between actual and predicted annual accident frequency Significance level of paired t-test = 0.05						
Median Type	Actual vs. Project			Actual vs. Parsonson		
	$\bar{d}$	t	P>|t|	$\bar{d}$	t	P>|t|
Raised	5.6	0.56	0.5820	104.9	8.35	0.0001*
TWLT	-2.1	-0.20	0.8393	69.9	1.74	0.0945*

*Denotes significant difference.

A number of considerations must be used in comparisons between the three models. The primary consideration is that the data used to compare the models is the same data that were used to develop the project model. It can be expected, therefore, that the project model should provide a better fit. Another consideration is that, while sites were selected that most closely satisfied the project parameters of Parker and Parsonson, the data base was not specifically designed to perform comparisons. Some of the parameters of the Parker and Parsonson models, such as area population, may not have been controlled as closely as they would have been if the data were being obtained specifically for those models. What the comparison does display however, is that the project model is a better predictor of accident frequency than the Parker or Parsonson model in those cases where the arterial environment is more general, as for the project model, than specific.

Model Limitations

In some cases the project model tends to over or under predict the number of vehicle and pedestrian accidents, resulting in an abnormally high or low prediction ratio. Re-evaluation of the data, indicates that the fluctuation in the prediction ratio is attributable to high actual values with 4 lanes and an ADT of 15000 vpd. For example, undivided segments had an actual average annual number of accidents of 0.2 for a 1/2-mi (0.8 km) (SI) segment. Another undivided site had an annual average value of to 3.13 for a 1/2-mi (0.8 km) (SI) segment with the same number of lanes and an ADT of 28400 vpd. As indicated by the plots of the predicted ratios, the latter situtaiton is the most common among the data for all three median types. The range of those data items which were inlcuded as independent variables in the project model are presented in tables 43 and 44 for arterials and midblock segments, respectively. The models should not be applied to urban unlimited access arterials that have data values outside the ranges indicated in tables 43 and 44.

Table 43. Independent variable ranges used in the development of arterial models.

Independent variable	Independent variable range	
	Minimum	Maximum
ADT (vpd)	11500	60000
Arterial Length (miles)	0.5	5.6
# Driveways per mile	4.3	90.0
# Minor Roads per mile	0.0	20.0
# Crossovers per mile RAISED	4.3	11.0
Median width (ft) RAISED TWLT	3.0 10.0	40.0 12.0
# Signals per mile	1.0	20.0
Speed (mi/h)	25.0	55.0
# Lanes	2.0	6.0

1 mi = 1.6 km

Table 44. Independent variable ranges used in the development of midblock segment models.

Independent variable	Independent variable range	
	Minimum	Maximum
ADT (vpd)	3,000	60,000
Segment Length (miles)	0.1	3.0
# Driveways per mile	0.0	150.0
# Minor Roads per mile	0.0	33.3
# Crossovers per mile RAISED	 0.0	 18.0
Median width (ft) RAISED TWLT	 3.0 10.0	 40.0 12.0
# Signals per mile	1.0	20.0
Speed (mi/h)	25.0	55.0
# Lanes	2.0	6.0

1 mi = 1.6 km

MODEL PREDICTION OF ANNUAL ACCIDENT FREQUENCY

Appendix D contains a list of annual accident frequencies predicted by the nonlinear project model for typical ranges of the independent varibles. This table can be used to obtain estimates of annual accident frequency for a limited number of conditions. The predictive models have also been developed into a user friendly and interactive computer program for use on MS-DOS and compatable systems. This program, "Selecting a Central Business District and Suburban Median Treatment," and the accompanying users guide is available from:

Center for Microcomputers
in Transportation
Transportation Research Center
University of Florida
512 Weil Hall
Gainesville, FL 32611-2083

CHAPTER 7 - FINDINGS AND CONCLUSIONS

The findings and conclusions presented below are based on the results of the state-of-the-practice survey, analysis of vehicle and pedestrians accidents, nonlinear accident prediction model development and a review of prior studies. A detailed summary of the literature review activities is presented in chapter 2. In accordance with the objectives of the study, the conclusions are applicable to raised, TWLT, and undivided cross-sections located in CBD and suburban environments. The conclusions are not applicable to rural environments or limited access roadways:

- Factors that States consider in determining the need for installing medians include accident history (20 percent), traffic volumes (15 percent), cost (10 percent), number and location of driveways (10 percent), and type of access control (10 percent). Ten percent of the State agencies do not regularly use any guidelines. Criteria used by cities with populations under 100,000, include accident history (18 percent), AASHTO and MUTCD criteria (36 percent), State design criteria (9 percent), and availability of right-of-way (18 percent). Cities with populations between 100,000 and 150,000 consider the following criteria: classification of street (20 percent), available safe gaps (10 percent), AASHTO criteria (10 percent), and the city's own standard plans (10 percent). Thirty percent use no guidelines. Cities with populations ranging from 150,000 to 500,000 generally use medians to provide an orderly flow of traffic (20 percent) or install medians with newly constructed arterials (20 percent). Twenty percent do not use any guidelines. The large cities (over 1/2 million population) consider traffic volumes (14 percent), pedestrian volumes (14 percent), available right-of-way (29 percent), and arterial classification of street (72 percent) as their criteria. Fourteen percent use their own guidelines.

- Pedestrian refuge islands do not receive much attention from roadway agencies. Some agencies do not intend to use medians as pedestrian refuge areas. One agency stated that they do not specifically design medians to be used by pedestrians, although pedestrians do use them. Other agencies have low pedestrian volumes and do not account for pedestrians in roadway design, nor time traffic signal phases to allow pedestrians to cross the entire roadway.

- In some agencies the needs of the elderly and handicapped are currently, or soon will be, included in their specifications for median design. There was mixed response on the questions of acceptable widths for pedestrian refuge islands. Fifty-five percent of the States feel that 4 ft (1.2 m) is an acceptable minimum width for pedestrian refuge. The cities results, however, did not concur. The majority of cities in both the 100,000 to 150,000 population range, and the 500,000 and over range felt that 4 ft (1.2 m) is acceptable. However, only 36 percent of the cities with populations less than 100,000 felt that 4 ft (1.2 m) was acceptable. Seventy percent of the cities in the 150,000 to 500,000 population range felt that 4 ft (1.2 m) is unacceptable for a pedestrian refuge. All agencies, in general, felt that pedestrian refuge widths of 6 to 16 ft (1.8 to 4.9 m) are desirable.

- States are evenly split on the question of installing different types of medians based on pedestrian use: 45 percent install different types of medians based on pedestrian use; while 55 percent, do not. Most cities (at least 60 percent in each category) do not install different types of medians based on pedestrian use.

- In almost all classes of jurisdictions, a majority of the agenices feel that flat medians increase pedestrian and vehicle safety. In the class of cities under 100,000 people, however, 45 percent feel that flat medians do not increase safety, 36 percent felt that flat medians do increase safety. Many agencies comment that flat medians increase vehicle safety, but not pedestrian safety since they offer no physical protection from vehicular traffic (unlike raised medians).

- An analysis of vehicle and pedestrian accidents was conducted during this project for accidents occurring over a 3- to 5-year period on 51.9 mi (83.5 km) of raised, 55.1 miles (88.7 km) of TWLT, and 38.9 mi (62.6 km) of undivided cross-sections arterial. A total of 32,894 vehicle and 1,012 pedestrian accidents were analyzed from three cities.

- It was initially assumed that pedestrian activity, and hence pedestrian accident rate, is higher in CBD areas than in suburban areas. This assumption was necessary since actual pedestrian volumes for roadway segments were not available. The assumption was tested by developing pedestrian accident rates based on pedestrian accident frequency, vehicular volumes and roadway length. Pedestrian accidents displayed a significantly higher accident rate in CBD areas than in suburban areas for all three median types. CBD and suburban areas can, therefore, be used as a surrogate measure of pedestrian activity. In addition, the development of models to predict pedestrian accidents should be performed separately for CBD and suburban areas.

- Vehicle accidents do not exhibit as large an influence by area as do pedestrian accidents. This supports the assumption that CBD areas have more pedestrian activity than suburban areas.

- TWLT medians, located in CBD areas, had a lower vehicle accident rate than both raised curb medians and undivided cross-sections. Undivided arterials had the highest vehicle accident rate in CBD areas. Comparisons between the three types of cross sections revealed that TWLT medians had a significantly lower vehicle accident rate than undivided arterials. No significant differences were identified between comparison of vehicle accident rate between raised and TWLT or raised and undivided cross-sections.

- The pedestrian accident rate, for CBD locations, of undivided arterials was significantly higher than both raised and TWLT medians. The pedestrian accident rate for raised was lower than both TWLT and undivided cross-sections in CBD locations.

- In suburban areas, raised curb medians, provide a significantly lower vehicle accident rate than both TWLT and undivided cross-sections.

- Raised curb medians in suburban areas had the lowest pedestrian accident rate. The raised medians had a significantly lower pedestrian accident rate than undivided cross-sections. There was not a significant difference between the pedestrian accident rate of raised and TWLT median types.

- An analysis of the type of vehicle accidents occurring in CBD locations indicated that there were significant differences in the occurrence of right angle accidents between the three types of cross-sections. A multiple comparisons test between the three types of cross-sections did not indicate a significant difference between pairs of median type.

- In suburban areas raised curb arterials have a significantly lower vehicle accident rate than TWLT medians for rear-end, right-angle and left-turn accident types. Raised medians also had a significantly lower rate than undivided cross-sections for right angle type vehicle accidents.

- TWLT medians, in CBD areas, have the lowest vehicle accident severity rate of any of the three types of cross-section. The vehicle accident severity rate of TWLT medians is significantly less than that of undivided cross-sections.

- In suburban locations, raised medians have a lower vehicle accident severity rate than both TWLT and undivided cross-sections. The raised median vehicle accident severity rate was significantly lower than TWLT medians. Undivided arterials had a significantly lower vehicle accident severity rate than TWLT medians in suburban areas.

- Study results indicate that, where possible, undivided cross sections should not be used in CBD areas. In CBD areas, undivided arterials result in the highest accident rates for both pedestrians and vehicles.

- With one exception there is no significant difference in either pedestrian or vehicle accident rates between raised and TWLT median types. The one exception was vehicle accident rates in suburban areas where raised medians was significantly less than TWLT medians.

- Pedestrians aged 18 to 60 years exhibit a significantly higher walking speed at TWLT medians, for both signalized intersections and midblock locations (4.81 ft/s (1.47 m/s), 4.79 f/s (1.46 m/s)), than that exhibited at undivided cross-sections (3.84 ft/s (1.17 m/s), 3.90 f/s (1.19 m/s)). Elderly pedestrians also exhibited higher walking speeds at TWLT signalized intersection locations but the sample size of elderly pedestrian observations is too small for reliability. The increased walking speed for TWLT lanes may be due to the pedestrian perception of increased walking distance resulting from the presence of the TWLT lanes.

- The walking speed for the 18 to 60 age group is significantly higher than that of the over 60 age group for both signalized intersections and midblock locations. Both age groups have significantly higher walking speeds at midblock locations than at signalized intersections. This may indicate that pedestrians feel somewhat protected at signalized intersections and do not exercise the same urgency to cross as at midblock locations.

- Pedestrian conflict data were obtained at 25 signalized intersections and midblock locations in both CBD and suburban areas. The majority of CBD observations were conducted at TWLT medians and undivided arterials due to the insufficient availability of raised medians in CBD areas. Pedestrian-vehicle conflicts were categorized by the type of vehicle maneuver taking place at the time of the conflict.

- The analysis of conflicts and accidents indicates that there is no difference in the type of conflict observed between raised, TWLT and undivided cross-sections for either intersection or midblock locations. There is also no difference in the conflict rates observed between CBD and suburban environments. The absence of the difference between CBD and suburban may, however, have been more due to the selection of high pedestrian volume locations than due to the environment. The data did indicate that there is a relationship between conflicts and accidents for through and right-turn types. This relationship should be verified by a larger study. If a definite relationship can be established then the use of ADT as a normalizing agent for conflicts and the use of conflict types to estimate accidents and develop countermeasures can be established.

- Equations to estimate the frequency of vehicle and pedestrian accidents for raised, TWLT and undivided cross-sections were developed for median segments and midblock arterials. The models which provide the best estimates are nonlinear negative binomial models.

- The number of signalized intersections is not included in the vehicle or pedestrian, nonlinear arterial models. This caused some concern resulting in a check of the data and in forcing signalized intersections to stay in the model. The data proves to be correct and forcing signalized intersections resulted in a change in the model constant and decreased model accuracy. The efffect of signalized intersections is not as important in pedestrian accident frequency as the other independent variables retained by the model. It is also interesting to note that an increase in speed results in a reduction of accidents. At first this may appear as erroneous. Higher speeds, however, usually occur where development intensity, and hence vehicle interactions, are less, thereby, resulting in lower accident frequency.

- Prediction ratio plots for the vehicle nonlinear models display a relatively equal distribution of predicted vehicle accidents above and below unity. The vehicle accident prediction models which display the largest deviation from unity ($\pm$2.12) are raised and undivided cross-section models. The TWLT arterial model displays the smallest deviation from unity with 90 percent of the observations occurring within $\pm$1.50 of unity.

- Plots of the prediction-ratios for the pedestrian nonlinear models indicate that the pedestrian models do not predict pedestrian accidents as accurately as the vehicle accident models. The pedestrian models tend to underestimate accidents, especially for TWLT arterials. Ninety percent of the pedestrian accident prediction ratios are within $\pm$2.5 of unity.

- Comparisons were performed on the accident prediction accuracy between the project median models and models developed from prior research. In the majority of cases the project nonlinear models provided a better estimate of annual accident frequency than the prior linear models. There is no significant difference between the actual frequencies and the frequencies predicted by the project model for all median types. There are significant differences in the actual and predicted frequencies in all cases with the prior models except for one undivided model. Even in the one undivided model the mean difference of the prior model was greater than that of the project model. The project model, therefore, provides a better estimate of vehicle accident frequency than developed from prior research.

- The predictive models have been developed into a user friendly and interactive computer program for use on MS-DOS and compatible systems. This program, "Selecting a Central Business District and Suburban Median Treatment," and the accompanying users guide is available from:

  Center for Microcomputers
    in Transportation
  Transportation Research Center
  University of Florida
  512 Weil Hall
  Gainesville, FL 32611-2083

APPENDIX A
EXAMPLE OF SURVEY INSTRUMENT AND SUMMARY OF RESPONSES

State-of-the-Practice Survey

Background Information: (This information is only requested for anonymous survey summary needs. You and your agency will not be identified in any report or correspondence).

1. State/City/County name:______________________________

2. Person responding:______________________________

   Address: ______________________________

   ______________________ Phone Number______________

   ____

   Would you like a summary of the results? Yes___ No___

3. Size of jurisdiction (square miles): ______________________

4. Population of jurisdiction (1989): ______________________

   Metropolitan Population: ______________________

5. Total street miles maintained (1989): ______________________

6. Total annual motor vehicle accidents reported in jurisdiction (1989): ____________

7. Total annual pedestrian accidents in jurisdiction (1989): ______________

Median and Refuge Island Survey

1. What warrants, guidelines and/or criteria do you use to determine whether medians or refuge islands should be installed at the following kinds of locations:

- ☐ New residential areas:

- ☐ New commercial areas:

- ☐ Existing residential areas:

- ☐ Existing commercial areas:

- ☐ School areas:

- ☐ I have attached relevant information.

2. What "minimum" and "desirable" widths of pedestrian refuge islands are used by your agencies? Minimum: _____ft. Desirable: _____ft.

3. Do you consider a 4 ft. width of curbed median to be acceptable for pedestrian refuge? Yes____ No____

4. How do you prioritize locations for the installation of medians or refuge islands?

5. Have you had any problems or difficulties using any of the warrants, guidelines or prioritization procedures? Please explain.

6. What factors do you think should be considered in developing new warrants or guidelines?

7. What additional information (e.g., pedestrian volume counts) would you be willing to collect if the information were needed to use a newly developed median or refuge island construction warrant?

8. What are your design specifications for median or refuge islands?

   □ I have attached relevant information.

9. Do you install different types of medians or refuge islands depending on the anticipated level of pedestrian use? (e.g. flush painted, raised etc).

10. If different types of medians or refuge islands are installed, is the identification of the specific type accomplished by warrants? (If yes, please provide the types and warrants.)
   □ I have attached relevant information.

11. What funding sources do you use to cover the costs of median or refuge island construction (e.g., assess adjacent property owners, capital improvement fund, etc)?

12. Are you aware of other warrants or guidelines used by other agencies for the installation of median or refuge islands? If so, who could we contact to obtain this information?

13. Have you conducted any research or operational studies to determine the effectiveness of median or refuge islands in improving pedestrian safety? Do you know any other agencies that have? (If yes, please provide a copy.)

14. Have you conducted any research or operational studies to determine appropriate design specifications for medians or refuge islands? Do you know any other agencies that have?

15. Do you consider flat medians (such as continuous left turn lanes) effective in increasing vehicle and pedestrian safety?

16. Does your jurisdiction have over 20 medians and/or refuge island locations with relatively high vehicle and pedestrian volumes?

Thank you for your input. Please mail or FAX by Friday, January 18, 1991 to:

Brian L. Bowman
Department of Civil Engineering
238 Harbert Engineering Center
Auburn University, AL 36849-5337
FAX 205/844-2672

AGENCIES RESPONDING TO SURVEY

States	Arizona California Delaware Florida Illinois Iowa Kansas Maine Maryland Michigan Nevada North Carolina Oklahoma Pennsylvania South Carolina Texas Virginia Washington, D.C. (2) West Virginia Wisconsin	19 + DC
Counties	Orange Co., California	1
Cities	Austin, TX Billings, MT Campbell, CA Cedar Rapids, IA Clearwater, FL El Paso, TX Fargo, ND Farmington Hills, MI Fort Worth, TX Hartford, CT Houston, TX Huntsville, AL Minneapolis, MN Modesto, CA Monterey, CA Mountain View, CA New Haven, CT Olympia, WA Oxnard, CA Phoenix, AZ Pueblo, CO Rapid City, SD St. Louis, MO	36

Salt Lake City, UT
San Antonio, TX
San Diego, CA
San Jose, CA
San Francisco, CA
Santa Fe, NM
Scottsdale, AZ
Sioux Falls, SD
Southfield, MI
Tempe, AZ
Troy, MI
Tucson, AZ
Tulsa, OK
Virginia Beach, VA

Summary of Survey Results

1. What warrants, guidelines and/or criteria do you use to determine whether medians or refuge islands should be installed?

States:

	Number of Responses	%
Costs	2	10
Existing condition	1	5
Traffic volumes	3	15
Pedestrian volumes	1	5
Safety (accident history)	4	20
Type of traffic control	1	5
Existing/future pedestrian crossings	1	5
Width of streets	1	5
Existing/future land use	1	5
Number and location of driveways	2	10
Parcel size	1	5
Locations of signalized intersections	1	5
Types of access control	2	10
Specific design vehicle operation	1	5
AASHTO "Green Book"	1	5
MUTCD standard	1	5
State design manual	4	20
No normal guidelines	2	10
No response	6	30

Cities with a population less than 100,000:

	Number of Responses	%
Used in new design projects	1	9
Costs	1	9
Safety (accident history)	2	18
Available ROW	2	18
Political	1	9
State Design Manual	1	9
Non-residential areas	1	9
AASHTO "Green Book"	2	18
MUTCD standards	2	18
No response	4	36

Cities with a population between 100 and 150 thousand:

	Number of Responses	%
Available safe gaps and pedestrian activity	1	10
Arterial	2	20
AASHTO "Green Book"	1	10
Standard details for undivided and divided arterial	1	10
No normal guidelines	3	30
No response	1	10

Cities with a population between 150 and 500 thousand:

	Number of Responses	%
An orderly flow of traffic	2	20
A restricted broad expanse of pavement		
Major-major street intersections	1	10
Newly constructed arterial	2	20
Commercial areas within 300' of an intersection	1	10
ITE Guidelines for Urban Major Street Design	1	10
No normal guidelines	2	20
No response	3	30

Cities with a population over 500,000:

Costs	1	14
Traffic Volumes	1	14
Pedestrian volumes	1	14
Signal phasing	1	14
Available ROW width	2	29
Arterial	3	43
Arterial that have 6 through lanes or more	2	29
Geometric Design Guidelines for Subdivision Streets	1	14

2. What "minimum" and "desirable" widths of pedestrian refuge islands are used by your agencies? Minimum: _____ft. Desirable: _____ft.

States:

MINIMUM (ft)		%	DESIRABLE (ft)		%
2	2	10	6	4	20
4	6	30	7	1	5
6	4	20	10	1	5
8	1	5	12	2	10
14	1	5	16	1	5
N/A	6	30	16-22	1	5
			N/A	9	45
			4	1	5

Cities under 100,000:

MINIMUM (ft)		%	DESIRABLE (ft)		%
4	5	45	6	4	36
5	1	9	12	1	9
N/A	4	36	30-50	1	9
30	1	9	200	1	9
			N/A	3	27
			50	1	9

Cities 100,000 - 150,000:

MINIMUM (ft)		%	DESIRABLE (ft)		%
2	2	20	4	1	10
4	3	30	6	1	10
5	1	10	8	2	20
6	1	10	10	1	10
N/A	2	20	16	1	10
			N/A	3	30

Cities 150,000 - 500,000:

MINIMUM (ft)		%	DESIRABLE (ft)		%
4	3	30	6	2	20
6	4	40	6-10	1	10
10	1	10	10	1	10
N/A	2	20	12	1	10
			16	2	20
			N/A	3	30

Cities over 500,000:

MINIMUM (ft)		%	DESIRABLE (ft)		%
4	4	57	6	2	29
6	2	29	12	1	14
N/A	1	14	14	2	29
			N/A	2	29

3. Do you consider a 4 ft. width of curbed median to be acceptable for pedestrian refuge? Yes _____ No _____

Summary of Survey Results (Con't)

States	11 (55%)	9 (45%)	0

Cities

0 - 100,000	4 (36%)	5 (45%)	2 (18%)
100 - 150,000	5 (50%)	3 (30%)	2 (20%)
150 - 500,000	3 (30%)	7 (70%)	0
500,000 and over	4 (57%)	3 (43%)	0

4. How do you prioritize locations for the installation of medians or refuge islands?

States:

	Number of Responses	%
Traffic volumes	6	30
Pedestrian volumes	1	5
Safety (accident history)	7	35
Shielding Traffic	1	5
Adjacent land use	1	5
State guides	3	15
Case-by-case	3	15
No application	5	25

Cities 0 - 100,000:

Available Funds	1	9
Political consideration	1	9
Traffic volumes	1	9
Safe gaps	1	9
Street width	1	9
Commercial/school use	1	9
No application	7	63
No response	1	9
To Improve capacity	1	9
As a buffer between different land uses	1	9

Cities 100,000 - 150,000:

Political	1	10
Pedestrian volumes	1	10
Arterials constructed by		

private development /widened by capacity improvement	1	10
A street being designed for constructed/reconstructed or traffic signals being revised	1	10
Traffic engineer judgement	1	10
No application	3	30
No response	1	10

Cities 150,000 - 500,000:

Political consideration	2	20
Traffic system management study	1	10
Traffic volumes	1	10
Pedestrian volumes	2	20
Classification of roadways	1	10
Arterials that have 6 lanes or more	1	10
No application	2	20
No response	2	20

Cities 500,000 and over:

Political consideration	2	29
Capacity	1	14
Safety (accident history)	3	43
Channelization of traffic	1	14
Protect traffic signal equipment	1	14
Completion of sections of roadway previously un-done	1	14
Landscaping (beautification)	1	14
No application	3	43

5. Have you had any problems or difficulties using any of the warrants, guidelines or prioritization procedures? Please explain.

	Yes	No	No Response
States	3 (15%)	13 (65%)	4 (20%)

Cities

0-100,000	2 (18%)	6 (54%)	3 (27%)
100,000 - 150,000	1 (10%)	6 (60%)	2 (20%)
150,000 - 500,000	3 (30%)	4 (40%)	3 (30%)
500,000 and over	3 (43%)	3 (43%)	1 (14%)

6. What factors do you think should be considered in developing new warrants or guidelines?

States:

	Number of Responses	%
Speed	6	30
Safety (accident history)	6	30
Capacity	1	5
Traffic volumes	13	65
Availability of traffic gaps	1	5
Pedestrian volumes	11	55
Pedestrian usage	1	5
Age of pedestrians	1	5
Access control	1	5
Vehicle classification	1	5
LOS at access points	1	5
Roadway geometrics	1	5
Number of lanes	2	10
Width of roadway	5	25
Width of medians	1	5
Width of intersection	1	5
Traffic control	4	20
Efficiency of traffic signal operation with pedestrian phasing	1	5
Adjacent land use	2	10
Functional class of street	2	10
Visibility	1	5
Location: rural or urban	1	5
No response	3	15

Cities under 100,000:

Speed	2	18
Safety (accident history)	1	9
Traffic volumes	7	63
Pedestrian volumes	4	36
Pedestrian comfort	1	9
Available gaps	3	27
Intersection geometrics	1	9

Summary of Survey Results (Con't)

Number of lanes	1	9
Width of street	4	36
Available ROW	1	9
Type of traffic control	1	9
No response	3	27

Cities 100,000 - 150,000:

	Number of Responses	%
Speed	1	10
Traffic volumes	4	40
Pedestrian volumes	4	40
Age of pedestrians	1	10
Crossing time	1	10
ROW availability	1	10
Type of roadway land use		10
Access control	1	10
None	2	20
No response	3	30

Cities 150,000 - 500,000:

	Number of Responses	%
Speed	1	10
Capacity	1	10
Safety (accident history)		20
Traffic volumes	2	20
Pedestrian volumes	1	10
Pedestrian crossing time		20
Roadway geometrics	2	20
Number of lanes	1	10
ROW	1	10
Sound buffers/sight distance impact	1	10
Drainage	1	10
Aesthetics	1	10
No response	4	40

Cities 500,000 and over:

	Number of Responses	%
Speed	2	29
Safety (accident history)	2	29
Traffic volumes	4	57
Pedestrian volumes	3	43
Age of pedestrians	1	14
Gap length and frequency	1	14
Roadway width	1	14
ROW width	1	14
Available ROW	2	29
Land use	2	29
Type of traffic control	1	14
Signal timing	1	14
Street classification	1	14
Regional differences	1	14
Easy application	1	14
Allow for engineering judgement	1	14
Litigation	1	14

7. What additional information (e.g., pedestrian volume counts) would you be willing to collect if the information were needed to use a newly developed median or refuge island construction warrant?

States:

	Number of Responses	%
Hwy class	1	5
Speed	3	15
Safety (accident history)	3	15
Capacity	1	5
Traffic volumes	6	30
Pedestrian volumes	10	50
Pedestrian crossing gaps	2	10
Roadway width	1	5
Adjacent land use	1	5
Data providing a sensitivity analysis	1	5
Data from various ongoing projects	1	5
No response	4	20
Access control	1	5
Vehicle class	1	5

Summary of Survey Results (Con't)

Cities under 100,000:

	Number of Responses	%
Traffic volumes	3	27
Pedestrian volumes	3	27
Physical condition of pedestrian	1	9
Anything	2	18
None	1	
No response	3	27

Cities 100,000 - 150,000:

	Number of Responses	%
Traffic volumes	1	10
As needed	1	10
None	2	20
No response	4	40

Cities 150,000 - 500,000:

	Number of Responses	%
Traffic volumes	1	10
Pedestrian volumes	3	30
All required	1	10
No response	6	60

Cities 500,000 and over:

	Number of Responses	%
Costs	1	14
Political consideration	1	14
Safety (accident history)	2	29
Speed	2	29
Traffic volumes	3	43
Pedestrian volumes	2	29
Age of pedestrian volumes	1	14
Gap length and frequency	1	14
Roadway width	1	14
Type of traffic control	1	14
Signal timing	1	14

Access study	1	14
None	1	14
No response	2	29

8. What are your design specifications for median or refuge islands?

States:

AASHTO "Green Book"	2	10
BLE Manual	1	5
Arizona DOT Highway Division plan guide	1	5
California Highway Design Manual	1	5
Florida DOT methods	1	5
NC Roadway Design Manual	1	5
Texas State Department of Highways and Public Transportation Highway Design Division Operation and Procedures Manual	1	5
VDOT Instructional and Information Memorandum No. L-90(D)	1	5
Wisconsin DOT Facilities Development Manual	1	5
The minimum/maximum width is 4/100 ft	1	5
4/6 ft minimum width for median/refuge islands	1	5
Minimum/desirable 14/16 width	1	5
Maryland SHA Standards	1	5
Minimum/desirable 2/4 ft width	1	5
General guidelines	1	5
No application	2	10

Cities under 100,000:

	Number of Responses	%
ASHTO "Green Book"	4	36
MUTCD standards	1	9
Washington State DOT		

Summary of Survey Results (Con't)

	Number of Responses	%
Design Manual	1	9
California specifications	1	9
None	1	9
No response	3	27

Cities 100,000 - 150,000:

	Number of Responses	%
City of Scottsdale Policy	1	10
6 ft width	1	10
4 ft minimum width	1	10
-40/45-50/55- mph speed, 25/19.5/15/5 ft width	1	10
None	1	10
No response	3	30

Cities 150,000 - 500,000:

	Number of Responses	%
ITE Guidelines for Urban Major Street Design	1	10
State standards for Minnesota	1	10
City of Fort Worth Street Design Criteria	1	10
City of Modesto Policy	1	10
16 ft median (4 ft at intersection)	1	10
No response	5	50

Cities over 500,000:

	Number of Responses	%
MUTCD standards	1	14
City of Phoenix Traffic Operation Handbook	1	14
City of Houston Geometric Design Guidelines for Subdivision Streets	1	14
City of El Paso Subdivision Design Standards	1	14
Minimum/maximum 2/14 ft width	1	14

No application	1	14
No response	1	14

9. Do you install different types of medians or refuge islands depending on the anticipated level of pedestrian use? (e.g. flush painted, raised etc).

	Yes	No	No Response
States	9 (45%)	11(55%)	0
Cities:			
0-100,000	2(18%)	7(63%)	2(18%)
100,000-150,000	3(30%)	6(60%)	1(10%)
150,000-500,000	2(20%)	6(60%)	2(20%)
500,000 and over	1(14%)	6(86%)	0

10. If different types of medians or refuge islands are installed, is the identification of the specific type accomplished by warrants? (If yes, please provide the types and warrants).

	Yes	No	No Response
States	2(10%)	11(55%)	7(35%)
Cities:			
0-100,000	1(9%)	8(72%)	2(18%)
100,000-150,000	0	7(70%)	3(30%)
150,000-500,000	0	6(60%)	4(40%)
500,000 and over	1(14%)	6(86%)	0

11. What funding sources do you use to cover the costs of median or refuge island construction (e.g., assess adjacent property owners, capital improvement fund, etc)?

States:

	Number of Responses	%
Normal roadway construction funds	6	30
Federal funds	6	30
State funds	6	30
Local funds	2	10
Road user taxes	2	10
Private funds	4	20
Capital improvement funds	4	20
Highway improvement/ development funds	2	10
Spot safety/hazard elimination funds	1	5
No response	1	5

Cities under 100,000:

	Number of Responses	%
Normal roadway construction funds	3	27
Federal funds	2	18
State funds	3	27
Local funds	2	18
Private funds	1	9
Tax increment finance district	1	
Capital improvement funds	6	54
No response	2	18

Cities 100,000-150,000:

	Number of Responses	%
Normal roadway construction funds	2	20
Local funds	1	10
Capital improvement funds	4	40
Intersection improvement funds	1	10
No response	2	20

Summary of Survey Results (Con't)

Cities 150,000-500,000:

	Number of Responses	%
Normal roadway construction funds	2	20
Federal funds	1	10
State funds	2	10
Local funds	1	10
Private funds	2	20
Capital improvement funds	9	90

Cities over 500,000:

	Number of Responses	%
Normal roadway construction funds	1	14
Federal funds	1	14
State funds	1	14
Capital improvement funds	4	57
Special funds: TSI, HES, TDA	1	14
Facilities benefit assessments	2	29
Gas tax/sales tax	1	14

12. Are you aware of other warrants or guidelines used by other agencies for the installation of median or refuge islands? If so, who could we contact to obtain this information?

	Yes	No	No Response
States	0	19(95%)	1(5%)
Cities:			
0-100,000	1(9%)	8(72%)	2(18%)
100,000-150,000	1(10%)	8(80%)	1(10%)
150,000-500,000	1(10%)	7(70%)	2(20%)
500,000 and over	1(14%)	6(86%)	0

13. Have you conducted any research or operational studies to determine the effectiveness of median or refuge islands in improving pedestrian safety? Do you know any other agencies that have? (If yes, please provide a copy).

	Yes	No	No Response
States	1(5%)	19(95%)	0
Cities:			
0-100,000	0	10(90%)	1(9%)
100,000-150,000	0	9(90%)	1(10%)
150,000-500,000	0	8(80%)	0
500,000 and over	3(43%)	4(57%)	0

14. Have you conducted any research or operational studies to determine appropriate design specifications for medians or refuge islands? Do you know any other agencies that have?

	Yes	No	No Response
States	1(5%)	19(95%)	0
Cities:			
0-100,000	1(9%)	9(81%)	1(9%)
100,000-150,000	0	9(90%)	1(10%)
150,000-500,000	2(20%)	5(50%)	3(30%)
500,000 and over	0	7(100%)	0

15. Do you consider flat medians (such as continuous left turns lanes) effective in increasing vehicle and pedestrian safety?

	Yes	No	No Response
States	11(55%)	3(15%)	6(30%)
Cities:			
0-100,000	4(36%)	5(45%)	2(18%)

100,000-150,000	6(60%)	2(20%)	2(20%)
150,000-500,000	7(70%)	3(30%)	0
500,000 and over	2(29%)	5(71%)	0

16. Does your jurisdiction have over 20 medians and/or refuge island locations with relatively high vehicle and pedestrian volumes?

	Yes	No	No Response
States	13(65%)	5(25%)	2(10%)
Cities:			
0-100,000	1(9%)	8(72%)	2(18%)
100,000-150,000	4(40%)	5(50%)	0
150,000-500,000	8(80%)	2(20%)	0
500,000 and over	5(71%)	2(29%)	0

APPENDIX B
LIST OF DATA USED IN VEHICLE AND PEDESTRIAN DATA BASES

VEHICLE ACCIDENT DATABASE

I. VARIABLE DESCRIPTION

```
cityid   = city id
accid    = accident number
accdate  = accident date
acctime  = accident time
accday   = day of week
routeid  = route id
xroad1   = 1st cross road
xroad2   = 2nd cross road
nveh     = number of vehicles involved
acctype  = type of accident
severity = severity
ninjured = number of injuries
nfatal   = number of fatalities
vehtype1 = type of vehicle 1
vehroad1 = road on which vehicle 1 was traveling
vehdir1  = direction of vehicle 1
vehmov1  = maneuver of vehicle 1
vehtype2 = type of vehicle 2
vehroad2 = road on which vehicle 2 was traveling
vehdir2  = direction of vehicle 2
vehmov2  = maneuver of vehicle 2
vehalc1  = if driver 1 was drunk driving or not
vehact1  = contributing factor of vehicle 1
vehalc2  = if driver 2 was drunk driving or not
vehact2  = contributing factor of vehicle 2
roadcon  = road surface condition
lightcon = light condition
```

II. DATA FORMAT

```
cityid    1 = atlanta
          2 = phoenix
          3 = los angles
          4 = pasadena
istype    0 = midblock
          1 = intersection
accday    1 = sunday
          2 = monday
          3 = tuesday
          4 = wednesday
          5 = thursday
          6 = friday
          7 = saturday
acctype   1 = rear-end
          2 = right-angle
          3 = sideswipe
          4 = head-on
          5 = fixed object
          6 = parked vehicle
          7 = driveway/alley
          8 = overturn
          9 = left-turn
         10 = u-turn
         11 = ran-off
         12 = right turn
         13 = backing
         14 = others
severity  1 = pdo
          2 = injury
          3 = fatal
vehtype1  1 = passenger car
          2 = truck/bus
```

```
          3 = motorcycle
          4 = bicycle
          5 = others
vehroad1  1 = minor road
          2 = major road
vehdir1   1 = n
          2 = s
          3 = e
          4 = w
          5 = nw
          6 = ne
          7 = sw
          8 = se
vehmov1   1 = straight
          2 = stop
          3 = right turn
          4 = left turn
          5 = parked
          6 = overturn
          7 = back
          8 = u-turn
          9 = out of control
         10 = others
         11 = changing lanes
vehact1   1 = none
          2 = speed
          3 = yield r/w
          4 = wrong side
          5 = ran stop
          6 = ran signal
          7 = impr pass
          8 = too close
          9 = impr turn
         10 = impr drive
         11 = others
         12 = unsafe lane change
vehalc1   0 = no
          1 = dui
vehtype2  1 = passenger car
          2 = truck/bus
          3 = motorcycle
          4 = bicycle
          5 = others
vehroad2  1 = minor road
          2 = major road
vehdir2   1 = n
          2 = s
          3 = e
          4 = w
          5 = nw
          6 = ne
          7 = sw
          8 = se
vehmov2   1 = straight
          2 = stop
          3 = right turn
          4 = left turn
          5 = parked
          6 = overturn
          7 = back
          8 = u-turn
          9 = out of control
         10 = others
         11 = changing lanes
```

```
vehact2   1 = none
          2 = speed
          3 = yield r/w
          4 = wrong side
          5 = ran stop
          6 = ran signal
          7 = impr pass
          8 = too close
          9 = impr turn
         10 = impr drive
         11 = others
         12 = unsafe lane change
vehalc2   0 = no
          1 = dui
roadcon   1 = dry
          2 = wet/muddy
          3 = show/ice
          4 = others
lightcon  1 = light
          2 = dark
          3 = dawn/dusk
```

III. DATA INFORMAT

```
cityid    1
accid     3-10
istype    12
accyear   14-15
accmonth  17-18
accdate   20-21
accday    23
acctime   25-28
routeid   30-32
xroad1    34-37
xroad2    39-42
acctype   44-45
severity  47
ninjury   49-50
nfatal    52-53
nveh      55-56
vehtype1  58
vehdir1   60
vehroad1  62
vehmov1   64-65
vehact1   67-68
vehalc1   70
vehtype2  72
vehdir2   74
vehroad2  76
vehmov2   78-79
vehact2   81-82
vehalc2   84
roadcon   86
lightcon  88
```

PEDESTRIAN ACCIDENT DATABASE

I. DATA DESCRIPTION

```
cityid   = city id
accid    = accident number
istype   = midblock/intersection
accyear  = accident year
accmonth = accident month
accdate  = accident date
acctime  = accident time
accday   = day of week
routeid  = route id
xroad1   = 1st cross road
xroad2   = 2nd cross road
nveh     = number of vehicles involved
acctype  = type of accident
severity = severity
ninjury  = number of injuries
nfatal   = number of fatalities
vehtype  = type of vehicle
vehroad  = road on which vehicle was traveling
vehdir   = direction of vehicle
vehmov   = maneuver of vehicle
vehalc   = if driver was drunk driving or not
vehact   = contributing factor of vehicle
pedage   = age group of pedestrian
peddir   = direction of pedestrian
pedroad  = road on which pedestrian was crossing
pedmov   = placement of pedestrian
pedact   = contributing factor of pedestrian
pedalc   = if pedestrian was drunk or not
distint  = distance from entry point
distfar  = distance from far curb
roadcon  = road surface condition
lightcon = light condition
```

II. DATA FORMAT

```
cityid   1 = atlanta
         2 = phoenix
         3 = los angles
         4 = pasadena
istype   0 = midblock
         1 = intersection
accday   1 = sunday
         2 = monday
         3 = tuesday
         4 = wednesday
         5 = thursday
         6 = friday
         7 = saturday
acctype  1 = pedestrian
         2 = bicycle
severity 1 = pdo
         2 = injury
         3 = fatal
vehtype  1 = passenger car
         2 = truck/bus
         3 = motorcycle
         4 = bicycle
         5 = others
vehroad  1 = minor road
         2 = major road
vehdir   1 = n
         2 = s
```

```
          3 = e
          4 = w
          5 = nw
          6 = ne
          7 = sw
          8 = se
vehmov    1 = straight
          2 = stop
          3 = right turn
          4 = left turn
          5 = parked
          6 = overturn
          7 = back
          8 = u-turn
          9 = out of control
         10 = others
         11 = changing lanes
vehact    1 = none
          2 = speed
          3 = yield r/w
          4 = wrong side
          5 = ran stop
          6 = ran signal
          7 = impr pass
          8 = too close
          9 = impr turn
         10 = impr drive
         11 = others
         12 = unsafe lane change
vehalc    0 = no
          1 = dui
pedage    1 = under 14
          2 = 14 to 64
          3 = over 64
          4 = unknown
peddir    1 = n
          2 = s
          3 = e
          4 = w
          5 = nw
          6 = ne
          7 = sw
          8 = se
pedroad   1 = minor road
          2 = major road
pedmov    1 = crossing in x-walk at intx
          2 = crossing in x-walk not at intx
          3 = crossing not in x-walk at intx
          4 = crossing not in x-walk not at intx
          5 = in rdwy
          6 = not in rdwy
          7 = others/unknown
pedact    0 = others
          1 = red violation
          2 = disregarded signal
          3 = did not use x-walk
          4 = failed to yeild row
          5 = walked on wrong side
          6 = inattention
pedalc    0 = no
          1 = dui
roadcon   1 = dry
          2 = wet/muddy
          3 = show/ice
```

```
              4 = others
     lightcon 1 = light
              2 = dark
              3 = dawn/dusk

III.  DATA INFORMAT
      cityid     1
      accid      3-10
      istype    12
      accyear   14-15
      accmonth  17-18
      accdate   20-21
      accday    23
      acctime   25-28
      routeid   30-32
      xroad1    34-37
      xroad2    39-42
      acctype   44-45
      severity  47
      ninjury   49-50
      nfatal    52-53
      nveh      55-56
      vehtype   58
      vehdir    60
      vehroad   62
      vehmov    64-65
      vehact    67-68
      vehalc    70
      pedage    72
      peddir    74
      pedroad   76
      pedmov    78
      pedact    80
      pedalc    82
      distint   84-86
      distfar   88
      roadcon   90
      lightcon  92
```

APPENDIX C
TABLES OF COMPARISONS WITH BOTH PARKER'S AND PARSONSON'S MODELS

median type=twltl

	NACC	NACC1	NACC3
	SUM	SUM	SUM
SEGID			
1	315.33	257.84	322.02
2	295.17	438.22	337.98
3	559.50	474.59	447.44
6	469.83	368.15	644.88
7	182.17	223.53	206.33
10	305.50	215.23	-37.68
11	67.33	59.75	-17.37
12	426.83	436.63	-17.47
13	69.50	59.31	123.04
14	264.17	306.47	402.00
18	77.83	123.21	149.55
19	57.50	71.66	128.38
22	26.17	32.81	26.95
23	73.50	97.54	208.47
24	230.83	188.79	482.50
33	29.60	44.30	182.02
36	13.50	18.02	24.95
40	6.00	8.17	50.72
46	91.40	122.87	155.86
51	91.75	86.52	322.10
52	28.25	20.92	92.13
53	48.75	60.84	297.97
54	8.13	8.22	45.50
55	127.63	106.02	430.36
56	141.50	126.85	746.14

median type=twltl

	RATIO1	RATIO2
	SUM	SUM
SEGID		
1	81.77	102.12
2	148.47	114.50
3	84.82	79.97
6	78.36	137.26
7	122.71	113.27
10	70.45	-12.33
11	88.74	-25.79
12	102.30	-4.09
13	85.33	177.03
14	116.01	152.18
18	158.30	192.14
19	124.63	223.27
22	125.37	102.99
23	132.71	283.63
24	81.78	209.03
33	149.66	614.95
36	133.51	184.81
40	136.12	845.36
46	134.44	170.53
51	94.30	351.06
52	74.06	326.12
53	124.80	611.23
54	101.18	560.01
55	83.07	337.20
56	89.65	527.31

NOTE:

1 = PROJECT MODEL

2 = PARKER'S MODEL

3 = PARSONSON'S MODEL

median type=raised median

	NACC	NACC1	NACC3
	SUM	SUM	SUM
SEGID			
38	8.60	8.13	30.75
39	70.60	92.83	151.36
41	41.60	23.81	121.35
42	4.80	6.77	75.06
43	39.10	67.93	234.77
44	87.80	74.87	327.71
45	8.80	16.11	100.15
47	4.75	7.37	162.37
49	26.50	60.09	374.83
50	2.25	5.59	94.29
57	35.75	16.87	126.44
58	15.75	17.83	86.92

	BETTER	
	ours	parsonson
	N	N
median type		
raised median	28.00	4.00
twlt1	21.00	4.00

median type=raised median

	RATIO1	RATIO2
	SUM	SUM
SEGID		
38	94.50	357.54
39	131.48	214.38
41	57.23	291.70
42	141.02	1563.73
43	173.73	600.43
44	85.27	373.25
45	183.06	1138.06
47	155.21	3418.24
49	226.77	1414.44
50	248.67	4190.51
57	47.20	353.68
58	113.20	551.87
4	190.43	132.26
5	223.41	169.88
8	119.78	229.84
9	85.10	144.32
15	232.84	232.29
16	133.74	173.77
17	128.00	574.13
20	77.55	240.95
21	83.24	272.41
25	59.36	132.95
26	190.23	379.63
27	64.74	266.47
28	66.77	318.53
29	92.18	147.46
30	76.60	126.68
31	61.86	186.58
32	86.51	452.57
34	84.70	322.79
35	193.39	833.12
37	126.12	372.43

--------------------------- median type=raised median ---------------------------

Variable	Mean	Std Error	T	Prob>|T|
DIFF1	23.9225772	13.7751953	1.7366416	0.1017
DIFF2	-52.9480367	18.9289683	-2.7971961	0.0129

--------------------------- median type=twltl ---------------------------

Variable	Mean	Std Error	T	Prob>|T|
DIFF1	-1.9211480	7.4538652	-0.2577385	0.7999
DIFF2	-56.9108483	19.5854439	-2.9057727	0.0103

--------------------------- median type=undivided ---------------------------

Variable	Mean	Std Error	T	Prob>|T|
DIFF1	-1.7165893	3.5409750	-0.4847787	0.6319
DIFF2	-3.3053187	7.4855059	-0.4415625	0.6625

--------------------------- median type=raised median ---------------------------

Variable	Mean	Std Error	T	Prob>|T|
DIFF1	5.6002706	10.0657612	0.5563683	0.5820
DIFF2	104.8573593	12.5604447	8.3482203	0.0001

--------------------------- median type=twltl ---------------------------

Variable	Mean	Std Error	T	Prob>|T|
DIFF1	-2.0483237	9.9927553	-0.2049809	0.8393
DIFF2	69.8847726	40.1437409	1.7408635	0.0945

median type-raised median

SEGID	NACC SUM	NACC1 SUM	NACC2 SUM
1	214.67	408.78	35.23
2	104.33	233.09	33.58
8	31.67	73.73	14.93
9	30.00	27.03	-63.48
10	187.00	250.09	95.28
11	13.67	17.49	26.36
16	27.17	21.07	18.07
17	61.00	50.78	47.82
28	25.80	21.85	14.38
29	6.50	12.57	18.99
34	8.60	8.13	12.61
35	70.60	92.83	38.24
39	8.80	16.11	28.85
57	35.75	16.87	-20.86
59	20.38	9.23	-34.21
60	17.13	8.00	-18.48
61	15.75	17.83	-268.61
4	**214.67**	**408.78**	**283.93**
5	**104.33**	**233.09**	**177.25**
8	**125.17**	**149.93**	**287.68**
9	**490.50**	**417.42**	**707.90**
15	**31.67**	**73.73**	**73.56**
16	**187.00**	**250.09**	**324.95**
17	**13.67**	**17.49**	**78.46**
20	**27.17**	**21.07**	**65.46**
21	**61.00**	**50.78**	**166.17**
25	**415.33**	**246.55**	**552.19**
26	**22.33**	**42.48**	**84.78**
27	**30.50**	**19.74**	**81.27**
28	**30.17**	**20.14**	**96.09**
29	**108.00**	**99.56**	**159.26**
30	**178.33**	**136.60**	**225.92**
31	**75.20**	**46.52**	**140.31**
32	**51.80**	**44.81**	**234.43**
34	**25.80**	**21.85**	**83.28**
35	**6.50**	**12.57**	**54.15**
37	**50.60**	**63.82**	**188.45**

median type-raised median

SEGID	RATIO1 SUM	RATIO2 SUM
1	190.43	16.41
2	223.41	32.18
8	232.84	47.13
9	90.11	-211.61
10	133.74	50.95
11	128.00	192.88
16	77.55	66.51
17	83.24	78.40
28	84.70	55.73
29	193.39	292.18
34	94.50	146.58
35	131.48	54.17
39	183.06	327.85
57	47.20	-58.36
59	45.31	-167.92
60	46.71	-107.93
61	113.20	-1705.47

median type=undivided

SEGID	NACC SUM	NACC1 SUM	NACC2 SUM
49	25.00	18.01	19.85
50	15.00	29.94	45.63
52	12.38	28.71	19.46
53	21.88	47.97	40.71
54	11.00	14.86	19.70
56	11.00	16.13	20.30
58	8.50	5.76	9.66
14	75.00	94.49	29.02
15	232.33	233.28	100.63
19	168.17	104.32	85.11
20	28.67	29.76	-22.29
23	88.33	93.91	92.39
24	248.50	255.39	248.14
25	109.40	89.21	167.63
26	15.60	19.66	24.93
27	91.00	84.20	160.31
31	4.60	5.86	9.72
37	10.60	11.11	24.03
38	8.60	14.79	16.10
41	28.50	25.08	21.10
42	20.75	35.98	32.97
43	28.25	27.91	35.35
44	4.25	10.67	15.77
45	49.63	30.72	18.65
46	40.63	24.31	26.87
47	88.00	47.30	48.02
48	55.50	55.37	57.47

median type=undivided

SEGID	RATIO1 SUM	RATIO2 SUM
49	72.02	79.42
50	199.61	304.20
52	231.99	157.27
53	219.30	186.10
54	135.13	179.11
56	146.63	184.52
58	67.72	113.64
14	125.99	38.70
15	100.41	43.31
19	62.03	50.61
20	103.82	77.74
23	106.31	104.59
24	102.77	99.86
25	81.55	153.22
26	126.05	159.81
27	92.52	176.16
31	127.46	211.38
37	104.81	226.67
38	172.03	187.18
41	87.99	74.03
42	173.38	158.89
43	98.81	125.12
44	250.97	371.17
45	61.90	37.58
46	59.84	66.15
47	53.75	54.56
48	99.77	103.55

median type=twitl

	NACC	NACC1	NACC2
	SUM	SUM	SUM
SEGID			
3	305.50	215.23	93.76
4	67.33	59.75	23.34
5	426.83	436.63	161.55
6	69.50	59.31	37.81
7	264.17	306.47	104.43
12	77.83	123.21	14.37
13	57.50	71.66	40.48
18	26.17	32.81	20.40
21	73.50	97.54	68.07
22	230.83	188.79	144.13
30	13.50	18.02	27.37
32	112.20	100.88	63.18
33	29.40	18.59	18.05
36	6.00	8.17	17.18
40	15.00	12.79	14.43
51	28.25	20.92	-0.96
55	8.13	8.22	-3.44

median type=twitl

	RATIO1	RATIO2
	SUM	SUM
SEGID		
3	70.45	30.69
4	88.74	34.67
5	102.30	37.85
6	85.33	54.41
7	116.01	39.53
12	158.30	18.46
13	124.63	70.40
18	125.37	77.95
21	132.71	92.61
22	81.78	62.44
30	133.51	202.74
32	89.91	56.31
33	63.22	61.38
36	136.12	286.30
40	85.24	96.20
51	74.06	-3.38
55	101.18	-42.36

	BETTER	
	ours	parker
	N	N
median type		
raised median	14.00	3.00
twitl	14.00	3.00
undivided	18.00	9.00

APPENDIX D
MEDIAN ARTERIAL VEHICLE ACCIDENT RATES RESULTING FROM TYPICAL INDEPENDENT VARIABLES

RAISED MEDIAN

OBS	AREA	LANDUSE	SPEED	MDW	NCV	RATEVKH
1	cbd or suburban	residential or business	25	6	4	568
2	cbd or suburban	residential or business	25	6	6	688
3	cbd or suburban	residential or business	25	6	8	834
4	cbd or suburban	residential or business	25	9	4	521
5	cbd or suburban	residential or business	25	9	6	631
6	cbd or suburban	residential or business	25	9	8	768
7	cbd or suburban	residential or business	25	12	4	481
8	cbd or suburban	residential or business	25	12	6	581
9	cbd or suburban	residential or business	25	12	8	703
10	cbd or suburban	residential or business	35	6	4	282
11	cbd or suburban	residential or business	35	6	6	342
12	cbd or suburban	residential or business	35	6	8	414
13	cbd or suburban	residential or business	35	9	4	259
14	cbd or suburban	residential or business	35	9	6	314
15	cbd or suburban	residential or business	35	9	8	381
16	cbd or suburban	residential or business	35	12	4	239
17	cbd or suburban	residential or business	35	12	6	289
18	cbd or suburban	residential or business	35	12	8	351
19	cbd or suburban	residential or business	45	6	4	140
20	cbd or suburban	residential or business	45	6	6	170
21	cbd or suburban	residential or business	45	6	8	206
22	cbd or suburban	residential or business	45	9	4	129
23	cbd or suburban	residential or business	45	9	6	156
24	cbd or suburban	residential or business	45	9	8	189
25	cbd or suburban	residential or business	45	12	4	119
26	cbd or suburban	residential or business	45	12	6	144
27	cbd or suburban	residential or business	45	12	8	174
28	cbd or suburban	residential or business	55	6	4	69
29	cbd or suburban	residential or business	55	6	6	84
30	cbd or suburban	residential or business	55	6	8	102
31	cbd or suburban	residential or business	55	9	4	64
32	cbd or suburban	residential or business	55	9	6	78
33	cbd or suburban	residential or business	55	9	8	94
34	cbd or suburban	residential or business	55	12	4	59
35	cbd or suburban	residential or business	55	12	6	71
36	cbd or suburban	residential or business	55	12	8	86
37	cbd or suburban	office	25	6	4	363
38	cbd or suburban	office	25	6	6	439
39	cbd or suburban	office	25	6	8	533
40	cbd or suburban	office	25	9	4	334
41	cbd or suburban	office	25	9	6	405
42	cbd or suburban	office	25	9	8	490
43	cbd or suburban	office	25	12	4	307
44	cbd or suburban	office	25	12	6	372
45	cbd or suburban	office	25	12	8	451
46	cbd or suburban	office	35	6	4	180
47	cbd or suburban	office	35	6	6	218
48	cbd or suburban	office	35	6	8	264
49	cbd or suburban	office	35	9	4	166
50	cbd or suburban	office	35	9	6	201
51	cbd or suburban	office	35	9	8	243
52	cbd or suburban	office	35	12	4	153
53	cbd or suburban	office	35	12	6	185
54	cbd or suburban	office	35	12	8	224
55	cbd or suburban	office	45	6	4	89
56	cbd or suburban	office	45	6	6	108
57	cbd or suburban	office	45	6	8	131
58	cbd or suburban	office	45	9	4	82
59	cbd or suburban	office	45	9	6	100
60	cbd or suburban	office	45	9	8	121
61	cbd or suburban	office	45	12	4	76
62	cbd or suburban	office	45	12	6	92
63	cbd or suburban	office	45	12	8	[illegible]
64	cbd or suburban	office	55	6	4	44
65	cbd or suburban	office	55	6	6	54
66	cbd or suburban	office	55	6	8	65
67	cbd or suburban	office	55	9	4	41
68	cbd or suburban	office	55	9	6	50
69	cbd or suburban	office	55	9	8	60
70	cbd or suburban	office	55	12	4	38
71	cbd or suburban	office	55	12	6	46
72	cbd or suburban	office	55	12	8	55

TWLT MEDIAN

OBS	AREA	LANDUSE	SPEED	MDW	NXBD	NDWY	RATEVEH
1	cbd or suburban	residential or business	25	10	8	10	431
2	cbd or suburban	residential or business	25	10	8	20	491
3	cbd or suburban	residential or business	25	10	8	30	561
4	cbd or suburban	residential or business	25	10	8	40	639
5	cbd or suburban	residential or business	25	10	8	50	727
6	cbd or suburban	residential or business	25	10	12	10	340
7	cbd or suburban	residential or business	25	10	12	20	387
8	cbd or suburban	residential or business	25	10	12	30	441
9	cbd or suburban	residential or business	25	10	12	40	502
10	cbd or suburban	residential or business	25	10	12	50	571
11	cbd or suburban	residential or business	25	10	16	10	267
12	cbd or suburban	residential or business	25	10	16	20	304
13	cbd or suburban	residential or business	25	10	16	30	346
14	cbd or suburban	residential or business	25	10	16	40	394
15	cbd or suburban	residential or business	25	10	16	50	448
16	cbd or suburban	residential or business	35	10	8	10	309
17	cbd or suburban	residential or business	35	10	8	20	351
18	cbd or suburban	residential or business	35	10	8	30	400
19	cbd or suburban	residential or business	35	10	8	40	455
20	cbd or suburban	residential or business	35	10	8	50	518
21	cbd or suburban	residential or business	35	10	12	10	242
22	cbd or suburban	residential or business	35	10	12	20	276
23	cbd or suburban	residential or business	35	10	12	30	314
24	cbd or suburban	residential or business	35	10	12	40	357
25	cbd or suburban	residential or business	35	10	12	50	407
26	cbd or suburban	residential or business	35	10	16	10	190
27	cbd or suburban	residential or business	35	10	16	20	217
28	cbd or suburban	residential or business	35	10	16	30	246
29	cbd or suburban	residential or business	35	10	16	40	280
30	cbd or suburban	residential or business	35	10	16	50	319
31	cbd or suburban	residential or business	45	10	8	10	220
32	cbd or suburban	residential or business	45	10	8	20	250
33	cbd or suburban	residential or business	45	10	8	30	285
34	cbd or suburban	residential or business	45	10	8	40	324
35	cbd or suburban	residential or business	45	10	8	50	369
36	cbd or suburban	residential or business	45	10	12	10	173
37	cbd or suburban	residential or business	45	10	12	20	197
38	cbd or suburban	residential or business	45	10	12	30	224
39	cbd or suburban	residential or business	45	10	12	40	255
40	cbd or suburban	residential or business	45	10	12	50	290
41	cbd or suburban	residential or business	45	10	16	10	136
42	cbd or suburban	residential or business	45	10	16	20	154
43	cbd or suburban	residential or business	45	10	16	30	176
44	cbd or suburban	residential or business	45	10	16	40	200
45	cbd or suburban	residential or business	45	10	16	50	227
46	cbd or suburban	residential or business	55	10	8	10	157
47	cbd or suburban	residential or business	55	10	8	20	178
48	cbd or suburban	residential or business	55	10	8	30	203
49	cbd or suburban	residential or business	55	10	8	40	231
50	cbd or suburban	residential or business	55	10	8	50	263
51	cbd or suburban	residential or business	55	10	12	10	123
52	cbd or suburban	residential or business	55	10	12	20	140
53	cbd or suburban	residential or business	55	10	12	30	159
54	cbd or suburban	residential or business	55	10	12	40	181
55	cbd or suburban	residential or business	55	10	12	50	207
56	cbd or suburban	residential or business	55	10	16	10	97
57	cbd or suburban	residential or business	55	10	16	20	110
58	cbd or suburban	residential or business	55	10	16	30	125
59	cbd or suburban	residential or business	55	10	16	40	142
60	cbd or suburban	residential or business	55	10	16	50	162
61	cbd or suburban	residential or business	25	12	8	10	465
62	cbd or suburban	residential or business	25	12	8	20	530
63	cbd or suburban	residential or business	25	12	8	30	603
64	cbd or suburban	residential or business	25	12	8	40	686
65	cbd or suburban	residential or business	25	12	8	50	781
66	cbd or suburban	residential or business	25	12	12	10	365
67	cbd or suburban	residential or business	25	12	12	20	416
68	cbd or suburban	residential or business	25	12	12	30	471
69	cbd or suburban	residential or business	25	12	12	40	538
70	cbd or suburban	residential or business	25	12	12	50	613
71	cbd or suburban	residential or business	25	12	16	10	287
72	cbd or suburban	residential or business	25	12	16	20	326
73	cbd or suburban	residential or business	25	12	16	30	371
74	cbd or suburban	residential or business	25	12	16	40	423
75	cbd or suburban	residential or business	25	12	16	50	481
76	cbd or suburban	residential or business	35	12	8	10	332
77	cbd or suburban	residential or business	35	12	8	20	377
78	cbd or suburban	residential or business	35	12	8	30	429
79	cbd or suburban	residential or business	35	12	8	40	489
80	cbd or suburban	residential or business	35	12	8	50	556
81	cbd or suburban	residential or business	35	12	12	10	260
82	cbd or suburban	residential or business	35	12	12	20	296
83	cbd or suburban	residential or business	35	12	12	30	337
84	cbd or suburban	residential or business	35	12	12	40	384
85	cbd or suburban	residential or business	35	12	12	50	437
86	cbd or suburban	residential or business	35	12	16	10	204
87	cbd or suburban	residential or business	35	12	16	20	232
88	cbd or suburban	residential or business	35	12	16	30	265
89	cbd or suburban	residential or business	35	12	16	40	301
90	cbd or suburban	residential or business	35	12	16	50	343

OBS	AREA	LANDUSE	SPEED	MDW	NXRD	NDWY	RATEVEH
91	cbd or suburban	residential or business	45	12	8	10	236
92	cbd or suburban	residential or business	45	12	8	20	269
93	cbd or suburban	residential or business	45	12	8	30	306
94	cbd or suburban	residential or business	45	12	8	40	348
95	cbd or suburban	residential or business	45	12	8	50	396
96	cbd or suburban	residential or business	45	12	12	10	185
97	cbd or suburban	residential or business	45	12	12	20	211
98	cbd or suburban	residential or business	45	12	12	30	240
99	cbd or suburban	residential or business	45	12	12	40	273
100	cbd or suburban	residential or business	45	12	12	50	311
101	cbd or suburban	residential or business	45	12	16	10	146
102	cbd or suburban	residential or business	45	12	16	20	166
103	cbd or suburban	residential or business	45	12	16	30	188
104	cbd or suburban	residential or business	45	12	16	40	215
105	cbd or suburban	residential or business	45	12	16	50	244
106	cbd or suburban	residential or business	55	12	8	10	168
107	cbd or suburban	residential or business	55	12	8	20	192
108	cbd or suburban	residential or business	55	12	8	30	218
109	cbd or suburban	residential or business	55	12	8	40	248
110	cbd or suburban	residential or business	55	12	8	50	282
111	cbd or suburban	residential or business	55	12	12	10	132
112	cbd or suburban	residential or business	55	12	12	20	150
113	cbd or suburban	residential or business	55	12	12	30	171
114	cbd or suburban	residential or business	55	12	12	40	195
115	cbd or suburban	residential or business	55	12	12	50	222
116	cbd or suburban	residential or business	55	12	16	10	104
117	cbd or suburban	residential or business	55	12	16	20	118
118	cbd or suburban	residential or business	55	12	16	30	134
119	cbd or suburban	residential or business	55	12	16	40	153
120	cbd or suburban	residential or business	55	12	16	50	174
121	cbd or suburban	residential or business	25	14	8	10	499
122	cbd or suburban	residential or business	25	14	8	20	568
123	cbd or suburban	residential or business	25	14	8	30	647
124	cbd or suburban	residential or business	25	14	8	40	736
125	cbd or suburban	residential or business	25	14	8	50	838
126	cbd or suburban	residential or business	25	14	12	10	392
127	cbd or suburban	residential or business	25	14	12	20	446
128	cbd or suburban	residential or business	25	14	12	30	508
129	cbd or suburban	residential or business	25	14	12	40	578
130	cbd or suburban	residential or business	25	14	12	50	658
131	cbd or suburban	residential or business	25	14	16	10	308
132	cbd or suburban	residential or business	25	14	16	20	350
133	cbd or suburban	residential or business	25	14	16	30	399
134	cbd or suburban	residential or business	25	14	16	40	454
135	cbd or suburban	residential or business	25	14	16	50	516
136	cbd or suburban	residential or business	35	14	8	10	356
137	cbd or suburban	residential or business	35	14	8	20	405
138	cbd or suburban	residential or business	35	14	8	30	461
139	cbd or suburban	residential or business	35	14	8	40	525
140	cbd or suburban	residential or business	35	14	8	50	597
141	cbd or suburban	residential or business	35	14	12	10	279
142	cbd or suburban	residential or business	35	14	12	20	318
143	cbd or suburban	residential or business	35	14	12	30	362
144	cbd or suburban	residential or business	35	14	12	40	412
145	cbd or suburban	residential or business	35	14	12	50	469
146	cbd or suburban	residential or business	35	14	16	10	219
147	cbd or suburban	residential or business	35	14	16	20	249
148	cbd or suburban	residential or business	35	14	16	30	284
149	cbd or suburban	residential or business	35	14	16	40	323
150	cbd or suburban	residential or business	35	14	16	50	368
151	cbd or suburban	residential or business	45	14	8	10	254
152	cbd or suburban	residential or business	45	14	8	20	289
153	cbd or suburban	residential or business	45	14	8	30	328
154	cbd or suburban	residential or business	45	14	8	40	374
155	cbd or suburban	residential or business	45	14	8	50	426
156	cbd or suburban	residential or business	45	14	12	10	199
157	cbd or suburban	residential or business	45	14	12	20	227
158	cbd or suburban	residential or business	45	14	12	30	258
159	cbd or suburban	residential or business	45	14	12	40	293
160	cbd or suburban	residential or business	45	14	12	50	334
161	cbd or suburban	residential or business	45	14	16	10	156
162	cbd or suburban	residential or business	45	14	16	20	178
163	cbd or suburban	residential or business	45	14	16	30	202
164	cbd or suburban	residential or business	45	14	16	40	230
165	cbd or suburban	residential or business	45	14	16	50	262
166	cbd or suburban	residential or business	55	14	8	10	181
167	cbd or suburban	residential or business	55	14	8	20	206
168	cbd or suburban	residential or business	55	14	8	30	234
169	cbd or suburban	residential or business	55	14	8	40	266
170	cbd or suburban	residential or business	55	14	8	50	303
171	cbd or suburban	residential or business	55	14	12	10	142
172	cbd or suburban	residential or business	55	14	12	20	161
173	cbd or suburban	residential or business	55	14	12	30	184
174	cbd or suburban	residential or business	55	14	12	40	209
175	cbd or suburban	residential or business	55	14	12	50	238
176	cbd or suburban	residential or business	55	14	16	10	111
177	cbd or suburban	residential or business	55	14	16	20	127
178	cbd or suburban	residential or business	55	14	16	30	144
179	cbd or suburban	residential or business	55	14	16	40	164
180	cbd or suburban	residential or business	55	14	16	50	187

OBS	AREA	LANDUSE	SPEED	MDW	NXRD	NDWY	RATEVEH
181	cbd or suburban	office	25	10	8	10	466
182	cbd or suburban	office	25	10	8	20	530
183	cbd or suburban	office	25	10	8	30	604
184	cbd or suburban	office	25	10	8	40	687
185	cbd or suburban	office	25	10	8	50	782
186	cbd or suburban	office	25	10	12	10	366
187	cbd or suburban	office	25	10	12	20	416
188	cbd or suburban	office	25	10	12	30	474
189	cbd or suburban	office	25	10	12	40	539
190	cbd or suburban	office	25	10	12	50	614
191	cbd or suburban	office	25	10	16	10	287
192	cbd or suburban	office	25	10	16	20	327
193	cbd or suburban	office	25	10	16	30	372
194	cbd or suburban	office	25	10	16	40	423
195	cbd or suburban	office	25	10	16	50	482
196	cbd or suburban	office	35	10	8	10	332
197	cbd or suburban	office	35	10	8	20	378
198	cbd or suburban	office	35	10	8	30	430
199	cbd or suburban	office	35	10	8	40	489
200	cbd or suburban	office	35	10	8	50	557
201	cbd or suburban	office	35	10	12	10	261
202	cbd or suburban	office	35	10	12	20	297
203	cbd or suburban	office	35	10	12	30	338
204	cbd or suburban	office	35	10	12	40	384
205	cbd or suburban	office	35	10	12	50	437
206	cbd or suburban	office	35	10	16	10	204
207	cbd or suburban	office	35	10	16	20	233
208	cbd or suburban	office	35	10	16	30	265
209	cbd or suburban	office	35	10	16	40	302
210	cbd or suburban	office	35	10	16	50	343
211	cbd or suburban	office	45	10	8	10	237
212	cbd or suburban	office	45	10	8	20	269
213	cbd or suburban	office	45	10	8	30	306
214	cbd or suburban	office	45	10	8	40	349
215	cbd or suburban	office	45	10	8	50	397
216	cbd or suburban	office	45	10	12	10	186
217	cbd or suburban	office	45	10	12	20	211
218	cbd or suburban	office	45	10	12	30	241
219	cbd or suburban	office	45	10	12	40	274
220	cbd or suburban	office	45	10	12	50	312
221	cbd or suburban	office	45	10	16	10	146
222	cbd or suburban	office	45	10	16	20	166
223	cbd or suburban	office	45	10	16	30	189
224	cbd or suburban	office	45	10	16	40	215
225	cbd or suburban	office	45	10	16	50	245
226	cbd or suburban	office	55	10	8	10	169
227	cbd or suburban	office	55	10	8	20	192
228	cbd or suburban	office	55	10	8	30	218
229	cbd or suburban	office	55	10	8	40	249
230	cbd or suburban	office	55	10	8	50	283
231	cbd or suburban	office	55	10	12	10	132
232	cbd or suburban	office	55	10	12	20	151
233	cbd or suburban	office	55	10	12	30	171
234	cbd or suburban	office	55	10	12	40	195
235	cbd or suburban	office	55	10	12	50	222
236	cbd or suburban	office	55	10	16	10	104
237	cbd or suburban	office	55	10	16	20	118
238	cbd or suburban	office	55	10	16	30	135
239	cbd or suburban	office	55	10	16	40	153
240	cbd or suburban	office	55	10	16	50	174
241	cbd or suburban	office	25	12	8	10	500
242	cbd or suburban	office	25	12	8	20	569
243	cbd or suburban	office	25	12	8	30	648
244	cbd or suburban	office	25	12	8	40	737
245	cbd or suburban	office	25	12	8	50	839
246	cbd or suburban	office	25	12	12	10	392
247	cbd or suburban	office	25	12	12	20	447
248	cbd or suburban	office	25	12	12	30	508
249	cbd or suburban	office	25	12	12	40	579
250	cbd or suburban	office	25	12	12	50	659
251	cbd or suburban	office	25	12	16	10	308
252	cbd or suburban	office	25	12	16	20	351
253	cbd or suburban	office	25	12	16	30	399
254	cbd or suburban	office	25	12	16	40	454
255	cbd or suburban	office	25	12	16	50	517
256	cbd or suburban	office	35	12	8	10	356
257	cbd or suburban	office	35	12	8	20	406
258	cbd or suburban	office	35	12	8	30	462
259	cbd or suburban	office	35	12	8	40	525
260	cbd or suburban	office	35	12	8	50	598
261	cbd or suburban	office	35	12	12	10	280
262	cbd or suburban	office	35	12	12	20	318
263	cbd or suburban	office	35	12	12	30	362
264	cbd or suburban	office	35	12	12	40	412
265	cbd or suburban	office	35	12	12	50	469
266	cbd or suburban	office	35	12	16	10	220
267	cbd or suburban	office	35	12	16	20	250
268	cbd or suburban	office	35	12	16	30	284
269	cbd or suburban	office	35	12	16	40	324
270	cbd or suburban	office	35	12	16	50	368

OBS	AREA	LANDUSE	SPEED	MDW	NXRD	HDWY	RATEVEH
271	cbd or suburban	office	45	12	8	10	254
272	cbd or suburban	office	45	12	8	20	289
273	cbd or suburban	office	45	12	8	30	329
274	cbd or suburban	office	45	12	8	40	374
275	cbd or suburban	office	45	12	8	50	426
276	cbd or suburban	office	45	12	12	10	199
277	cbd or suburban	office	45	12	12	20	227
278	cbd or suburban	office	45	12	12	30	258
279	cbd or suburban	office	45	12	12	40	294
280	cbd or suburban	office	45	12	12	50	334
281	cbd or suburban	office	45	12	16	10	156
282	cbd or suburban	office	45	12	16	20	178
283	cbd or suburban	office	45	12	16	30	203
284	cbd or suburban	office	45	12	16	40	231
285	cbd or suburban	office	45	12	16	50	262
286	cbd or suburban	office	55	12	8	10	181
287	cbd or suburban	office	55	12	8	20	206
288	cbd or suburban	office	55	12	8	30	234
289	cbd or suburban	office	55	12	8	40	267
290	cbd or suburban	office	55	12	8	50	304
291	cbd or suburban	office	55	12	12	10	142
292	cbd or suburban	office	55	12	12	20	162
293	cbd or suburban	office	55	12	12	30	184
294	cbd or suburban	office	55	12	12	40	209
295	cbd or suburban	office	55	12	12	50	238
296	cbd or suburban	office	55	12	16	10	111
297	cbd or suburban	office	55	12	16	20	127
298	cbd or suburban	office	55	12	16	30	144
299	cbd or suburban	office	55	12	16	40	164
300	cbd or suburban	office	55	12	16	50	187
301	cbd or suburban	office	25	14	8	10	537
302	cbd or suburban	office	25	14	8	20	611
303	cbd or suburban	office	25	14	8	30	695
304	cbd or suburban	office	25	14	8	40	792
305	cbd or suburban	office	25	14	8	50	901
306	cbd or suburban	office	25	14	12	10	421
307	cbd or suburban	office	25	14	12	20	480
308	cbd or suburban	office	25	14	12	30	546
309	cbd or suburban	office	25	14	12	40	621
310	cbd or suburban	office	25	14	12	50	707
311	cbd or suburban	office	25	14	16	10	331
312	cbd or suburban	office	25	14	16	20	376
313	cbd or suburban	office	25	14	16	30	428
314	cbd or suburban	office	25	14	16	40	488
315	cbd or suburban	office	25	14	16	50	555
316	cbd or suburban	office	35	14	8	10	383
317	cbd or suburban	office	35	14	8	20	435
318	cbd or suburban	office	35	14	8	30	496
319	cbd or suburban	office	35	14	8	40	564
320	cbd or suburban	office	35	14	8	50	642
321	cbd or suburban	office	35	14	12	10	300
322	cbd or suburban	office	35	14	12	20	342
323	cbd or suburban	office	35	14	12	30	389
324	cbd or suburban	office	35	14	12	40	443
325	cbd or suburban	office	35	14	12	50	504
326	cbd or suburban	office	35	14	16	10	236
327	cbd or suburban	office	35	14	16	20	268
328	cbd or suburban	office	35	14	16	30	305
329	cbd or suburban	office	35	14	16	40	347
330	cbd or suburban	office	35	14	16	50	395
331	cbd or suburban	office	45	14	8	10	273
332	cbd or suburban	office	45	14	8	20	310
333	cbd or suburban	office	45	14	8	30	353
334	cbd or suburban	office	45	14	8	40	402
335	cbd or suburban	office	45	14	8	50	457
336	cbd or suburban	office	45	14	12	10	214
337	cbd or suburban	office	45	14	12	20	243
338	cbd or suburban	office	45	14	12	30	277
339	cbd or suburban	office	45	14	12	40	315
340	cbd or suburban	office	45	14	12	50	359
341	cbd or suburban	office	45	14	16	10	168
342	cbd or suburban	office	45	14	16	20	191
343	cbd or suburban	office	45	14	16	30	218
344	cbd or suburban	office	45	14	16	40	248
345	cbd or suburban	office	45	14	16	50	282
346	cbd or suburban	office	55	14	8	10	194
347	cbd or suburban	office	55	14	8	20	221
348	cbd or suburban	office	55	14	8	30	252
349	cbd or suburban	office	55	14	8	40	286
350	cbd or suburban	office	55	14	8	50	326
351	cbd or suburban	office	55	14	12	10	152
352	cbd or suburban	office	55	14	12	20	174
353	cbd or suburban	office	55	14	12	30	197
354	cbd or suburban	office	55	14	12	40	225
355	cbd or suburban	office	55	14	12	50	256
356	cbd or suburban	office	55	14	16	10	120
357	cbd or suburban	office	55	14	16	20	136
358	cbd or suburban	office	55	14	16	30	155
359	cbd or suburban	office	55	14	16	40	176
360	cbd or suburban	office	55	14	16	50	201

UNDIVIDED

OBS	AREA	LANDUSE	NDWY	RATEVEH
1	suburban	residential	10	165
2	suburban	residential	20	188
3	suburban	residential	30	215
4	suburban	residential	40	245
5	suburban	residential	50	280
6	suburban	office	10	478
7	suburban	office	20	546
8	suburban	office	30	623
9	suburban	office	40	711
10	suburban	office	50	812
11	suburban	business	10	318
12	suburban	business	20	363
13	suburban	business	30	415
14	suburban	business	40	473
15	suburban	business	50	540
16	cbd	residential	10	260
17	cbd	residential	20	297
18	cbd	residential	30	339
19	cbd	residential	40	387
20	cbd	residential	50	442
21	cbd	office	10	754
22	cbd	office	20	861
23	cbd	office	30	983
24	cbd	office	40	1122
25	cbd	office	50	1281
26	cbd	business	10	502
27	cbd	business	20	573
28	cbd	business	30	655
29	cbd	business	40	747
30	cbd	business	50	853

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