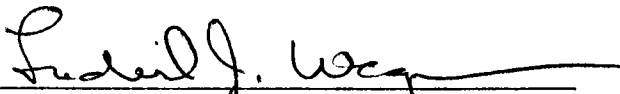
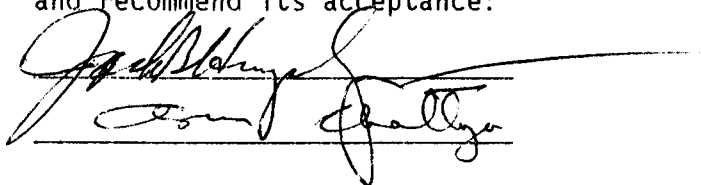


To the Graduate Council:

I am submitting herewith a thesis written by Nicholas Joseph Fortey entitled "An Analysis of the Effect of a Pedestrian Signal Upon Pedestrian Behavior at a Given Intersection." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.


Frederick J. Wegmann, Major Professor

We have read this thesis
and recommend its acceptance:



Accepted for the Council:


Vice Provost
and Dean of The Graduate School

AN ANALYSIS OF THE EFFECT OF A PEDESTRIAN SIGNAL UPON
PEDESTRIAN BEHAVIOR AT A GIVEN INTERSECTION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Nicholas J. Fortey

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ABSTRACT

This research studied pedestrian behavior at an intersection equipped with pedestrian signals and at the same intersection without pedestrian signals. Two video cameras were used to record the behavior of pedestrians engaged in a crossing maneuver at two marked crosswalks at the intersection.

Several hypotheses were prepared and tested in a statistical fashion. An analysis was performed to determine if the proportion of illegal crossing maneuvers increased in the absence of a pedestrian signal. The results indicated that the proportion of illegal crossing maneuvers did not increase. Furthermore, results indicated that looking behavior was not significantly affected by the presence of pedestrian signals. In addition, the mean wait time, and mean walk times of pedestrians were not affected by the presence of pedestrian signals.

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CHAPTER I

INTRODUCTION

General Remarks

It is readily apparent from even the most cursory examination of accident statistics that a pedestrian safety problem exists. An analysis of National Safety Council accident statistics clearly shows that the percentage of pedestrian fatalities has remained constant for some time, and for 1985 accounted for approximately 16% of all highway-related deaths (FHWA, p. 2). A further analysis of accident data may prove to be of interest in attempting to understand both the nature and the magnitude of the pedestrian safety problem. Although children represented only 14% of the total population, they accounted for nearly 30% of all pedestrian accidents (FHWA, p.3). Additionally, although adults 35 and over had a lower percentage of accidents when compared to their population distribution, adults 65 and over were overrepresented. Furthermore, pedestrian accidents and fatalities were concentrated in urban areas. An analysis of accidents in urban areas revealed that over 40% of pedestrian accidents occurred in the crosswalk, while over 50% of pedestrian accidents occurred at some other location on the roadway (FHWA, p. 7).

In spite of the clarity of the pedestrian safety problem, there appears to be a lack of interest or concern with the problem, especially in comparison to highway safety (FHWA, p. 1):

Highway safety from the viewpoint of the pedestrian, on the other hand, is rarely a topic of great or continuing interest. Why is this? Most if not all of us are pedestrians

daily, for at least part of our travel. Except for collisions with another motor vehicle, pedestrians are the most frequently struck object in fatal traffic accidents. Despite the magnitude of the problem, too often pedestrian safety is viewed as the individual's responsibility, correctable if one were just "more careful". Yet there are many actions that can be taken by traffic engineers, city administrators, highway designers, public agencies, etc. which can considerably improve the environment within which the individual pedestrian must act . . .

The majority of motorists (whose directional movement is confined, but at a fast pace) have been trained and tested, and are obligated to operate vehicles in a legal manner while observing the "rules of the road" and traffic control devices. However, pedestrians--who cover a wide range of ages and physical abilities (and who have relative directional freedom but a slow pace)--are not well trained. Many may not be physically and/or psychologically able to cope with the pedestrian environment and facilities provided. The challenges faced by the pedestrian must be realized and programs to reduce these challenges implemented if significant reductions in pedestrian conflicts and accidents are going to be made.

There appears to be a need to provide a safer environment for pedestrians. In addition to the need to consider pedestrian accidents, the study of pedestrian behavior can also yield important results which not only bear on pedestrian safety concerns but transcend these boundaries and impact on other areas--areas in which the results from a behavioral study may be more fruitful (Hill, pp. 1-3):

First, the deceptive simplicity of the pedestrian experience provides an excellent empirical focus for examination of a wide range of topics prominent in recent work in the emerging field of human environment studies. . . . [Second, the] very ubiquity of pedestrians presents researchers with a wonderful opportunity to observe a cross section of normal individuals engaged in normal routines in everyday, normally experienced environments. . . While the control possible in an experimental laboratory is lost when observations are made in the undisturbed, natural environment, it is this everyday, ordinary environment to which the human-environment relations researchers ultimately wishes to be relevant. This argument is not offered to denigrate the insightful research suggestions that have sometimes issued from laboratory research, but merely to emphasize that to be

useful in applied design work, the concepts of human-environment relations must be interpretable in everyday settings.

It is within this context that the present research takes place. Although neither safety nor individual behavior are the *raison d'etre* of this study, both form the framework of the study design. This study, then, is designed to analyze and evaluate the behavior of pedestrians at a signalized crosswalk in an effort to increase the safety of the crossing maneuver and to provide information regarding human behavior, specifically pedestrian behavior.

As has been previously stated, the majority of pedestrian accidents and fatalities occur in urbanized areas. Furthermore, a rather large percentage of pedestrian accidents occur in crosswalks. Pedestrian signals have often been used in an effort to reduce pedestrian-vehicular conflicts at an intersection. The Manual of Uniform Traffic Control Devices (MUTCD) allows pedestrian signals to be installed in the following circumstances (MUTCD, pp. 4D-1-4D-2):

1. When a traffic signal is installed under the pedestrian Volume or School Crossing warrant.
2. When an exclusive interval or phase is provided or made available for pedestrian movements in one or more directions, with all conflicting vehicular movements being stopped.
3. When vehicular indications are not visible to pedestrians such as one one-way streets, at "T" intersections; or when the vehicular indications are in a position which would not adequately serve pedestrians.
4. At established school crossings at intersections signalized under any warrant.

Pedestrian signal indications may also be installed under any of the following conditions (MUTCD, p. 4D-1):

1. When any volume of pedestrian activity requires use of a pedestrian clearance interval to minimize vehicle-pedestrian conflicts or when it is necessary to assist pedestrians in making a safe crossing.
2. When multi-phase indications (as with split-phase timing) would tend to confuse pedestrians guided only by vehicle signal indications.
3. When pedestrians cross part of the street, to or from an island, during a particular interval (where they should not be premitted to cross another part of that street during any part of the same interval).

The MUTCD also state the signal timings that can be used for pedestrian signals (MUTCD, p. 4D-5):

1. Combined Pedestrian-Vehicular Interval--a signal phasing wherein pedestrians may use certain crosswalks and vehicles are permitted to turn across these crosswalks (the pedestrian indication shall be flashing WALK or steady WALK).
2. Exclusive Crosswalk Interval--a signal phasing wherein pedestrians may use certain crosswalks but vehicles are not permitted to move across these crosswalks during the pedestrian movement (the pedestrian indication shall be steady WALK).
3. Leading Pedestrian Interval--a signal phasing wherein an exclusive pedestrian interval, in advance of the vehicular indication shall be steady WALK. When the leading pedestrian interval is terminated, and a combined pedestrian-vehicular interval begins, the WALK indication may begin to flash.
4. Exclusive Pedestrian Phase--a signal phasing wherein pedestrians may proceed to cross the intersection in any direction during an exclusive phase while all vehicles are stopped (the pedestrian indication shall be steady WALK).

Pedestrian signals should affect safety, operations, and the behavior of both vehicles and pedestrians at an intersection. In most cases, the effectiveness of a pedestrian signal or other counter measure has been gauged by the reduction in the number, type, or severity of accidents at the intersection. Analysis based solely on

accident data can be misleading, due to the wide variety of variables which come into play and due to the nature of accidents themselves--random events. Indeed, except at extremely busy intersections, there would probably be so few pedestrian accidents that a statistical treatment and analysis could not be performed.

Pedestrian signals are not provided without cost. The question concerns the cost of the signal system compared to the benefits received. This research seeks to examine and quantify these benefits, if any exist, and to indicate whether funds, could perhaps be better allocated to more worthwhile (in terms of safety benefits) traffic control or safety schemes.

Signalization is used to control, guide, and regulate vehicular and/or pedestrian traffic. Traffic signals are the predominant fixtures of urban intersections, and although they primarily provide for vehicular traffic control, they also serve to guide pedestrian traffic. Pedestrian signals function as an adjunct to traffic signals and are provided expressly for pedestrian traffic. This research is aimed toward a behavioral study and evaluation of pedestrian use of crosswalks in an urban area. A study was made at single intersection and pedestrian behavior with only a traffic signal for pedestrian guidance and pedestrian behavior with both the signal and pedestrian signals was recorded and analyzed. Such an analysis was designed to yield not only information concerning pedestrian behavior but to also yield clues toward increasing safety at urbanized intersections.

Study Objectives

As previously stated, the aim of this study was to conduct a behavioral analysis of pedestrian crossings. Specifically, the research focused on the behavior of pedestrians at a signalized intersection without pedestrian signals and the behavior at the same signalized intersection with pedestrian signals. In order to more fully understand pedestrian behavior and, in the process, to gain information on the safety of pedestrian crossing behavior, the following questions were raised as a means of directing the research effort:

1. How is the pedestrian's decision to cross affected by the presence or absence of a pedestrian signal?
2. How is the average delay affected by the presence or absence of a pedestrian signal?
3. What factors influence the decision to cross with the signal or not with the signal?
4. How is looking behavior affected by the presence or absence of a pedestrian signal?
5. How are pedestrian-vehicular conflicts related to the presence or absence of a pedestrian signal?

Limitations

At the outset of this research effort, after the study objectives had been formalized it was recognized that certain limitations would exist in the research methodology. In an effort to define these limitations and to provide a further structuring of the research the following list is presented:

1. Limitations on road crossings observed. This research focused on one intersection in which two crossings (major and minor streets) were analyzed. Due to camera location limitations and owing to limitations on the amount of data which could be analyzed, these were the only crossings studied.
2. Limitations on the number and type of pedestrians observed. A total of 368 pedestrians were observed for the entire study. One hundred and seventy-five pedestrians were observed in the before case, with 45 of them having crossed Cumberland Avenue and 130 of them having crossed Seventeenth Street. One hundred and ninety-three pedestrians were observed in the after case, with 64 having crossed Cumberland Avenue and 129 having crossed Seventeenth Street. In addition, due to the location of the intersection adjacent to a major college campus, most of the pedestrians were in their early to mid twenties.
3. Limitations on time periods observed. Pedestrians were observed between 9:00 A.M. and 3:00 P.M. which coincided with the duration of the 90 second cycle for the intersection. This was an intentional decision as it was desired to conduct the analysis for one cycle length so as to minimize affects on behavior which may have been created by cycle variations. Also, not all days of the week were analyzed. Efforts were made to

analyze the same days--Monday, Tuesday, and Wednesday--
in both the before and after case to minimize the
effects on behavior.

This is but a set of initial limitations which became apparent after the study objectives had been outlined. A more comprehensive list of limitations was drawn following the data analysis portion of this research and is presented therein.

Before conducting a research effort, it is necessary to examine previous research conducted in the area so as to gain an insight into the subject. Such a review aided this study by providing information on various research methodologies in addition to the results and conclusions obtained on pedestrian behavior.

CHAPTER II

LITERATURE REVIEW

A review of the current literature reveals that there have been a number of studies conducted concerning the behavior of pedestrians. A veritable field of questions awaits the pedestrian researcher, who can reap a bountiful harvest. Of particular interest for this research is the behavioral aspect of the road crossing task. The current research sought to examine pedestrian behavior by first examining research that had been conducted in the area, so as to use that as a springboard for further research and analysis. As there was a wide variety of research concerning pedestrian behavior, it was of value to divide the various studies into certain categories according to the main thrust of the research effort. To this end, studies were be examined with regard to study methodology, pedestrian crossing behavior, and pedestrian-vehicular interactions.

Studies Concerning Pedestrian Behavior

A number of studies concerning various aspects of pedestrian behavior are germane to this research effort. For the purpose of this review, it is the results of these studies rather than the methodologies that are of interest. These studies focus on pedestrian accidents, pedestrian signal operations, and crossing behavior. As a point of departure, an early study of pedestrian behavior will be examined. One of the most widely quoted studies on pedestrian behavior was the pioneering work of Fleig and Duffy conducted in the late 1960's in New York City. This study had the dual purpose of

illustrating the technique of activity sampling and evaluating the effect of pedestrian signals on pedestrian behavior. Activity sampling aims at collecting a large amount of data in a short time period to avoid statistical unreliability which occurs when data is gathered over a long period and a whole host of variables outside the range of experimental control could account for the observed variation.

Activity sampling is briefly described below (Fleig and Duffy, pp. 106-107):

1. Taking a number of brief observations, as short as are compatible with adequate perception, during a succession of time periods.
2. Computing the percent of observation in each time period that fall in a category of interest. For example, computing the percent of observations when unsafe acts were observed during each period.
3. Examining the percentages computed using the control chart [A graph which indicates statistically significant changes over time] to see if any variable changed significantly during the periods studied.
4. Pooling the observations from all periods, if the control chart indicates the absence of significant changes, future periods.

Prior to actually conducting their study, Fleig and Duffy studied pedestrian accident statistics gathered by the City of New York Police Department. Attempts were made to randomize significant variables which were believed to effect pedestrian accidents, although due to the nature of the study the location and month of the year were fixed, as installation of the pedestrian signals had already been scheduled. The pedestrian phasing scheme used was a "Barnes' Dance" type in which pedestrian movements are prohibited during both major and minor vehicular movements and these pedestrian movements are only permitted

during the final phase, when vehicular traffic is stopped in both streets. Fleig and Duffy categorized the following pedestrian acts as being unsafe (Fleig and Duffy, p. 107):

1. Crossing at the intersection when the vehicular signal is green or red and the pedestrian signal is red.
2. Crossing away from the crosswalk and coming from behind parked cars at any time.
3. Standing in the roadway when the pedestrian signal is red.

Although such acts are clearly unsafe--standing in the road, crossing behind parked cars, and crossing against the signal--no hierarchy of risks is proposed, nor are other, perhaps more subtle acts, listed as being unsafe. More importantly, crossing against the pedestrian signal may not be unsafe if there is no potential pedestrian-vehicle conflict, although the existence of Barnes' Dance phasing would imply a high likelihood of vehicular-pedestrian interactions and thus the need for an exclusive pedestrian phasing. No mention is made of pedestrian-vehicle conflicts, pedestrian walking speeds, looking behavior, and other aspects which are felt to influence pedestrian safety. Based on the aforementioned unsafe acts listed by Fleig and Duffy, the following results were obtained from the examination of one intersection in New York before and after the installation of pedestrian signals: 28.8% of all pedestrians engaged in unsafe acts before the installation of the pedestrian signals compared with 29.0% after installation, a difference that was not statistically significant (Fleig and Duffy, p. 110). The authors thus concluded (Fleig and Duffy, pp. 110-111):

1. There is no significant difference between the means of the ratio of the number of unsafe acts observed to total population observed before and after the installation of pedestrian traffic signals at the intersection studied. Thus, the installation of pedestrian traffic signals did not improve pedestrian safety behavior and reduce unsafe acts. Assuming that changes in safety behavior are a valid criterion for evaluating the effectiveness of a method designed to reduce accidents and that the safety behavior observed was a representative sample, it may be concluded that pedestrian traffic signals are not an effective method for reducing pedestrian accidents.
2. There is no significant difference between the number of accidents recorded one year prior to and one year after, the installation of pedestrian traffic signals at eleven New York City intersections. Assuming that the accident occurrences at the intersections studied are a representative sample of all of the City's installations and, further, that no important change occurred at these intersections during the two years studied except the installation of pedestrian signals, it may be concluded that pedestrian traffic signals are not an effective method for reducing pedestrian accidents.

The conclusions of the accident record study as to the effectiveness of pedestrian traffic signals in reducing pedestrian accidents, agrees with the conclusion of the safety behavior study.

A study conducted by Zegeer, et al. sought to determine the effect of pedestrian signals and signal timing strategies on pedestrian accidents. The researchers noted the pioneering study performed by Fleig and Duffy which found no significant reduction in unsafe acts or pedestrian accidents with a scramble-timed pedestrian signal, although the researchers had some criticisms to offer (Zegeer, et al., p. 62):

Their [Fleig and Duffy] accident data were limited to 27 accidents in the before period and 25 accidents in the after period, with each of these periods only one year in duration. The authors of the study concluded that pedestrian signals are not effective in reducing pedestrian accidents, but the limited data raise questions about the statistical validity of this conclusion.

The researchers also cited other studies that had been performed concerning pedestrian compliance and behavior to gauge the effectiveness of pedestrian signals, although, importantly, they point out that a clear relationship has not been established between pedestrian behavior and pedestrian accidents.

For this study a comparative analysis approach was used in which nearly 1,300 signalized intersection in fifteen American cities were studied. The data gathered were analyzed in the following fashion (Zegeer, et al., p. 64):

The analysis first included a review of accident characteristics to provide an understanding of the factors associated with pedestrian accidents. Next, correlation analysis was used to determine what traffic and roadway variables were most highly related to pedestrian accidents. A branching analysis was used to indicate variables that explained the most variation in pedestrian accidents and to identify the breakpoint levels that were important in subsequent statistical tests.

Based on the results of the correlation and branching analysis, chi-square and analysis of variance and covariance tests were applied. The chi-square test was used to compare the distributions of accidents for locations with and without pedestrian signals and for different timing schemes (i.e., concurrent versus exclusive timing) for various data groups. Finally, analysis of variance and covariance tests were used to isolate the effect of pedestrian signals and timing on accidents while controlling for other influencing variables.

From an analysis of the characteristics of pedestrian accidents it was concluded that approximately one-half of the pedestrian accidents were caused by pedestrians in violation of the pedestrian or traffic signal, while the remaining one-half of pedestrian accidents were caused by motorists who failed to properly observe or yield to the pedestrian engaged in a proper crossing (Zegeer, et al. p. 65). The correlation analysis revealed weak relations between variables,

and thus further techniques were used to more adequately describe the pedestrian accident experiences. One of the techniques employed was branching analysis whereby traffic and roadway variables were examined to determine their explanatory power in accounting for the variation in pedestrian accidents (Zegeer, et al., p. 65). It was found that pedestrian volume explained the greatest variation. Of particular interest, the branching analysis indicated that (Zegeer, et al., p. 66):

Although all intersections in the analysis had a traffic signal, the presence or absence of a pedestrian signal indication had no significant effect on pedestrian accident experience.

A breakdown of the results obtained from the branching analysis was then performed to indicate the pedestrian accidents for different categories of pedestrian volume, vehicular volume, and signal-timing schemes. A chi-square test was used to indicate the strength of the association between pedestrian accidents and the pedestrian timing arrangement. The chi-squared analysis revealed several important points which bear directly upon the current study (Zegeer, et al., p. 68):

1. No significant difference was found in pedestrian accident distributions when comparing locations that did not have pedestrian signals to locations that had concurrent [pedestrian and vehicular movements occurred simultaneously] pedestrian signals . . .
2. For intersections that had fewer than 1,200 pedestrians/day, no significant difference was found in pedestrian accident distributions when comparing exclusive-timed pedestrian signals with both the no-pedestrian-signal groups and also locations that had concurrent pedestrian signals. [It is important to note that the authors state that this result may be due to the low number of exclusive-timed signals in this volume group.]

3. For intersections that have 1,200 or more pedestrians/day, a significant difference was found between accident distributions for exclusive-timed pedestrian signals compared with locations that did not have pedestrian signals as well as locations that had concurrent pedestrian signals (0.01 level of confidence in each case). A higher proportion of exclusive-timed locations were in the low accident groups than in the concurrent signal group or the no-pedestrian-signal group.

The analysis of variance and covariance was used to further analyze the data set. It was found that the mean pedestrian accidents per year were significantly affected by different pedestrian-timing schemes (Zegeer, et al., p. 69). Further, no significant difference was found between the total mean number of pedestrian accidents at intersections without pedestrian signals compared to intersections with pedestrian signals (Zegeer, et al., p. 69). Statistical analysis also revealed that the total mean pedestrian accidents were significantly different for intersections with concurrent signal timing and intersections having exclusive pedestrian signal timing (Zegeer, et al., pp. 69-70).

The authors acknowledge that although concurrent timing is the most widely used pedestrian timing scheme, it does not appear to be particularly effective in reducing pedestrian accidents. The authors suggest several possibilities that may account for this phenomena (Zegeer, et al., p. 71):

1. Pedestrian respect for and compliance with pedestrian signal indications is poor in most cities. Violations of the DON'T WALK message are higher than 50 percent in many cities. This disrespect and violation of the pedestrian signals is a major reason for their ineffectiveness in reducing pedestrian accidents.
2. The presence of a pedestrian signal indication may tend to create a false sense of security and may cause many

pedestrians to have the mistaken impression that they are fully protected and have no reason to use caution. The absence of a pedestrian indication at a signalized locations sometimes gives pedestrians the feeling that they are on their own. This could cause many pedestrians to exercise more caution regarding turning vehicles.

3. The use of the flashing WALK has been shown in other studies to be ineffective in adequately warning pedestrians to watch for turning vehicles. In fact, one study found that only 2.5 percent of the pedestrians understood the intended meaning of the flashing and steady WALK indications. Also, many states have not incorporated the flashing WALK signal into their state policies, which has caused nonuniformity in the use of pedestrian signal messages in the United States.
4. Some studies have found that the flashing DON'T WALK indication (clearance interval) is also not well understood by many pedestrians, and many pedestrians believe that traffic will be released during the flashing DON'T WALK interval.
5. Pedestrian-actuation devices are used too infrequently by pedestrians and, therefore, the use and respect for pedestrian signals may be minimized at such locations. One study showed that they are used by less than 35 percent of the pedestrians in crossing at many sites.

Several researchers have commented on pedestrian reaction to the flashing WALK indication on pedestrian signal equipment. One such study and concerned pedestrian reaction to the flashing WALK as well as to the steady WALK indication. The researcher calculated the observation rate, or the percentage of legal crossing, and the conflict rate, or the percentage of road crossings which had specifically defined interruptions. The pedestrian crossings were categorized as follows (Sterling, p. 20):

1. Decision legal crossing. An individual waits until the WALK interval before crossing.
2. Nondecision legal crossing. An individual continues across the street without interruption during a WALK interval.

3. Flashing DON'T WALK crossing. An individual continues across the street illegally during flashing DON'T WALK interval.
4. Decision illegal crossing. An individual waits during the steady DON'T WALK interval until an adequate gap appears in traffic and then crosses, usually without conflict.
5. Arrival illegal crossing. An individual continues across the street during the steady DON'T WALK interval, usually by weaving through the vehicular traffic.

The two major conclusions of the study are presented below (Sterling, p. 20):

1. A significantly higher percentage of both legal crossings and decision legal crossings occurred with the steady WALK than with the flashing WALK.
2. A significantly higher percentage of illegal conflict crossings occurred with the flashing WALK than with the steady WALK.

Considering all crossings, the observation rate of the steady WALK was found to be 51% while the observation rate of the flashing WALK was found to be 29% compliance, although the author questions both these percentages (Sterling, p. 20). It was further found that 6% of crossings were conflict crossings for the steady WALK indication while 8% were conflict crossings for the flashing WALK indication, a small but nonetheless statistically significant difference (Sterling, p. 20). As can be seen from the results of this study there appears to be a misunderstanding concerning the message and purpose of the flashing WALK signal used on pedestrian signal equipment.

Concern for vehicular and pedestrian delay at pedestrian signalized crossings was the subject of a 1978 paper by Smith. Smith began by criticizing inconsistencies in the timing of the pedestrian clearance interval and then computed vehicle right turn and pedestrian

delays for two timing schemes: (1) minimum clearance timing, which had only a minimum flashing DON'T WALK indication providing just enough time to cross the street, and (2) minimum WALK alternative, which had only the minimum WALK interval time (7 seconds) and which allocated the remaining time to the flashing DON'T WALK indication (Smith, p. 34). Vehicular delay was computed from 68 hours of time lapse photography at intersections in Washington, D.C.; Phoenix, Arizona; Akron, Ohio; and Cambridge, Massachusetts. Pedestrian delay was computed using a bi-level arrival rate: "It was found that the arrival rate of pedestrians at a signalized intersection crosswalk is highest during and just prior to the WALK interval and approximately half that rate following the WALK interval" (Smith, p. 35). Smith's study indicated that the minimum WALK alternative reduced vehicle right-turn delay, because no pedestrians should be present in the crosswalk to interfere with vehicles once the initial platoon of pedestrians has crossed (Smith, p. 35). The minimum WALK alternative served to increase pedestrian delay, and this delay was found to be significantly greater than the computed vehicular delay (Smith, p. 35). Regarding delay, Smith concluded that increasing clearance intervals over the minimum served to increase overall delay (Smith, p. 35). Smith further analyzed pedestrian compliance by examining pedestrian compliance to flashing DON'T WALK indications which were longer than the minimum clearance interval for intersections in the cities of Washington, D.C.; Phoenix, Arizona; and Buffalo, New York. Different pedestrian signal timings were tested, ranging from ones with the minimum clearance interval to ones with the minimum walk

interval. It was found that timings offering the shortest WALK interval resulted in the lowest compliance rate. It was further found that (Smith, p. 36):

. . . pedestrians generally comply to the clearance interval up to a certain interval length (specifically, an interval times closed [sic] to the minimum clearance) and that longer clearance times encourage non-compliance.

Smith concluded that the reduction in compliance for clearance intervals longer than the minimum stems from previous behavior which indicates the time needed to safely cross the intersection: "Consequently, if they know that there is a long clearance interval, they will not hesitate to begin their crossing during that interval" (Smith, p. 36).

Studies Concerning Methodologies

This study also sought to develop an appropriate methodology for the analysis of pedestrian behavior. Several research studies concentrated efforts in this area, and they will now be examined. In one study the researchers examined pedestrian behavior at signalized intersections that had experienced numerous pedestrian accidents in Portland, Oregon (Jennings, et al.). Video recordings of pedestrian crossings were analyzed according to a set of behavioral categories (Table 1). These behavioral categories were patterned after a previous study (Heimstra et al.) and on a pilot video data analysis. The interaction between individual behavior and the signal indication was examined in the following fashion (Jennings, et al., p. 28):

The camera was directed to record the state of the pedestrian control signal and behavior of pedestrians before "Curb 1" and after "Curb 2" where Curb 1 was an area on the

Table 1
Behavioral Categories for Portland Pedestrian Study

BEHAVIORAL CATEGORY	CODE
(1) Sex	male female
(2) Group	yes no
(a) Size	2 3
(b) Structure	active nonactive
(3) Approach movement	run walk
(4) Signal	walk don't walk
(5) Stop at Curb 1	yes no
(6) Stop at Curb 2	yes no
(7) Look at Curb 1	yes no
(a) Direction of look	both correct wrong
(8) Look at Curb 2	yes no
(a) Direction of look	both correct wrong
(9) Vehicle - Pedestrian conflict	yes no
(10) Legal cross	yes no

Source: Roger D. Jennings, Mary A. Burki, and Burton w. Onstine, "Behavior Observations and the Pedestrian Accident," Journal of Safety Research, March 1977, Vol. 9, No. 1, pp. 26-33.

sidewalk within two steps of the curb and Curb 2 was an area in the street extending two steps from the curb.

A further discussion of the data categories used in the study is presented below (Jennings, et al., p. 28):

The presence of social interaction in the group, i.e., the degree to which group members were attending to each other, was coded in item 2b. The state of the pedestrian control signal, noted when the approaching pedestrian was at the outer edge of Curb 1, was recorded in item 4. Stopping, a brief cessation of forward movement with both feet placed side by side on the pavement, was recorded in items 5 and 6. Looking was recorded when the pedestrian's head (face) was turned to the right or left. Both directions was coded when the pedestrian looked to the right and the left. Correct direction looking was coded if the pedestrian looked only in the direction of oncoming traffic on his, the near side of the street. Conversely, wrong direction looking was coded when the pedestrian only looked away from oncoming traffic on the near side of the street. Vehicle-pedestrian conflict was scored yes in those situations where cars and pedestrians competed for the right of way in the crosswalk. A legal cross was marked yes when the pedestrian obeyed the pedestrian control signal.

The study reached several conclusions which are germane to this research. The study found that pedestrians generally stopped at the DON'T WALK signal and did not stop for the WALK signal (Jennings, et al., p. 30). Furthermore, a strong association was revealed between looking and the pedestrian signal (Jennings, et al., p. 30). Stopping and looking behavior at Curb 2 revealed no significant associations (Jennings, et al., p. 30). A significant association existed between stopping and looking at Curb 1 for all pedestrians (Jennings, et al., p. 30). Also, a strong association existed between stopping and looking at Curb 1 when a DON'T WALK signal was present (Jennings, et al., p. 30). The researchers summarized their findings as follows (Jennings, et al., p. 32):

Assuming that the categories selected for analysis were both reliable and valid, pedestrian behavior could be described in terms of its unsafe aspects. Numerous pedestrians do not obey the don't walk signal. Numerous pedestrians do not look in the presence of either a walk or don't walk signal before crossing the street. Moreover, the pedestrians who do not stop also do not look. Finally, if the pedestrians at a walk signal has not looked at Curb 1 then he will not look at Curb 2. In short, there are a reasonable number of pedestrians who do not appear to assess the traffic situation before crossing the street.

Despite the admirable intentions of the study it is fraught with methodological problems and, at times, unsupportable conclusions. To begin with, a total of 3.5 hours of video taping of three different intersections was performed which resulted in a total of 106 pedestrian observations--a rather small total. Looking behavior was measured by head movements, although it is obvious that looking does to necessitate head movements and, for that matter, head movements do not necessarily relate to eye movements. The researchers state: "By not looking or looking in the wrong direction, pedestrians increase the likelihood of being struck by an oncoming auto"(Jennings, et al., p. 29). There is no proof that this statement is true. While "correct" looking behavior may appear to increase the likelihood of a safe street crossing there is no proof of this, nor is there yet an acceptable definition of correct behavior (Chapman, citing Grayson, pp. 60-61):

Children tend to walk across the road at right angles while adults frequently cross diagonally. In addition children are more likely to run across the road. Adults display what seems like dangerous behavior. They are more likely to start crossing before the road is clear, moving into the road closely behind the passing vehicle. Far from being the dangerous maneuver it first appears, this is a very efficient one because it maximizes the time before the arrival of the next vehicle. Adults then, may choose smaller gaps in which to cross, but they effectively have more time in

which to make the crossing . . . The behaviors of children can be considered to be inefficient in terms of the criteria described above, but it is far better according to the criteria laid down for safe road crossing. Children's behavior is more like that advocated by road safety education literature than is that of adults. In fact, the literature is designed specifically to discourage the adoption of adult strategies by young children.

Furthermore, another study in which researchers acted as pedestrians and began street crossing maneuvers as vehicles approached the intersection and then examined the results, found that drivers reduced speed or stopped more often when, among other reasons, the pedestrian did not look at the approaching vehicle (Katz, et al., p. 23).

A 1973 study sought to conduct a behavioral evaluation of pedestrian signals (Mortimer). The study design was prompted by the lack of effective data to evaluate pedestrian signals (Mortimer, p. 23):

Since the extent of objective data collected to determine pedestrian signal effectiveness is sparse, two further studies were conducted. In the first, the type of pedestrian crossing start (legal or illegal) and type of pedestrian arrival (successful or unsuccessful) were recorded.

In the second, the pedestrian crossing mode (walk or run) were noted as were pedestrian and driver collision avoidance behavior. These measures were intended to show how the pedestrian signal affected the pedestrians' observance of the signal and their safety on the crosswalk.

Four observers selected two close comparable traffic signal-controlled intersection. One had pedestrian signals and the other did not. Eight different sites were studied in the Detroit area. Each observer sampled each intersection twice on different days, taking three consecutive sequences of 15 minutes of pedestrian counts and five minutes of traffic counts for a total of one hour of observation on each occasion.

For each pedestrian who crossed an intersection, the type of start (legal or illegal) and the type of arrival (successful or unsuccessful) was recorded. A legal start was defined as entry onto the crosswalk when the traffic signal was green; an illegal start was entry on amber or red. A successful arrival was defined as arrival at the

opposite curb when the traffic signal was green or amber, an unsuccessful arrival was on red.

A total of 1,471 pedestrians was observed crossing the chosen intersections. Compared to intersections without pedestrian signals, intersections with pedestrian signals had 34.4% fewer illegal starts and 14.4% more successful crossings (Mortimer, p. 23). A chi-squared analysis of the data was performed and showed that there were significantly fewer illegal starts and more successful arrivals at intersections equipped with pedestrian signals compared with those without these signals (Mortimer, p. 23).

A total of 1,836 pedestrian crossings were observed of which 911 occurred at the intersections without pedestrian signals and 925 occurred at the intersections with pedestrian signals. Substantial differences were found between the signal indication and the crossing mode, although the percentages of crossings for each mode were fairly similar for signal indications for intersections with and without the pedestrian signals (Mortimer, p. 23). More than 60% of the crossings were made at a walk, although nearly 20% of the pedestrians ran during the road crossing (Mortimer, p. 23). Both pedestrian actions and driver actions, which were defined as any action in which the pedestrian or vehicle stopped, slowed, or altered course, occurred during crossings, with the percentages being nearly the same for pedestrian signalized and non-pedestrian signalized intersections (Mortimer, p. 25). At intersections without pedestrian signals, 24.8% of the crossings occurred when the signal indication was red, compared to intersection with pedestrian signals at which significantly fewer

crossings, 14.8%, occurred when the signal indication was red, although it must be noted that (Mortimer, p. 23):

Since the red phase is longer at intersections with pedestrian signals . . . The greater percent of pedestrians crossing during the red signal at intersections without a pedestrian signal cannot be attributed to a longer mean waiting time.

It was further found that for legal starts there were significantly more unsuccessful arrivals at non-pedestrian signalized intersections compared to pedestrian signalized intersections (Mortimer, p. 23). Concerning illegal starts, it was found that there were no significant differences between arrival types at non-pedestrian signalized intersections and pedestrian signalized intersections (Mortimer, p. 23).

A second study was also undertaken utilizing a similar methodology to that employed by the first study but collecting different data. Seven pairs of intersections comprised of two comparable intersections, one having pedestrian signals and the other not having pedestrian signals, were chosen for analysis. The starting and crossing mode were recorded by observers for each pedestrian crossing in the following fashion (Mortimer, p. 25):

The crossing mode consisted of four classifications: walk; run; pedestrian action--engaging in avoidance behavior, such as to stop, increase pace, or run to move out of the way of a car--and driver action with the pedestrian in a hazardous situation and the vehicle operator engaging in avoidance behavior, such as slowing down or swerving to avoid the pedestrian.

The start mode was the phase of the signal at the instant the pedestrian entered the crosswalk; traffic signal on green, amber or red; or pedestrian signal on "Walk," (green), "Don't Walk," (green or amber) or "Don't Walk," (red).

It was further found that fewer crossings were made on amber at intersections with pedestrian signals compared to those without pedestrian signals, 8.6% and 11.5% respectively, although the difference is not significant (Mortimer, p. 25). The researchers also studied crossing speed (walk or run) in an effort to identify pedestrian crossing hazards (Mortimer, p. 25):

One measure of relative hazard in the behavior of pedestrians at the two types of intersections can be obtained by comparing the percent of crossings involving running to those made walking. A chi-square analysis of the frequency of walk and run crossings showed that they are significantly affected by the signal phases. The values show that pedestrians felt the need to run across the street twice as often on the green signal than when a "Walk" signal also was shown, and the appearance of "Don't Walk" on the green signal greatly increased the proportion of pedestrians observed running to those walking.

A study concerning the development of a methodology for examining child pedestrian behavior focused on a film study of kindergarten children, as they were released before other school children and could thus be easily studied as a group (Heimstra, et al.). Although both approach and crossing behavior were filmed, only approach behavior was examined in this study. Two types of unsafe behavior were singled out for further analysis: (1) not stopping at the curb before entering the street, and (2) not looking for oncoming traffic (Heimstra, et al., p. 834).

A film recording was made of kindergarten children as they approached and crossed the street on their way home at noon. The film was then reviewed by slow-motion techniques and the behavior of the children was analyzed. An analysis chart was completed for each child which contained the following information (Heimstra, et al., p. 834):

(1) sex; (2) social conditions (whether child was alone or in group); (3) interaction level of child in group (active interaction or noninteracting); (4) approach rate of child (whether child was running or walking. Additional information concerning actual rate of approach, i.e., racing, normal run, and so forth, was included on the analysis chart); (5) activities of child during the approach (whether child appeared to be oriented toward the other children, toward an inanimate object and so forth); (6) observing behavior of child during approach (whether child appeared to look for vehicles in one direction, two directions, behind, or did not appear to observe for traffic at all); (7) the direction of the child's approach to the curb. This was shown on a sketch of the intersection included on each analysis chart. (8) Whether the child stopped at the curb. If child stopped, duration of pause was indicated. If child did not stop, any change in rate of locomotion was recorded. (9) Social conditions at the curb. If the child was in a group at curb, information concerning the group was included. Also indicated was whether the observed child left the curb with the group, with some members of the group, or by himself. (10) The child's observing behavior at the curb. Whether he did not look, looked one way, two ways, and/or behind him was indicated on the analysis chart. (11) Traffic conditions--the location of any vehicles was indicated on the chart of the intersection.

Two hundred children were analyzed: 100 boys and 100 girls. It was found that 83% of the children were in small groups as they approached the curb (Heimstra, et al., p. 836). Two types of curb behavior were recorded: (1) whether the child looked for traffic, and (2) whether the child walked or ran (Heimstra, et al., p. 836). A greater percentage of girls than boys was observed running, although girls were recorded as observing traffic more often than were boys (Heimstra, et al., p. 836). The researchers categorized the childrens' approach activities as "other-child oriented" or "inanimate-object oriented" and found that most activities involved other children and noticed no significant differences between behavior exhibited by girls or boys (Heimstra, et al., p. 836).

Curb behavior was studied in a similar fashion with the following types of behavior being recorded: whether the child stopped at the curb before entering the street, and whether the child looked for traffic before entering the street (Heimstra, et al., p. 837). It was found that only 32% of the children stopped before proceeding to cross the road, with no significant differences recorded between girls and boys (Heimstra, et al., p. 837). The researchers also found that "whether a child stopped at the curb was largely unrelated to whether he had been running or walking during the approach" (Heimstra, et al., p. 837). It was further found that girls were observed as looking for traffic more frequently than were boys. The researchers summarize their findings as follows (Heimstra, et al., p. 837):

. . . under the conditions involved in this study, a surprising number of children entered the street without stopping or without apparent observation for possible traffic hazards. Also of interest was the fact that girls tended to observe significantly more frequently than the boys. However, aside from observing behavior there were few differences between boys and girls in the types of pedestrian behavior analyzed.

It is quite apparent from even the most cursory examination that this study suffers from a paucity of observational categories. It must be noted that this study was primarily concerned with designing a methodology for a behavioral analysis rather than attempting to fully classify pedestrian behavior, or in this case, child pedestrian behavior. More observations would probably be necessary in order to arrive at statistically valid conclusions. Furthermore, a whole range of pedestrian activities needs to be examined if pedestrian behavior is to be adequately described. This study did provide some ideas on

the construction of an analysis method for pedestrian behavior--ideas which will be incorporated in the current research.

Studies Concerning Pedestrian-Vehicular Interactions

Hill emphasizes that pedestrian behavior cannot be fully understood unless pedestrian-vehicular interaction is examined (Hill, p. 26). This is logical since pedestrians and vehicles share the roadway. To fully understand, efforts were made to uncover previous research in this area. Results were, unfortunately, rather scant, as little research appears to exist in this area, ironically emphasizing the importance of such study. Nevertheless, a rather comprehensive paper was found (Cynecki). That research will be commented upon in depth because of the paucity of study in this area and its relevance to the present research.

Cynecki's study sought to develop a pedestrian conflict analysis technique that could be used to identify hazardous intersections. Thirteen principal types of pedestrian conflicts were identified and formed the basis of the conflict data form which further categorized these types of conflicts by severity. This conflict analysis technique was then tested at five pedestrian crossing locations at Wayne State University and Detroit in which a total of twenty-five hours of data was collected. Although a large amount of research has been conducted regarding vehicular-vehicular conflicts, little has been performed on pedestrian-vehicular conflicts, which differ in important ways (Cynecki, pp. 3-4):

1. Vehicle-pedestrian accidents are not as numerous as vehicle-vehicle (or vehicle-fixed object) accidents.

2. Accidents are considerably more severe when they involve pedestrians. There is a low chance of a Property Damage Only (PDO) accident when a pedestrian is struck by a vehicle and there is a very good chance of a type A injury or fatality, particularly at high speed locations.
3. Many of the pedestrians involved in accidents are school age, preschool, or elderly. Pedestrians in these age groups may not have adequate knowledge of highway safety, lack responsibility and maturity, or have reduced eyesight and reflexes (in the case of the elderly) which are factors in many pedestrian accidents. On the other hand, motorists must be at least 16 years of age and have good eyesight and health to drive. Although this is not always the case (i.e. drunk drivers, etc.), on the average, drivers should have better eyesight and reflexes than children and elderly pedestrians.
4. The operation of a motor vehicle is considerably more complex involving many more "distractions" than does the action of a pedestrian crossing a roadway.
5. Pedestrians are more maneuverable than automobiles in the actions of stopping and changing directions.
6. There is a considerable speed differential between automobiles and pedestrians. Automobiles usually travel in the speeds ranging from 15 mph to 60 mph (24-100 kph), while pedestrian speeds average at about 3 mph (5 kph).
7. Most pedestrian conflicts occur at right angles when pedestrians are in the action of crossing a roadway. This is not the case with vehicle conflicts.
8. Pedestrians may access a roadway at almost any point. Automobiles normally access a roadway at specified points (i.e., other roadways, driveways, curb side parking spaces, etc.). Therefore, a motorist must be cognizant of pedestrians at every point along a roadway.
9. Sight restrictions may be more prevalent in pedestrian conflicts than in vehicle conflicts. A pedestrian is smaller than a vehicle and can access a roadway from between parked cars and may be shielded from a motorist until he is in the roadway (without giving the motorist advance warning).

10. For nighttime conditions, vehicles have headlights, taillights, and running lights which make them more visible to other motorists. Pedestrians are often dressed in dark clothing and are more difficult to detect at night.
11. Pedestrian conflicts and conflict severity can be measured from the movements and reactions of vehicles and pedestrians. When only vehicles are involved, conflicts and conflict severity can usually be measured by watching the movements and reactions on only one vehicle. The example of this is a slow-for-right-turn rear-end conflict. The first vehicle slows for a right turn while the second vehicle brakes or weaves to avoid a collision. The conflict can only be viewed and measured by watching the second vehicle. When pedestrian conflicts occur, a conflict can be viewed from the vehicle's actions (braking/weaving) to avoid a collision or from the pedestrians actions (stopping, changing directions, running, etc.).

The author then defines the various types of pedestrian conflicts that can occur. Reasons for these conflicts are also suggested, as are possible countermeasures (Cynecki, pp. 6-11):

1. Slow or weave for walking pedestrian (PW) - This is a conflict which occurs when a pedestrian accesses a roadway at a normal walking pace (at a right angle to vehicle traffic) and a vehicle weaves or brakes to avoid a collision. This type of conflict does not include vehicles turning into the path of a pedestrian at intersection locations or violations of a traffic signal by a motorist or pedestrian. . . .

The occurrence of this type of conflict may, for example, indicate a sight restriction for the motorist or pedestrian. If this is the case, conflicts may be reduced by removing sight obstructions or by improving warning to motorists of pedestrian access points or crosswalks. However, slow for walking pedestrian is a very general conflict type which may indicate many diverse safety hazards. PW conflicts may also be caused by inadequate gaps in vehicle traffic, excessive street width, excessive vehicle speeds, too many pedestrian crossing locations, etc. Thus, recording the conflict type alone may not indicate a specific operational deficiency. Other data, such as condition diagrams, vehicle and pedestrian volume counts, gap studies, etc. may also be needed to determine the actual locational deficiencies.

2. Slow or weave for running pedestrian (PR) - this conflict occurs when a pedestrian accesses a roadway while running (at right angles to vehicle traffic). The conflict is similar to the PW conflict in other respects. A PR conflict may indicate the existence of a similar type of problem situation that a PW conflict indicates, except with an increasing degree of severity. This conflict type is also very general in description and the specific locational deficiency should be further identified by collecting additional site-related data.

Because younger children are more apt to run into a roadway without due caution, PR conflicts may occur more often at a school crossing or near playgrounds. These conflicts may be reduced by using crossing guards for elementary school age children and by fencing off play areas and, if possible, locating schools and play areas away from major roadways. The conflict may also occur at crossings of very wide roadways or may indicate the lack of gaps in traffic large enough to allow crossing. Countermeasures may include the implementation of pedestrian actuated signals or pedestrian islands.

3. Pedestrian Walking/Running in the Roadway With the Flow of Traffic (WF) - A conflict of this sort is a result of a vehicle weaving or braking because of a pedestrian walking or running in the roadway or on the shoulder in the direction of vehicle traffic. Such conflicts may indicate the need for sidewalks or wider shoulders to safely accomodate [sic] pedestrian traffic.

A WF conflict may also occur in areas of on-street parking due to pedestrians accessing parked vehicles. Countermeasures for this problem may include the reduction or the elimination of on-street parking, and the widening of parking lanes and shoulders to safely accommodate pedestrians accessing parked vehicles.

4. Pedestrian Walking/Running in the Road Against the Flow of Traffic (AF) - This is similar to the WF conflict with the exception that the pedestrian is walking or running in the road opposing the direction of traffic
5. Diagonal Pedestrian Crossing (PD) - This conflict occurs when a pedestrian crosses a road at an angle other than 90° to the flow of traffic (i.e., close to 45°). This type of crossing can occur at mid-block or

an intersection. . . . A diagonal pedestrian crossing is a hazardous situation because the pedestrian will be in the roadway for a longer time interval and, if the road is a two way street, the pedestrian will have his back to traffic during a portion of the crossing.

This type of conflict may occur due to the offset of sidewalks accessing a roadway or due to the location of pedestrian traffic generators which are not directly across the street from each other. This problem may be corrected by utilizing better alignment of sidewalks or by implementing pedestrian barriers.

6. Pedestrian in Center Lane (CL) - This conflict designates the presence of a pedestrian in the center left hand turn lane or a roadway during the commission of a conflict with a vehicle. This conflict can involve a vehicle in the center lane or the lane adjacent to it. CL conflicts will only be recorded at wide roadways, usually consisting of five lanes or more. This type of conflict will indicate the necessity of additional protection for pedestrians from through and/or turning traffic. Countermeasures for this problem may include the restriction of vehicle turning movements or pedestrian crossings at the specified location.
7. Outside Crosswalk (OC) - At locations where crosswalks are marked out, it may be desirable to indicate the number of conflicts which occur outside of the crosswalk. Studying OC conflicts may be useful in investigating the effectiveness of crosswalks in reducing the number of pedestrian access points to a roadway and in identifying the effectiveness of the crosswalk as a safety countermeasure for pedestrians. If a considerable number of OC conflicts are observed, it may be desirable to implement countermeasures to channelize the pedestrians to the crosswalk. This may be achieved by utilizing pedestrian barriers, repainting the crosswalk, or relocating the crosswalk. If, however, a sizable number of conflicts occur within the crosswalk, it may indicate that the crosswalk is not providing adequate safety to the pedestrians, and additional protective measures may be required. These measures may include additional warning to motorists, lower speeds, additional police enforcement, pedestrian signals, grade separations and others. . . .
8. Right Turning Conflicts (VR) - This conflict is the result of a right turning vehicle at an intersection or from a vehicle making a right turn into or out of a driveway. For a more involved analysis, this conflict

can be subcategorised into two different types: (A) vehicles turning right from the roadway being observed and (B) vehicles turning right onto the roadway of interest. This is shown in Figure 6. Countermeasures to reduce this type of conflict may include restricting turning movements, special signal phasing to protect pedestrian crossing or the location of pedestrian crossing points at alternative locations.

9. Left Turning Conflicts (VL) - This conflict occurs from a left turning vehicle at an intersection or from a vehicle turning left out of or into a driveway. As in VR conflicts, this conflict can also be subcategorised into two separate types: (A) vehicles turning left from the road being observed or (B) vehicles turning left onto the road being observed. . . . Countermeasures for this type of conflict may include, but not be limited to, prohibition of left turns, special phasing to protect crossing pedestrian, grade crossing separations, etc.
10. Right-Turn-on-Red Conflicts (RR) - This conflict occurs when a vehicle initiates a right turn during a red signal phase which conflicts with a crossing pedestrian. The recording of RR conflicts at signalized intersections is optional, but may yield useful information regarding the safety implications when right-turn-on-red movements are allowed. There may be two types of RR conflicts: (a) right-turn-on-red off of the road under investigation or (b) right-turn-on-red onto the road. . . .
11. Signal Change (SC) - This conflict occurs only at signalized pedestrian crossings or at signalized intersections. A conflict of this type occurs when a pedestrian crosses a street with the signal and before the pedestrian completes his crossing the signal changes to red and a vehicle brakes, weaves or hesitates to avoid a collision. This type of conflict may be caused due to improper signal timing and may be corrected by utilizing pedestrian islands, improved signal timing or by the installation of "walk don't walk" signals.
12. Pedestrian Violation (PV) - This designates a conflict which occurs as a result of pedestrian violation of a traffic signal. A pedestrian violation can be either a pedestrian walking against a traffic signal or a pedestrian starting to cross when the pedestrian signal is flashing a "don't walk" sign. Recording this type of conflict is optional and may be used to indicate pedestrian compliance with traffic signals.

13. Vehicle Violation (VV) - This designates a conflict which occurs as a result of a vehicle violation of a traffic control device. The vehicle violation can be a failure to stop, failure to yield, running a red light at a traffic signal, or an illegal right-turn-on-red (i.e. where signing prohibits a right turn on red). Recording this type of conflict is optional and may be more appropriate at intersections or signalized locations. It may also be desirable to subclassify these conflicts to identify specific hazardous vehicle actions. Depending on the site and the type of vehicle violations observed, these conflicts may be reduced by added enforcement, improving visibility of traffic signs and signals, upgrading traffic control devices, adding a delayed red signal phase, and others.

Since there is a major difference between the activities at intersection and non-intersection locations, some of the defined conflicts will not be applicable to all situations. For example, PW, PR, WF, and AF conflicts may be recorded only at mid-block locations (Cynecki, p. 11). Furthermore, conflict types such as VL, VR, SC, RR, and PV can only occur at intersections (Cynecki, p. 11).

To further categorize pedestrian-vehicular conflicts, conflict severity was measured. Both actors in the conflict, the pedestrian and the vehicle, were analyzed in the conflict, and separate rating categories were developed for each actor. Pedestrian actions used to measure conflict severity are listed below by increasing severity, with the "p" subscript referring to pedestrian action (Cynecki, P. 12):

1. Hesitation (Hp) - Pedestrian hesitates momentarily in his travel across a street in response to vehicular traffic.
2. Backup Movement (Bp) - Pedestrian momentarily reverses his direction of travel while in the roadway in response to vehicular traffic.

3. Running Movement (B_p) - Pedestrian increases his speed to avoid a collision with through traffic while in the roadway. (Similar to an erratic maneuver)
4. Near Miss Accident (N_p) - A collision is eminent, but is avoided just before impact.
5. PDO Accident (P) - Property damage only accident
6. Injury Accident (I)
7. Fatality (F)

Actions taken by the second actor, the vehicle, were also examined to determine conflict severity. Vehicular actions used to measure conflict severity are listed below in order of increasing severity, with the "v" subscript referring to vehicular action (Cynecki, pp. 12-13):

1. Routine Conflict (C_v) - When a vehicle brakes or weaves routinely to avoid a collision with a pedestrian.
2. Complete Stop/Erratic Maneuvers (E_v) - When a vehicle comes to a complete stop or swerves erratically to avoid a collision.
3. Near Miss Accidents (N_v) - A collision is eminent but is avoided just prior to impact.
4. PDO Accident (P) - Property damage only to the vehicle and the pedestrian does not sustain an injury.
5. Injury Accident (I)
6. Fatality Accident (F)

In addition to these measures of conflict severity, a further measure, that of moving vehicle action (M) was defined (Cynecki, p. 12):

This action occurs when a pedestrian moves across the path of a through or turning vehicle and is approximately 25 feet (7 meters) "downstream" of that moving vehicle but the vehicle takes no evasive action to avoid a collision. The pedestrian is in the moving lanes of traffic when this

action occurs. Although the vehicle does not brake or weave in this action, this is still considered a hazardous situation and should be recorded. The hazard is usually indicated by a pedestrian hesitating, backing up, or running to avoid a collision.

In spite of creating a pedestrian action severity scale, the decision was made to determine conflict severity based on vehicular actions "because it was felt that severity defined by vehicle actions would provide more consistent [sic] results and would be easier for the observer to view" (Cynecki, p. 13). Such may indeed be the case; however, a hazardous situation may exist in which no vehicular action is taken although a pedestrian action occurs. Also, a hazardous situation may exist although neither a pedestrian action nor a vehicular action occurs. The author has taken notice of some of these conflicts in the moving vehicle action category, although this category only covers pedestrians 25 feet "downstream" of the moving vehicle. This definition suffers from two faults. One fault is that distance is used as a measure of hazard rather than time. Because pedestrian speeds are low and do not exhibit a great range of values such a fault is not as great as is the second fault. The moving vehicle category only considers downstream pedestrian and not "upstream" pedestrians, in which the vehicle arrives at some point before the pedestrian does. Hazardous situations can and do exist when pedestrians pass "upstream" of the vehicle. Although vehicular actions may not occur, pedestrian actions may, and often do, occur. Time and distance measures of this upstream hazard would help to quantify the hazard of the conflict, or, as is often the case, of the possible conflict that could have occurred.

Three levels of conflict severity were finally used in this conflict analysis technique (Cynecki, p. 13).

The least severe type of conflict (minor conflict) is defined as moving vehicle conflicts (M) where a hazardous situation exists, but no actual weaving or braking takes place. Moderate conflicts are defined as routine conflicts (Cv) and complete stop/erratic maneuver (Ev) conflicts. Therefore, a moderate conflict is when a braking or weaving action is taken by a vehicle to avoid a collision with a pedestrian. The third level of conflict severity is a severe conflict, which is defined as a near miss accident (Nv)

Using this conflict analysis technique five intersections were examined. The average number of conflicts per hour was recorded, with this value being subdivided by the severity of the conflict. Because of the limited survey time, valid conclusions could not be made concerning the hazardousness of these intersections, although the conflict analysis technique did indicate types of conflict maneuvers such as right turning conflicts, left turning conflicts, etc. This study, although commendable for attempting to classify pedestrian-vehicular interactions, lacks a quantifiable measurement procedure. Although behavioral analysis is a subjective technique, quantifiable measures, in this case, time and distance "upstream" and "downstream" of moving vehicles, need to be taken into account. Furthermore, just as pedestrian-vehicular conflicts should not be separated or omitted from a pedestrian behavior study, neither can a pedestrian-vehicular study be conducted separate from a pedestrian behavior study. A study of pedestrian behavior should be as complete as possible and analyze the approach to the crossing, the wait at the curb, departure behavior, crossing behavior (which should include pedestrian-vehicular

conflicts), and the arrival at the opposite curb. Only through such a comprehensive analysis can pedestrian behavior and pedestrian safety be better understood.

Summary

A study of the literature on pedestrian behavior, then, served to sharpen the focus of the research effort. The research cited herein tended to indicate that pedestrian signals did not measurably affect pedestrian accidents or pedestrian behavior. This research effort sought to concentrate on pedestrian behavior at one intersection, specifically examining behavior with and without pedestrian signals. In addition, a rather detailed paper on pedestrian-vehicular conflicts aided in establishing a methodology of analysis for such interactions.

CHAPTER III

STUDY DESIGN

Introduction

This study sought to examine pedestrian behavior at an intersection with pedestrian and traffic signals and to analyze behavior at that same intersection having only traffic signals present. In order to properly address the previously formulated research questions it was necessary to devise a suitable study methodology. Care had to be taken to gather data in such a manner that pedestrian behavior would not be measurably affected while obtaining all the needed information.

Data Collection

Several data collection and analysis methods are available for studies of human behavior. In an effort to obtain precise and reliable data, various data collection methods were considered for their suitability for the current project. One such method is the moving observer method in which an unbiased researcher follows an individual and records observational information on a written form or by microphone. Such a procedure would provide for close scrutiny of movements, although the same close observation would be difficult to carry out unnoticed by the subject. Furthermore, to gather sufficient data for statistical validity, several properly trained observers would be required, and, even in such a case, subjective, interpretive differences would surely occur. Due to the difficulty in carrying out such data collection while remaining unnoticed and not influencing the

subject, and due to the fact that only one individual could collect data for this research, this method was rejected.

Another data collection method involves the use of an observer located at a concealed or unobtrusive vantage point. Such a method offers an obvious advantage over the moving observer method as the observer is not so readily noticeable, which thus lessens the risk of biasing the experiment. Because of the vantage point of the observer, fewer observers are needed than in the moving observer method. Unless there are few subjects per observation period, more than one observer would be necessary, which would also result in subjective differences in certain observations. Due to the difficulty of selecting an appropriate vantage point and the availability of only one observer, this method was rejected for this study.

Another data collection method is that of film recording. Such recording can be made on time-lapse equipment, which allows a frame-by-frame analysis of behavior, or by conventional video tape recording. Although time lapse equipment was available, it was not used in this case due to the cost of film processing and the need for two cameras, and requisite equipment, to complete the analysis. The method chosen for this analysis was video tape recording. Such a method preserved behavior for later analysis and allowed a more thorough and detailed analysis than would have been possible with observational analysis. This method was selected because of the wide variety of data which was to be collected and the availability of suitable recording and playback equipment. Two video cameras, using standard video tapes, were used to provide a complete coverage of the

intersection. A tripod mounting was provided for both cameras to provide a steady picture. Color video tape was used because of its low cost and the added advantage of easier discernment of pedestrians and vehicles when compared to black and white film.

Study Site

The aim of this research was to study pedestrian behavior. Specifically, this study sought to examine pedestrian behavior at an intersection having only traffic control signals and at an intersection having traffic and pedestrian control signals. Because no two locations are exactly alike and could differ in a wide variety of ways, such as pedestrian volumes, traffic volumes, turning volumes, crossing distances, etc., it was felt that the only valid comparison procedure would involve a study at one intersection. Fortunately, the Knoxville Traffic Engineering Department had recently installed a pedestrian signal at the intersection of Cumberland Avenue (a major urban arterial) and Seventeenth Street, adjacent to the campus of the University of Tennessee (see Figure 1). As this signal had been recently installed, the Traffic Engineering Department was willing to permit the covering of the pedestrian signals to simulate a non-pedestrian signalized intersection. Thus, the groundwork was laid for the study. A valid study could now be conducted as significant variables would not vary, or only vary slightly, as the physical features of the intersection would not alter (save for the presence of the pedestrian signal) and traffic features such as traffic volumes and turning volumes were felt to vary only slightly (the analysis was conducted over the same days and for the same time periods for the

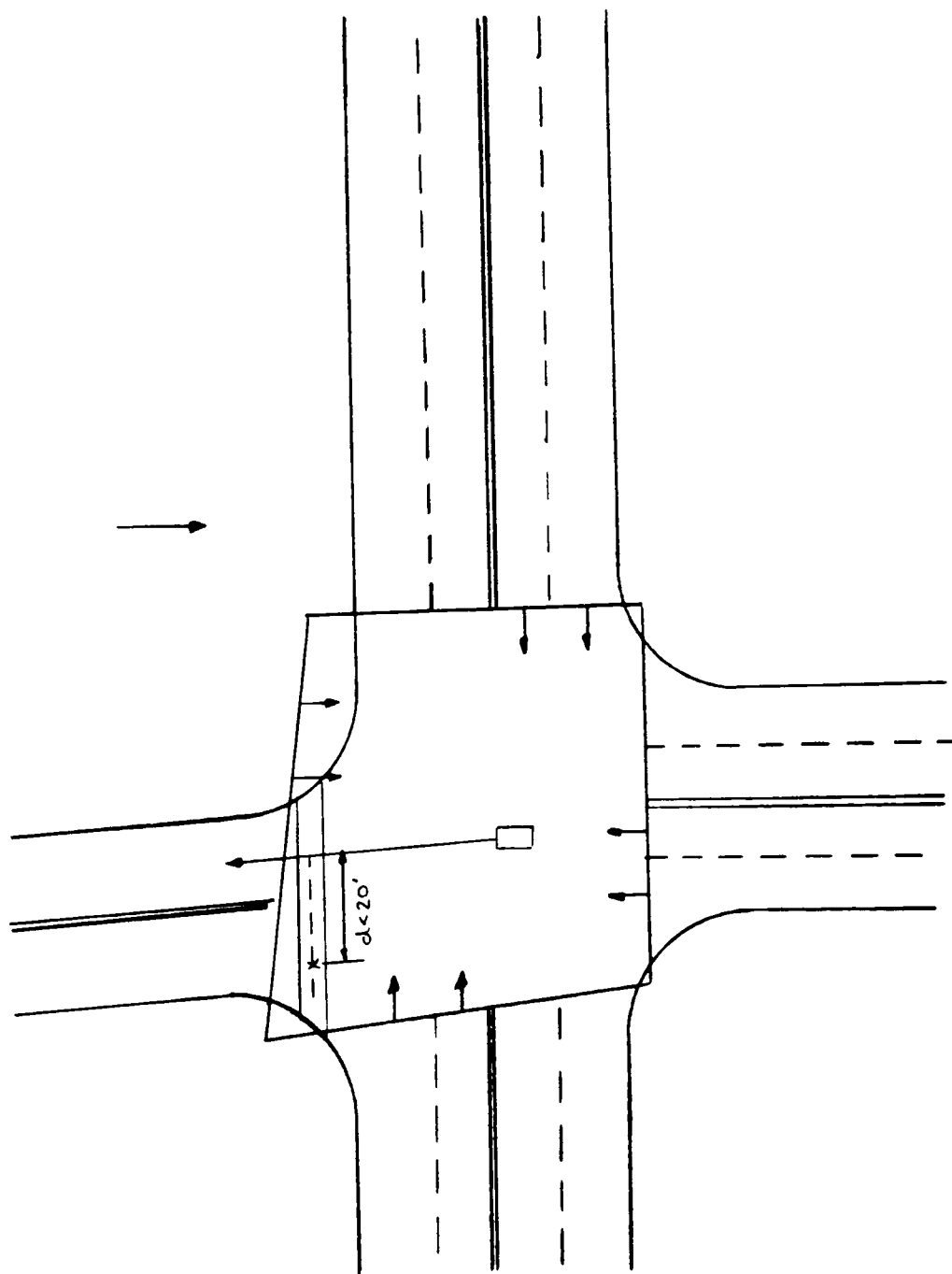


Figure 1
Ahead Interaction

pedestrian signalized and non-pedestrian signalized case, although an interval of nearly two weeks separated the two phases of the study). Because of the proximity to a major college campus it was anticipated that pedestrians would be nearly universally in the early to mid twenties in age, and would thus produce results which could not be extended to the population at large. A more detailed description of the intersection is provided below:

1. The major road, Cumberland Avenue, was a four lane arterial road. The road had a posted speed limit of 35 m.p.h. This road provided an excellent means for examining the crossing behavior of four lane roads with high vehicular speeds and high vehicular volumes.
2. The minor road, Seventeenth Street, was a two lane street in the southern quadrant and a four lane facility (two lanes northbound, one right turn lane, and one lane for through and left turns) in the northern quadrant. The road had a posted speed limit of 35 m.p.h. As previously mentioned, due to the vantage point only the southern quadrant was observed. This provided an excellent opportunity for examining the crossing behavior exhibited on two lane roads with low to moderate traffic volumes and with moderate speeds.
3. The presence of a building at the northeast corner of the intersection served as the location for the mounting of the cameras. The roof of the building could be

accessed easily and the equipment was secure during the duration of the filming.

4. Relatively wide sidewalks with few street appurtenances permitted a clear view of the approach and curb behavior of the pedestrians. This also allowed pedestrians clear views of each crossing.
5. A marked pedestrian crossing existed for both Seventeenth Street and Cumberland Avenue. This provided a clearly defined path or channel for the pedestrians to use. It should be noted that the intersection was offset and thus the Cumberland crossing was also offset. It was found that the majority of pedestrians crossing Seventeenth crossed within, or very near to, the marked crossing. A large proportion of pedestrians crossing Cumberland also crossed within the crosswalk, and although a number of pedestrians may have begun outside the crosswalk the majority completed the crossing within the crosswalk, especially if vehicles had stopped in the westbound direction on Cumberland.
6. The location of the intersection provided sufficient pedestrian volumes so that a relatively large number of crossings could be analyzed. These pedestrian volumes, coupled with the moderate to high vehicular volumes created the existence of pedestrian-vehicular conflicts which were of extreme interest in this study.

Filming Sequence

This study concerned pedestrian behavior with and without the presence of pedestrian signals. In the first phase of the study, pedestrian crossing behavior with both traffic and pedestrian signals was examined. Because of the westerly orientation of the intersection camera and the preponderance of pedestrian traffic during the morning and early afternoon, filming was conducted from approximately 9:00 A.M. to 2:00 P.M. Monday, July 6, Tuesday, July 7, and Wednesday, July 8, 1987. The camera equipment was set up and the camera lenses were focused early in the morning by the observer, who then left the equipment so as to preclude any bias on pedestrian behavior. The observer returned periodically to check that the equipment was functioning properly.

Part of this research focused on pedestrian-vehicular interactions. In order to analyze pedestrian-vehicular conflicts both time and distance measures were used. Distance measures were obtained from markings which had been placed on the crossings and on the curb sides at five foot intervals. All markings on Cumberland Avenue were made with white spray paint, while markings on Seventeenth Street were made by using strips of yellow pavement marking tape. It was felt that such markings would not affect the validity of the study by influencing pedestrian or vehicular behavior. Street markings simplified the analysis for pedestrian-vehicular conflicts, while curb markings helped define the points of entry and exit for the crossing.

In the second phase of the study all pedestrian signals were covered with a plastic covering which did not permit the pedestrian

indication to be seen. The pedestrian signals were covered Tuesday, July 14, 1987 and were left so covered for the remainder of that week and the following week before being filmed, to allow pedestrians to adjust to the new conditions. Filming for the second phase of the study began on Monday, July 27 and continued on Tuesday, July 28, and Wednesday, July 29, 1987 with filming occurring each day from approximately 9:00 A.M. until 2:00 P.M. As with the first phase of the study, the equipment was set up in the morning and all the equipment activated and checked before the observer left. Periodic inspections were made to ensure that filming was being conducted correctly and that equipment was operating properly. A more in-depth description of the data collection procedure follows.

Detailed Data Collection

The crucial problem in filming was the necessity to view the entire intersection while also being able to correctly note the behavior of pedestrians. These two differing requirements necessitated the use of two video cameras--one providing a close-up view of approach and curb departure behavior, and the other providing a wider view of the entire intersection to examine pedestrian-vehicular conflicts and curb arrival behavior. After experimenting with different camera locations and lens settings, it was found that the best technique utilized one camera focused on the departure curb and one camera focused on the entire intersection. The curb camera was initially to be used solely for the observation and recording of curb behavior. Under this arrangement, all other pedestrian behavior, such as approach behavior, crossing behavior, and behavior upon arrival at the

opposite curb had to be recorded by the second camera. It was found that the image size of the pedestrians recorded by the second camera was too small to permit an accurate assessment of pedestrian behavior. Thus, the first camera was given the same location as before but with a wider angle of vision so that approach behavior, curb behavior, crossing indication, and lane crossing behavior in lanes one and two of Seventeenth Street and lanes one and two of Cumberland Avenue (the two eastbound lanes) could be observed. In addition, preliminary data concerning pedestrian-vehicular conflicts could be gained from camera one such as vehicular and pedestrian movements, although camera two was used to supplement and certify observed conflicts.

Each camera was wired to a separate video recorder, which received power from a nearby electric outlet. A steady power source helped to guard against equipment failure and to assure steady-speed recording so that events would be recorded in real-time and subsequent time measurements made with play-back equipment (also using a steady power supply) would be accurate.

The selection of a suitable data collection procedure insured that the proper data could be obtained so that the research questions could be addressed in a substantive manner through the preparation of hypothesis and subsequent statistical tests. Video recording served to collect the necessary data while offering minimal interference with pedestrian behavior.

CHAPTER IV

DATA REDUCTION

Data Collected

This study sought to examine pedestrian and vehicular behavior at an intersection for two separate cases: (1) with both traffic signals and pedestrian signals present, and (2) with only traffic signals present. A survey of the literature on pedestrian behavior and pedestrian signalized and non-pedestrian signalized intersections had provided a number of questions which the current research sought to answer. In order to answer those questions, or at least to address them in a formative and complete manner, the requisite data had to be obtained from the raw video tapes. A rough data collection form was created and then a pilot video tape analysis was run to ensure that all the necessary data could be obtained easily and accurately. The data collection form was then modified and the video tape data were analyzed. In order to understand the type of data collected and the collection methodology, an explanation of the video reduction method and the data collection form will be presented.

Film Reduction

A conventional video tape recorder/player was used for data analysis. The player was then connected to a color television screen to permit viewing of the image. This equipment could perform a number of functions which greatly aided in the data analysis:

1. The use of a color monitor allowed the preservation of the

original color recording and thus allowed for easier discernment of pedestrian and vehicular actions.

2. The fast-forward control allowed the quick movement from one road crossing to the next. As filming was continuous and there were often long periods of time between pedestrians, this feature proved to be most useful.
3. The rewind control allowed the review of film segments so that missed data could be collected and, more importantly, the data could be checked for accuracy--this proved to be quite valuable in collecting data on pedestrian-vehicular interactions.
4. The pause button allowed the image to be frozen so that the necessary data could be extracted and the slow motion button allowed actions to be viewed at a reduced speed. This later function was initially thought to be quite useful for judging looking behavior, but because of the small image size (especially the head size) and the video distortion caused by slow motion playback this feature was not used very often.

As there were two video cameras used in this study with two separate sets of recording equipment, there were two video tapes for each study day. As previously discussed, one camera was focused at the departure curb and was used to provide data regarding approach behavior, curb behavior, and departure behavior. The other video tape was recorded by a camera having a wider field of view and thus contained data on crossing behavior, pedestrian-vehicular interactions, and arrival at the opposite curb. Initially, it was hoped that one camera, perhaps the intersection camera, could also record the traffic

signal indication (red, amber, or green) so that the signal indication and time into each signal indication could be recorded. The basis of comparison for the entire study was the signal indication (pedestrian and/or traffic signal) when the pedestrian crossed the roadway. Unfortunately, the camera position did not permit the traffic signal indication to be seen. Thus, an alternate method was necessary if the traffic signal data were to be obtained. A time-date generator was used to provide a time in the form of hours, minutes, and seconds which could in turn be used to derive the appropriate traffic signal indication. The time-data generator necessitated the playing of one tape through the time-date generator which produced a time, and then recording this original intersection image with some reference time overlaid. In most cases care was taken to use the actual time if known, although this was of little importance as only a reference time was needed. For the video tapes produced for the second phase of the study, in which the pedestrian signals were covered and only the traffic signals provided pedestrian and vehicular guidance, the actual time had been recorded along with the time when the red phase began. For recordings made in the first phase the pedestrian indication could be viewed, and the start of a certain pedestrian signal indication could be related to the start of the red traffic signal indication. In addition, the approximate time at which taping had begun had been recorded earlier for the first phase of the study. Early on, the decision was made to study only one cycle length pattern, namely the 90 second cycle which existed from 8:55 A.M. until 3:00 P.M. Thus, once all the data were properly prepared and assembled, the next step

in the process was the analysis of the video tape data. An understanding of and an appreciation for the data collected during the course of this study can probably be best appreciated by examining, in a step-by-step fashion, the data form that was finally used to collect information on pedestrian behavior.

Pedestrian Data Form--Walking and Looking

As previously stated, a preliminary data form was prepared based on the literature survey and various other questions and hypotheses concerning pedestrian behavior. A pilot video data analysis was then conducted and the data form was modified (see Figure 2). An in-depth examination of this form would be helpful in understanding the aims, goals, and methodology of this research.

1. Crossing

Both pedestrians crossing Cumberland Avenue and pedestrians crossing Seventeenth Street were the subjects in this study. Unfortunately, due to equipment limitations, only pedestrians departing from the southeast curb were studied. That is, only pedestrians crossing on the south side of Seventeenth Street and moving in a westerly direction and only pedestrians crossing on the east side of Cumberland Avenue and moving in a northerly direction were subjects of this research. Thus, the crossing was coded as either Cumberland or Seventeenth.

2. Sex

Data on the sex of the pedestrian was collected to determine if there were any differences in behavior between men and women. In most

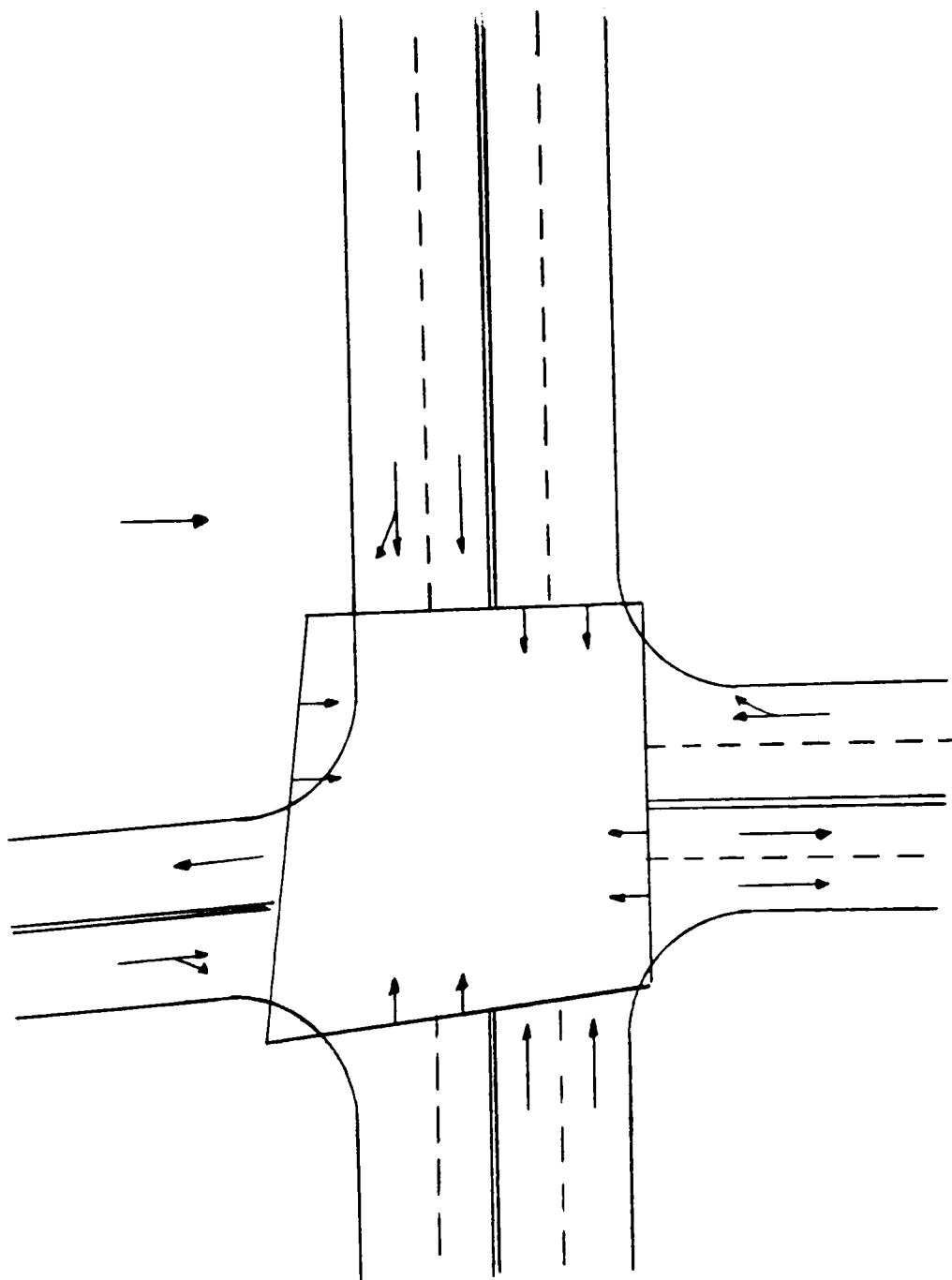


Figure 2
Intersection View

cases the determination of an individuals sex was quite simple, although in some cases there was a difficulty due to the image size, even though the camera focused on the curb was used to provide this information.

3. Age

Data on the age of the pedestrians was felt to be useful for categorizing pedestrian behavior by age. There was more difficulty in distinguishing between categories than there was for the previous data set. An effort was made to correctly identify the age, although such efforts were sometimes difficult given the small image size.

4. Social Situation

Pedestrian crossings were coded as being made alone or in a group. If there appeared to be some type of interaction between pedestrians during a road crossing, then the crossing was classified as a group crossing, with the size of the group then being recorded. Clearly, this classification was somewhat subjective. In some instances, such as a family or a couple holding hands, the classification was clear; in other cases it was not so simple to make the determination. A further subjective measure was employed when the interaction level of the members in the group was recorded. Both the existence of a group and the cohesiveness of that group were felt to be important indicators of pedestrian behavior. Interactions in the group were grouped into three levels: (1) low, in which there was slight interaction among members and fairly large distances separating pedestrians in the group; (2) medium, in which there was a moderate level of interaction although group members did not touch one another

or walk beside one another; and (3) high, in which group members established physical contact with one another or walked closely side-by-side. Partly because of the subjective nature of this categorization scheme and also because of the relatively low number of pedestrian groups, but, more importantly, indecision regarding the way in which to analyze groups of pedestrians, groups of pedestrians were excluded from this study. This does not negate the importance of analyzing groups but only serves to highlight the difficulties therein. The methodology discussed could serve as a point of departure for future studies in this area.

5. Approach Rate

The approach rate of the pedestrian was coded as being either running or walking during the approach to the curb. These data were obtained to see if any link existed between the approach rate and wait time, and between other variables such as the departure signal indication and subsequent looking behavior for the roadway crossing.

6. Observing Behavior During Approach

Curb behavior was also recorded as this was believed to have a significant bearing upon subsequent looking behavior and upon potential pedestrian-vehicular interactions. Information was recorded concerning whether the pedestrian looked left or right, looked in both directions, did not look at all, and, in a separate category, if the pedestrian looked behind. A pedestrian crossing Cumberland Avenue was judged to have looked behind if he/she looked south toward the Seventeenth Street intersection approach. A pedestrian crossing Seventeenth Street was judged to have looked behind if he/she looked east

toward the Cumberland Avenue approach. The pedestrian was considered to be at the curb if he/she was at the curb or if he/she was in the roadway but within one or two feet from the curb and had stopped or paused before starting to cross the roadway. The total number of looks was not recorded, only the type of look that had been made. As with other data, observation movements were difficult to observe. In this case, head movements were used to indicate observing behavior. To be sure, a pedestrian could look left or right without any noticeable head movement, but it was felt that any looking behavior that would provide a complete view of the traffic situation would require a definite and noticeable head movement.

7. Direction of Approach to Curb

Information was collected on the approach direction (North, South, East, or West) in an effort to determine if looking behavior or pedestrian-vehicular interaction were influenced by the directional approach. As no significance could be attached to approach direction this information was not used.

8. Stop Time

Time spent at the curb before crossing the road was measured to learn the average wait or delay time experienced by a pedestrian. Attempts were also made to link stop time to looking behavior both at the curb and during the crossing maneuver.

9. Signal Indication on Arrival

As previously mentioned, a date-time generator was used to affix a clock time in the form of hours, minutes, and seconds to the video tape recording covering the entire intersection. The generator was

synchronized with the video recorder so that the real time movements on the original tape were preserved on the recorded tape and the time indicated on this recorded tape corresponded to real time on the tape. That is to say that if ten seconds of real time had elapsed the clock time would also indicate that ten seconds of time had passed. Thus, calibrations and measurements using this clock time would correspond exactly to the time, or rather difference or change in times, in which events actually did occur at the intersection.

To determine the arrival signal indication it was first necessary to know the clock time, or the reference time which had been created by the date-time generator. It should be noted that the arrival signal was the signal indication when the pedestrian arrived at the curb. Thus, if the pedestrian did not stop at the curb, the wait time would be zero and the signal indication upon arrival and the signal indication upon departure would be the same. If the pedestrian stopped at the curb then the signal indication upon arrival would be the signal indication when forward motion (approach motion) ceased or the exact moment when the wait began. Then, a computer program was written in the BASIC computer language to indicate the signal indication (green, amber, or red) and the time into each of these indications given some clock time. As the signal cycle length was set at 90 seconds for the period in which observations were made, only the time when the indication (in this case the red indication) began needed to be known. The BASIC program was then used to create the signal indication and time, in seconds, into that indication given a clock time.

10. Signal Indication on Departure

Information was also collected on the signal indication and time into that indication when the pedestrian left the curb. To provide for consistent results, departure was considered to be that instant in which one or both of the pedestrians feet touched the roadway. In some cases the pedestrian paused or stopped at the curb and then paused or stopped at some distance in the roadway. In such an instance the pedestrian was considered to be at the curb if he/she was within two feet of the curb. Then, departure time was taken to be the instant in which movement initiated from this pause or stop position in the roadway. This consideration was made after a preliminary video tape analysis indicated the existence of this type of maneuver. This type of crossing maneuver was especially prevalent for the Seventeenth Street crossing, which may have been related to the relatively wide curb radii and the moderate traffic levels. Although in the roadway, the pedestrian was not considered to be in the vehicular path because of the short distance to the raised curb. In some cases the pedestrian waited in this position for a rather long period of time, and including this time as part of the walk time would only lengthen the average crossing time and thus serve to increase the time the pedestrian was apparently exposed to vehicles when, although in the roadway, the crossing had not yet been initiated.

The same procedure used for calculating the signal indication on arrival and time into the arrival signal was used for calculating the departure signal.

11. Walk Speed

An additional piece of information that was obtained from the video tape data was the walk speed of the pedestrian, which was coded as either walk or run. Again, there was some judgement involved in this categorization, although a walk was considered a movement in which one foot was on the ground at all times. The pedestrian was considered to have run if both feet left the ground at any time and if this act occurred for at least one-third the length of the lane. This behavior was recorded for each lane. Thus, it was recorded for lanes one and two for Seventeenth Street and for lanes one, two, three, and four for Cumberland Avenue.

12. Looking Behavior

Just as information had been collected on looking behavior at the curb, information was collected on looking behavior for each lane the pedestrian traversed. Again, head movements were used to indicate looking behavior. There were four categories of looking behavior: left, right, both directions, and neither left nor right. The number of looks made was not recorded, only the type of look that had been made. Problems arose when curb looking behavior was being examined because of the same image size of the pedestrian and thus the small image size of the pedestrian's head. This problem was compounded when looking behavior for the traffic lanes was to be examined, because the intersection view rather than the curb camera view had to be used, with the resulting image size even smaller than was the case for the curb view. In addition, the position of the cameras created problems. Although the curb camera nearly squarely faced northbound pedestrians

crossing Cumberland, the lens was perpendicular to Seventeenth Street pedestrians; however, this was not as great a problem as it initially appeared, because the curb camera was focused on the curb and had larger image sizes than did the intersection camera. The angular displacement of the intersection camera, coupled with the reduced image size necessitated by complete coverage of the intersection, often created problems in judging the looking behavior of pedestrians. Because of these problems, looking behavior will still be examined to test for influences on other behavioral aspects, but the results will be treated with caution given the uncertainty of the data.

13. Signal indication upon arrival at opposite curb

Information was also collected on the signal indication and time into that signal indication when the pedestrian arrived at the opposite curb and had completed the crossing. In this case, arrival was that instant in which one or both of the pedestrians feet touched the opposite curb. In certain instances the pedestrian did not go to the opposite curb but turned in the street and began to cross the other street. In such cases the arrival time was taken to be the time when the pedestrian altered course; obviously, in certain cases this directional change could not be calculated to the exact second but an error of one or two seconds in those few cases was not judged to be critical.

As for the arrival and departure signals, the signal indication and time into that indication was calculated by using the clock time shown on the video screen and the time in which the red cycle on

Cumberland Avenue began and inserting these values into the computer program which calculated the signal indication.

Pedestrian Data Form--Interactions

Part of this research sought to examine vehicular-pedestrian interactions. The next set of information was used as data for this study. An effort will be made to explain the data collection procedure and so that the type of data collected may be better understood.

In an effort to quantify vehicular-pedestrian interactions, and to also provide a definition, time and distance measurements were utilized. Based on the previously cited paper by Cynecki and the pilot video tape analysis, vehicular-pedestrian interactions were arbitrarily defined as any interaction between a crossing pedestrian and a vehicle in which, for the "ahead" case, the vehicle passed within twenty feet of the pedestrian. In other words, twenty feet or less separated the vehicle from the pedestrian when the vehicle passed point in space some time before the pedestrian arrived at that same point. For cases in which the vehicle was ahead of the pedestrian, the time separation refers to the time it would take the pedestrian to reach the point where the vehicle was and thus depends upon pedestrian walking speeds. Because walking speeds are rather low, especially when compared to vehicular speeds, and because pedestrians can alter course and speeds much more rapidly and easily than can vehicles, time separation is not as useful a measure as is distance separation. Thus, for the ahead case, distance measurements were nominally taken. Distances were measured from the video tape data by using the physical grid that had been created on the intersection. As can be inferred

from this discussion, curb interactions would only occur for the ahead case, as a behind case could only occur if the pedestrian were in the roadway. Also, the location of the vehicular-pedestrian interaction was defined by the lane occupied by the vehicle when the incident occurred. A few examples will help to clarify this placement scheme. If a vehicle travelled southbound on Seventeenth Street through the intersection and passed a point in the crosswalk at some time while the pedestrian was in the first lane of Seventeenth, this would be defined as an ahead interaction, but would only be recorded if the vehicle passed within twenty feet of the pedestrian. This would further be regarded as an ahead interaction occurring in lane two (see Figure 3). If a vehicle turned left from Seventeenth Street into lane one of Cumberland Avenue and proceeded to travel in an eastbound direction and crossed some point in the crosswalk, or path of the pedestrian, within five seconds after the pedestrian passed that same point, then the interaction would be termed a behind interaction which occurred in lane one (see Figure 4). As can be seen from the discussion, the vehicle position does not indicate in precise terms the pedestrian position. This information was not deemed critical to this part of the study, as only the relative positions of the vehicles and pedestrians were important. The time and distance measures for spatial separation were felt to be far more important items for this research.

The study of vehicular-pedestrian interactions also sought to focus on avoidance maneuvers or compensatory behavior made by either the vehicle or the pedestrian. The pilot video data analysis revealed

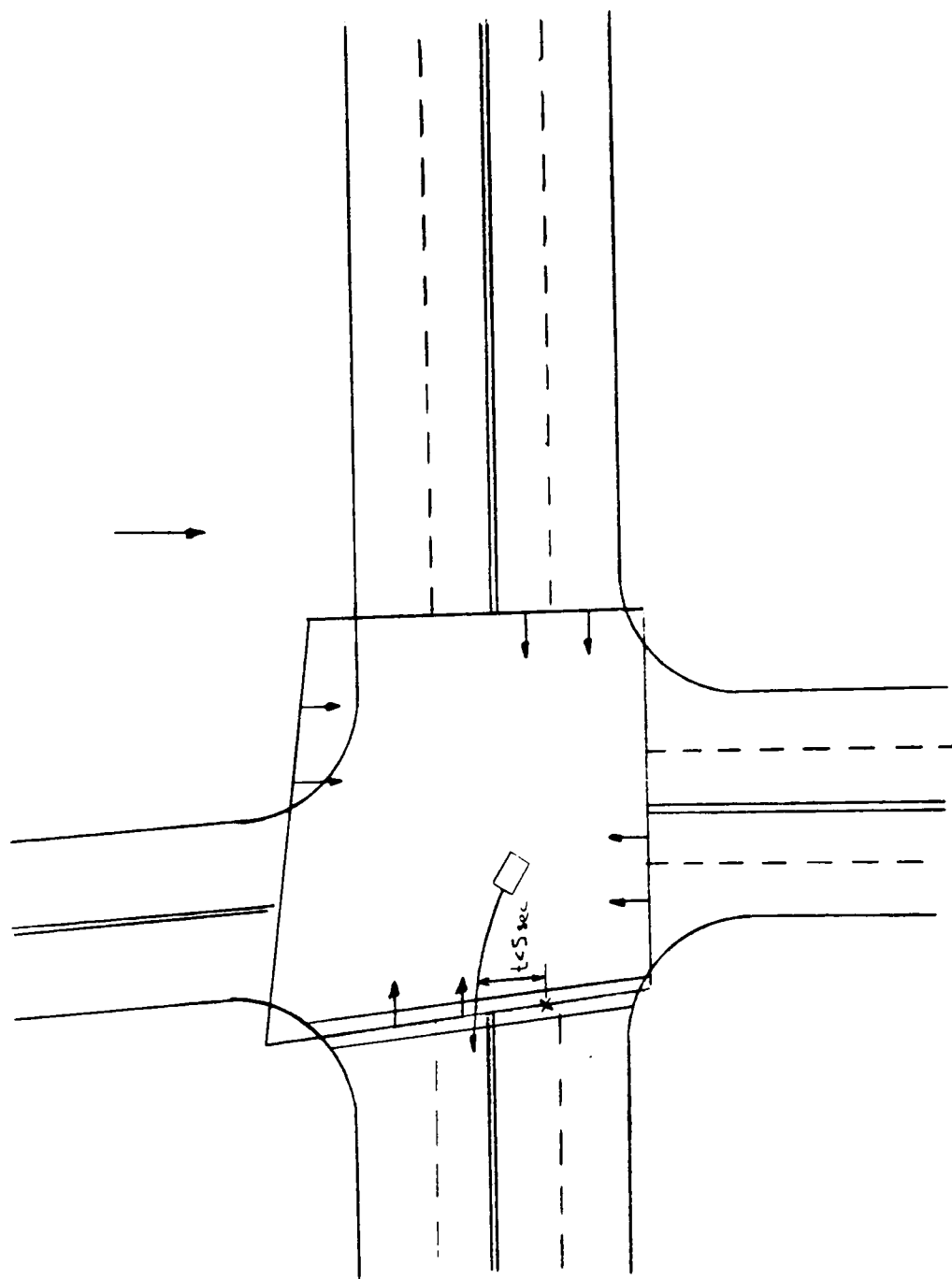


Figure 3
Behind Interaction

BEHAVIORAL ANALYSIS DATA FORM

(1) Crossing _____

(2) Sex: M _____
F _____

(3) Age: 0-10 _____
10-20 _____
20-30 _____
30-40 _____
40-50 _____
50+ _____

(4) Social Situation: Alone _____
Group _____
Group size _____
Interaction level of individual in group: low _____
medium _____
high _____

(5) Approach Rate: Run _____
Walk _____

(6) Observing behavior during approach: one-direction _____
two-direction _____
behind _____
did not observe traffic _____

(7) Direction of approach to curb: N _____
S _____
E _____
W _____

(8) Stop time: _____

(9) Signal indication on arrival: Clock Time: _____
Signal and Time: _____

(10) Signal indication on departure: Clock Time: _____
Signal and Time: _____

(11) Walk speed lane 1: _____

(12) Looking behavior lane 1: _____

(13) Walk speed lane 2: _____

(14) Looking behavior lane 2: _____

(15) Walk speed lane 3: _____

(16) Looking behavior lane 3: _____

(17) Walk speed lane 4: _____

(18) Looking behavior lane 4: _____

(19) Signal indication upon arrival at opposite curb: Clock Time: _____
Signal and Time: _____

(20) Move _____

(21) Time Separation _____

(22) Distance Separation _____

(23) Pedestrian Avoidance Maneuver
Yes _____
No _____

(24) Vehicular Avoidance Maneuver
Yes _____
No _____

Figure 4

Behavioral Analysis Data Form

several type of maneuvers that were performed in the case of a vehicular-pedestrian interaction. The pedestrian could stop, change direction and/or change speed, or take no apparent action. The vehicle was more constrained than the pedestrian in terms of its speed and the ease with which it could make sudden maneuvers. Vehicles could stop, change direction and/or change speed, or take no apparent action. Initially, it was desired to classify the avoidance action taken by either the pedestrian or the vehicle, but it soon became apparent that such a classification, though admirable, was, for this study at least, not feasible. Although hard vehicle braking and pedestrian running and stopping were clearly visible, more subtle effects such as slowing or increasing speed by either the vehicle or the pedestrian were not so clear. In addition, a host of other factors could account for an observed vehicular-pedestrian action, not necessarily the presence of an interaction, but perhaps another vehicle or pedestrian or the signal indication or any number of factors. Rather than attempting to classify the avoidance maneuvers, the decision was made to simply record whether or not the vehicle and/or the pedestrian took some type of avoidance behavior, regardless of the kind of behavior taken.

The pilot video tape analysis also revealed the existence of another type of vehicular-pedestrian interaction. This was the simultaneous arrival or, in practice, the projected simultaneous arrival of both the pedestrian and the vehicle at the same point in space. This incident occurred as a vehicle approach the crosswalk as the pedestrian was crossing. As no collisions were recorded, a

vehicle could either change lanes, in which case the interaction altered to a before or after interaction, or continue in the present lane while slowing down and stopping. Thus, for all these cases, the vehicle stopped. The time or distance measure could then be used to infer the "seriousness" of the interaction, although as the vehicle was already in the process of slowing its speed, these measures only served to approximate the hazard. Ideally, it would have been advantageous to have collected speed-time data so that deceleration rates could have been computed, which would have had much meaning for this type of interaction. For this type of interaction, pedestrian avoidance maneuvers were recorded, but for the vehicular maneuver all maneuvers were defined as stop maneuvers, as it was not possible to judge the deceleration rate and thus indicate whether the stop was a normal braking maneuver or a harsh stop. Any sudden movements or hard stops would have been dealt with differently but no such maneuvers were encountered in the video tape analysis.

In order to alleviate any confusion, the basic methodology for classifying vehicular-pedestrian interactions is described below. A behind pedestrian-vehicular interaction was defined as an interaction in which the vehicle passed a point in space after the pedestrian passed that point in space within a five second time interval. An ahead pedestrian-vehicular interaction was defined as an interaction in which a vehicle crossed within twenty feet of the pedestrian's path in advance of the pedestrian arriving at that point. This definition underscores the fact that a vehicle arriving ahead of a pedestrian in another lane would not be considered an interaction if it stopped,

that is, did not cross the pedestrians path. Finally, a simultaneous arrival was defined as a potential arrival by both vehicle and pedestrian at the same point at the same time.

Now that the definitions for pedestrian-vehicular interactions have been presented and the methodologies have been given for their categorization a brief explanation can be given on the data collected for the interaction phase of this study.

20. Movement

The first item of data collected concerning pedestrian-vehicular interactions was the vehicular movement. This information was obtained to indicate the type of vehicular movements which were most frequent in these interactions. The movements were placed in three categories: (1) through movements in which the vehicle continued on its path through the intersection, (2) right turn movements, and (3) left turn movements.

21. Time

Time separation between the vehicles and pedestrians was gathered for all behind interaction cases and for some of the ahead interaction cases. The common point in space where the paths of the vehicle and the pedestrian crossed was marked and a stopwatch giving time in hundredths of seconds was used to indicate the time separation. The measurements were made at the curb and lanes one, two, three, and four.

22. Distance

Distance separation between the vehicles and the pedestrians was gathered for all ahead interaction cases and for some of the behind interaction cases. The common point in space where the paths of the vehicle and the pedestrian crossed was marked on the video screen and distances were scaled using the grid system on the intersection. The pavement marking strips were set at five foot intervals, but distances were estimated to the nearest foot. The measurements were made at the curb and at lanes one, two, three, and four.

23. Pedestrian Action

As previously mentioned, although several types of pedestrian avoidance maneuvers were noticed in the pilot video tape analysis, valid measures for these maneuvers were difficult to find. This being the case, it was decided to measure only the existence or nonexistence of a pedestrian maneuver.

24. Vehicular Action

As was the case with pedestrian maneuvers, vehicle maneuvers were also hard to define. Thus, only the existence or nonexistence of a vehicular maneuver was recorded.

Data Limitations

In the proceeding discussion the type of data and the way in which the data were gathered has been examined. It can be seen that a number of limitations exist in the data and the methodology of collection. Some of these limitations are described below:

1. Limitations on the days and time periods observed. Video recordings were conducted for three days from 9:00 A.M. to 2:00 P.M.

for the first phase of the study and for three days from 9:00 A.M. to 2:00 P.M. for the second phase of the study. Although both phases of the study were made on Monday, Tuesday, and Wednesday, a two week period separated the two phases of the study. Different values may have been obtained by filming on different days and the selection of the same days of the week for filming was an attempt to reduce variation in this regard. Similarly, variation was also reduced by filming of the same time period for the first and second phase of the study; however, different values may have been obtained for different time periods and thus these results may not be transferable to different time periods.

2. Limitations on the crossings observed. Although both Seventeenth Street (two lanes) and Cumberland Avenue (four lanes) were studied, only westbound crossers on Seventeenth Street and northbound crossers on Cumberland Avenue were studied. There were two reasons why only these crossings were examined. First, a pedestrian signal apparatus did not exist at the northwest quadrant, and thus the northern crossing of Seventeenth Street and the western crossing of Cumberland Avenue were not candidates for this study. In addition to this constriction, only one directional flows on each crossing were observed, namely westbound and northbound for Seventeenth Street and Cumberland Avenue, respectively. This data gathering constriction was imposed because of data collection limitations.

3. Difficulties in age categorization. Age data were collected to determine if there were behavioral differences based on pedestrian age. As with all the data, only one observer classified and examined data, which did not provide cross checks on the accuracy of the categorization scheme employed. Pedestrians were grouped in age categories with ten year intervals. Efforts were made to be as accurate as possible, but because of the image size, precise categorization was often impossible. Furthermore, it was later found that most pedestrians were in their early to mid twenties. This served to restrict the application of the results to the entire population.
4. Limitations on types of pedestrians observed. Although data on pedestrian behavior were initially collected for both individual pedestrians and groups of pedestrians, a decision was made to concentrate on the behavior of the individual pedestrian. This stemmed in part from the difficulty in defining a group of pedestrians, particularly the interaction level among the members of a group. Further difficulties arose when trying to examine the behavior of the group. It was not clear whether the behavior of all the pedestrians in the group should be examined or whether only the behavior of the leader should be examined. For that matter, it was often difficult to clearly identify the leader. It was unclear if the leader should be defined as the individual who first arrived at the curb, the individual who first crossed, the individual who lead during the crossing (or a substantial

portion of it), or the individual who first arrived at the opposite curb. A further complication was that pedestrians often shifted position within the group, thus making identification of the leader quite difficult.

5. Limitations on curb looking behavior. As previously mentioned, information collected on curb looking behavior covered the type of look being made--left, right, both left and right, neither left nor right, and behind--not the number of looks which had been made. It was decided, after viewing the pilot video data, that it would be more useful to record the type rather than the total number of looks. Thus, for example, if a pedestrian looked left, then right, and then left before leaving the curb, this was counted as a left look and a right look, or a look in both directions. The key piece of information desired was whether a view of traffic conditions had been obtained rather than the number of times this view was obtained. It should be noted that looking behavior was taken to be regarding the traffic environment and this looking behavior was measured by head movements to either the right, left, or behind.
6. Limitations on lane looking behavior. Lane looking behavior was measured in a similar fashion to curb looking behavior. An important difference was present for lane looking behavior compared to curb looking behavior. Curb looking behavior was confined to one fairly fixed point, the curb. Although pedestrians may have moved about a bit they generally stayed within a few

feet of the edge of the curb. Lane looking behavior, by contrast, could occur at any point in the lane. Attempting to locate the positions where each look began would have been an immensely time-consuming experience and would probably not have yielded any enlightening results, but rather served to over-categorize the data and reduce it to meaninglessness. Thus, looking behavior was recorded in each lane for any head maneuver made by a pedestrian while in that lane. Because of difficulties in viewing looking behavior it was decided not to note behind looking behavior.

Cognizant of these limitations present in the collection of data, the data could now be properly analyzed. As a first step, the data were tabulated in various formats so as to indicate the types and amounts of data gathered. Various hypotheses were then examined and tested in a statistical fashion.

CHAPTER V

RESULTS

Introduction

The data collected in this pedestrian behavior study were subject to statistical analysis in order to examine theorized relationships between the variables concerned with pedestrian crossing behavior. Because of the wide variety of data, initial efforts focused on providing a description of the data. This served to emphasize the wide variety of information collected and also served to indicate the number of observations that were recorded for each variable. After providing a summary of the data collected, attention will focus on the various hypothesis tested in this research. Statistical procedures utilized in this testing process will be described along with the results of these analyses.

Description of Data and Summary Statistics

Before delving into the various statistical tests used to analyze the data, a proper introduction should first be made by providing summary statistics of the data collected in this project, so that the the scope of the research can be better understood and appreciated.

As previously mentioned, filming was conducted for six days--three days for the before situation and three days for the after study. Because of an error in camera placement, the data from one day in the after study filming were unusable. Thus, the data collected on Tuesday, July 28, were not used and data were collected for the other two filming days, that is Monday, July 27 and Wednesday, July 29,

1987. Table 2 indicates the number of single pedestrians observed during these days. As can be seen a total of 368 pedestrian were studied.

Two crossings were studied--Cumberland Avenue and Seventeenth Avenue. One hundred and nine pedestrians in the study crossed Cumberland Avenue and 259 crossed Seventeenth Avenue. A total of 231 males and a total of 137 females were observed. The age distribution for the entire study is shown in Table 3. As can be seen, by far the largest segment of the population falls into the 20 to 30 years of age category. Because of the previously described difficulty experienced with the classification and subsequent analysis of group behavior, only individual pedestrians were examined. Thus, all pedestrians observed were placed in group size one, signifying one pedestrian, and all pedestrians had an interaction level of zero, signifying no interaction, which naturally follows as no groups were examined. Of further interest, 362 of the pedestrians observed walked on their approach to the curb while only 6, or 1.6%, ran on the approach. The number and types of looking behavior recorded at the curb are presented in Table 4. After viewing the summary statistical information the scope and size of the research effort can be gained. The various hypothesis tested will now be presented along with the statistical tests used and the results.

Analysis of Pedestrian Signal Violations

Several hypotheses had been developed concerning pedestrian behavior and it was desired to test these hypotheses. One hypothesis was that pedestrian signals reduce violations. The term "violation"

Table 2

Number of Pedestrians Observed by Day

Study	Day	Pedestrians Observed	Percent
Before --	[Monday, July 6	46	12.5
	[Tuesday, July 7	72	19.6
	[Wednesday, July 8	57	15.5
After --	[Monday, July 27	104	28.3
	[Wednesday, July 29	89	24.2

Table 3
Number of Pedestrians Observed by Age

Age Group (years)	Pedestrians Observed	Percent
< 10	0	0
10-20	9	2.5
20-30	249	67.7
30-40	70	19.0
40-50	20	5.4
> 50	<u>20</u>	<u>5.4</u>
Total	368	100.0

Table 4
Curb Looking Behavior

Type of Looking Behavior	Number of Pedestrians	Percent
Left	99	26.9
Right	26	7.1
Both	186	50.5
Did not Look	<u>57</u>	<u>15.5</u>
Total	368	100.0
Looked Behind	12	3.3
Did not Look Behind	<u>356</u>	<u>96.7</u>
Total	368	100.0

is purposely ambiguous in this case as a wide variety of crossing types were deemed to warrant study. Initially a rather broad definition of a legal crossing maneuver was adopted; namely, a legal maneuver was defined as a crossing which both began and finished in the red phase of the appropriate signal. An illegal crossing maneuver was defined as any crossing which did not either begin or end in the red phase of the traffic signal. Afterwards, another legal crossing maneuver was defined and used as the basis for further hypothesis testing. A legal type 2 crossing was defined as any crossing which both began and ended in the walk phase of the pedestrian signal. This was more restrictive than the earlier definition of a legal type 1 crossing as the walk indication only appears for a portion of the red signal indication. Once an initial hypothesis had been developed, the next step was the selection of the appropriate statistical analysis. For this case a test of proportions was used. The test of proportions can be used with a random variable which follows the binomial distribution. The test of proportions calculates a test statistic Z_0 which can be used to test the hypothesis in question by calculating the critical region for the two-sided alternative hypothesis and the one-sided alternative hypothesis. A more complete explanation of this test is provided in Appendix A-1.

A decision was made to determine if there was a difference in the proportion of illegal crossings, both type 1 and type 2, in the case in which a pedestrian and traffic signal were present and in the case in which only a traffic signal was present. It was hypothesized that the presence of a pedestrian signal would serve to reduce the number

of violations, or illegal crossings. The first hypothesis sought to examine whether the proportions of illegal type 1 crossings on Cumberland Avenue decreased, and the second hypothesis sought to examine whether the proportion of illegal type 1 crossings on Seventeenth Street decreased. The third hypothesis examined whether the proportion of illegal type 1 crossings on Cumberland Avenue decreased for females, and the fourth hypothesis examined whether the proportion of illegal Type 1 crossings on Seventeenth Street decreased for females. These four hypotheses were then tested again with the only difference being that illegal type 2 crossings, rather than illegal type 1 crossings, were examined. Table 5 contains the results of the first set of hypotheses and Table 6 contains the results of the second set of hypotheses. All tests were made at the level of significance $\alpha = 0.05$. As can be observed from the table, in all cases the null hypothesis was accepted. The results of this statistical analysis indicated that there was not a greater proportion of illegal type 1 crossings for either Cumberland Avenue or Seventeenth Street for the after phase compared to the before phase. Similarly, the proportion of illegal type 2 crossings was no greater in the after case. Furthermore, it was found the proportions of illegal type 1 or illegal type 2 crossings of either Cumberland or Seventeenth was not greater for males versus females.

Analysis of Curb Looking Behavior

An examination of curb looking behavior was also made. As previously mentioned looking behavior had been coded as looking to the right, looking to the left, looking both left and right, and neither

Table 5

Hypothesis Concerning Illegal Type 1 Crossings

Hypothesis H_o	Alternative H_a	Test Statistic Z	Probability P	Conclusion
The proportion of illegal type 1 crossings on Cumberland was not greater in the after phase compared to the before phase	The proportion of illegal type 1 crossings on Cumberland was greater in the after phase of the study	-0.583	0.2810	Accept Hypotheses H_o
The proportion of illegal type 1 crossings on Seventeenth was not greater in the after phase compared to the before phase	The proportion of illegal type 1 crossings on Seventeenth was greater in the after phase	0.710	0.2389	Accept Hypothesis H_o
The proportion of illegal type 1 crossings on Cumberland was not greater for males compared to females	The proportion of illegal type 1 crossings on Cumberland was greater for males	-0.411	0.3409	Accept Hypotheses H_o
The proportion of illegal type 1 crossings on Seventeenth was not greater for males compared to females	The proportion of illegal type 1 crossings on Seventeenth was greater for males	0.824	0.2061	Accept Hypothesis H_o

Table 6

Hypotheses Concerning Illegal Type 2 Crossings

Hypothesis H_0	Alternative H_a	Test Statistic Z	Probability p	Conclusion
The proportion of illegal type 2 crossings on Cumberland was not greater in the after phase compared to the before phase	The proportion of illegal type 2 crossings on Cumberland was greater in the after phase of the study	-0.884	0.1894	Accept Hypotheses H_0
The proportion of illegal type 2 crossings on Seventeenth was not greater in the after phase compared to the before phase	The proportion of illegal type 2 crossings on Seventeenth was greater in the after phase	0.073	0.4721	Accept Hypothesis H_0
The proportion of illegal type 2 crossings on Cumberland was not greater for males compared to females	The proportion of illegal type 2 crossings on Cumberland was greater for males	0.266	0.3936	Accept Hypotheses H_0
The proportion of illegal type 2 crossings on Seventeenth was not greater for males compared to females	The proportion of illegal type 2 crossings on Seventeenth was greater for males	-0.121	0.4522	Accept Hypothesis H_0

looking left nor right. These categories were combined so as to indicate whether a pedestrian had looked in any direction before crossing or had not looked at all. Several hypotheses were proposed concerning curb looking behavior. It was first decided to examine whether a difference existed in the proportion of illegal crossings on Cumberland Avenue when the pedestrian did not look between the before and after phases of the study. In a similar fashion, it was decided to test whether a difference existed in the proportion of legal crossings. It was also decided to test illegal and legal crossings which did not involve looking for the Seventeenth Street crossings to determine if there were any differences. A clearer view of these hypotheses can be gained from Tables 7, 8, 9, and 10, which show the hypotheses tested and the results.

It was decided to test these hypotheses by the use of a test of proportions. As for the previous tests, these tests were made at the $\alpha = 5$ per cent level of significance. The results of the analysis indicated that for the Cumberland crossing and for either illegal type one or legal type 1 crossings, the proportion of pedestrians who did not look in the before phase of the study was not significantly different from the proportion who did not look in the after phase. The analysis also indicated that for the Cumberland crossing and illegal type 2 crossings, there was no significant difference in the proportion of pedestrians who did not make a left or right look in the before phase of the study than in the after phase of the study. The test of proportions also indicated that for the Seventeenth crossing and illegal type 1 or illegal type 2 crossings there was no

Table 7

Hypotheses Concerning Curb Looking Behavior for
Cumberland Avenue Crossing and Illegal Type 1 Crossings

Hypothesis H_o	Alternative H_a	Test Statistic $\bar{z}$	Probability p	Conclusion
Considering the Cumberland crossing and illegal type 1 crossing, the proportion of pedestrians who did not look was not significantly different in the after phase compared to the before phase	Given these considerations, the proportion of pedestrians who did not look was significantly different for the two phases	0.890	0.1867	Accept Hypotheses H_o
Considering the Cumberland crossing and legal type 1 crossings, the proportion of pedestrians who do not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who did not look was not the same for both phases of the study	1.217	0.1112	Accept Hypothesis H_o

Table 8

Hypotheses Concerning Curb Looking Behavior for
Seventeenth Street Crossing and Illegal Type 1 Crossings

Hypothesis H_o	Alternative H_a	Test Statistic z	Probability p	Conclusion
Considering the Seventeenth crossing and illegal type 1 crossing, the proportion of pedestrians who did not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who do not look is significantly different for the two phases	-0.209	0.4168	Accept H_o
Considering the Seventeenth crossing and legal type 1 crossings, the proportion of pedestrians who do not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who did not look is significantly different for the two phases	-2.1496	0.0162	Reject H_o

Table 9

Hypothesis Concerning Curb Looking Behavior for
Cumberland Avenue Crossing and Illegal Type 2 Crossings

Hypothesis H_0	Alternative H_a	Test Statistic Z	Probability p	Conclusion
Considering the Cumberland crossing and illegal type 2 crossing, the proportion of pedestrians who do not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who do not look is significantly different for the two phases	0.650	0.4721	Accept Hypotheses H_0
Considering the Cumberland crossing and legal type 2 crossings, the proportion of pedestrians who do not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who do not look is significantly different for the two phases	1.027	0.1515	Accept Hypothesis H_0

Table 10

Hypothesis Concerning Curb Looking Behavior for
Seventeenth Street Crossing and Illegal Type 2 Crossings

Hypothesis H_o	Alternative H_a	Test Statistic Z	Probability P	Conclusion
Considering the Seventeenth crossing and illegal type 2 crossing, the proportion of pedestrians who do not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who do not look is significantly different for the two phases	-0.2943	0.3859	Accept Hypotheses H_o
Considering the Seventeenth crossing and legal type 2 crossings, the proportion of pedestrians who do not look is the same in the before and after phases	Given these considerations, the proportion of pedestrians who do not look is significantly different for the two phases	2.195	0.0139	Reject Hypothesis H_o

significant difference between the before and after studies for pedestrians who did not look at the curb. Furthermore, it was found that for the Seventeenth Street crossing and legal type 1 or legal type 2 crossings, there was a significant difference between the before and after studies for pedestrians who did not look left or right at the curb.

Analysis of the Effect of Pedestrian Signals on Wait Times

Efforts were also made to examine the effects pedestrian signals exerted on wait times. An analysis of the data collected on time spent by the pedestrian at the curb indicated that the data were not normally distributed but were rather highly skewed to one side. As this was the case the decision was made to utilize the Wilcoxon rank-sum test to analyze the data. The Wilcoxon test involves first placing all the data in increasing order and then assigning a rank to the ordered data. The sum of the ranks for each case or group, which in this case would be the before and after phase of the study, is then computed. These sums are then tested to determine whether one is statistically different than the other. A more thorough description of this statistical test is provided in Appendix A-2.

It was decided to test the hypothesis that the presence of pedestrian signals affected looking behavior, which was measured by directional head movements. The results from the Wilcoxon rank sum test shown in Table 11 indicated that the probability that the medians differed by chance alone was 0.0861. Since $\alpha = 0.05$, the null hypothesis that the wait times at the curb do not differ in the before versus the after case cannot be dismissed. In addition an analysis

Table 11
Results of the Wilcoxon Rank-Sum Test Analysis of
Wait Time at the Curb

	N	Wilcoxon Sum of Scores	Scores Expected Under H_0	Standard Deviation Under H_0	Mean Score
Before	175	30711.5	32287.5	918.05	175.49
After	193	37184.5	35608.5	918.05	192.67

$$S = 30711.5$$

$$Z = 1.7161$$

Probability greater than $|Z| = 0.0861$

Result: Accept hypothesis H_0

H_0 : Mean wait time at curb in the before case =
mean wait time at curb in the after case

H_a : Mean wait time at curb in the before case $\neq$
mean wait time at curb in the after case

was performed on the two crossings separately. It was found that the probability that the median wait times for Cumberland Avenue differed by chance was 0.9142 (see Table 12) and thus the null hypothesis that the wait times in the before and after cases for the Cumberland Avenue crossing could not be dismissed. Also, a Wilcoxon rank-sum test was performed to examine whether the median wait times on Seventeenth Street differed in the before and after cases. The results of this analysis, shown in Table 13, indicate that there was no significant difference in the wait time in the before and the after cases for the Seventeenth Street crossings. Thus, for none of the situations examined were the median wait times significantly different in the before (pedestrian and traffic signals) versus the after (traffic signal) phases of this study.

Analysis of the Effect of Pedestrian Signals on Walk Time

Early on in the research study, it was theorized that pedestrian signals would effect the walk time of pedestrians, that is the time spent in the roadway from the time of departure to the time of arrival at the opposite curb. An analysis of the data revealed that walk times were not normally distributed, thus the decision was made to use the Wilcoxon rank-sum test to indicate whether walk times were significantly different in the before versus the after case.

The results of the Wilcoxon rank-sum test are shown in Table 14 which indicated that the probability that the means differed by chance alone was 0.7200. As $\alpha = 0.05$, the null hypothesis that the mean walk times did not differ in the before versus the after case cannot

Table 12

Results of the Wilcoxon Rank-Sum Test Analysis of
Wait Time at the Cumberland Avenue Curb

	N	Wilcoxon Sum of Scores	Scores Expected Under H_0	Standard Deviation Under H_0	Mean Score
Before	45	2492.5	2475.0	157.77	55.39
After	64	3502.5	3520.0	157.77	54.73

$$S = 2492.5$$

$$z = 0.1078$$

Probability greater than $|z| = 0.9142$

Result: Accept hypothesis H_0

H_0 : Mean wait time at Cumberland curb in the before case =
mean wait time at Cumberland curb in the after case

H_a : Mean wait time at Cumberland curb in the before case $\neq$
mean wait time at Cumberland curb in the after case

Table 13

Results of the Wilcoxon Rank-Sum Test Analysis of
Wait Time at the Seventeenth Street Curb

	N	Wilcoxon Sum of Scores	Scores Expected Under H_0	Standard Deviation Under H_0	Mean Score
Before	130	16053.0	16900.0	512.26	123.48
After	129	17617.0	16770.0	512.26	136.57

$$S = 17617.00$$

$$Z = 1.6525$$

Probability greater than $|Z| = 0.0984$

Result: Accept hypothesis H_0

H_0 : Mean wait time at Seventeenth curb in the before case =
mean wait time at Seventeenth curb in the after case

H_a : Mean wait time at Seventeenth curb in the before case $\neq$
mean wait time at Seventeenth curb in the after case

Table 14

Results of the Wilcoxon Rank-Sum Test Analysis of Walk Time

	N	Wilcoxon Sum of Scores	Scores Expected Under H_0	Standard Deviation Under H_0	Mean Score
Before	171	30683.5	31036.5	983.41	179.44
After	191	35019.5	34666.5	983.41	183.35

H_0 : Mean walk time in the before case =
mean walk time in the after case

H_a : Mean walk time in the before case $\neq$
mean walk time in the after case

$$S = 30683.5$$

$$Z = 0.3584$$

Probability greater than $|z| = 0.7200$

Result: Accept hypothesis H_0

be dismissed. Furthermore, separate analyses were performed on the two crossings. The probability that the mean walk times for the Cumberland Avenue crossing differed by chance was 0.5452 (see Table 15) and thus the null hypothesis that the walk times in the before and after case did not significantly differ for the Cumberland Avenue crossing could not be dismissed. A Wilcoxon rank-sum test was also performed to determine whether the median walk times for the Seventeenth Street crossing were significantly different in the before compared to the after case. The results of this analysis, shown in Table 16, indicate there was no significant difference in the mean walk time in the before and after cases for the Seventeenth Street crossings. Therefore, for none of the situations were the mean walk times significantly different in the before versus the after phases of the study.

Summary of Results

Pedestrians crossing behavior at marked crosswalks at an intersection of a major and a minor road was studied. The results obtained from this research are presented below:

1. A comparison of legal and illegal pedestrian crossings for the case of pedestrian and traffic signals versus the case of traffic signals revealed that:
 - a. The proportion of illegal type 1 crossings of Cumberland Avenue was not significantly greater in the after phase compared to the before phase
 - b. The proportion of illegal type 1 crossings of Seventeenth Street was not significantly

Table 15

Results of the Wilcoxon Rank-Sum Test Analysis of Walk Time for the
Cumberland Avenue Crossing

	N	Wilcoxon Sum of Scores	Scores Expected Under H_0	Standard Deviation Under H_0	Mean Score
Before	44	2376.0	154.54	56.14	56.14
After	63	3308.0	3402.0	154.54	52.51

H_0 : Mean walk time for Cumberland crossing before =
mean walk time for Cumberland crossing after

H_a : Mean walk time for Cumberland crossing before $\neq$
Mean walk time for Cumberland crossing after

$$S = 2470.0$$

$$Z = 0.6050$$

Probability greater than $|z| = 0.5452$

Result: Accept hypothesis H_0

Table 16

Results of the Wilcoxon Rank-Sum Test Analysis of Walk Time for the
Seventeenth Street Crossing

	N	Wilcoxon Sum of Scores	Scores Expected Under H_0	Standard Deviation Under H_0	Mean Score
Before	127	16511.0	16256.0	579.23	130.01
After	128	16129.0	16384.0	579.23	126.01

H_0 : Mean walk time for Seventeenth crossing before =
mean walk time for Seventeenth crossing after

H_a : Mean walk time for Seventeenth crossing before $\neq$
Mean walk time for Seventeenth crossing after

$$S = 16511.0$$

$$Z = 0.4394$$

Probability greater than $|z| = 0.6604$

Result: Accept hypothesis H_0

greater in the after phase compared to the before phase

- c. The proportion of illegal type 1 crossings of Cumberland Avenue was not significantly greater for males than for females
 - d. The proportion of illegal type 1 crossings of Seventeenth Street was not significantly greater for males compared to females
 - e. The proportion of illegal type 2 crossings of Cumberland Avenue was not significantly greater in the after phase compared to the before phase
 - f. The proportion of illegal type 2 crossings of Seventeenth Street was not significantly greater in the after phase compared to the before phase
 - g. The proportion of illegal type 2 crossings of Cumberland Avenue was not significantly greater for males than for females
 - h. The proportion of illegal type 2 crossings of Seventeenth Street was not significantly greater for males than for females
2. The following results were obtained from the analysis of looking behavior at the curb:
- a. For illegal type 1 crossings on Cumberland Avenue, the proportion of pedestrians who did

not look was the same in the before and after phase of the study.

- b. For legal type 1 crossings on Cumberland Avenue, the proportion of pedestrians who did not look was the same in the before and after phases of the study.
- c. For illegal type 1 crossings on Seventeenth Street, the proportion of pedestrians who did not look was the same in the before and after phases of the study.
- d. For legal type 1 crossings on Seventeenth Street, the proportion of pedestrians who did not look was significantly different in the after phase compared to the before phase.
- e. For illegal type 2 crossings on Cumberland Avenue, the proportion of pedestrians who did not look was the same in the before and after phases of the study.
- f. For legal type 2 crossings on Cumberland Avenue, the proportion of pedestrians who did not look was the same in the before and after phases of the study.
- g. For illegal type 2 crossings on Seventeenth Street, the proportion of pedestrians who did not look was the same in the before and after phases of the study.

- h. For legal type 2 crossings on Seventeenth Street, the proportion of pedestrians who did not look was significantly different for the after phase versus the before phase.
- 3. An analysis of the effects of pedestrian signals on wait times at the curb revealed the following:
 - a. The mean wait time of pedestrians on Cumberland Avenue was the same in the before and after phases of the study.
 - b. The mean wait time of pedestrians on Seventeenth Street was the same in the before and after phases of the study.
- 4. An analysis of the effects of pedestrian signals on walk times revealed that:
 - a. The mean walk time of pedestrians on Cumberland Avenue was the same in the before and after phases of the study.
 - b. The mean walk time of pedestrians on Seventeenth Street was the same in the before and after phases of the study.
- 5. Due to the low number of pedestrian-vehicular interactions recorded in this study it was not possible to conduct a statistical analysis. In spite of this shortcoming, the refinement of a methodology for analysis is believed to be of prime

importance in subsequent data collection and analysis efforts.

CHAPTER VII

CONCLUSIONS

The statistical analysis of the data collected resulted in a number of interesting results concerning pedestrian behavior. An attempt will now be made to analyze these results together with their implications on pedestrian behavior.

Several hypotheses concerning crossing violations was developed and tested. The proportion of illegal crossings (types one or two) of Cumberland Avenue or Seventeenth Street was not significantly greater for the after phase compared to the before phase. Furthermore, the proportions of illegal pedestrian crossings was not significantly greater for males compared to females. Pedestrian signals did not appear to affect the violation rate, that is they did not appear to reduce it. While it may be supposed that for Cumberland Avenue, a major four-lane road with high traffic volumes, pedestrians would be unlikely to cross against the light, the same cannot be said for the Seventeenth Street crossing. For the latter crossing adequate gaps existed for legal and illegal crossings. Pedestrians may be quite adept at judging the relative risk of the street crossing maneuver and can process traffic data internally without necessary reliance on an external signal. Apparently, pedestrian signals do not, in themselves, encourage safe pedestrian behavior. Enforcement of pedestrian signalization and, more importantly, proper education on the use and interpretation of pedestrian signals should be encouraged to induce a higher level of compliance with this pedestrian signal.

Of further interest concerning crossing violations, it was found that for illegal crossings of Cumberland Avenue or Seventeenth Street there were not a significantly greater proportion of male pedestrians crossing in the after case compared to the before case. The hypothesized sex bias did not materialize; however, efforts must still be made to reduce illegal crossings. Again, further emphasis should perhaps be placed on education to encourage the adoption of correct crossing strategies and to also encourage the use, but not dependence upon, of crossing devices which are designed and intended to encourage correct crossing maneuvers.

Looking behavior at the curb was also analyzed. For both legal and illegal crossings of Cumberland Avenue, there was no significant difference in the proportion of pedestrians who looked in the before phase compared to the after phase. Furthermore, for illegal type one and two crossings of Seventeenth Street, there was no significant difference in the proportion of pedestrians who looked in the before phase compared to the after phase. For legal crossings of Seventeenth Street it was found that the proportion of pedestrians who did not look was significantly different in the after phase of the study compared to the before phase. It thus appears that for the Cumberland Avenue crossing, pedestrian signals did not influence looking behavior. One possibility for this result is that Cumberland Avenue is a four lane major thoroughfare with few gaps to allow pedestrians to safely cross the road against the traffic signal. Because of the apparent relatively higher risk associated with the Cumberland Avenue crossing compared to the Seventeenth Street crossing, it is necessary

to obtain information on the traffic situation through looking which is not altered by the presence or absence of a pedestrian signal. Although pedestrian signals may provide information on the crossing decision, they do not appear to affect looking behavior. Pedestrian signals should not be intended to reduce looking behavior, but only to provide additional information so the pedestrian can make a safe road crossing. It also appears that for illegal crossings of Seventeenth Street, pedestrian signals did not influence looking behavior. Because of the illegal nature of the crossing, it was perhaps necessary to obtain the same information on the traffic situation regardless of the presence of pedestrian signals. Thus, because the pedestrian indication had been violated there would be no reason that it should affect looking behavior. Concerning legal crossings of Seventeenth Street, the proportion of pedestrians who did not look was significantly different in the after phase of the study compared to the before phase. It can be theorized that pedestrian signals affect looking behavior for legal crossings on the minor road. Looking behavior at major road crossings does not appear to be affected by pedestrian signals because of the risks involved in crossing, which necessitate the same observance of traffic regardless of the presence or absence of a pedestrian signal. Looking behavior at minor road crossings appears to be influenced by pedestrian signals. Illegal crossings for which the pedestrian signal was obviously disregarded will see no differences in looking behavior with pedestrian signals compared to the situation with no pedestrian signals. Looking

behavior for legal crossings appears to be influenced by pedestrian signals.

The analysis of the effect of pedestrian signals on wait times revealed that mean wait times on either crossing were not significantly different in the before and after phases of the study. Pedestrian signals do not appear to affect pedestrian delay, although it must be noted from the earlier results that the pedestrian signals did not seem to be functioning in their intended manner, that is to inform and guide the pedestrian. As previously mentioned, the proportion of legal and illegal crossings did not alter with pedestrian signals compared to having no pedestrian signals. With this in mind, it would be of value to study mean wait times at locations where the pedestrian signals did reduce violations.

The analysis of the effect of pedestrian signals on walk times revealed that mean walk times for either the Cumberland Avenue or the Seventeenth Street crossing were not significantly different in the before versus the after phase of the study. Pedestrian signals did not appear to affect pedestrian walk times, although, as was the case for wait time, the pedestrian signals did not appear to be functioning in their intended fashion.

Suggestions for Further Research

As previously mentioned, several limitations were recognized in the data collection and analysis stage of this project. In addition to the reduction or elimination of these limitations it is hoped that serious consideration will be given to the study of pedestrian behavior. As a means to this end, some further research suggestions are

presented so that the would-be researcher may gaze upon this fruitful research field and harvest results that will hopefully not just aid in reducing the number and severity of pedestrian accidents but will, at a more fundamental level, aid in the search for clues to human behavior.

1. It would be of interest to study the effects time-of-day has on pedestrian crossing behavior. The analysis of pedestrian behavior during the evening hours would be of considerable interest. For such a study serious consideration would have to be given to data collection, as low light levels may preclude night filming unless a more sensitive lens and/or film is used. For this intersection, it would probably be necessary to have an observer or researcher stationed near the camera to eliminate the possibility of theft or equipment tampering.
2. The effects of varying cycle lengths on pedestrian behavior would be of much interest. Such data could be collected for the intersection in the study; however, sufficient observations would have to be made for each cycle length to be examined so that statistically valid results could be obtained.
3. It would be of interest to conduct a pedestrian behavior study at an intersection at which various signal and movement patterns existed. In this case there were no exclusive turn signals and, more importantly, left turns

from the major street to the minor street were not permitted. It may be interesting to test whether the existence of left turn bays and left turn signals would have a significant effect on pedestrian crossing behavior, for example.

4. Because of the location of the study site adjacent to a major university, a large percentage of the pedestrians were in their early to mid twenties. It would be interesting to sample a more evenly distributed population, and it would be most useful to concentrate on two groups in particular--young children, and the elderly--which are overrepresented in pedestrian accident statistics. Although research has been conducted concerning the crossing behavior of children, especially at school crossings, a serious lack of data exists on the road crossing behavior of elderly pedestrians, a data and research limitation which needs to be remedied given the wealth of knowledge that could be extracted, but more importantly, because the elderly are overrepresented in pedestrian accident statistics and they are becoming a greater percentage of the population.
5. The effects of environmental variables on pedestrian behavior would also be a worthwhile research study. The previously discussed variable time of day and various climatic conditions could be studied to determine their effects on pedestrian behavior.

6. Of particular interest would be a study concerning the behavior of pedestrian groups. Groups could be designed and categorized and the functioning of various members in the road crossing maneuver could be examined. It would also be of interest to compare the behavior of single pedestrians to those in groups.
7. The area of pedestrian-vehicular interaction deserves further investigation and appears to offer a wealth of information to the serious researcher. An entire study could be devoted to the definition and categorization of interactivity and studying the effects interactions have on pedestrian and vehicular behavior and the relationship to pedestrian and vehicular accidents. The categories in this study were, unfortunately, rather arbitrarily drawn. It would also have been productive to have deceleration and speed data available for vehicles, although this would obviously increase data processing and equipment needs.

Summary of Conclusions

A variety of hypotheses concerning pedestrian crossing behavior were examined. For these hypotheses, pedestrian signals did not appear to have an effect on pedestrian behavior, that is theorized differences in pedestrian behavior for the case in which the intersection had both traffic and pedestrian signals compared to the case in which the intersection had only traffic signals did not materialize. For this intersection, pedestrians seem quite able to judge the risks

involved in the crossing maneuver. Pedestrians appear to make crossing decisions based on the size and availability of gaps in the traffic stream rather than to consciously use information presented by the pedestrian signal. The results obtained from this study must be placed in their proper context. Only one intersection was observed and this intersection had a simple two-phase timing arrangement. Complicated phasing such as leading or lagging green indications did not exist at this intersection. Furthermore, the pedestrians observed in this study were primarily college age individuals, with probable high mobility. Different groups such as children or the elderly, whose mobility is more limited, may exhibit different types of behavior. Thus, given these circumstances, pedestrian signals did not appear to effect pedestrian behavior.

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APPENDIX

APPENDIX A - 1

A Description of the Test of Proportions

The test of proportions is a statistical procedure that can be used with a random variable that follows a binomial distribution. The test methodology will be illustrated by analyzing the data in a step-by-step manner. The first hypothesis to be examined sought to test whether there was a significant difference in illegal crossings in the after (no pedestrian signals present) case versus the before case (pedestrian signals present).

1. The null hypothesis, H_0 , was formulated along with the alternative hypothesis, H_A .

H_0 : The proportion of illegal crossings was not greater in the after phase compared to the before phase.

H_A : The proportion of illegal crossings was greater in the after phase.

These hypothesis can be restated as follows:

$$H_0 : P_1 \leq P_2$$

$$H_A : P_1 > P_2$$

2. Random samples having sizes of N_1 and N_2 are taken from the population. The proportion of these samples corresponding to the hypothesis to be tested are then computed.

$$P_1 = \frac{X_1}{N_1}$$

$$P_2 = \frac{X_2}{N_2}$$

A further value, is computed:

$$\hat{P} = \frac{X_1 + X_2}{N_1 + N_2}$$

The null hypothesis is tested by calculating the following statistic:

$$Z_0 = \frac{P_1 - P_2}{\sqrt{\hat{P}(1-\hat{P})\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

In this case if $Z_0 > Z_{\alpha/2}$, as the one-sided test is being used, the null hypothesis would be rejected.

3. The calculations of the relevant statistics for testing, as an example, the hypothesis that the proportion of illegal type 2 crossings on Seventeenth was not greater in the after phase of the study compared to the before phase are presented below:

- a. One hundred and twenty-nine pedestrians were observed crossing Seventeenth Street in the after case. Seventy-nine of these pedestrians committed an illegal type 2 crossing maneuver (did not start and finish the crossing in the WALK phase of the Seventeenth pedestrian signal).

$$\begin{aligned}\text{Thus, } N_1 &= 129 \\ X_2 &= 79\end{aligned}$$

Now,

$$\begin{aligned}P_1 &= \frac{X_1}{N_1} \\ &= \frac{79}{129} \\ &= 0.5814\end{aligned}$$

- b. One hundred and thirty pedestrians were observed crossing Seventeenth Street in the after case. Seventy-five of these pedestrians made illegal type 2 crossings.

$$\text{Thus, } N_2 = 130$$

$$X_2 = 75$$

$$\begin{aligned}\text{Now, } P_2 &= \frac{X_2}{N_2} \\ &= \frac{75}{130} = 0.5769\end{aligned}$$

- c. From these values, $\hat{P}$ can be computed:

$$= \frac{X_1 + X_2}{N_1 + N_2}$$

$$= \frac{79 + 175}{129 + 130}$$

$$= 0.5969$$

d. The Z statistic can now be calculated:

$$0.5814 - 0.5969$$

$$Z = \frac{0.5814 - 0.5969}{\sqrt{(0.5946)(1-0.5946)\left(\frac{1}{129} + \frac{1}{130}\right)}}$$

$$Z = 0.0733$$

e. The corresponding P value is:

$$P = 0.4721$$

Thus, the null hypothesis cannot be rejected using

$\alpha = 0.05$ and a one-sided test.

APPENDIX A - 2

A Description of the Wilcoxon Rank-Sum Test

The Wilcoxon rank-sum test is an example of a nonparametric test. Nonparametric tests can be used to analyze data that is not normally distributed but which is continuous. If two independent, nonnormal sets of data exist, the Wilcoxon rank-sum test can be used to determine whether the two means are significantly different from one another, that is

$$H_0 : M_1 = M_2$$

$$H_A : M_1 \neq M_2$$

A random sample is taken from both populations with N being the sample selected from population 1 and the sample selected from population 2. The following procedure, outlined below in a step-by-step fashion, constitutes the Wilcoxon Rank-Sum Test procedure:

1. Arrange both samples in order of increasing magnitude, and keep the unique rank of each sample point intact. For tied values, average the ranks.
2. Add the ranks in the smaller size sample and call this sum R .
3. Let $R_1 = N_1 (N_1 + N_2 + 1) - R$
4. If $M_1 = M_2$ then the sum of the ranks for sample 1 should be nearly the same as the sum of the ranks for sample 2. Thus, the test statistic R' can be used to indicate whether the means are equal.

VITA

Nicholas Joseph Fortey was born in Birmingham, England on September 22, 1962. He later moved to Knoxville, Tennessee and attended elementary schools in that city. He was graduated from Knoxville Catholic High School in May 1980. During that summer he entered The University of Tennessee and received a Bachelor of Science degree in Civil Engineering in December 1985. In the winter of 1985 he began study toward a Master's degree at The University of Tennessee. This degree was awarded in December 1987.

The author is a member of Tau Beta Pi, Chi Epsilon, and the Institute of Transportation Engineers. Mr. Fortey will be employed by the Federal Highway Administration after graduation.