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URBAN INTERSECTION IMPROVEMENTS FOR PEDESTRIAN SAFETY

Vol. II. Identification of Safety and Operational Problems at Intersections

December 1977

Final Report

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Prepared for

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FOREWORD

This five-volume report describes pedestrian problems at urban intersections and timing and display improvements for pedestrian signals. This report will be of interest to traffic engineers and others responsible for pedestrian safety.

The five volumes are:

- Vol. I - Executive Summary
- Vol. II - Identification of Safety and Operational Problems at Intersections
- Vol. III - Signal Timing for the Pedestrian
- Vol. IV - Pedestrian Signal Displays and Operation
- Vol. V - Evaluation of Alternatives to Full Signalization at Pedestrian Crossings

Sufficient copies of the five volumes are being distributed to provide a minimum of one copy to each FHWA Regional and Division office. Additional copies of the Executive Summary have also been provided to allow wider distribution of this report. Copies sent direct to the Division Offices should be distributed to the State highway agency, Governor's Representative for Highway Safety, and to major metropolitan areas.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

This report summarizes the research completed in the first phase of a three-phase project. This phase was directed at identifying and defining the safety *and* operational problems associated with the interaction of pedestrians and vehicles at intersections. Both signalized and nonsignalized intersections were investigated. Four sources of information were used to define problems and uncover implications for countermeasure concepts. These sources included:

- Accident Data
- Behavioral Observations
- Expert Opinion
- Conceptual Investigations

The significant findings from all four sources are presented in terms of the following categories:

- Undesirable Pedestrian and Vehicle Interactions
- Undesirable Pedestrian and/or Driver Behaviors
- Undesirable Intersection Characteristics
- Undesirable Traffic Control Device Characteristics

Several countermeasure concepts that address some of the above problems were identified. The information required in order to design the specific countermeasures is documented in the body of the report (see Tasks IA, IB, and ID). Likewise, the means for evaluating the effectiveness of the specific countermeasures have been developed and are reported in Task IC.

Other Volumes in this series include:

Volume I – Executive Summary
Volume III – Signal Timing for the Pedestrian
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PREFACE

This research project was conducted in three phases. Phase I dealt with the investigation and identification of both operational and safety problems encountered by pedestrians and motorists at urban-type intersections. Phase II dealt with the development, evaluation, and design criteria formulation of countermeasures that address the problems identified in Phase I. Phase III evaluated some alternatives to full signalization at intersections requiring pedestrian protection.

Volume I of the Final Report is the Executive Summary of the project. Phase I is reported in Volume II and Phase II is reported in Volumes III and IV. Specifically, Volume III addresses the subject of signal timing for the pedestrian; and Volume IV deals with pedestrian signal displays and signal operation. Phase III is reported in Volume V.

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PHASE I SUMMARY OF SIGNIFICANT FINDINGS

This report summarizes the research completed in the first phase of a three-phase project. This phase was directed at identifying and defining the safety *and* operational problems associated with the interaction of pedestrians and vehicles at intersections. Both signalized and nonsignalized intersections were investigated. Four sources of information were used to define problems and uncover implications for countermeasure concepts. These sources included:

- Accident Data (Task IA)
- Expert Opinion (Task IB)
- Behavioral Observations (Task IC)
- Conceptual Investigations (Task ID)

The purpose of Task IA was to determine the design and operational features of urban intersections that are related to pedestrian/vehicle safety. Over 5300 pedestrian intersection accident records from four different data bases were analyzed. Three of the data bases were from in-depth accident investigation studies, while the fourth contained police accident reports covering a three-year period. More than 25 different urban areas were represented in the sample.

The primary objective of Task IB was to obtain expert opinions on current urban intersection problems and potential solutions to those problems. Over 70 traffic engineers and safety experts were surveyed. From the responses, ten major problems were identified and 17 potential solutions were suggested. An Advisory Panel was also formed during this task to review project results and provide practical technical inputs during the course of the project.

Two field studies and a series of field observations were conducted in Task IC. The field studies were directed at developing vehicle and pedestrian behavioral measures. Of 16 behavioral measures tested at 120 intersections, seven were retained and refined for use later in the countermeasure evaluation phase of the project. The field observations were directed at identifying site characteristics associated with high accident locations. Based on 30 matched (same traffic controls, geometric shape, and direction of flow) intersection *pairs*, our observations revealed that the high accident intersections more often exhibited greater pedestrian and vehicle volumes, were more commercial or had a higher population density, and exhibited a less desirable socio-economic environment.

Task ID consisted of two parts. The first part was a review of the human factors data and concepts having a potential impact on intersection design and control as they relate to pedestrian safety. This step provided the human factors criteria for the development of countermeasure concepts. Secondly, a review was conducted of the behavioral and operational literature dealing specifically with pedestrian and driver safety at intersections. This step provided supporting data for the problems and potential solutions identified in the first three tasks. In all, approximately 1000 pieces of literature were reviewed, resulting in an annotated bibliography of over 300 relevant references.

The significant findings from all four tasks are presented in terms of the following categories:

A. Undesirable Pedestrian and Vehicle Interactions

1. Turning vehicle conflicts with pedestrians
2. Acceptance of small vehicle gaps on the part of pedestrians
3. Pedestrians crossing when through vehicles are moving through the crosswalk area
4. Short time exposure of pedestrians to drivers
5. Pedestrian required to run in response to a turning or through vehicle in close proximity
6. Pedestrian required to hesitate in response to a turning or through vehicle while engaged in crossing
7. Pedestrian entering the roadway and moving in front of a stopped or standing vehicle (not a parked vehicle) into a lane of traffic moving in the same direction

B. Undesirable Pedestrian and/or Driver Behaviors

1. Pedestrian crossing the intersection diagonally
2. Pedestrian running in or into the roadway
3. Pedestrian crossing the roadway entirely against the signal
4. Pedestrian starting to cross during the caution indication on the signal
5. Pedestrian anticipating the signal (starts to cross against the signal which changes before the crossing is completed)
6. Vehicle backing through the crosswalk after being trapped by the signal
7. Pedestrian and driver inattention while approaching and traveling through the intersection
8. Failure by pedestrian to use available traffic control devices (pushbuttons, marked crossings, etc.)

C. Undesirable Intersection Characteristics

1. Inadequate driver and pedestrian sight distances (caused by parked vehicles, street furniture, and vegetation)
2. Inadequate roadway lighting
3. Wide roadways without adequate provisions for pedestrian crossing
4. Lack of enforcement of laws and ordinances
5. Complex presentation of numerous signs, signals, and markings

6. Environmental and roadway distractions
7. Inadequate provisions for handicapped pedestrians
8. Near side bus stops

D. Undesirable Traffic Control Device Characteristics

1. Nonstandard devices or device application
2. Inadequate signal timing
3. Nonuniform and/or improper signal color, size, and message
4. Inconsistent use of messages
5. Failure of device to convey the proper message
6. Failure of device to meet pedestrian and/or driver expectancies
7. Crosswalks conveying a false sense of security to pedestrians

Several countermeasure concepts that address some of the above problems came to light during the course of the project. These include:

- Increasing driver and pedestrian sight distances.
- Reducing turning vehicle/pedestrian conflicts.
- Improving signal timing.
- Improving visibility (lighting).
- Shielding vehicle and pedestrian signals.
- Improving crosswalk applications.
- Providing far side bus stops.
- Improving pedestrian signal messages, colors, and displays.
- Providing additional clarification at the intersection of the required pedestrian and driver actions.
- Improving enforcement.
- Improving driver and pedestrian education.

The information required in order to design the specific countermeasures is documented in the body of the report (see especially Tasks IA, IB, and ID). Likewise, the means for evaluating the effectiveness of the specific countermeasures have been developed and are reported in Task IC.

TABLE OF CONTENTS

TABLE OF CONTENTS *(Continued)*

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report summarizes the research completed in the first phase of a three-phase project. Phase I deals with the investigation and identification of both operational and safety problems encountered by pedestrians and motorists at urban-type intersections. Phase II deals with the development, evaluation, and design criteria formulation of countermeasures that address the problems identified in Phase I. Phase III evaluates some alternatives to full signalization at intersections.

Background

In 1973, approximately 400,000 pedestrians were involved in accidents with motor vehicles. About 10,000 of these accidents resulted in pedestrian fatalities. A majority of these fatalities occurred in urban areas, and some 24 percent could be termed intersection accidents. The investigation and treatment of the causal factors of intersection accidents is clearly an area of potential reward in terms of reducing both cost and human suffering.

The installation of traffic control devices (signals, signs, and markings) at intersections has traditionally been viewed as the means of reducing vehicle and pedestrian accidents. Overall, studies to date (Civic Administration, 1967; Fleig & Duffy, 1967; *Public Works,* 1969; Rotman, 1961; Young, 1967) have *not* conclusively shown that the installation of traffic signals, signs, or crosswalks has substantially improved pedestrian safety. Some studies (Mackie & Older, 1965; Malo, 1967; Road Research Laboratory, 1965) have shown, however, that certain traffic control device improvements directed at meeting driver and pedestrian expectancies have resulted in a reduction in the number of pedestrian accidents. The one thing that is clear is the fact that a safety problem does exist.

In addition to safety, there is the operational efficiency of the intersection to consider. The competition for space between pedestrians and vehicles is increasing, particularly in densely populated areas. Provisions for pedestrian movements and pedestrian/vehicle conflicts reduce intersection capacity and increase delay. The traffic engineer is thus confronted with two, sometimes conflicting, considerations: safety and operational efficiency.

In attempting to accommodate both of these considerations, traffic engineers have sought to improve and standardize traffic control devices. This approach has met with some success, but not to the degree desired. Complaints regarding the effectiveness of standard devices are being voiced both by traffic engineers and highway users. There are indications that the highest payoff potential may lie with a human factors approach to the design of operational and safety improvements at intersections.

With regard to pedestrian research needs, Mueller and Rankin (1970) point out the following in *Traffic control and Roadway Elements – Their Relationship to Highway Safety/Revised:*

> Meaningful exposure measures, including those related to age, residence, race and sex, should be developed.
>
> More precise measures of the effectiveness of control devices, regulations and design features, such as sidewalks used to improve pedestrian safety, are needed to allow their use on a more selective basis.
>
> Research is needed to provide more information on the sociological and psychological aspects of pedestrian behavior and to identify how this information can be used to improve pedestrian safety.

Study Objectives

The objectives of Phase I were to determine the answers to the following questions:

- What are the causal factors involved in urban intersection accidents?
- What measures most appropriately characterize the conflicts between vehicles and pedestrians?
- What measures characterize the actual and perceived difficulties with existing pedestrian/vehicle segregation?
- What are the opinions and ideas of traffic engineers with regard to the problems encountered by pedestrians at intersections?
- What are the countermeasures concepts that apply to the urban intersection pedestrian and vehicle interaction?

Scope

Phase I was directed at identifying and defining the problems associated with the interaction of pedestrians and vehicles at intersections. Problem definitions necessitated the development of measures that could sense and characterize the accident- or conflict-related behaviors of pedestrians. Both signalized and nonsignalized intersections were investigated. These intersections covered a wide range of high and low volumes (both pedestrian and vehicle). Basically, four sources of information were tapped in the search for problem definitions and implications for countermeasure concepts. These sources included:

- Accident Data (Task IA)
- Expert Opinions (Task IB)
- Behavioral Observations (Task IC)
- Conceptual Investigations (Task ID)

The findings from each source are discussed in the sections that follow.

IDENTIFICATION OF ACCIDENT FACTORS (TASK IA)

Accidents and accident rates have traditionally been accepted as the ultimate measures of safety since they represent the ultimate failure of safety provisions. Much effort has been devoted to the analysis of accident data. Because of the relative infrequency of a given accident type (e.g., pedestrian or vehicle) occurring at a given location (e.g., intersection or nonintersection) under comparable circumstances (e.g., same time of day, same weather, same age of persons involved, same actions, same lighting conditions, etc.), accident studies generally examine accidents from numerous locations over a considerable period of time. From within these samples, characteristics are grouped and synthesized. In this manner, comparisons can be made across similar accident types, similar locations, or various sets of similar circumstances.

The data analysis conducted in this task followed this general procedure. The analysis treated urban pedestrian intersection accidents only. Intersection accidents were defined differently for each data base examined, but, in general, included any pedestrian accident that occurred within 100 feet of the intersection. The purpose of the task was to determine the design and operational features of urban intersections that are related to pedestrian/vehicle safety.

Accident Data Base

Four existing data bases containing over 5300 accidents were obtained and examined. These included the following:

- 2685 District of Columbia pedestrian intersection accidents – 1971 through 1973
- 973 pedestrian intersection accidents from 13 cities collected during the Snyder and Knoblauch (1971) study
- 1443 pedestrian intersection accidents from seven cities collected during the Berger and Knoblauch (1975) studies
- 213 pedestrian intersection accidents from six states collected during the ongoing Knoblauch study (Contract DOT-HS-355-3-718)

These data bases will hereafter be referred to as the D.C., ORI, PEDACC, and RUPED data bases, respectively. The D.C. data base contained only information from the police accident report. The other data bases contained behavioral data which resulted from in-depth investigations in addition to police report information. The RUPED data base was the most detailed and the PEDACC data base was the least.

Each data base was in a different format and first had to be made compatible with the computer system used to analyze the data. A computer data file was created for each data base. Next, a codebook was developed for each data base so that each element of information in each accident record could be identified and specified. Lastly, the computer software that would permit the necessary accessing and sorting required in the analysis was developed.

Accident Data Analysis

Since all of the data bases included nonintersection as well as intersection pedestrian accidents, the first step of the analysis was to sort out the intersection accidents for further study. In the case of the RUPED data (which is concerned primarily with suburban and rural pedestrian accidents), it was necessary to also eliminate the rural accidents. This sorting resulted in the approximately 5300 urban intersection pedestrian accidents outlined above. For each data base, intersection accidents represented the following proportion of the total pedestrian accidents: D.C., 56 percent; ORI, 47 percent; PEDACC, 38 percent; and RUPED, 21 percent.

For each data base, a computer run was made which sorted each accident record by type of traffic control, i.e., traffic signal, stop/yield, and none.* The RUPED data base had a fourth category, pedestrian signal. Next, a frequency distribution with associated percentages was computed for each codebook item within each data base for each type of signal control.

Pedestrian Intersection Accident Characteristics

The significant findings of the accident data analysis are presented below for each of the four data bases.

D.C. Data

Of the 2685 pedestrian intersection accidents that occurred in Washington, D.C. from 1971 through 1973, 39 percent were at intersections controlled by a traffic signal, ten percent were on the minor street at a nonsignalized intersection, and 51 percent were on the major street at a nonsignalized intersection.

Significantly** fewer accidents occurred on weekends (Saturday and Sunday) than during the rest of the week for all three types of traffic control; however, there were proportionately fewer accidents (31 percent) at signal-controlled intersections during the weekends than during the week (41 percent). This probably reflects fewer pedestrians in the central business district and more pedestrians in the suburbs where there are fewer signalized intersections. More accidents occurred on Friday than on any other day.

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*The category "none," with respect to type of traffic control, indicates that the accident occurred on the major street of a nonsignalized intersection.

**"Significantly," as used throughout this report, implies statistical significance at the 0.05 level unless otherwise stated.

Figure 1 shows a plot of the hourly variation of pedestrian intersection accidents by signal type. Note the similarity in shape of the three curves. The most dangerous time of day for pedestrians crossing at intersections is between 3 p.m. and 6 p.m. Thirty-six percent of the accidents occurred during this three-hour period.

With regard to environment, 85 percent of the accidents occurred in clear weather as opposed to 13 percent in rainy weather. Sixty-three percent (63%) of the accidents occurred in daylight as opposed to 33 percent at night, with only four percent being coded as occurring during either dawn or dusk. The road was dry at 81 percent and wet at 18 percent of the accident sites.

Turning vehicles hitting the pedestrian accounted for 17 percent of the total accidents. Turning vehicle accidents occurred at signalized intersections significantly more often than expected, and significantly more of the turning vehicle accidents involved left turning vehicles.

Males represented 62 percent of the pedestrians injured; however, a significantly greater proportion of females (43 percent) than males (36 percent) were hit at signalized intersections.

The five to nine age group experienced 25 percent of the total accidents, while those pedestrians under 15 years of age accounted for 42 percent of the total accidents. The 15 to 30 age group was involved in 25 percent of the accidents. Pedestrians 65 and over represented six percent of the total accidents. A significantly greater proportion of those under 15 were hit at nonsignalized intersections than was any other age group. This same effect was experienced by the 65 and over age group at signalized intersections.

Only two percent of the pedestrians were fatally injured. No significant differences were noted when comparing injury severity to type of control.

Eighteen percent (18%) of the pedestrian accidents involved the pedestrian coming from between parked cars. Significantly more of this behavior occurred at nonsignalized intersections than at signalized intersections, and significantly more of these accidents occurred on the major street than on the minor street. Forty-two percent (42%) of the pedestrians hit were in a marked crosswalk. Of these, 45 percent were walking with the signal and 29 percent were walking against it. Thirty-one percent (31%) of the pedestrians hit were crossing in a crosswalk at a signalized intersection.

In summary, the greatest danger appeared to be when the pedestrian crossed the major street at a nonsignalized intersection. Weekdays were more dangerous than weekends, with Friday being the most dangerous day. A composite pedestrian accident happened to a male under 15 years of age between 3 p.m. and 6 p.m. on a clear day on a dry road. Although most vehicles that hit pedestrians were going straight, turning vehicles were more often involved at signalized intersections than at nonsignalized intersections. Left turning vehicles were more involved than right turning vehicles.

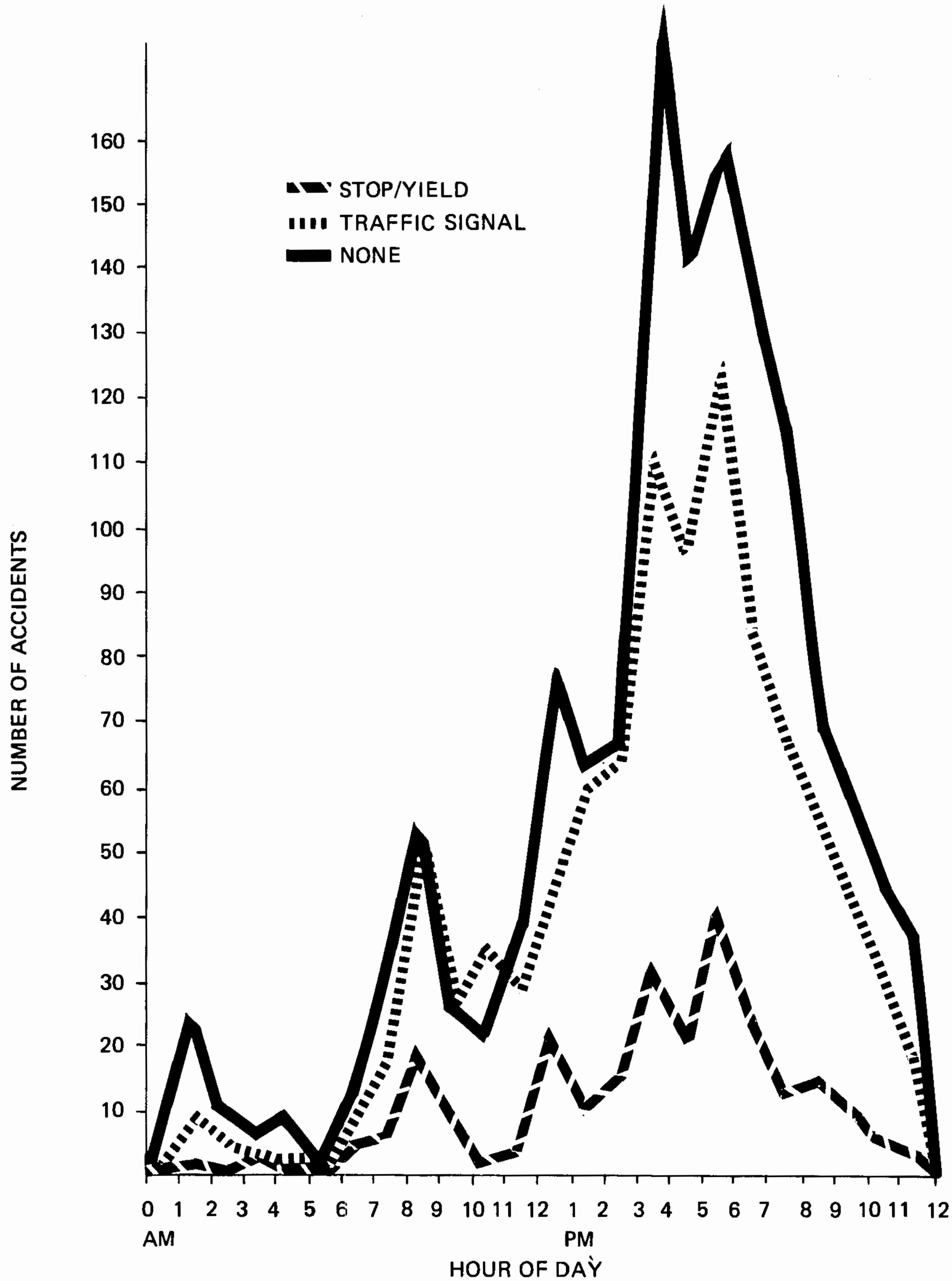

Figure 1. Hourly Variation of D.C. Pedestrian Intersection Accidents By Signal Type

Females and the elderly had more trouble than males and younger pedestrians, respectively, at signalized intersections. Younger pedestrians were overinvolved in accidents in relation to the other age groups, experiencing a greater difficulty at nonsignalized intersections (probably related to exposure). There appeared to be a problem with vehicles parking too close to the intersection. There also appeared to be a problem of pedestrian noncompliance with signals, and possibly an unjustified reliance by pedestrians on crosswalks and signals alone as adequate protective measures.

ORI Data

Of the 973 pedestrian intersection accidents from 13 cities investigated by Snyder and Knoblauch (1971), 49 percent occurred at signalized intersections, while 37 percent and 14 percent occurred at nonsignalized intersections on the major and minor streets, respectively.

Eighty-seven percent (87%) of the pedestrians were crossing the street when hit. Sixty-four percent (64%) of the pedestrians did not recognize a need for evasive action before being hit, even though 45 percent of these pedestrians were at a signalized intersection. Thirty-two (32%) of the pedestrians were running prior to being hit. A significantly greater proportion of the pedestrians were running at nonsignalized than at signalized intersections.

Turning vehicles were involved in 22 percent of the accidents. Sixty-three percent (63%) of these conflicts occurred at signalized intersections.

Seventy-six percent (76%) of the accidents occurred at four-leg intersections. Figure 2 is a histogram of pedestrian intersection accidents by intersection type by method of traffic control. Sixty-six percent (66%) of the intersections had marked crosswalks. Eighty percent (80%) of the accidents occurred on two-way streets compared to 20 percent on one-way streets.

There were several indications of a problem existing with legally parked vehicles. Thirty percent (30%) of the drivers and 31 percent of the pedestrians were coded as having their vision obscured by legally parked cars. In both cases, 60 percent of these occurrences were on the major street at nonsignalized intersections. This problem was supported by responses related to driver causal factors. A significantly greater proportion of responses (65 percent) indicated parked cars as the driver causal factor compared to all other responses (31 percent) indicating other factors for accidents on the major street at nonsignalized intersections. The problem was further supported by the pedestrian causal factor of short time exposure being listed proportionally higher for accidents on the major street at nonsignalized intersections (also a significant result).

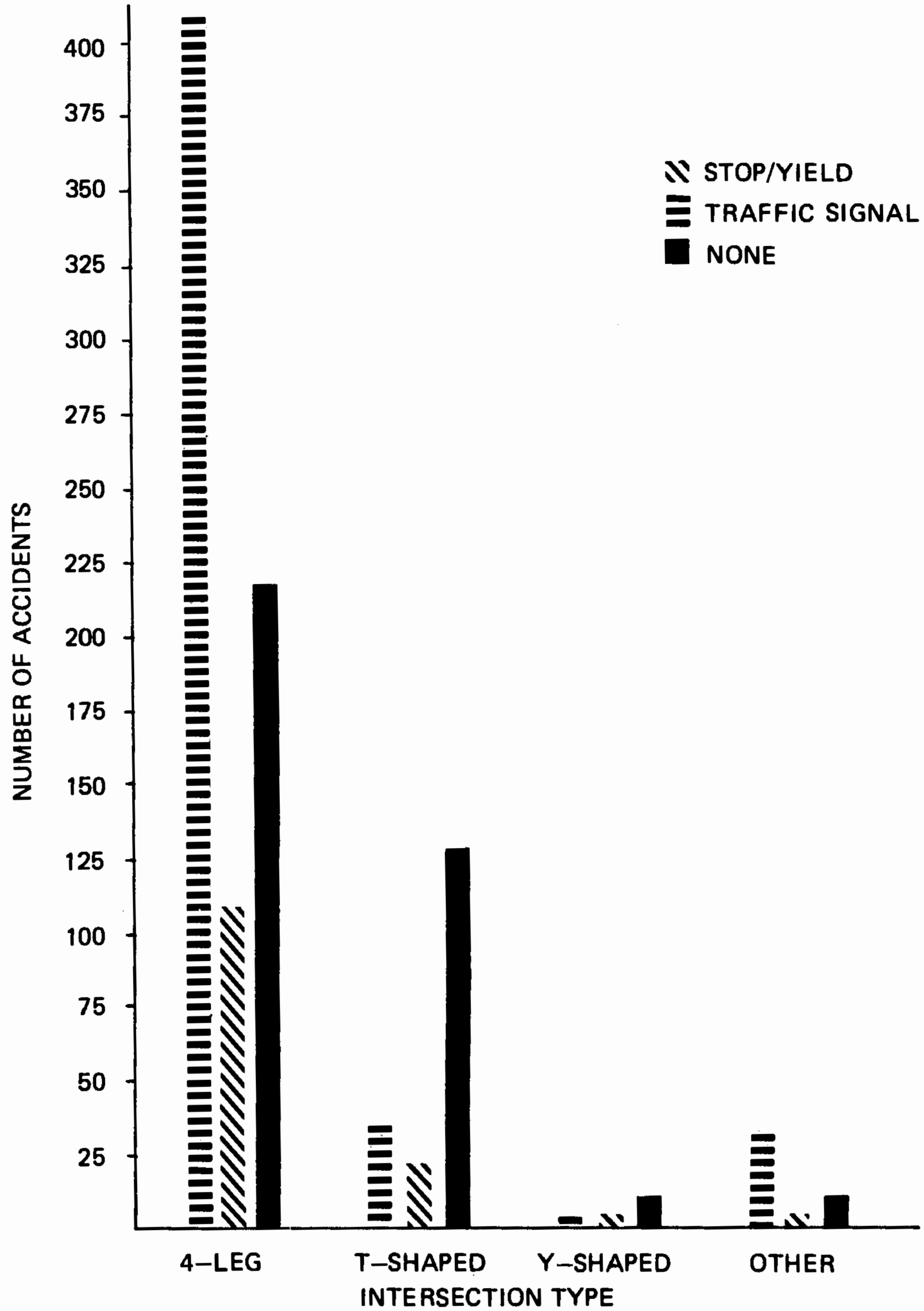

Figure 2. O.R.I. Pedestrian Intersection Accidents By Intersection Type

Regarding the environment, 88 percent of the accidents occurred in clear or cloudy weather, with only eight percent having occurred in the rain. Seventy-three percent (73%) were daytime accidents. Six percent (6%) were coded as dawn or dusk. Of the remaining night accidents (21 percent), 93 percent were coded as having light at the site. Eighty-two percent (82%) occurred on dry roads. Figure 3 presents accident frequency by posted speed limit and type of control. The posted speeds are indicative of urban areas.

The most dangerous hours of the day were 3 p.m. to 6 p.m., the period during which 36 percent of the accidents occurred.

Young pedestrians (under 15 years) accounted for 40 percent of all accidents, while pedestrians 65 and over represented 17 percent of all accidents. Young pedestrians were underrepresented at signalized intersections and overrepresented on the major street at nonsignalized intersections compared to the other age groups. The elderly compared closely with all age groups over 15 years with respect to type of traffic control.

Males accounted for 58 percent of the pedestrians hit. No significant differences were found with respect to sex versus type of traffic control. Twelve percent (12%) of the pedestrians were fatally injured. Sixty-three percent (63%) of these fatalities occurred at signalized intersections, a higher proportion than expected. Finally, signalization (12 percent) was second only to training and education (52 percent) as countermeasures suggested by the individuals investigating the accidents.

In summary, about half of the accidents occurred at signalized intersections. Almost all of the pedestrians were attempting to cross when hit, and most did not realize they were going to be hit until impact. One-third of the pedestrians were running. Running was in greater evidence at nonsignalized intersections. Nearly one-fourth of the accidents involved turning vehicles. Three-fourths of the accidents occurred at four-leg intersections. Two-thirds of the intersections had marked crosswalks. Cars legally parked on the major street at nonsignalized intersections caused blocked vision problems.

A composite pedestrian accident was most likely to result in minor injury to a young male on a dry road in the daytime during clear weather between 3 p.m. and 6 p.m.

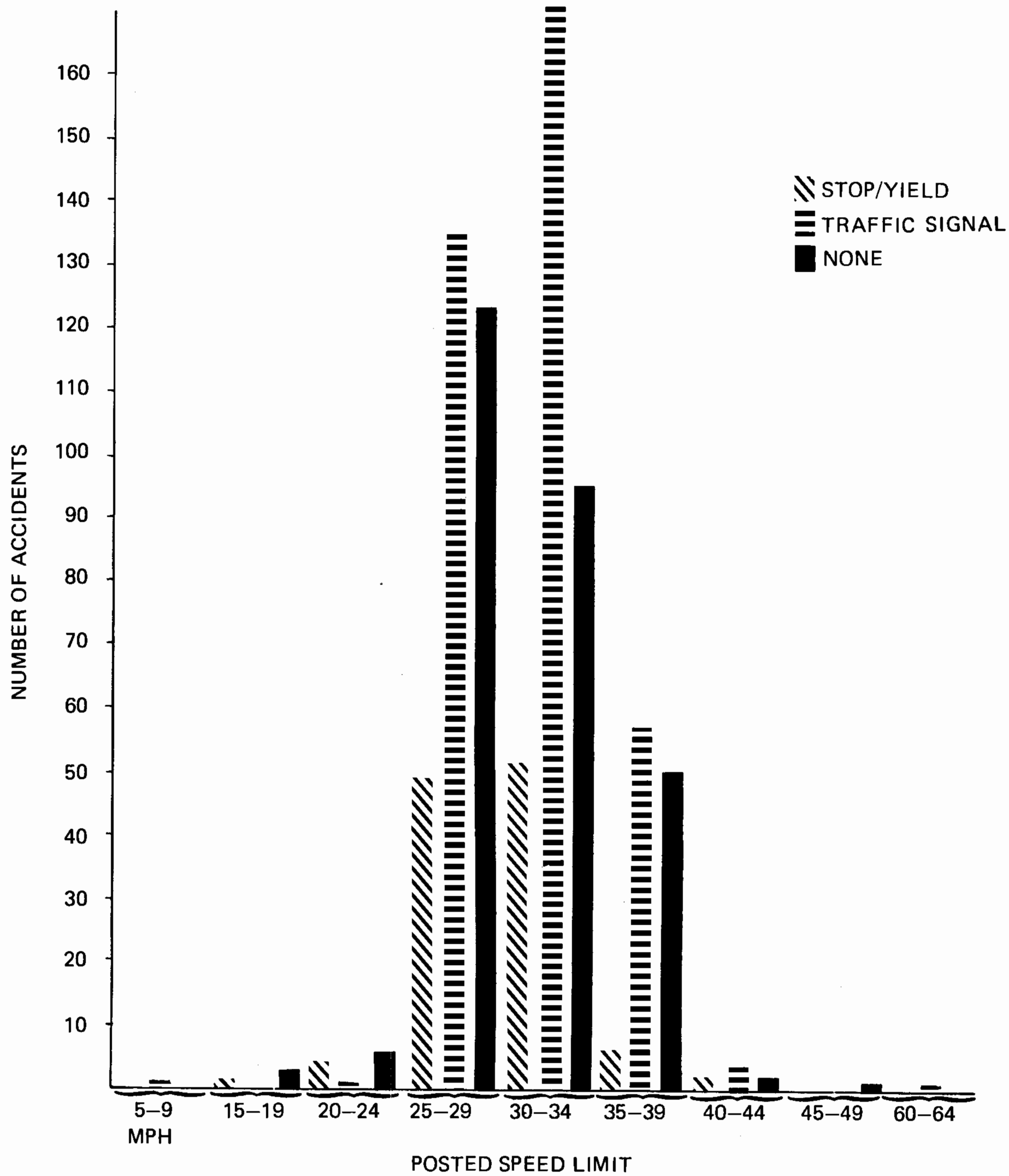

Figure 3. O.R.I. Pedestrian Intersection Accidents by Posted Speed Limit

PEDACC Data

Of the 1443 pedestrian intersection accidents from seven cities that were investigated by Berger and Knoblauch (1975), 49 percent occurred at signalized intersections while 35 percent and 16 percent occurred at nonsignalized intersections on the major and minor streets, respectively.

The period from 3 p.m. to 6 p.m. was the most dangerous time of day for pedestrians, accounting for 28 percent of the total accidents. Figure 4 shows accident frequencies by time of day. Note the similarity in the shape of the three curves representing type of traffic control. Friday was the most dangerous day of the week, representing 19 percent of the total accidents.

Young pedestrians (under 15 years) accounted for 32 percent of the total accidents. More young pedestrians were hit on the major streets at nonsignalized intersections than were expected. Elderly pedestrians were involved in 18 percent of the accidents. Fifty-five percent (55%) of the pedestrians hit were males. Eleven percent (11%) of the pedestrians were fatally injured. Sixty-three percent (63%) of the fatalities occurred at signalized intersections.

Sixty-seven percent (67%) of the accidents occurred in the daytime compared to 29 percent at night. Eighty-six percent (86%) occurred in clear or cloudy weather compared to 12 percent in the rain. Eighty-two percent (82%) of the accidents were on dry roads compared to 16 percent on wet roads. Eighty-one percent (81%) were on two-way roads as opposed to 11 percent on one-way roads. Significantly more accidents occurred at signalized intersections having three or more traffic lanes than would be expected.

Turning vehicles were involved in 25 percent of the accidents, with left turning vehicles hitting more pedestrians than right turning vehicles. Significantly more turning vehicles were involved at signalized intersections than would be expected, with vehicles turning left again predominating. The above is supported by the fact that 24 percent of the drivers were reported to be engaged in a turning/merging maneuver when the accident occurred. This action also occurred more at signalized intersections than would be expected.

Thirty-seven percent (37%) of the accidents occurred in marked crosswalks, 35 percent in unmarked crosswalks, and 28 percent not in a crosswalk. Significantly more accidents occurred not in a crosswalk at a nonsignalized intersection on the major street than would be expected. Pedestrian signals were present when 14 percent of the accidents occurred.

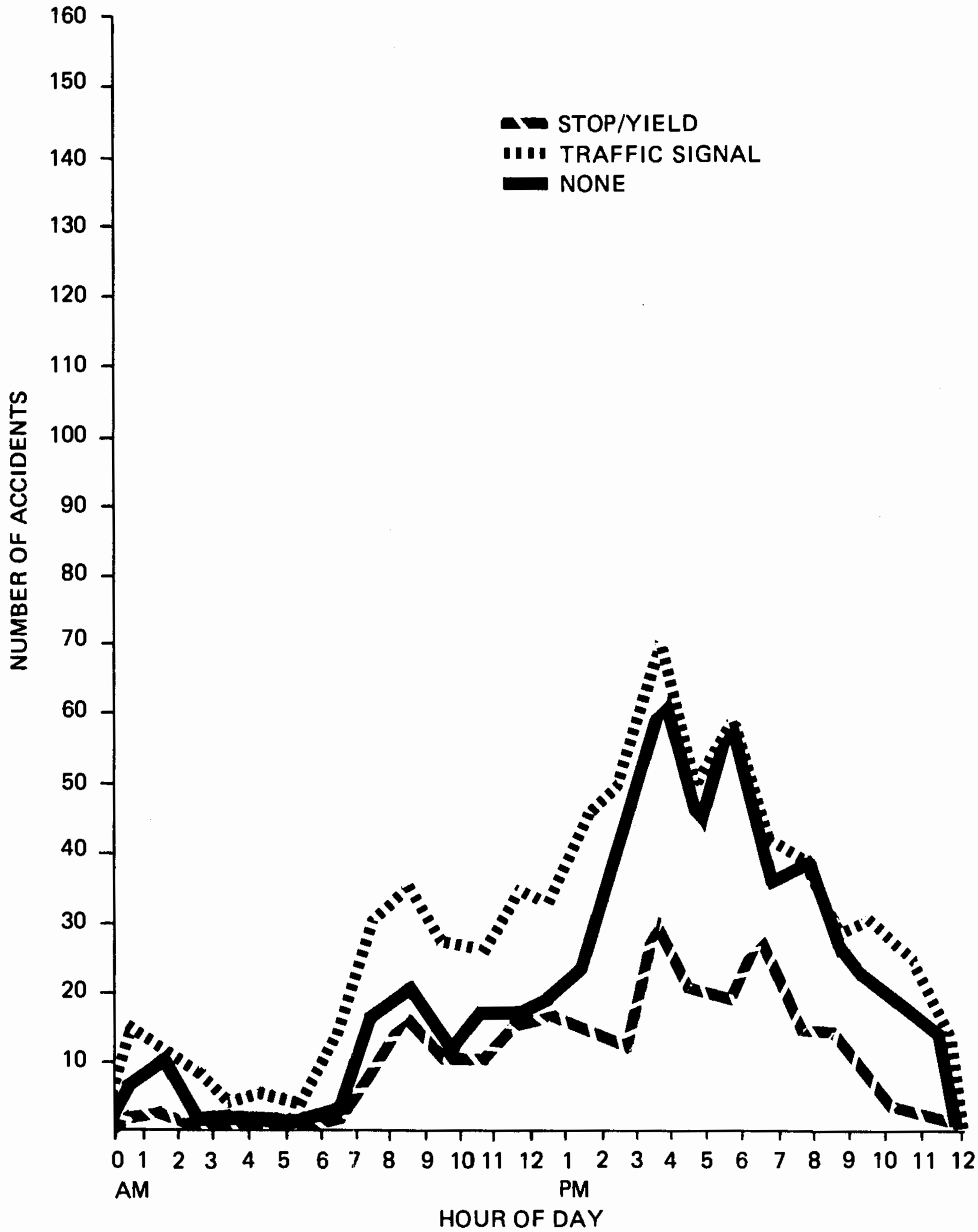

Figure 4. Hourly Variation of PEDACC Pedestrian Intersection Accidents By Signal Type

Driver vision was reported blocked by parked cars in 19 percent of the accidents, with the greatest frequency of occurrence being at nonsignalized intersections on a major street. Of the pedestrians (five percent) that were reported as having crossed from behind a parked vehicle, significantly more of these occurrences were at nonsignalized intersections on the major street than would be expected.

Only 36 percent of the drivers were reported as having attempted evasive action to avoid the accident. Seventeen percent (17%) of the drivers were reported as attending to traffic and not seeing the pedestrian. This occurred significantly more at signalized intersections than would be expected.

The pedestrian appeared suddenly in the path of the vehicle in 39 percent of the accidents. Significantly more of this behavior occurred at nonsignalized intersections on the major street. Only six percent of the pedestrians were reported as attempting evasive action to avoid the vehicle. Fifteen percent (15%) of the pedestrians were crossing against the signal. Twenty-nine percent (29%) of the pedestrians were running. Significantly more of this behavior occurred at nonsignalized intersections on the major street than expected. Only seven percent of the pedestrians were not attempting to cross the roadway.

In the subjective typing of intersection accidents, those types occurring with disproportionately greater frequency at signalized intersections included: turn/merge conflicts; trapped and turning vehicles. At nonsignalized intersections on the major street, the disproportionate accident types that occurred with greater frequency included: first-half dartout, second-half dartout, and multiple threat. These accident types impacted on the selection of behaviors for manual coding in Task IC.

In summary, almost half of the accidents occurred at signalized intersections. Friday was the most dangerous day of the week and 3 p.m. to 6 p.m. was the most dangerous time period. Pedestrians under 15 years of age accounted for one-third of the accidents. The composite pedestrian accident occurred on a clear day in the daytime on a dry road. Well over half of the fatalities occurred at signalized intersections. Turning vehicles were involved in one-fourth of the accidents, with left turning vehicles at signalized intersections predominant. Over one-third of the accidents occurred in marked crosswalks. Vehicles parked on the major street at nonsignalized intersections appeared to cause problems related to blocked driver vision and the sudden appearance of the pedestrian. Almost one-third of the pedestrians were running, mainly across the major street at nonsignalized intersections.

RUPED Data

This data base consists of a sample of nonurban accidents which were investigated by the state police. The sample therefore represents suburban and rural accidents, resulting in the relatively small proportion of urban and suburban intersection accidents (21 percent). Of the 213 pedestrian accidents, only 17 percent occurred at signalized intersections. Because of these constraints, only the significant findings that can be compared to the other urban oriented data bases will be included.

Friday was the most dangerous day of the week, representing 20 percent of the accidents. The 3 p.m. to 6 p.m. time period accounted for 29 percent of the accidents. Sixty-six percent (66%) of the accidents occurred in the daytime. The weather was clear or cloudy when 91 percent of the accidents occurred. Eighty-six percent (86%) occurred on dry roads compared to 12 percent on wet roads.

Forty-eight percent (48%) of the pedestrians were under 15 years of age, while ten percent (10%) were 65 or over. Males made up 60 percent of the pedestrians.

Nearly half of the accidents (45%) occurred in the suburbs. The area around the accident site was described as residential for 42 percent of the accidents. Twenty-four of the 28 intersections controlled by pedestrian signals were four-legged.

The most frequently mentioned pedestrian causal factor (19% of the responses) was running. This fact was supported by 24 percent of the pedestrian actions having been coded as running.

Of 28 suggested countermeasures, providing signals (seven percent of the responses) was second only to pedestrian and driver education (38 percent of the responses).

The results from this data base were not particularly germane to the present study. The point demonstrated was that the pedestrian intersection accident is primarily an urban phenomenon when viewed in terms of where the highest payoff lies in increasing safety.

Synthesis of Accident Characteristics

The results just presented for each data base contain a number of similar and comparable findings. Table 1 exhibits a comparison of several accident characteristics across the four data bases. The percentage of occurrence is indicated for each data base where this information was available.

Table 1

A Comparison of Accident Characteristics Across Data Bases
(Numbers indicate percentage of total data base responses)

Characteristic	D.C.	ORI	PEDACC	RUPED
Type of Traffic Control:				
Traffic Signals	39	49	49	17
Stop/Yield Signs (minor street)	10	14	16	8
None (major street with right-of-way)	51	37	35	75
Environmental Factors:				
Daytime	63	73	67	66
Clear or Cloudy Weather	85	88	86	91
Dry Road Surface	81	82	82	86
Pedestrian Factors:				
Males	62	58	55	60
Pedestrian under 15 years of age	42	40	32	48
Pedestrian 65 years and over	6	17	18	10
Pedestrian hit by turning vehicles	17	22	25	—
Pedestrian fatalities	2	12	11	6
Pedestrian running	—	32	29	24
Pedestrian in a marked crosswalk	42	66	37	—
Pedestrian crossing against signal	12	—	15	—

Other characteristics common to all of the data bases included the following:

- Approximately 90 percent of all pedestrians hit were engaged in crossing the street.
- The period from 3 p.m. to 6 p.m. was the most dangerous time of day for pedestrians crossing at intersections.
- Friday was the most dangerous day of the week.
- Over 60 percent of all pedestrian fatalities occurred at signalized intersections.
- More pedestrians were hit by left turning than right turning vehicles.
- Most turning vehicle accidents occurred at signalized intersections.
- More pedestrians were hit at nonsignalized intersections while running.
- Young pedestrians (under 15) were hit mainly at nonsignalized intersections.
- Parking on the major street at nonsignalized intersections appeared to cause blocked vision problems for both pedestrians and drivers.

Some of the results appeared to support the findings of other studies.* Between ten and twenty percent of the pedestrian intersection accidents occurred on one-way streets, which tends to support the findings of Fruin (1973) and Bruce (1967) that one-way streets are safer for pedestrians than two-way streets.

Between one-third and two-thirds of the accidents occurred in marked crosswalks, which supports, to some extent, the findings of Herms (1972) regarding the unsafe attitude of pedestrians using marked crosswalks.

Driver and pedestrian inattention continued to appear in the form of pedestrians not recognizing the need to take evasive action, drivers not seeing the pedestrians, and drivers not attempting evasive action. These results appear to reinforce the findings of Drahos and Treat (1975) that many drivers enter an intersection not fully alert to the possibility of suddenly encountering a situation requiring evasive action.

Countermeasures suggested by the project field investigators were heavily oriented toward pedestrian and driver education and training. Signalization and signing came in a distant second.

Conclusions

With respect to urban intersection pedestrian accidents, the following problem areas need to be addressed in order to improve intersection safety.

- Turning vehicle conflicts with pedestrians.
- Signalization with regard to timing, display, location, and public understanding of operation.
- Visibility at nonsignalized intersections.
- Driver and pedestrian education and training.
- Driver and pedestrian behavior.

*An extensive annotated bibliography was prepared as a supplement to this report. Copies are available for review from either the Federal Highway Administration or BioTechnology, Inc.

USE OF EXPERT OPINION TO IDENTIFY PROBLEMS, COUNTERMEASURES, AND CONSTRAINTS (TASK IB)

The objectives of this task were to develop a process to obtain expert opinions on current urban intersection problems and to form an advisory panel which could periodically recommend and review potential solutions. JHK & Associates had primary responsibility for this task.

BioTechnology provided inputs to and approval of the recommended criteria for selection of the individuals surveyed, provided inputs to the survey designs to insure that the information required in Tasks IC, ID, IIA, and IIB was obtained, and provided inputs to and concurrence on the recommended advisory panel.

Methodology

The first step in the conduct of this task was to identify the characteristics of the potential participants in the research effort. Resources that existed within established groups and committees relating to this research were utilized. Within the Institute of Transportation Engineers,* the key committees contacted included Committee 4B-A, "Application of Traffic Control Devices at Nonsignalized Pedestrian Crossings," and Committee 4B-M, "Signal Timing Methods." These committees were contacted directly at the ITE Annual Meeting in Detroit in September 1974. Specific committees within the Transportation Research Board, as well as the members of the National Advisory Committee on Uniform Traffic Control Devices, were also considered as excellent sources of information relevant to the project effort.

A group of surveys was prepared (see Figure 5) and distributed to members of these committees. The surveys were also distributed to traffic engineers who were identified as having installed new pedestrian devices in recent years, as well as others who indicated, through personal contacts, an interest in the project. These surveys generally went to traffic engineers at both the city and county level, to individuals involved in pedestrian research at various universities, and to engineers in federal and state governments with responsibility in the area of pedestrian safety. This list of respondents was carefully reviewed to assure that the surveys reached individuals in all areas of the United States and that a full range of city sizes and demographic factors were covered. We also attempted to obtain responses from areas having distinct pedestrian age factors, unique tourist conditions, and varying economic situations. Responses were received from 22 states.

The surveys were tailored to small groups of respondents with specific questions developed for each unique group. Of 78 surveys sent out, 55 were returned, a response rate of 71 percent.

*Formerly the Institute of Traffic Engineers.

Name ______________________________

Position ______________________________

Address ____

Phone ______________________________

1. Have you, or your city, installed or tested any new or unique pedestrian traffic control devices in the past 2 years?

   Briefly describe:

   ____

   ____

   ____

   ____

2. What kind of data on pedestrian activities does your city collect (e.g. crosswalk volumes, walking rates, observance studies, etc.)?

   Briefly describe:

   ____

   ____

   ____

   ____

3. Would your city or agency be willing to participate to the extent of allowing the installation and testing of experimental devices?

   ____ Yes ____ No

4. What are the major pedestrian safety problems at the intersections in your city?

   1. ____
   2. ____
   3. ____

5. What procedures or devices might eliminate these problems? (List in same order as above).

   1. ____
   2. ____
   3. ____

Figure 5. Sample Survey of Urban Intersection Improvements for Pedestrian Safety

6. Approximately how many intersections are in your city? ____________

7. How many are signalized? _____________

8. How many intersections have pedestrian signals? ____________

9. Would you be interested in participating in this research as a member of a Project Adivsory Panel?

_____ Yes _____ No

10. Do you normally attend the following meetings:

ITE Annual Meeting?	_____ Yes	_____ No
TRB Annual Meeting? (Washington, D.C.)	_____ Yes	_____ No
TRB Midyear Meeting?	_____ Yes	_____ No

11. Are there any technical activities in your local section of ITE which relate to pedestrian problems and potential countermeasures?

Briefly describe:

____

____

____

____

12. How much money would your city permit to be spent on improving a single intersection? ________________

13. What percent of your city's highway budget is available for intersection improvement and maintenance? ________

Figure 5 (continued). Sample Survey of Urban Intersection Improvements for Pedestrian Safety

Survey Results

In general, the survey results were satisfactory in terms of supplying the information sought. A number of unique problems and potential countermeasures were identified, and a list of potential members of the project advisory panel was developed. As anticipated, the details of various items were not particularly explicit in many cases. Finally, it should be noted that the survey results are not an end in themselves, but will be used for input into later stages of the project.

The key items gained from the results of the survey include a listing of the major problems as perceived by city traffic engineers, a list of new devices which are presently being tested, and indications of other possible countermeasures that may be used to promote pedestrian safety.

All major pedestrian safety problems mentioned by the respondents, along with the percentage of respondents indicating each problem, are presented and discussed below.

1. Lack of compliance with pedestrian signals (51%). This was the most frequently documented complaint from the surveys received. Very few locations had any data to indicate the severity of the problem or the extent, if any, to which it related to safety.

2. Lack of enforcement (31%). Many respondents indicated that they had very strict pedestrian laws and ordinances in effect in their cities, but that there was inadequate enforcement of these laws. These respondents noted that very few, if any, citations were given for violations.

3. Turning vehicle conflicts (31%). This was mentioned in a large proportion of the surveys, with different types of problems being encountered. Several cities indicated that the major problem was channelized intersections where right turning vehicles were controlled only by a yield sign. Several cities indicated problems with right turn on red provisions. One city indicated that there were problems where arrows permitting certain vehicular turning movements conflicted with pedestrian walk indications. The flashing WALK was considered by some to be an inadequate device in alleviating turning conflicts.

4. Lack of understanding (24%). Many respondents indicated that there was a considerable amount of confusion with regard to the meaning of the flashing DONT WALK. There was also considerable confusion with the flashing WALK elements of pedestrian signals.

5. School crossings (22%). This was brought up by a number of respondents as the major problem in their city.

6. Elderly pedestrians (13%). Several cities indicated the need for addressing the particular problems of elderly citizens in terms of visual and signal timing requirements.

7. Failure to use pushbuttons (11%). There was a general indication that pushbuttons were not being properly used in many locations. They were either improperly located or were being ignored by pedestrians who thought that some other individual had pushed the button.

8. Crossing wide roadways (11%). Several cities, particularly those in the western portion of the country, indicated that the problem of crossing six-lane or greater roadways was a major concern, and that there would have to be either partial crossing techniques developed or some means for storing pedestrians on a center island.

9. Roadway lighting (5%). Inadequate lighting at intersections and marked crossings was noted as a safety problem.

10. Too many crosswalks (5%). Several cities indicated that, because of their very stringent pedestrian laws and ordinances, many pedestrians were overconfident at marked, unsignalized crosswalks and, therefore, took unnecessary chances that often resulted in accidents.

Table 2 summarizes the problems discussed above.

Table 2

Summary of Major Safety Problems

Question: What are the major pedestrian safety problems at the intersections in your city?

Major Problems	Number of Responses*	Percent of Total
1. Lack of Compliance	23	51%
2. Lack of Enforcement	14	31%
3. Turning Vehicle Conflicts	14	31%
4. Lack of Understanding	11	24%
5. Treatment at School Crossings	10	22%
6. Treatment of Elderly Pedestrians	6	13%
7. Failure to use Pushbuttons	5	11%
8. Crossing Wide Roadways	5	11%
9. Inadequate Roadway Lighting	2	5%
10. Too Many Crosswalks	2	5%

*NOTE:

Of the questionnaires returned, 45 had responses to this question. Most of the questionnaires had multiple responses.

The respondents suggested a number of potential countermeasures for alleviating the problems documented on the surveys. These countermeasure suggestions are, for the most part, not particularly novel, but they do indicate the degree of concern with the pedestrian problem and a general willingness and enthusiasm for promoting new and improved devices and techniques. They included many items which are presently being tested and used in cities, as well as some which have not been researched. The more pertinent of these recommendations are listed below and summarized in Table 3.

Table 3

Summary of Potential Countermeasures

Question 1. What procedures or devices might eliminate these problems?
2. Have you, or your city, installed any new or unique pedestrian traffic control devices within the past two years?

Proposed Countermeasure	Number of Responses	Percent of Total
1. Increased Enforcement	24	65%
2. Improved Education	22	59%
3. Pedestrian Barriers	13	35%
4. Use of 3M Dynamic Signal	10	27%
5. Improved Pedestrian Signal Displays	9	24%
6. Improved Pedestrian Signal Phasing and Timing	9	24%
7. Elimination of Crosswalks	5	14%
8. Revise Colors of Pedestrian Signals	4	11%
9. Shielding Vehicular Signals and Programmed Visibility	4	11%
10. Improved Delineation of Crosswalks	4	11%
11. Develop New Pedestrian Clearance	2	6%
12. Type "A" Pushbuttons	2	6%
13. Improved Street Lighting	2	6%
14. Use of Symbolic Lenses	1	3%
15. Relocation of Bus Stops	1	3%
16. Pushbuttons for Bicycles	1	3%
17. Removal of Left Turn Bays	1	3%

Note:

The responses to the two questions above were similar, so the results have been calculated together. Of the questionnaires returned, thirty-seven had responses to these questions. Most of the questionnaires had multiple responses.

1. Increased enforcement. The most frequent response (65%) was to increase enforcement of existing pedestrian ordinances and laws in order to increase compliance with pedestrian signals and markings. There were also many comments regarding the need for improving present laws and ordinances.

2. Improved education. The second most frequent response (59%) indicated a need for improved education and information programs to inform and instruct pedestrians in the use of traffic control devices.

3. Use of pedestrian barriers (35%). These devices would essentially restrict and channel the flow of pedestrians toward intersections.

4. 3-M dynamic pedestrian signals (27%). This device presents a moving WALK indication to pedestrians in the crosswalk.

5. Improved pedestrian signal displays (24%). These were general comments that did not specify whether the improvement pertained to color, message content, design, or location.

6. Improved signal phasing and timing characteristics (24%). Most of these comments were general and did not include details.

7. Elimination of crosswalks (14%). Several cities indicated that pedestrian safety would be improved by eliminating crosswalks at midblock locations and unsignalized intersections.

8. Use of different colors for pedestrian devices (11%). Several cities indicated that the lunar white and portland orange signal indications are inferior and that other colors should be studied.

9. Shielding vehicular signals or using programmed visibility signals to prevent conflicting messages from being presented to the pedestrian (11%).

10. Delineation of crosswalks (11%). This included suggestions for the use of brick or tile or various novel types of painted pavement markings in the crosswalk area.

11. Develop new clearance interval (6%). Suggestions were made to add a third distinct indication to the present pedestrian signals to clarify the meaning of the clearance interval.

12. Use of Type "A" pushbuttons (6%). This term describes a California device which provides a light on the pushbutton panel, indicating to the pedestrian whether or not the detector has been actuated.

13. Unique or improved roadway lighting (6%). One suggestion was to provide spotlighting on the particular crosswalk(s) that are in the WALK interval. Another suggested lighting at all marked crossings.

14. Use of symbolic lenses on the pedestrian signals in lieu of word messages (3%).

15. Relocation of bus stops (3%).

16. Provision of pushbuttons for bicycles (3%). This suggestion was made in two cities where the pushbuttons could not be reached by people on bicycles trying to cross a major roadway.

17. Removal of left turn bays (3%). One city indicated that this had been done in several locations to improve the crossing capability at very wide streets and to provide a central island pedestrian refuge.

One interesting characteristic obtained from the surveys had to do with the use of pedestrian signal heads at signalized intersections within cities. The number of signal locations that were equipped with pedestrian indications ranged from 0 to 100 percent. Cities in the western region of the country ranked high, while cities in the eastern states ranked low, particularly in the northeast. In general, it would appear that, in the "typical" city, approximately 30 percent of the signalized intersections are equipped with pedestrian indications.

These latter comments reflect one significant result of the survey data. There was a marked difference in the application of pedestrian control devices which can almost be stratified by the different regions of the country. It would appear that certain areas have a more determined commitment to upgrading traffic control devices than others. This is indicated by both the city budgets and the staffing of the various jurisdictions. There are also a number of issues on which different parts of the country take positions on opposite sides. These considerations must be evaluated when particular countermeasures are tested and developed for eventual nationwide implementation.

Selection of Advisory Panel

Another objective of the survey in this task was to identify a project advisory panel. At a meeting with the Contract Manager to select the advisory panel, we decided that the panel should consist of eight city or county traffic engineers, one university researcher, and a representative of the Federal Highway Administration from the traffic operations area. The traffic engineers were to represent a reasonable cross section of regions of the country and various city sizes, and were to be familiar with and interested in the pedestrian safety problem. Consideration was given to the individual's response to items 3 and 9 on the survey and his availability at national meetings. (Annual meetings of the Transportation Research Board were viewed as logical opportunities to solicit panel opinions.)

With these criteria, the following panel members were selected:

David Fielder
P. Malcolm Smith, Jr.
Harvey Friedson
Dan W. Hoyt
Donald O. Robbins
Lester A. Hoel
James L. Brown
J. Mike Dawkins
Edward Swanson

All of these individuals agreed to serve on the panel.

It was decided that the advisory panel would formally meet twice during the project, in June 1975 and in January 1976. Travel expenses for the June meeting would be provided by the project. The January 1976 meeting would take place during TRB week with no project expenses involved. There would also be several queries made by mail and telephone.

A separate informal meeting was held near the end of Phase I for pedestrian signal manufacturers. They were briefed on the project and provided inputs to the selection of countermeasures for evaluation in Phase II.

IDENTIFICATION AND DEVELOPMENT OF BEHAVIORAL MEASURES (TASK IC)

This task is intended to evaluate the sensitivity and validity of promising vehicle and pedestrian measures through a field data collection effort. The resulting measures will be used in the evaluation study of Phase II.

Tasks IA, IB, and IC can all be viewed as an attempt to isolate a set of promising behavioral measures. They are of two rather general types: operational measures and conflict measures.

The science of traffic engineering has used operational measures to advantage in establishing the characteristics of pedestrian and vehicle movement. Examples of this type include volume, queue formation, delay, etc., all of which may be established as physical phenomena. Although the *method* for obtaining an operational measure may be subject to discussion, there is little disagreement regarding the *utility* of a measure such as delay.

The second type of measure is not nearly as well established. Conflict measures have been developed for certain vehicle studies primarily in an attempt to measure the relative hazard index of a traffic zone, such as an intersection. We are familiar with several studies of this nature, and believe that the feasibility of using conflict measures deserves consideration.

Unfortunately, in the specific area of pedestrian countermeasures, we find that conflict measures are not well established. The relation between such measures and the long-term pedestrian accident history of an intersection has not been demonstrated.

Before discussing our technical approach to Task IC, it is appropriate to briefly review the relevant past studies.

Previous Research

A review of previous observational studies indicates that they generally employed a single data collection procedure. The majority utilized manual observation and hand coding of pedestrian and vehicular activities. Some used manual tallies of vehicular and pedestrian volumes as their major data source, while still others used real-time and/or time-lapse photography to record vehicular and pedestrian behavior. Relatively few reports were located in which pedestrians and/or drivers were interviewed to determine their attitudes toward or reasons for their behavior. A notable exception to the reliance on a single procedure and the absence of interview data is the Berger (1975) study. Consequently, we have drawn heavily on the methods and findings developed during that study in structuring Task IC.

Manual Counts

One of the most simple, reliable, and commonly used data collection techniques involves tallying the number of pedestrians or vehicles performing a given action or passing by a given point. In a comparison study of painted and unpainted crosswalks, Herms (1970) tallied the number of pedestrians using each crosswalk and the number of vehicles passing through the intersection. Individuals can be trained to perform such field work with a minimum of effort and, since only one coder is needed per site, data can be collected for long periods of time at relatively low cost.

Kaiser (1959) evaluated the effect of pedestrian indication signals on pedestrian behavior. In so doing, he tallied vehicular flow by direction through the intersection as well as pedestrian movements "with" and "against" the light. Other work (Garwood & Moore, 1962; Jacobs & Wilson, 1967; Berger, 1975) reported simple vehicular and pedestrian tallies in combination with other manual observation and coding techniques.

Manual Observation and Coding

A number of studies, both in this country and abroad, have used various manual observation and coding techniques to record pedestrian activities. Cleveland (1969) presented a comprehensive compilation of techniques for recording information about pedestrian behavior at crosswalks. Utilizing the procedures set forth by Cleveland, Malo and coworkers (1971) evaluated a number of crosswalk information systems. They collected vehicular data on intersection volumes, spot speeds, travel time, gaps, access point volumes, and drivers' responses to the crosswalk configuration. The study determined pedestrian volumes, personal characteristics, crossing time, and gap acceptance, as well as various behavioral items at signalized intersections.

A number of pedestrian studies have been performed in England, most frequently under the auspices of the Road Research Laboratory (Jacobs, 1965 & 1968; Jacobs and Wilson, 1967; Mackie and Jacobs, 1965; Wilson and Older, 1970). These studies were primarily concerned with determining pedestrian and vehicular behavior at various types of crossing configurations. A wide variety of parameters were measured including:

- Driver response to crosswalk signals, with and without pedestrian present.
- Pedestrian flow at or near the vicinity of the crosswalk.
- Delay of pedestrians waiting at curb.
- Pedestrian crossing time.
- Vehicle time to pass through crosswalk sites.
- Total vehicular volumes.

Each of these studies involved strict adherence to a data collection schedule (sampling plan) and manual recording of selected categories of behavior.

Fleig and Duffy (1967) consulted police accident records to determine which unsafe behaviors were associated with accidents. They found that (1) crossing against the signal, (2) crossing away from the crosswalk, (3) coming from behind parked cars, and (4) standing in the roadway when the pedestrian signal is red were "unsafe" behaviors under the pedestrian-vehicle signal system being evaluated. They then used activity sampling to determine the number of "unsafe" acts being performed before and after the installation of pedestrian traffic signals at the intersection being studied. They found no significant change in the number of unsafe acts observed; however, their methodology suggests that activity sampling might be a promising way to collect large quantities of data in a short time, and thus avoid confounds associated with changes in time.

An interesting methodology for studying the characteristics of traffic conflicts was described by Harris and Perkins (1968). They defined over 20 objective traffic conflict situations and related them to four basic types of intersection accidents. Their procedure serves to measure the danger of traffic maneuvers by simultaneously counting both traffic conflicts and volumes, and, as such, is suited to measuring the effectiveness of traffic engineering changes through before and after studies.

Reading (1973) used manual tallies in an interesting study of behavior modification techniques as used on school age pedestrian crossing behavior. Using an intermittent reinforcement schedule, he reported a dramatic increase in safe crossing behavior at intersections near an elementary school in Salt Lake City.

Video Recording

A number of more recent studies have used 8 and 16 mm movie cameras to film vehicular and pedestrian activities. The filming has been both real-time and time-lapse. Filming provides a permanent record of the data and permits verification of the reliability of the film observers who reduce the films to a usable data format.

Heimstra and coworkers (1969) filmed 200 school age pedestrians and developed a detailed behavioral analysis consisting of social conditions, approach behavior, and curb behavior. Older (1968) filmed pedestrian flow on the sidewalks of shopping areas. Filming at 10 frames/second, he developed a relationship between the walking speed and density of pedestrians. Jacobs (1965) filmed pedestrian and vehicular traffic before and after the installation of a zebra crossing. Filming from a roof top, he was able to determine pedestrian delay times and crossing utilization, as well as vehicle speeds. Singer (1969) filmed pedestrians at intersections in three cities and found no consistently significant effect of enforcement campaigns on pedestrians' compliance with traffic signals.

Older and Grayson (1972) analyzed the preceptual processes and decision making involved in pedestrian crossing behaviors in terms of a task flow. The task flow provided an interesting theoretical framework against which to compare the results of many of the observational studies. However, as the authors themselves caution, their results are based on a small number of sites and more field studies are needed covering a wider range of behaviors over a variety of different conditions. However, it is apparent that if effective countermeasures are to be developed, future research should focus on explanations as well as descriptions of pedestrian behavior.

Welke (1968) filmed pedestrian and traffic flow at an intersection using a 16 mm camera set to operate at .5 frames per second. The number of pedestrians crossing during each signal cycle and the pedestrian-incurred vehicle delay was tallied from the filmed record.

Berger (1975) used Super 8 time-lapse and real-time photography to record a wide range of pedestrian and vehicle behaviors. Activity sampling and site matching (control-experimental) were the salient methodological aspects of this study. The findings indicated that the following behaviors were sensitive to countermeasure intervention:

- Pedestrian/Vehicle Separation
- Pedestrian Scanning
- Vehicle Speed
- Abort Crossing
- Entry in Front of Stopped Buses
- Pedestrian Hesitation in Traffic Lane
- Pedestrian Backing Up in Parking Lane
- Pedestrian in Front of Parked Vehicles
- Running in Roadway
- Sudden Appearance
- Crossing Outside of Crosswalk
- Vehicle/Stop Line Violations
- Vehicle/Crosswalk Violations
- Vehicle/Crosswalk Separation
- Midblock Crossings
- Crossings in Crosswalk Area

Unlike all of the other filming efforts which used a stationary camera, Jacobs (1968) filmed pedestrians using a motion picture camera mounted in a moving automobile. He was primarily interested in the effect of vehicle lighting on pedestrian movement.

Interviews

Surprisingly, very few research studies have involved interviewing pedestrians either to determine the reasons for their behavior or to trace the factors that led to unsuccessful behaviors and subsequent accidents. Synder and Knoblauch (1970) performed an in-depth evaluation of over 2000 urban pedestrian accidents, and obtained interviews with a number of involved pedestrians and involved drivers. Berger (1975) interviewed 2000 pedestrians to determine the reason for desirable and undesirable crossing behaviors. These interviews were structured around determining the predisposing and precipitating factors that were involved in the accidents. Some of the results will be presented in our discussion of Task ID.

Required Characteristics of the Behavioral Measures

In order for a behavior to be useful in the current effort, it must possess certain characteristics. First, the behavior must be definable in terms of objective, observable events so that coding is reliable. Secondly, it must occur with sufficient frequency to permit an efficient data collection schedule. Third, the behavior should have construct validity; that is, the candidate behaviors must have an association with intersection safety or flow (assumed or proven).

The behaviors must also be sensitive. In the content of this study, sensitivity implies the ability of the measures to reliably discriminate between intersections. In addition, the conflict measures should discriminate *on the basis of* accident history or vehicle/pedestrian flow. We emphasize the content of sensitivity for several reasons. "Validating" the measures will provide considerable guidance in the selection and modification of candidate measures. These selected measures will be used to identify study sites in Phase II. Additionally, the selected conflict measures can be used by city engineers to determine the warrants for intersection treatment. Also, the acceptance of the countermeasures will depend on the justification that can be shown for their effectiveness. Thus, the behaviors used to evaluate the countermeasures must be meaningful and believable to the city traffic engineer.

Finally, the behavioral techniques should be both cost effective and consist of measurement procedures that are currently available. The development of sophisticated instrumentation would be counterproductive. Our intent is to arrive at a set of behaviors and behavioral measurement procedures that can be used by operating traffic engineers.

Approach to the Development of Behavioral Measures

A basic component of our approach to Task IC involved the establishment and collection of behavioral measures at a set of intersections for which a complete set of accident records are available. Since two intersections having the same signalization and similar geometrics are often found to have different accident records, we concluded that different operational and conflict levels would be associated with the two intersections. Our intent was to determine which behaviors, if any, were more often associated with high pedestrian accident intersections.

A set of high pedestrian accident intersections (three or more accidents occurring from 1971 to 1973) was identified in Washington, D.C., San Francisco, and Oakland, California. We matched a number of these intersections with low pedestrian accident intersections (those experiencing 50 percent or fewer pedestrian accidents than the high accident locations). This matching procedure assured that the measures evaluation would be conducted within a common situational context, i.e., intersections with similar attributes. This design avoids confounding the results of our sensitivity study with the physical attributes of the intersections. (See Appendix A for a description of the site selection process.)

The field portion of Task IC was designed to meet the requirements of developing measures that are reliable, easily applied, have wide applicability, discriminate between the intersections, and, hopefully, are related to the intersection pedestrian safety record. Additionally, the field studies should provide insight as to the varying types of operational problems at different intersections and their possible remediation.

The remainder of this chapter deals with the extent to which we accomplished these objectives and the specific means we employed.

First Field Study: Development of Measurement Procedures, Selection of Promising Behavioral Measures, and Identification of Possible Intersection Accident Causal Characteristics

A candidate set of behaviors was generated from the literature previously cited. These behaviors were operationally defined and the measures were field tested. Figure 6 presents a brief definition of the candidate behaviors.

Simultaneously, the intersection selection process was initiated. A listing of the frequency of pedestrian accidents (1971 through 1973) by intersection was generated for Washington, D.C., San Francisco, and Oakland, California. All intersections experiencing three or more accidents were designated as potential study sites. Upon review of their geometric characteristics, it was apparent that the vast majority of these intersections had four legs. (The accident data reported in Task IA

Code	Definition
(A) -	Abort - Return to the curb after having both feet on the roadway or abandoning the crossing to cross the other street.
(B) -	Backup Movement - Momentary reversal in pedestrian direction of travel in the traffic lane, or hesitation in response to a vehicle in a traffic lane.
(D) -	Diagonal Crossing - Ped crosses the intersection diagonally.
(R) -	Running in Roadway - Pedestrian's feet leaving the ground at the same time (2 or more steps).
(RC)-	Running into Roadway - Pedestrian's feet leaving the ground at the same time (2 or more steps) when entering the roadway.
(OC)-	Outside Crosswalk - Pedestrian crosses all traffic lanes outside painted crosswalk (not coded for unmarked crosswalks).
*(CA)-	Crossing Against Don't Walk Signal - Crossing roadway entirely against the signal.
*(SC)-	Starting During Caution Signal - Starting crossing during the caution phase of the signal.
*(SA)-	Starting on Don't Walk Signal - Starting against don't walk signal which turns to walk before pedestrian completes crossing of roadway.
**(VS)-	Vehicle Going Straight Conflict - Number of vehicles going straight through the intersection that are involved in a ped conflict (ped within 20 feet and in vehicle path).
(VR)-	Vehicle Turning Right Conflict - Number of vehicles turning right into the crosswalk that are involved in a Turning Conflict (ped within 20 feet and in vehicle path).
(VL)-	Vehicle Turning Left Conflict - Number of vehicles turning left into the crosswalk that are involved in Turning Conflict.
(VT)-	Vehicle Moving Through Crosswalk, Then Turning Right Conflict - Number of vehicles moving through crosswalk then turning right that are involved in a Turning Conflict.
(VO)-	Vehicle Overtaking - Pedestrian enters roadway and moves in front of stopped or standing vehicle (not a parked vehicle) into a lane of traffic moving in the same direction.
(MV)-	Moving Vehicle - Through traffic moving through the crosswalk while ped is in a traffic lane.
**(PV)-	Proximity of Vehicle - Vehicle moving in a traffic lane 6 car lengths or less from ped as ped enters that lane.

*Signalized Intersections Only
**Nonsignalized Intersections Only

Figure 6. Candidate Behavior Definitions

substantiates this observation.) Therefore, only four-legged intersections were considered in the field studies. Sixty (60) of these high accident intersections (45 in Washington, D.C. and 15 in California) were matched with low accident intersections having similar geometrics.* In well over 90 percent of the cases, the matched intersections (referred to as a "pair") shared a common road and were within several blocks of each other. Some characteristics of the 60 pairs were:

- 30 pairs were right angle, two-way, two-way (15 of these were in California).
- 15 pairs were skew, two-way, two-way.
- 15 pairs were right angle, two-way, one-way.
- 19 pairs were not signalized.
- 24 pairs had traffic signals.
- 17 pairs had traffic signals and pedestrian signals.

These 60 pairs of intersections served as the test bed for the development of the behavioral measurement procedures. A subset of these site pairs was used in the selection of promising behavioral measures and identification of potential intersection accident causal characteristics.

Development of Behavioral Measurement Procedures

At the beginning of the project, we decided to attempt to capture the required data via manual tallies and observational procedures. This decision was based on reviewing the experience of previous studies. It was apparent that the use of nonmanual techniques involved a large investment in equipment and/or an equally unacceptable amount in data reduction costs. For example, Berger (1975) found that it required approximately three hours to reduce a 50-foot roll of time-lapse film taken over a one-half hour period.

A preliminary set of data collection forms were generated. These forms were designed to capture the behaviors selectcd from the literature (see Figure 6). Forms were also generated for the collection of pedestrian and vehicle volume data. About ten people were trained in the use of the preliminary forms. Training consisted of both classroom instruction and in-the-field practice. During the course of the training, the behavioral definitions were continually refined. In particular, several people-months of effort were devoted to the operationalization of the measures. The measurement procedures were then standardized and a revised set of data collection forms produced (see Figures 7 and 8).

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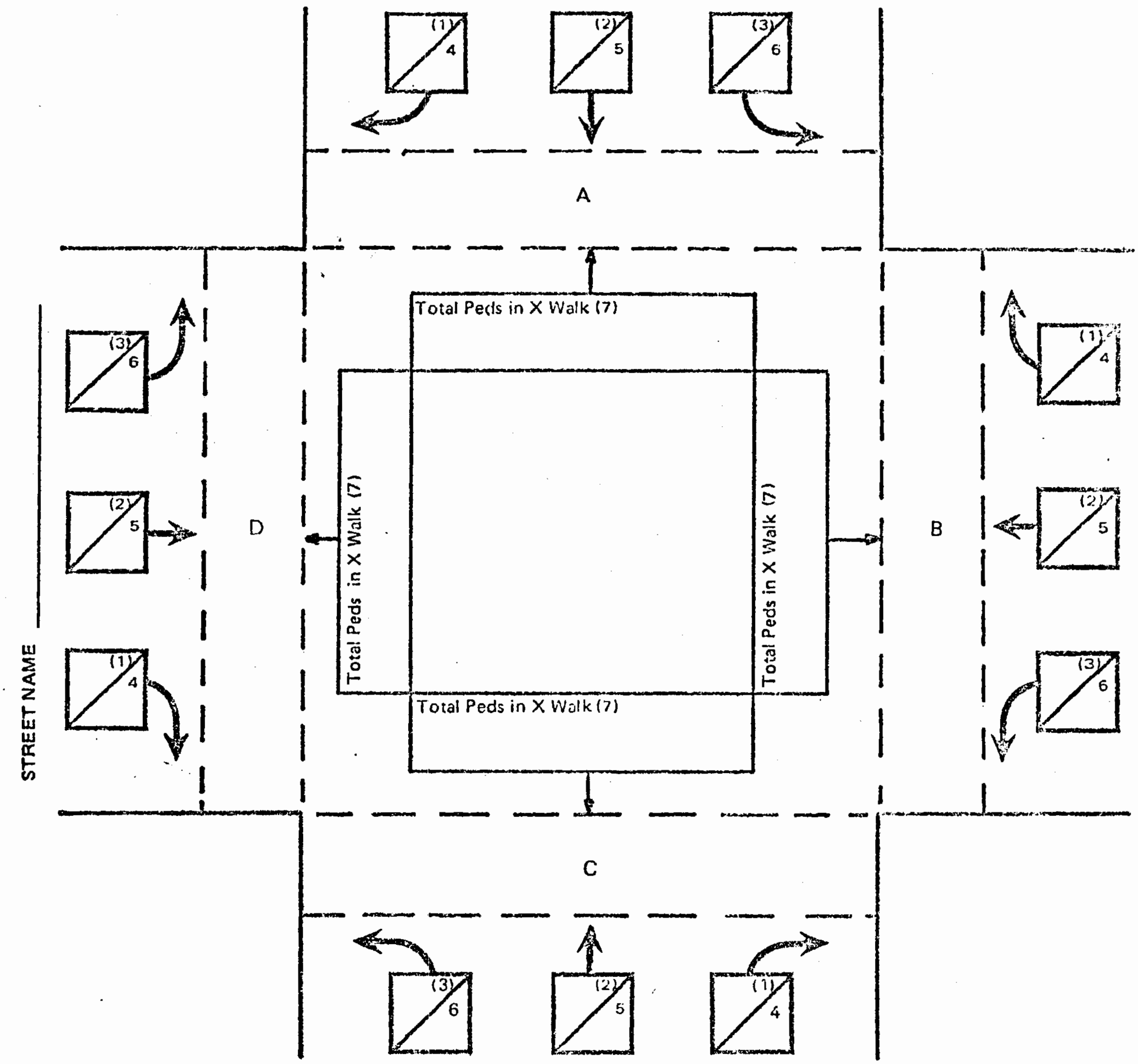
*As previously indicated, a low accident intersection had one-half or fewer accidents than its high accident match.

SITE #________ DATE ________ TIME PERIOD STARTED ____________ OBSERVER ____________



STREET NAME: ____________________ DIRECTION

KEY:

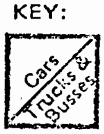


Figure 7. Data Form #2
Vehicle and Pedestrian Flow Characteristics

LEG A

[VS____] VR____ VL____ VT____

	Pedestrian Sex	Pedestrian Age	Pedestrian Actions
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16	Multiple Ped #		
17	Multiple Ped #		
18	Multiple Ped #		
19	Multiple Ped #		
20	Multiple Ped #		

LEG B

[VS____] VR____ VL____ VT____

	Pedestrian Sex	Pedestrian Age	Pedestrian Actions
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16	Multiple Ped #		
17	Multiple Ped #		
18	Multiple Ped #		
19	Multiple Ped #		
20	Multiple Ped #		

LEG C

[VS____] VR____ VL____ VT____

	Pedestrian Sex	Pedestrian Age	Pedestrian Actions
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16	Multiple Ped #		
17	Multiple Ped #		
18	Multiple Ped #		
19	Multiple Ped #		
20	Multiple Ped #		

LEG D

[VS____] VR____ VL____ VT____

	Pedestrian Sex	Pedestrian Age	Pedestrian Actions
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16	Multiple Ped #		
17	Multiple Ped #		
18	Multiple Ped #		
19	Multiple Ped #		
20	Multiple Ped #		

Figure 8. Data Form #3
Pedestrian Behavioral Sampling

A small sample was selected from the 60 intersection pairs to determine the reliability of the data collection procedures for each of the measures of interest. Table 4 summarizes the results of this reliability analysis. As indicated in the table, all reliabilities were high. These results demonstrated the feasibility of using the developed procedures to select the most promising behavioral measures.

Table 4

Task IC – Inter-rater Reliability for Pedestrian Activity Sampling

Codes*	Mean Correlation Coefficient**	Number of Independent Pairs of Coders
A	0.9724	5
B	0.8485	7
D	1.0000	3
R	0.8113	6
RC	0.8451	5
OC	0.8599	7
CA	0.8623	7
SC	0.9175	4
SA	0.8872	7
VS	***	–
VR	0.8843	7
VL	0.8816	4
VT	***	–
VO	***	–
MV	0.7508	7
PV	***	–

*See Figure 6 for Candidate Behavior Definitions.

**Each individual correlation coefficient was based on a sample of 20 cycles. All mean correlation coefficients were statistically significant at the .01 level.

***Activity occurred too infrequently to calculate a correlation coefficient.

Selection of Promising Behavioral Measures

Collection of the behavioral measures represented the major effort during Task IC. Teams of field investigators visited each site in order to collect the behavioral and operational data. The procedures that were developed indicated that from one to four field investigators would be needed per intersection (depending on pedestrian volumes).

Data were collected at all 60 intersection pairs in accordance with the schedule presented in Figure 9. The schedule was designed to sample the morning peak, off peak, and afternoon peak. A minimum of three hours of data were collected at each intersection in a pair, with the field investigators cycling back and forth between the two intersections in the pair. An additional data collection requirement was that at least 100 pedestrian crossings had to be observed at a pair (with a minimum of 40 crossings at one of the intersections).

Location	Activity	Time
A	Pedestrian and Traffic	7:30 – 8:00
TR		8:00 – 8:15
B	Pedestrian and Traffic	8:15 – 8:45
Break		8:45 – 9:15
TR		9:15 – 9:30
A	Pedestrian and Traffic	9:30 – 10:00
TR		10:00 – 10:15
B	Pedestrian and Traffic	10:15 – 10:45
B	Pedestrian and Traffic	10:45 – 11:15
TR		11:15 – 11:30
A	Pedestrian and Traffic	11:30 – 12:00
Lunch		12:00 – 1:00
TR		1:00 – 1:15
B	Pedestrian and Traffic	1:15 – 1:45
TR		1:45 – 2:00
A	Pedestrian and Traffic	2:00 – 2:30
A	Pedestrian and Traffic	2:30 – 3:00
TR		3:00 – 3:15
B	Pedestrian and Traffic	3:15 – 3:45
Break		3:45 – 4:15
TR		4:15 – 4:30
A	Pedestrian and Traffic	4:30 – 5:00
TR		5:00 – 5:15
B	Pedestrian and Traffic	5:15 – 5:45

Key:

A, B = Data Collection at Sites
TR = Travel between Sites

Figure 9. Data Collection Schedule for First Field Study

A continuous review of the collected data and field notes indicated that some intersection pairs should be discarded. At some sites, construction was started after the arrival of the field team; at others, the signals at one site in a pair were inoperative. In some cases, differences in geometrics were uncovered. A careful review of these field notes suggested that we base our selection of measures on 38 intersection pairs. Of these 38 sites:

- 21 pairs were right angle, two-way, two-way (eight of these were in California).
- 6 pairs were skew, two-way, two-way.
- 11 pairs were right angle, two-way, one-way.
- 15 pairs were not signalized.
- 20 pairs had traffic signals.
- 3 pairs had traffic signals and pedestrian signals.

Table 5 presents a summary of the data from the 38 selected intersection pairs. The first column in this table indicates the percent of intersection pairs exhibiting five percent or more of a particular type of behavior. To qualify, at least five percent of the pedestrians at one of the intersections in a pair had to be observed performing the behavior. Furthermore, only those intersections where the behavior *could* occur were included in the calculation of the percents. Thus, if an intersection pair did not have signals, it could not have any pedestrians crossing against the signal (CA).* Therefore, this intersection pair would be excluded from the CA calculations in Column 1. Less than half of the intersection pairs exhibited five percent or more of the following behaviors:

- Aborting a crossing.**
- Diagonal crossing.**
- Running into the roadway.
- Pedestrians within 20 feet and in the path of right-turning vehicles.
- Pedestrians within 20 feet and in the path of left-turning vehicles.
- Starting against caution phase of the signal.
- Nonrestricted vehicle going straight and pedestrian within 20 feet of direct path.
- Vehicles turning right and pedestrian within 20 feet of direct path.
- Vehicles turning left and pedestrian within 20 feet of direct path.

Because of their infrequent occurrence, these nine behaviors are candidates for elimination or redefinition.

---

*The codes appearing in all caps and/or parentheses are defined in Figure 6.

**These behaviors were excluded from this analysis because of their extremely low rate of occurrence.

Table 5

Summary of Data From Selected Intersection Pairs (N = 38)

Behaviors	Percentage Exhibiting Behavior (⩾5%)	Percentage High > Low (Frequency)*	Percentage High > Low (%)*
Traffic related pedestrian hesitation or reversal in traffic lane (B)	86.8	68.4	52.6
Running in roadway (R)	86.8	57.9	42.1
Running into roadway from curb (RC)	44.7	31.6	42.1
Pedestrian crosses all traffic lanes outside painted crosswalk (OC)	54.0	37.8	37.8
Through vehicle moving through crosswalk while pedestrian is in traffic lane (MV)	100.0	73.7	55.3
Pedestrians within 20 feet of and in the path of non-restricted vehicles going straight (VS, pedestrians)[1]	53.3	46.7	60.0
Pedestrians within 20 feet of and in the path of vehicles turning right (VR, pedestrians)	31.6	44.7	55.3
Pedestrians within 20 feet of and in the path of vehicles turning left (VL, pedestrians)	21.0	34.2	42.1
Nonrestricted moving vehicle within 6 car lengths of pedestrian entering lane (PV)[1]	93.3	60.0	46.7
Crossing entire roadway against pedestrian or traffic signal (CA)[2]	82.6	56.5	34.8
Starting against caution phase of pedestrian or traffic signal (SC)[2]	35.7	57.1	71.4
Starting against pedestrian or traffic signal, but signal changes to green during crossing (SA)[2]	91.3	69.6	52.2
Nonrestricted vehicles going straight and pedestrian within 20 feet of direct path (VS, vehicles)[1]	0	53.3	60.0
Vehicles turning right and pedestrian within 20 feet of direct path (VR, vehicles)	42.1	55.3	50.0
Vehicles turning left and pedestrian within 20 feet of direct path (VL, vehicles)	28.9	42.1	52.6
Pedestrian volumes	N/A	71.0	N/A
Total Right-turning vehicles	N/A	50.0	N/A
Total Left-turning vehicles	N/A	63.2	N/A

*Percèntages are based on the total number of intersection pairs where a particular behavior *could* occur (see notes below). Pairs exhibiting equal frequencies of percents of behaviors (including zero) were treated as "high < low."

NOTES:

[1]Applies to unsignalized intersections only.

[2]Applies to intersections with either traffic or pedestrian signals only.

The second column of the table indicates the percent of time that a particular behavior occurred more frequently at the high accident intersection. These data are an indication of the behaviors' ability to differentiate high accident from low accident locations. The third column of the table indicates the percent of time that the proportion of a particular behavior occurred more frequently at the high accident intersection.

An analysis of this data was performed via the Fisher's Distribution Free Sign Test to determine which behaviors significantly differentiated between the high and low members of a pair. This analysis deals only with the direction of the difference (more frequent at high site = +, less frequent at low site = -) and ignore ties. The results revealed that the following behaviors occurred more frequently at the high accident sites:

- Traffic-related pedestrian hesitation or reversal in traffic lane (B).
- Through vehicle moving through crosswalk while pedestrian is in traffic lane (MV).
- Starting against pedestrian signal, but signal changes to green during crossing (SA).
- Vehicles turning right and pedestrian within 20 feet of direct path (VR, vehicles).
- Vehicles turning left and pedestrian within 20 feet of direct path (VL, vehicles).

Although these results appear promising, it should be noted that the high accident sites had heavier pedestrian volumes. Thus, these differences in frequencies could be attributable to the fact that generally more people were present to perform these activities.* On the other hand, the differences in the frequency of these behaviors could be sufficient to contribute to the differences in the accident histories of the intersections.

Based on these results, we decided to further examine the percent of pedestrians performing each behavior. In particular, we wanted to determine if a combination of behaviors could be used to differentiate high and low accident intersections. Using a program developed by Yoo, Schmitz, and Berger (1975), we attempted to classify intersections based on the percent of pedestrians performing ten specific behaviors. These behaviors were:**

- Aborting a crossing (A).***
- Traffic-related pedestrian hesitation or reversal in traffic lane (B).
- Running in roadway (R).
- Running into roadway from curb (RC).
- Through vehicle moving through crosswalk while pedestrian is in traffic lane (MV).

---

*When we used the percent of pedestrians performing each activity as a measure, we found no difference between the percents at the high and low accident sites.

**These behaviors were selected because they could occur at any of the 38 site pairs.

***This behavior occurred with extremely low frequency and was therefore omitted from the previous univariate analysis. It was included in this analysis since it might interact with other variables.

- Pedestrians within 20 feet of and in the path of vehicles turning right (VR, pedestrians).
- Pedestrians within 20 feet of and in the path of vehicles turning left (VL, pedestrians).
- Nonrestricted vehicles going straight and pedestrian within 20 feet of direct path (VS, vehicles).
- Vehicles turning right and pedestrian within 20 feet of direct path (VR, vehicles).
- Vehicles turning left and pedestrian within 20 feet of direct path (VL, vehicles).

The program compares each intersection with every other intersection. These comparisons are made using all of the ten behaviors listed above. Those intersections having similar percentages of pedestrians involved in the same behaviors are grouped together (clustered).

Through this process, eight clusters of four or more intersections were created. In all, 36 of the 76 intersections were placed into one or more of these clusters. Seven of the eight clusters were "pure" in that they contained either all high or all low accident intersections. One cluster contained four low and one high intersection. The success of this classification process is impressive. In this regard, it should be noted that the program treated each intersection individually and not as a member of a pair. Therefore, signalized and nonsignalized, two-way and one-way, 90° and skew intersections were all classified using the same scheme.

The graphs for each of the eight clusters are presented in Figures 10 and 11. A distinctive feature of the low accident clusters (Figure 10) is that they are bimodal, i.e., the percent of MV's is equalled by the percent of B's (Clusters 1, 3, and 5) or R's (Clusters 4 and 8). The clusters containing the high accident locations (Figure 11) have a considerably higher MV percent than B or R. Reviewing our previous analysis (page 39), we found that B's occurred more frequently at the high accident sites; now we see that the percent of pedestrians displaying this behavior is less – maybe these locations would have a better accident record if a proportional number of people hestiated for vehicles (B) or ran in response to vehicles (R). Also, of the three high accident clusters, only Cluster 6 consists of nonsignalized intersections. This Cluster displays a higher percent of R's than Cluster 2 or 7. This finding is in keeping with accident data presented in an earlier section – a higher percentage of the pedestrians hit at nonsignalized intersections were running than those hit at signalized intersections.

This analysis indicates that the following five variables tend to carry the weight of differentiating between high and low accident locations:

- Traffic-related pedestrian hesitation or reversal in traffic lane (B).
- Running in roadway (R).
- Through vehicle moving through crosswalk while pedestrian is in traffic lane (MV).
- Vehicles turning right and pedestrian within 20 feet of direct path (VR, vehicles).
- Vehicles turning left and pedestrian within 20 feet of direct path (VL, vehicles).

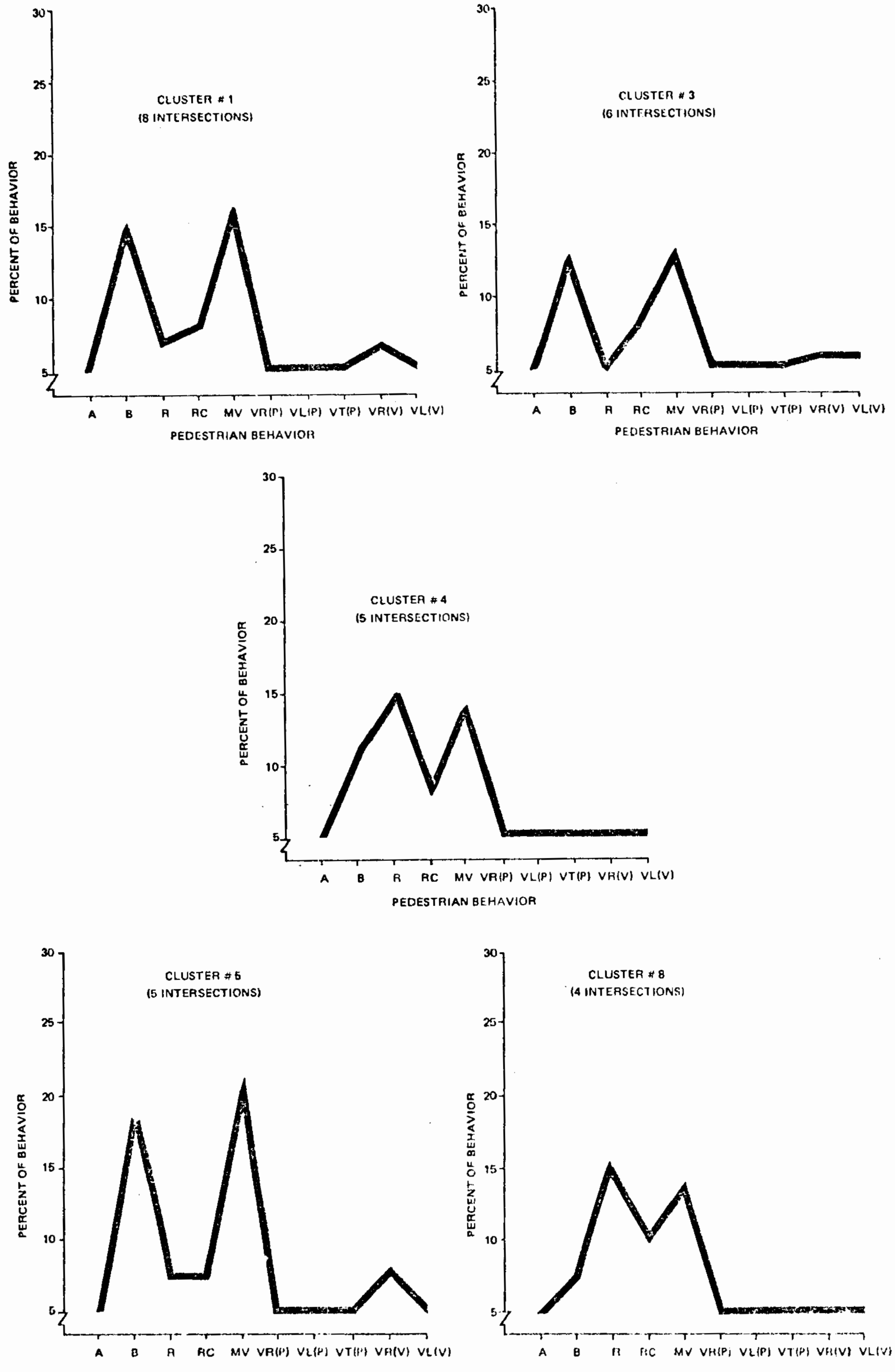


Figure 10. Profile of Low Accident Intersection Clusters

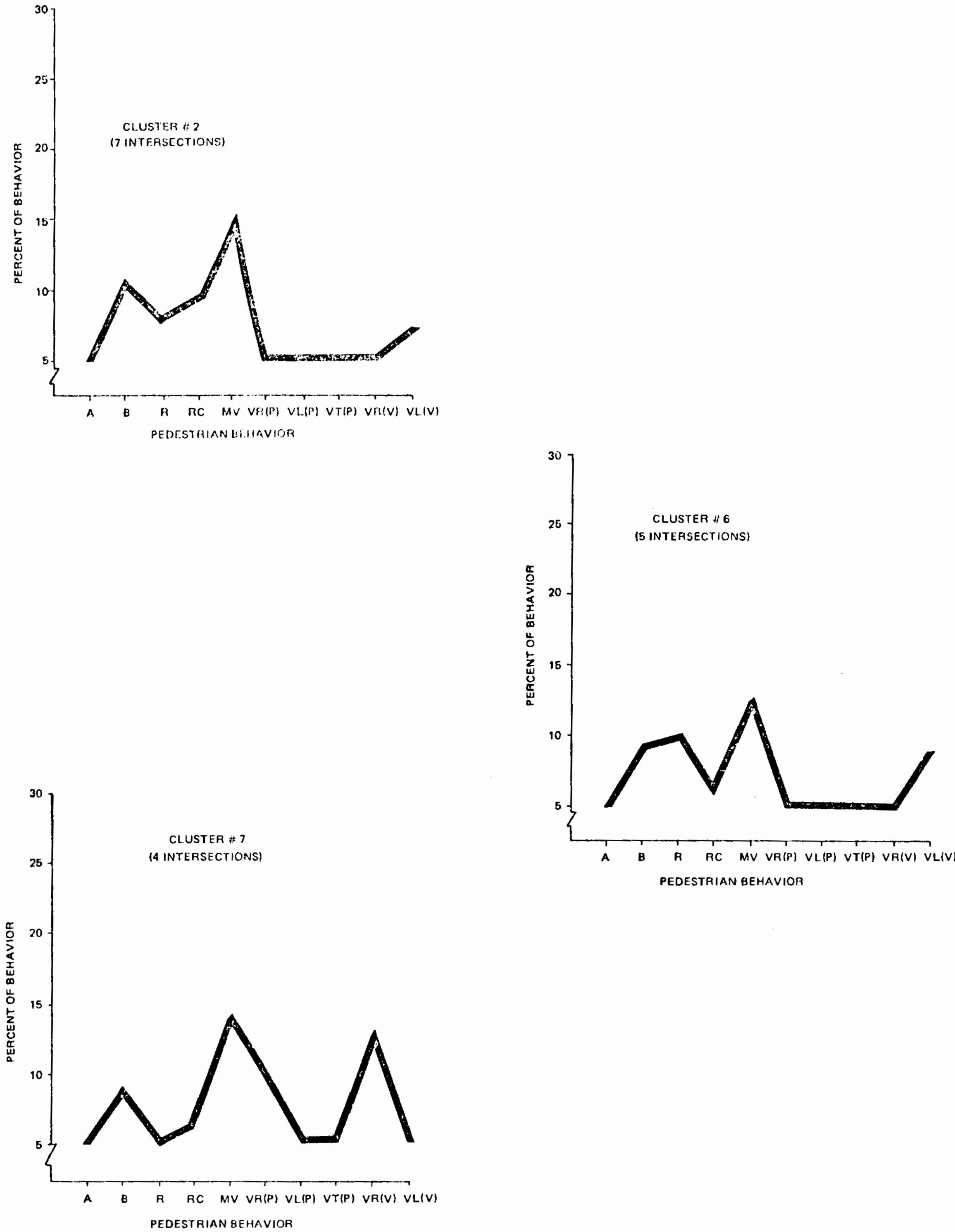


Figure 11. Profile of High Accident Intersection Clusters

These results tend to confirm our earlier analysis. Running in the roadway was added, while starting against the signal (SA) was excluded from this multivariate analysis since it could only occur at the 46 signalized sites. All in all, the results indicate the predictive value of several of the behavioral measures.

Identification of Possible Intersection Accident Causal Characteristics

The final step in the identification of accident causal factors entailed performing a detailed site survey of 30 of the 38 intersection pairs (Washington, D.C. sites). The previously collected data were used to guide the investigation of each site pair. Additional site-specific factors which might account for the differences in accident experience were explored during the activity.

Each site pair was reviewed in terms of pedestrian and traffic volume, the nature of the abutting property, and the type of vehicle regulations in effect. The high accident site did not differ from the low accident site in terms of the presence of schools, playgrounds, parking regulations or observance, turn restrictions, vehicle volumes, or turning volumes. It should be noted that the sites in a pair were selected to have a road in common; therefore, we would not expect to find any difference in vehicle volumes.

Several significant differences were uncovered, however. First, the pedestrain volumes were significantly higher at the high accident intersections*. Additionally, the high accident sites were significantly more commercial or higher in density than the low accident locations. The high accident sites significantly more often had a liquor store abutting on the intersection. The ages of the accident-involved pedestrians and the times of day of accident occurrence did not indicate that alcohol was a problem at these locations. Rather, we suspect that the presence of liquor stores is a general indication of the socio-economic environment surrounding the intersection. These neighborhoods often have a higher population density than the low accident sites and appear to be less desirable than their low accident counterparts.

Some additional potential causal factors were identified from a comparison of pedestrian crossing behaviors at pedestrian signal locations versus traffic signal only locations. Based on 40 signalized intersections (no pedestrian signals), 74 percent of the 3458 pedestrians observed crossed with the signal, 16 percent started against the signal, and ten percent crossed against the signal.

Based on four intersections with pedestrian signals displaying a flashing WALK indication, 58 percent of the 550 pedestrians observed started their crossing on the flashing WALK indication, 17 percent started on the flashing DONT WALK, seven percent crossed on the steady DONT WALK, and 18 percent started on DONT WALK with the signal changing to WALK before the crossing was completed.

*The term "significant" implies statistically significant at or beyond the 0.05 level.

Based on two intersections with pedestrian signals displaying a steady WALK indication, 59 percent of the 139 pedestrians observed started their crossing on the steady WALK indication, 16 percent started on the flashing DONT WALK, 11 percent crossed entirely on the steady DONT WALK, and 14 percent started on DONT WALK with the signal changing to WALK before the crossing was completed.

From the above results, it appears that pedestrians violate pedestrian signals more frequently than they violate traffic signals. Since the DONT WALK indications are displayed simultaneously with the traffic green for part of the interval, the difference in number of violations *may* represent those pedestrians who, while violating the pedestrian signal, are starting across while the vehicle signal is still green.* A significant number of pedestrians cross entirely against both traffic and pedestrian signals. An even greater number "jump" or "anticipate" the signals. Finally, there appears to be no significant difference in crossing behaviors at pedestrian signals with flashing WALK (which means that vehicles may be turning through the crosswalk) versus steady WALK (which means vehicles will not be turning through the crosswalk) indications.

Second Field Study: Refinement of Behaviors and Pilot Testing

Because of the promising nature of the behaviors identified in the first field study, we undertook to further refine the data collection methods and the behaviors in a second field study.

Refinements of Behaviors

Based on the field observations and the subsequent results, a review of the promising behaviors was initiated. Each behavior was reviewed in light of one of the project's major purposes – the assessment of pedestrian safety. Three major questions were asked about each behavior:

1. Does the occurrence of this behavior represent a safety hazard?
2. Are there other behaviors that are not presently being measured that represent distinctly hazardous situations?
3. Can we improve the procedure by which we measure each behavior?

We concluded that most of the behaviors identified as promising in our previous analyses satisfied question 1. However, the behavior "running," of and in itself, did not appear to be associated with a safety hazard. We would preserve this variable by considering it when it occurred in combination with other behaviors (to be discussed below).

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*Optically programmed traffic and pedestrian signals have been developed by the 3M Company to address this particular problem (***Public Works***, 1974; ***Rural and Urban Roads***, 1973). An optically programmed signal efficiency evaluation program (OPSEE) is currently being conducted by 3M. Results are anticipated in 1977.

A consideration of question 2 led to a reevaluation of the "proximity of vehicle" (PV) code used at nonsignalized intersections. This code was applied when a vehicle was within six car lengths of a pedestrian entering a lane. The code was felt to cover an important situation; however, its definition was a source of coder error and was considered too stringent. Therefore, a revised code, "VH," was proposed (see Figure 12 for a definition of all revised codes). VH was also used in combination with the R code.

Code	Definition
(B)	Backup Movement - Momentary reversal in pedestrian direction of travel in the traffic lane, or hesitation in response to a vehicle in a traffic lane.
(MV)	Moving Vehicle - Through traffic moving through the crosswalk while the pedestrian is in a traffic lane.
(TV)	Turning Vehicle - Pedestrian in the path and within 20 feet of a turning vehicle.
(VH)	Vehicle Hazard - Pedestrian entering a traffic lane when a through vehicle, unrestricted by a traffic control device, is approaching in that lane within one block.
(RVH)	Running Vehicle Hazard Conflict - Running in a traffic lane in response to a VH.
(RTV)	Running Turning Vehicle Conflict - Running in a traffic lane in response to a TV or TV potential.

Figure 12. Revised Behavior Code Definitions

Considering question 3 led to combining the previous left and right turn conflict codes into one code, "TV." TV could also be used in combination with the R code. A combination of questions 1 and 3 also resulted in the "fine tuning" of the definitions of B and MV. A set of revised data collection forms were generated to handle the new behaviors and their associated measurement requirements. These forms, presented in Figures 13 and 14, make it possible to collect over twice as much data per day and greatly simplify the analysis process.

Pilot Testing

The newly defined behaviors and the revised data collection procedures were pilot tested at nine pairs of intersections. These intersections were selected without bias from those used in the first field study. Three pairs had pedestrian signals, three had traffic signals only, and three were not signalized.

INTERSECTION ______________________ DATE ________ CODER ______________________

PERIOD AND LEG	COUNTS			
	B	RTV	MV	TV
1 A	# P = # T =			
1 B				
1 C				
1 D				
2 A				
2 B				
2 C				
2 D				
3 A				
3 B				
3 C				
3 D				
4 A				
4 B				
4 C				
4 D				

B= Momentary reversal in pedestrian direction of travel in the traffic lane or hesitation, in response to a vehicle in a traffic lane.
RVT= Running in a traffic lane in response to TV.
TV= Number of turning vehicles involved coming within 20 feet of a pedestrian (in path of vehicle).
MV= Thru vehicle moving thru the crosswalk while pedestrian is in a traffic lane (anyone vehicle and/or anyone pedestiain maybe counted only once).

KEY: #P= Number of pedestrians.
#T= Number of times per pedestrian (multiples).

Figure 13. Pedestrian Activity Sampling Sheet #1

INTERSECTION ______________________ DATE ________ CODER ______________

PERIOD AND LEG	RVH	VH	PEDESTRIAN COUNTS
1	#P =		
A	#T =		
1			
B			
1			
C			
1			
D			
2			
A			
2			
B			
2			
C			
2			
D			
3			
A			
3			
B			
3			
C			
3			
D			
4			
A			
4			
B			
4			
C			
4			
D			

RVH= Running in a traffic lane in response to VH potential.
VH= Thru vehicle in a traffic lane, unrestricted by a signal, at the time the pedestrian enters that lane.

KEY: #P= Number of pedestrians.
#T= Number of times per pedestrian (multiples).

Figure 14. Pedestrian Activity Sampling Sheet #2

A two-person team collected data at each site for a day. Data collection followed the schedule used in the first field study. The data collection procedures met the criteria of efficiency and required minimum retraining.

A summary of the results from this pilot study is presented in Table 6. On the basis of this small sample, MV, VH and RVH were found to significantly differentiate the high from the low accident intersections in a pair. This differentiation was based on the frequency of the behavior being higher at the high accident site. RVH also separated the high from the low sites on the basis of the percent of that behavior occurring at each site. On the basis of this pilot study, B, TV, and RTV did not significantly differentiate between the sites. Based on their performance during the first field study and the promising trends from this second study, the revised definitions of B, TV, and RTV, were retained.

Conclusions

A set of behaviors (see Figure 12 for definition of codes that follow) developed for use in Phase II addresses a variety of the pedestrian safety problems uncovered during the review of the accident data. B, VH, and RVH focus on the acceptance of small vehicle gaps on the part of pedestrians and the problems of short-time exposure. TV and RTV are a behavioral corollary of the turn/merge type of accident frequently noted at signalized intersections. MV and SA are indications of risk taking on the part of pedestrians. In both cases, the pedestrian is in a travel lane exposing himself to a potential conflict with a vehicle. The SA case also treats the pedestrian who anticipates the WALK interval (early starter) and may present a target to vehicles attempting to "beat" the traffic signal. The MV conflict can occur any time the pedestrian violates the traffic signal or enters the roadway while through vehicles are still moving through the crosswalk area. Based on the two field studies, the behaviors discussed above were judged to have considerable utility from both an operational and a research point of view.

Table 6

Results From Revised Behavioral Measures*

INTERSECTIONS

Behaviors	10		26		40		65		100		210		19**		21**		105**	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Traffic related hesitation or reversal by pedestrian in traffic lane (B)	+	+	+	+	+	+					+	+	+	+			+	+
Thru vehicle moving thru crosswalk while pedestrian is in traffic lane (MV)	+		+	+	+	+	+	+			+		+	+	+		+	+
Vehicles turning with pedestrian within 20 feet of direct path (TV) (TV, % = #TV/#PEDESTRIANS)	+		+	+							+	+	+	+	+	+		
Pedestrian running in traffic lane in response to TV (RTV) (RTV, % = #RTV/#pedestrians)	+	+	+	+			+	+	+	+			+		+	+		
Vehicles turning with pedestrian within 20 feet of direct path (TV) (TV, % = #TV/#vehicles)	+	+	+	+							+		+	+	+	+		
Pedestrian running in traffic lane in response to TV (RTV) (RTV, % = #RTV/#vehicles)	+		+	+			+	+	+	+			+		+	+		
Number of TV and RTV combined, divided by number of vehicles	+	+	+	+						+	+		+		+	+		
Unrestricted thru vehicles in traffic lane which pedestrian enters (VH)	+		+		+	+	+	+			+	+	+	+	+		+	+
Pedestrian running in traffic lane in response to VH (RVH)	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+
VH and RVH combined	+	+	+		+	+	+	+			+	+	+	+	+		+	+
Volumes	10	10C	26	26C	40	40C	65	65C	160	160C	210	210C	19	19C	21	21C	105	105C
Pedestrians	1125	624	853	269	188	156	139	130	149	130	530	365	154	76	123	94	129	72
Vehicles turning left (VL)	124	216	104	108	40	20	16	28	40	64	100	64	24	16	84	56	8	8
Vehicles turning right (VR)	120	76	192	132	40	60	44	18	56	64	172	60	72	12	44	48	8	12
Vehicle going straight (VH)	1044	1140	1168	960	452	368	408	700	1220	1072	1144	906	236	144	304	328	228	168

*A "+" indicates that the high accident site exhibited a greater frequency or % of the stated behavior.

**Non-signalized intersections.

IDENTIFICATION OF HUMAN FACTORS DESIGN PARAMETERS (TASK ID)*

This task had two primary objectives. One was to review the human factors data and concepts relevent to intersection design for pedestrian safety. Key to this review was a conceptual framework for organizing the necessary information. Therefore, a conceptual model of man was prepared. The model serves equally well for humans functioning as pedestrians or drivers. Considerable information on human functioning was available and, although it had not been generated in a highway context, it nevertheless appeared applicable to the situations of interest and was therefore useful in identifying intersection design factors.

The second purpose of this task was to review the behavioral literature dealing specifically with pedestrian and driver safety at intersections. For a complete review, this body of literature was considered within a series of topic areas. Usable human factors data within each topic area was then extracted, organized according to the conceptual model, and synthesized with the previous data to identify human factor considerations. The literature reviewed and discussed represents the state-of-the-art in human engineering and therefore also will provide the human factors input to countermeasure design.

The conceptual model used to represent the human in the highway system is shown in Figure 15. There is clearly an emphasis on information characteristics. This stems from several earlier models which demonstrated that much of the flexibility and adaptability characteristic of human functioning depends on information processing capability. Traditionally, human adaptability has been allowed to compensate for system failures, be they mechanical, operational, or design. This is often an advantage to system operations, but there are also some disadvantages. Because of their complexity and flexibility, humans can behave very differently from one another and any one human's behavior can vary drastically over time. This situation poses a challenge to the design engineer. Whenever the human interacts with or operates in an engineered system, the designer must allow for a range of human behaviors.

Within the context of this conceptual model, certain characteristics of the roadway-specific stimuli (e.g., traffic control devices), the situation or context for these stimuli (the intersection), and the viewer (pedestrian or driver) appeared particularly relevant to the present study.

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*A detailed annotated bibliography has been prepared as a supplement to this report and is available for inspection at FHWA or BioTechnology. The specific literature supporting the conclusions expressed in this chapter are presented in Appendix B.

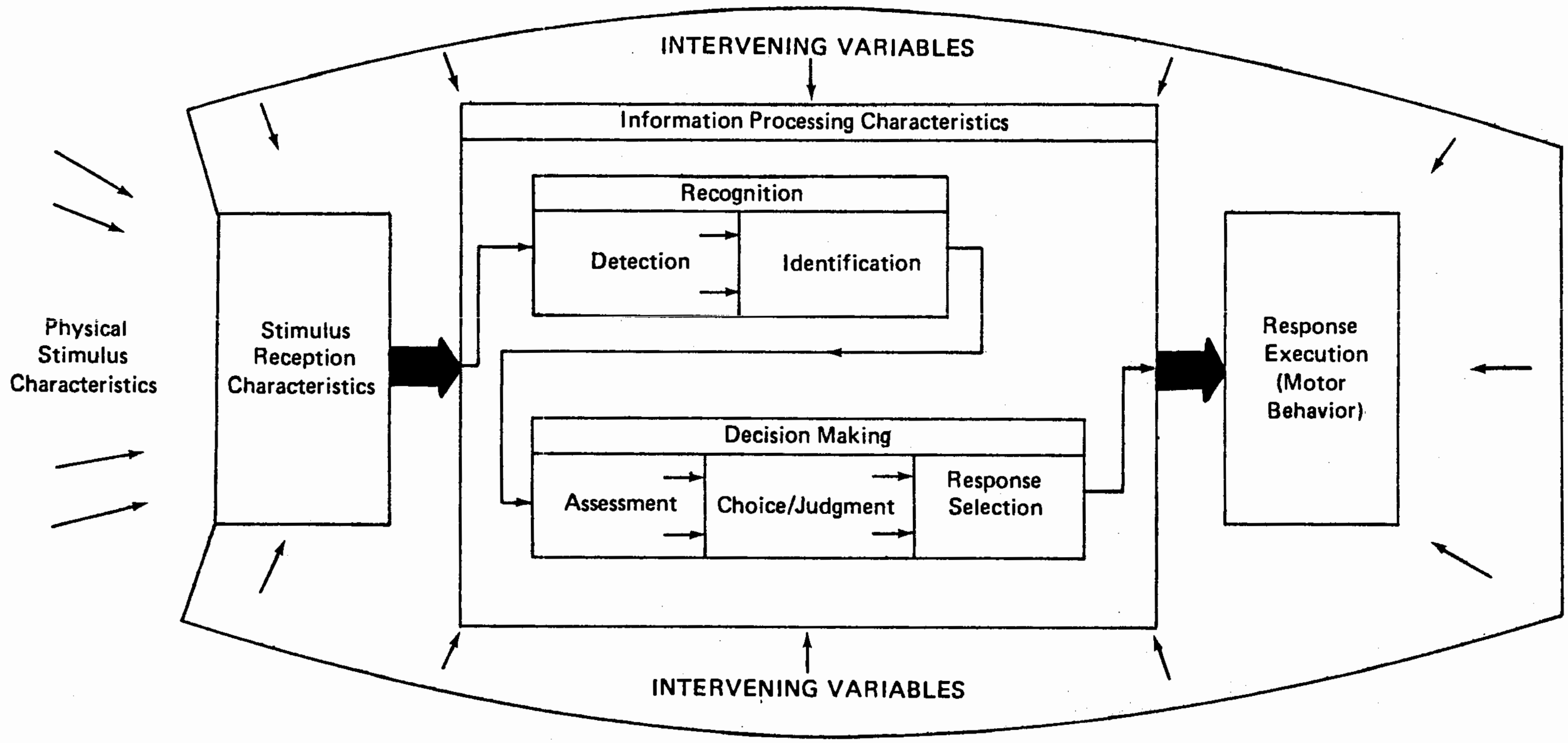

Figure 15. Pedestrian/Driver Conceptual Model

Roadway Specific Stimuli

The following characteristics of traffic control devices are likely to determine their effectiveness:

- The number of messages displayed affects driver comprehension and recognition. (The more messages displayed by a signal, the more measures carried by a sign, or the greater the number of signals and signs displayed together, the more difficult it becomes to detect, identify, and comprehend the relevant and intended message.)
- Physical distinctiveness enhances detectability. (The greater the difference between messages, the better the discrimination.)
- The physical characteristics most effective in providing distinctiveness are: contrast (brightness and color), motion, and size. (These same variables, if not carefully used, can degrade legibility.)
- A single coding dimension can be used to discriminate among the messages to some extent. (Color coding will be effective if it can be relied on to differentiate among all the messages.)*
- Symbols result in more accurate and consistent comprehension than word messages. (User preference, however, is for both word and symbol to appear.)
- The traffic control devices or marking must consistently meet the viewer's information needs and expectancies.** (This is particularly important in terms of location, coding, and meaning.)
- The amount of time available for viewing the stimulus enhances comprehension. (The more time there is available, the easier it is to classify and interpret the message before having to act. This is particularly important where several types of messages, e.g., multiple route guidance and traffic signals, are presented at one intersection.)

Situational Characteristics Influencing Pedestrian and Driver Behavior at Intersections

Most aspects of intersection design and operation impact on user recognition, decision making, and overt behavior. The following are the major situational factors.

- As visual complexity surrounding (and competing with) the intersection increases, driver uncertainty, hesitation, and erratic behavior increases. (To counteract uncontrollable complexity, all types of information, route guidance, traffic signals, and lane placement must adhere to the stimulus characteristics principles noted earlier.)

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*Color can be identified more accurately at close range than size, brightness, or geometric shape.

**Expectancies are frequently violated by the use of the same message (e.g., steady walk) under different conditions (e.g., protected vs. non-protected crossings).

- Any characteristic of the road or surround which takes scanning or search time from relevant information sources increases the probability of erratic behavior (e.g., rough road surface with potholes).
- Any perturbation in flow (vehicle or pedestrian) increases the probability of unsafe behavior. (Thus, network and individual signal timing are critical to safety.)
- The higher the vehicle volume, the less likely pedestrians are to violate traffic or pedestrian signals.
- The higher the vehicle speed, the less likely pedestrians are to violate signals or accept short gaps. (This effect diminishes with lower vehicle volumes.)
- The shorter the vehicle gap, the less likely pedestrians are to cross unsafely.
- Group action has a strong impact on individuals. (This occurs among drivers and pedestrians.)
- The visibility of a traffic signal results in some pedestrians ignoring the pedestrian signal.
- The visibility of pedestrians at night should be enhanced.
- Pedestrians and drivers need visual contact with the intersection and other users. (A pedestrian is more likely to step out in front of a vehicle if he cannot see around a bus, sign post, or parked car.)

User Characteristics

The pedestrian and driver bring certain perceptual and motor limitations and habits to the intersection. Some of these have an impact on behavior at intersections, particularly on the effectiveness of traffic control devices.

- The young and elderly do not process information as efficiently as the middle aged and therefore require more time to reach a decision.
- The above is true for an individual of any age when alcohol or fatigue is present.
- Pedestrians' age and sex both affect walking speed, with females and the elderly usually requiring more time to cross.
- Crossing behavior can be modified by peer and social pressure which can be applied through educational or legal (plus law enforcement) means.
- Time-critical events at the intersection (e.g., catch a bus) or personal reasons can cause pedestrians to take risks (accept shorter gaps, disobey signals) not otherwise accepted.
- Pedestrians and drivers alike do not take advantage of the scanning opportunities necessary to assure safe travel.
- If user expectancy is continually violated by differing signal messages (or the same message conveying different meanings), they begin to ignore the signals and depend on other cues.

- The information necessary for the pedestrian includes: when to leave the curb, if he will or will not, how much time he has left to cross, and when to stay on the curb. (If all this information cannot be provided at every intersection, the signal configuration or message should be such that the pedestrian knows what portions of the information he is receiving.)
- Certain stimuli have meaning through past experience. (Red, yellow, green are the most readily detectable, most accurately identified, and have inherent meaning in our culture.)
- The handicapped (blind, deaf, wheel chair) present unique problems to intersection design. (Some accommodations, e.g., ramps at intersections, can be standard practice, but facilities for the blind require further development.)

As part of this task, the literature on effectiveness of pedestrian signals was reviewed. Effectiveness appeared highly dependent on the specific application and situation. The overall conclusion was that pedestrian signals provide safer pedestrian travel at intersections. Upon closer analysis of the few negative findings, it was evident that several of the principles enumerated above were violated. If signal timing allowed more green for traffic than vehicle volume warranted, pedestrians would ignore the pedestrian signal indication. Similarly, if pedestrians could see the traffic signal on green when the pedestrian signal changed to DONT WALK, they would ignore the pedestrian signal. Finally, the general lack of understanding and inconsistent use of flashing signals resulted in pedestrians ignoring the signal.

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APPENDIX A
SITE SELECTION PROCEDURES

Site selection was perhaps the most critical step in the Task IC behavioral data collection effort, and was certainly the most troublesome.

Selection Criteria

Keeping in mind that the objective of Task IC was to evaluate the sensitivity and validity of a set of behavioral measures, it was crucial that sites be selected so as to minimize as many confounding factors as possible. The data collection plan called for the selection of 100 high pedestrian accident and low pedestrian accident site *pairs;* a total of 200 intersections. The selection of each site pair was based initially on the following criteria:

1. The number of pedestrian intersection accidents over a three-year period at the low accident site had to be one-half or less than the number of accidents at the high accident site.
2. The minimum number of accidents at the high accident site was three.
3. The site pair had to have the same number of approach legs and be the same geometric shape, i.e., 90 degree, diagonal, or skew.
4. The site pair had to have the same type of traffic controls, i.e., pedestrian signals, traffic signals, or no signals.
5. The site pair had to exhibit the same flow directions, i.e., two-way/two-way or one-way/two-way.
6. The site pair *should* have had one street in common and *should* have been within five blocks of each other.

At the completion of the first field study, the following additional criteria were applied in selecting site pairs prior to the second field study:

- The pedestrian signal operation had to be the same at the site pair, e.g., flashing WALK-flashing DONT WALK-steady DONT WALK.
- The width of the two intersecting streets had to be within 24 feet at each site, respectively.
- The site pair had to match with respect to the presence or absence of islands.
- Pavement markings (crosswalks) at the site pair had to be the same.

Procedure

The first step was to rank order, from high to low, all intersections in the accident data file by pedestrian accident frequency. Figure A-1 shows a sample page of this ranking for the

			PED	TOT				PED	TOT				PED	TOT				PED	TOT
STREET	CODE	QUAD	INJ	ACC	STREET	CODE	QUAD	INJ	ACC	STREET	CODE	QUAD	INJ	ACC	STREET	CODE	QUAD	INJ	ACC
5089	8944	1	10	12	70	7546	1	5	5	70	7286	1	4	4	4673	7936	3	3	4
130	6467	1	11	11	80	3438	2	5	5	70	8456	1	4	4	5284	6467	1	4	4
140	3458	1	10	11	90	6584	1	5	5	80	3861	2	4	4	5564	7416	2	4	4
160	2463	1	11	11	90	6981	1	5	5	80	4777	3	4	4	5945	7169	3	4	4
120	6981	1	8	9	110	4244	2	6	5	80	7189	3	3	4	6136	6422	1	2	4
80	4244	2	7	8	120	4244	2	5	5	90	6838	1	4	4	6246	9262	2	4	4
140	5232	1	7	8	120	6467	1	5	5	100	6981	1	3	4	6318	6467	5	4	4
140	8456	1	9	8	130	3861	1	6	5	110	2535	2	4	4	6409	9405	1	5	4
180	5089	1	8	8	130	5960	1	4	5	110	5089	1	3	4	6532	7416	5	4	4
4374	8008	1	7	8	140	4777	1	6	5	110	5785	1	4	4	6532	7546	5	4	4
10	7546	1	8	7	140	7416	1	5	5	110	6584	1	3	4	6532	8456	5	4	4
40	3672	1	7	7	150	936	3	5	5	110	6981	3	3	4	7416	8944	1	4	4
70	6981	3	7	7	160	6422	1	4	5	120	3133	1	4	4	8151	9288	3	7	4
110	6467	1	7	7	160	8456	1	5	5	120	3861	1	5	4	8235	8342	3	4	4
140	8723	1	7	7	170	8723	1	5	5	130	3386	1	4	4	20	6422	1	2	3
3672	6532	5	5	7	180	910	1	4	5	130	3672	1	4	4	30	3672	1	3	3
4797	5960	3	7	7	190	1534	2	5	5	130	4875	1	4	4	40	1170	3	3	3
4807	8151	5	8	7	210	6981	1	4	5	130	7546	2	4	4	40	3308	1	3	3
70	5960	1	5	6	949	2515	1	6	5	140	2411	1	4	4	40	4244	2	3	3
70	6981	1	6	6	1735	6981	3	3	5	140	3672	1	4	4	40	8846	1	3	3
80	3133	3	6	6	1963	4004	1	5	5	140	4244	1	4	4	50	1878	1	3	3
90	6467	1	5	6	2515	6376	1	3	5	140	4875	1	4	4	50	3672	1	2	3
110	3438	1	6	6	3438	5960	5	3	5	140	6467	1	4	4	50	3672	2	3	3
140	4075	3	8	6	4004	6422	1	4	5	140	9015	1	3	4	50	6318	1	2	3
140	4244	2	5	6	4244	6532	5	5	5	160	5375	1	5	4	50	8684	1	2	3
140	5089	1	4	6	5349	6532	5	5	5	170	6981	1	5	4	60	3861	1	3	3
160	3386	1	6	6	5622	8125	5	3	5	180	6981	1	3	4	60	4244	2	3	3
190	5785	1	7	6	5945	8463	3	5	5	210	5785	1	3	4	60	6129	3	3	3
200	5960	1	6	6	6129	9288	3	5	5	220	6981	1	4	4	60	6318	1	3	3
210	1534	2	9	6	6318	9405	1	3	5	250	4075	3	4	4	60	6981	3	3	3
936	8235	3	7	6	6532	7468	5	5	5	350	7533	1	4	4	60	7286	1	3	3
2515	5089	1	7	6	9002	9405	1	3	5	1170	6129	5	3	4	70	2535	1	3	3
5785	9405	1	5	6	10	2535	2	3	4	1982	7566	3	4	4	70	3133	1	3	3
6116	6981	3	6	6	10	6467	1	3	4	2002	9405	1	3	4	70	3438	2	7	3
10	3672	1	5	5	40	6428	1	4	4	2515	3672	1	4	4	70	3672	1	3	3
10	6838	1	5	5	50	5206	1	4	4	2515	6526	1	4	4	70	3672	2	3	3
40	2255	3	5	5	60	3672	1	3	4	2515	8892	1	4	4	70	5349	3	2	3
40	7546	2	6	5	60	3672	2	3	4	2535	8521	2	4	4	80	2691	2	3	3
40	8139	3	5	5	70	4244	1	4	4	4004	4875	1	3	4	80	5089	2	3	3
70	6838	1	6	5	70	4797	4	3	4	4004	4992	1	4	4	90	2535	1	1	3

Figure A-1. Sample Listing of All D.C. Pedestrian Intersection Accidents, Code 1

Washington, D.C. intersections. The intersections were identified by street code and quadrant, and indicated the number of pedestrians injured as well as accident frequency. Similar rankings were obtained for San Francisco and Oakland, California. The high accident intersections (three or more accidents in three years) were identified: 283 in Washington, 23 in San Francisco, and 133 in Oakland.

A set of aerial photographs (scale 1″ = 200′) was obtained for each city for use in making the initial site pair selection. A three-man team composed of a traffic engineer, a psychologist, and a pedestrian safety expert was formed to make the initial site selections from the aerial photos using criteria 1, 2, 3, and 6. Figure A-2 shows a segment of one of the aerial photos of Washington with one of the selected site pairs indicated.

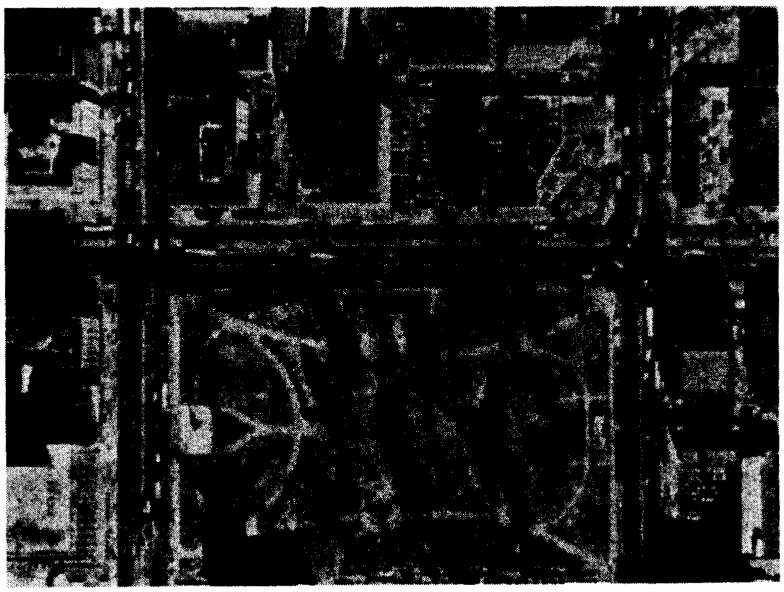


Figure A-2. Sample Air Photo of Site Pair

Engineering information, including signal timing, vehicle and pedestrian volumes, and intersection diagrams, was then obtained from the cities' traffic engineering departments for the tentatively selected site pairs. Figure A-3 is a completed sample of the form used to record the volume and signal timing information. Criteria 4 and 5 were then applied to each site pair.

If all criteria were met, a field inventory of the site pair was conducted to confirm, update, and supplement the engineering information already gathered. Street widths, parking restrictions, T.S. 715-C # 143

LOCATION: Conn Ave AT Van Ness NW # 143

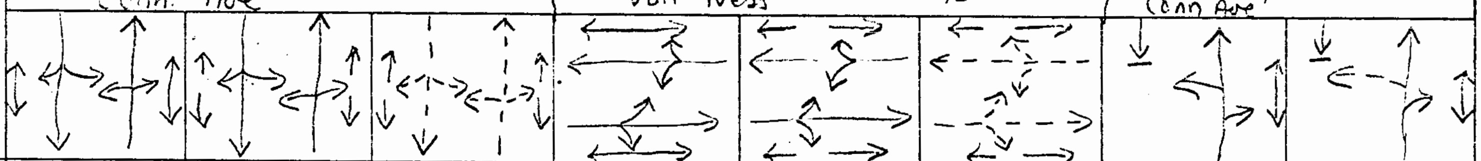
VEHICLE AND PEDESTRIAN COUNTS						TAKEN ON: 9-30-74							DAYS: Monday						WEATHER: Clear			
TRAFFIC ON	Conn Ave												Van Ness St									
MOVING	North West				E	South East				W	TOTALS		East				S	West				N	TOTALS	
	L	T	R	TOT	P	L	T	R	TOT	P	VEH	PED	L	T	R	TOT	P	L	T	R	TOT	P	VEH	PED
AM: 8:00-9:00	128	569	67	764	82	60	2878	171	3109	42	3873	124	111	44	75	230	294	102	68	50	220	43	450	377
PM: 5:00-6:00	119	2107	131	2357	194	28	694	130	852	177	3209	371	164	125	72	361	181	56	71	57	184	112	545	293
HR TOTAL: 10 hr	894	9131	718	10,743	1038	430	11,900	1084	13,414	957	24,157	1991	1132	673	790	2595	1315	572	513	447	1532	896	4127	2211

SIGNAL CONTROL DATA: Fixed time w/ ped heads (5:19 53; 5:54 55)

Cycle Length Time & Days	OFF-PEAK (6:30a)	AM PEAK (107)	PM PEAK (5:30 48)	
	80	20	90	
	Normal	M-F	M-F	1972, 74

PED OPERATION: DW-FW-FDW PED COLOR:

Conn. Ave — Von Ness 72 72 — Conn Ave 74



	1	2	3	4	5	6	7	8
INT	1	2	3	4	5	6	7	8
OP	22	5.6	4	8.	12.8	4	13.6	4
AM	21.6	20	4	7.2	12.2	4	6.7	4
PM	18.9	12	4.5	10.2	18	4.5	10.8	4.5

	Y ↓ R→ ←R ↑ Y			
INT	Flash			
OP	Normal			
AM				
PM				

ACTUATED TIMING

PH	INT	INIT	VEH	MIN	MAX	AMB	PED

Figure A-3. Sample Volume and Signal Timing Form pavement markings, locations of signs and signals, unusual characteristics, and differences between the site pair were noted on site diagrams. Figure A-4 is an example of the site inventory diagram from one of the sites in Oakland. During the inventory, black and white photos were made of each crosswalk area. Figure A-5 is an example of the photos taken at an intersection in Washington.

As the last step in finalizing the selection, at least one member of the team reviewed all of the information gathered on the site pair to insure that all selection criteria were met.

Problems Encountered

We initially estimated that it would be necessary to examine about 400 intersections in order to select 200 intersections (100 pairs) for study. In actuality, we examined over 1,500 intersections in order to select 120 intersections (60 pairs) for study. The list of high accident intersections (totaling 439) was completely exhausted. The first problem was simply meeting *all* of the selection criteria. We were astounded at the uniqueness of so many intersections with respect to satisfying our criteria. Metro construction in Washington was the source of many criteria failures.

The second problem was one of intersection pairs being disqualified after having been selected. This problem was primarily caused by highway maintenance activities. In a few cases, geometric or signal control changes were made at one of the sites, thereby disqualifying the site pair.

When disqualifications occurred, every effort was made to match the remaining site with another site in order to minimize the gathering of additional engineering information. Because of these problems, site selection activities continued through the next to last day of data collection.

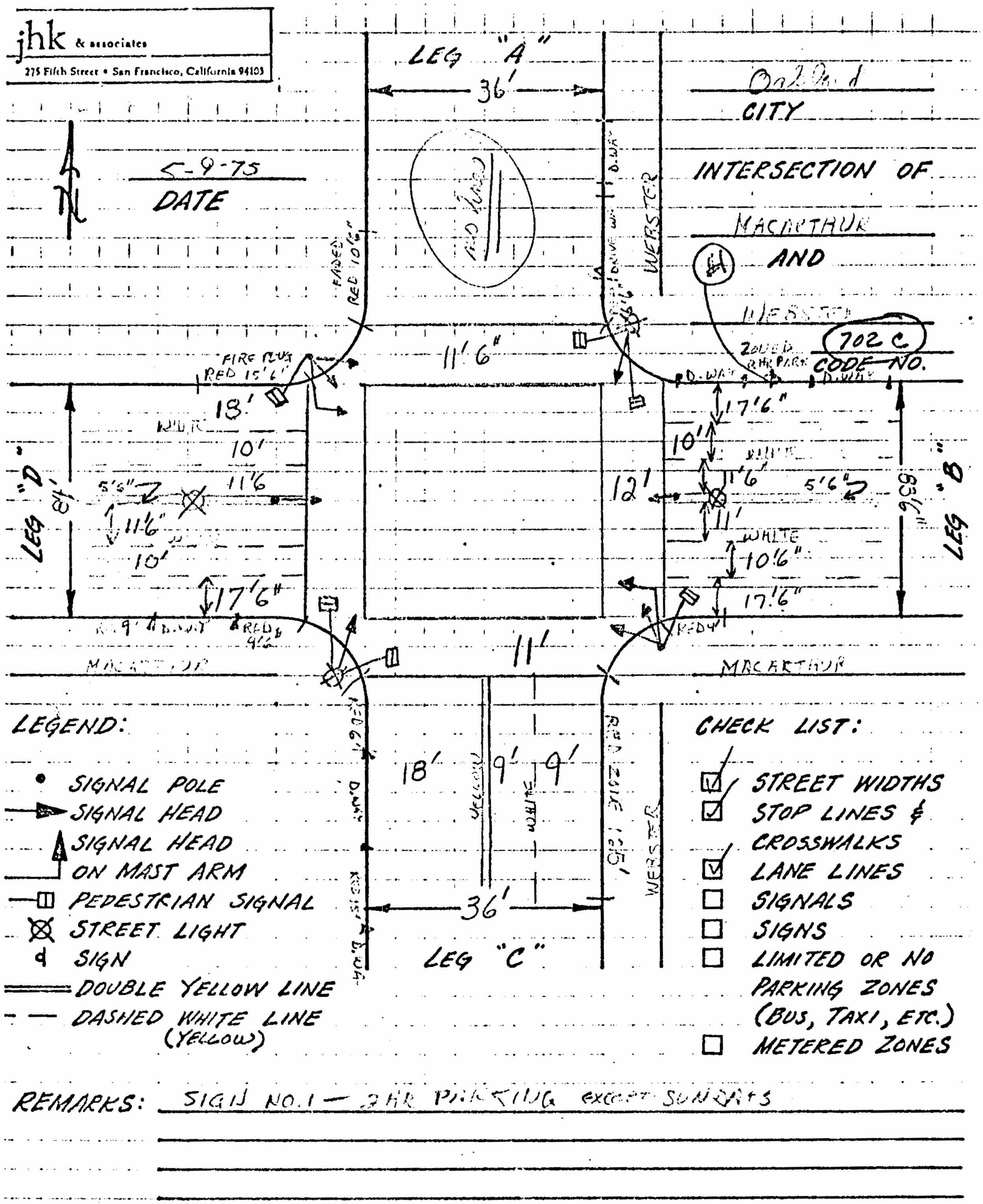
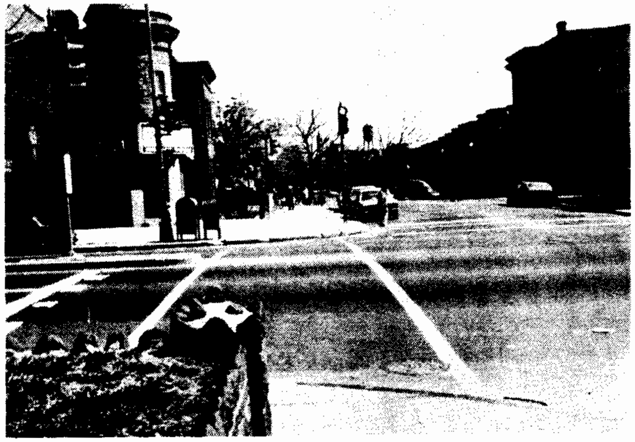


Figure A-4. Example of Site Inventory Diagram



Leg A

Leg B

Leg D

Leg C

Figure A-5. Example of Site Photos

APPENDIX B

CONCEPTUAL STUDIES FOR TASK ID

This appendix has two primary purposes. One is to review the human factors data and concepts which have potential impact on intersection design as it relates to pedestrian safety. Key to this review is a conceptual framework for organizing the necessary information. Therefore, a conceptual model of man is presented. The model serves equally well for humans functioning as pedestrians or drivers. Data from general human factors research literature is then discussed. Considerable information on human functioning is available, although it has not been generated in a highway context. Nevertheless, it is applicable in most situations and is therefore useful in identifying design considerations for intersections.

The second purpose of this appendix is to review the behavioral literature dealing specifically with pedestrian and driver safety at intersections. For a complete review, this body of literature must first be discussed by topic area. Then, usable human factors data can be extracted, organized according to the conceptual model, and synthesized with the previous data to identify human factor design considerations and problems.

Pedestrian/Driver Conceptual Model and Relevant Human Factors Information

The conceptual model used to represent the human in the highway system is shown in Figure B-1. There is clearly an emphasis on information characteristics. This stems from several earlier models (see Whittenburg, Pain, McBride, & Amidei, 1972; Bishop et al., 1970; Ellingstad, 1970; Lybrand, Cleary, & Bauer, 1968; Schlesinger & Safren, 1964; Ross, 1960; Gibson & Crooks, 1938) which demonstrate that much of the flexibility and adaptability characteristic of human functioning depends on information processing capability. Traditionally, human adaptability has been allowed to compensate for system failures, be they mechanical, operational, or design. This is often an advantage to system operations, but there are also some disadvantages. Because of their complexity and flexibility, humans can behave very differently from one another and any one human's behavior can vary drastically over time. This situation poses a challenge to the design engineer. Wherever the human interacts with or operates in an engineered system, the designer must allow for a range of human behaviors. A good example is the development of traffic flow theory. During the 1950s, mathematical models of traffic flow used relatively simple (if any) transfer functions to represent the driver. The fit between the models and actual flow data was far less than desired. As human variability was incorporated and accounted for, the models increased in accuracy (Forbes, 1963).

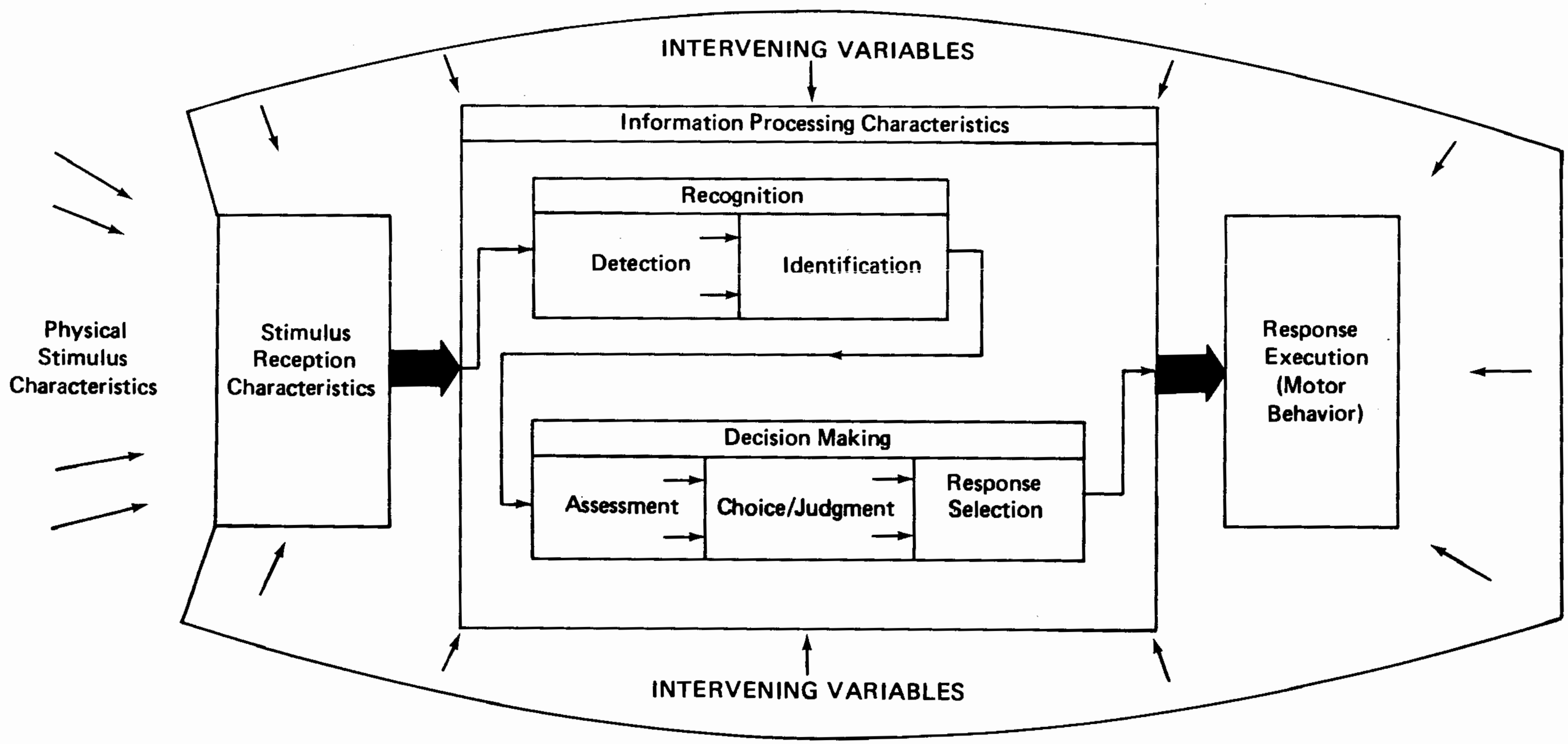


Figure B-1. Pedestrian/Driver Conceptual Model

In discussing the model here, the emphasis will also be on information processing characteristics and intervening variables. A voluminous amount of literature exists on physical stimulus characteristics, stimulus receptor characteristics (e.g., visual, aural, kinesthetic), and response or motor behavior. For example, human engineering handbooks and technical reports such as McCormick, 1969; Van Cott and Kinkade, 1972; Baker and Grether, 1954; or Roth, 1967, provide extensive human engineering data. An annotated bibliography of all literature identified for this task is provided as a separate supplement to this report.

The conceptual model begins with the physical stimuli from the intersection which are the pedestrian's and driver's source of information. Light stimuli are the most important and convey the greatest amount of information. Human visual (as well as other sensory mode) reception capabilities span a wide range of values (see Tables B-1 and B-2), but a variety of receptor characteristics do limit the usable levels of stimuli. A knowledge of the range of physical stimuli present at an intersection is critical for the designer since human receptor characteristics, notably visual, change under varied illumination levels. As Figure B-2 indicates, specific light levels affect different receptors within the eye, and these different parts have somewhat unique properties.

Table B-1

Stimulation-Intensity Ranges of Man's Senses

Sensation	Smallest detectable (threshold)	Largest tolerable or practical
Sight	10^{-6} mL.	10^{4} mL.
Hearing	2×10^{-4} dynes/cm^2	$<10^{3}$ dynes/cm^2.
Mechanical vibration	25×10^{-5} mm average amplitude at the fingertip (Maximum sensitivity 200 Hz).	Varies with size and location of stimulator. Pain likely 40 dB above threshold.
Touch (pressure)	Fingertips, 0.04 to 1.1 erg (One erg approx. kinetic energy of 1 mg dropped 1 cm.) "Pressure," 3 gm/mm^2.	Unknown.
Smell	Very sensitive for some substances, e.g., 2×10^{-7} mg/m^3 of vanillin.	Unknown.
Taste	Very sensitive for some substances, e.g., 4×10^{-7} molar concentration of quinine sulfate.	Unknown.
Temperature	15×10^{-5} gm-cal/cm^2/sec. for 3 sec. exposure of 200 cm^2 skin.	22×10^{-2} gm-cal/cm^2/sec. for 3 sec. exposure of 200 cm^2 skin.
Position and movement	0.2–0.7 deg. at 10 deg./min. for joint movement.	Unknown.
Acceleration	0.02 g for linear acceleration 0.08 g for linear deceleration 0.12 deg./sec^2 rotational acceleration for oculogyral illusion (apparent motion or displacement of viewed object).	5 to 8 g positive; 3 to 4 g negative. Disorientation, confusion, vertigo, blackout, or redout.

Table B-2

Frequency-Sensitivity Ranges of the Senses

Stimulus	Lower Limit	Upper Limit
Color (hue)	300 nm (300 × 10⁻⁹ m.)	800 nm.
Interrupted white light	Unlimited	50 interruptions/sec. at moderate intensities and duty cycle of 0.5.
Pure tones	20 Hz	20,000 Hz.
Mechanical vibration	Unlimited	10,000 Hz at high intensities.

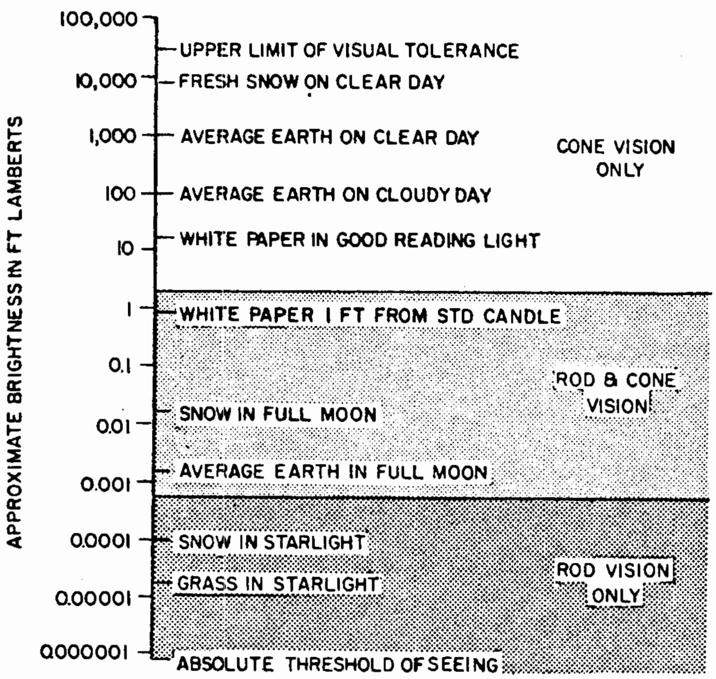


Figure B-2. Various Levels of Luminance and Affected Receptors in the Eye (From Van Cott & Kinkade, 1972)

Basic physical stimulus conditions are complicated by transient changes in the environment. Different types of weather modify transmission of light and sound. Various types of haze (both natural and man-made), rain, and snow affect the distance lights or signs can be seen, the ability to detect color, and the ability to resolve detail, i.e., to read signs or symbols. Figure B-3 (Middleton, 1952) gives an excellent example of how different densities of aerosol in the air (haze versus fog) do not have different effects on visual range but do differentially affect color.

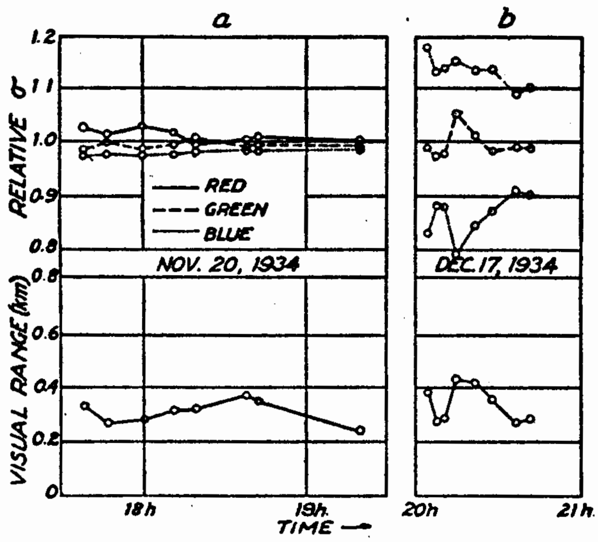


Figure B-3. Relative Extinction Coefficients (σ) in Fog (a) and in Haze (b)

In addition to physical variations, stimuli also differ in the amount of information carried, and this affects human reception and response. Information theorists, such as Attneave (1959), define the amount of information as the number of binary digits into which an event can be encoded. The basic concepts of information measurement can be explained as follows. For equally probable alternatives, the amount of information (usually symbolized by the letter H) is derived from the formula:

$$H = \log_2 n$$

where n is the number of equally probable alternatives.* Thus, where the probabilities of various alternatives are equal, the amount of information, in bits, is measured by the logarithm, to the base 2, of the number of such alternatives. For example, with only two alternatives, the information, in bits, is equal to the logarithm of 2 to the 2 base, which is then 1.

*H can also be expressed in terms of the probabilities of each alterantive, that probability being the reciprocal of n. The formula then takes the following form:

$$H = \log 1/p$$

where p is the probability of each such alternative.

It follows that the amount of information in the stimulus can be manipulated by varying (a) the number of equally probable alternatives from which the stimulus is to be chosen, (b) the proportion of times the stimulus could occur relative to the other possible alternatives, and (c) the probability of its occurrence as a function of the immediately preceding stimulus presentation.

In fact, a study by Hyman (1953) showed that subjects' reaction time to the stimulus linearly increased when the amount of information was increased via any of the three manipulations cited above.

There is a plethora of research related to subject performance as a function of the amount and complexity of the stimulus. In reviewing this literature, Berger and Hanscom (1973) found, for instance, that, with simple geometrical or alphabetical materials, search time is approximately proportional to the number of objects present in the display. "Within reasonable limits, the longer the viewing time, the greater is the discriminability" of attributes of single objects or the identification of a target object in a display (McCormick, 1964).

It appears that it is not simply the number of objects which determine performance, but rather the number of objects which are similar to the target. For example, in fields containing objects of different colors, search time is approximately proportional to the number of objects with colors similar to the target object. Support for a general statement about object similarity came from the review which found that search time was greater for fields containing objects more similar to the target in size, shape, and contrast.

Studies also indicate that subjects selectively use various attributes of the stimulus object when scanning. Williams (1966) found, for instance, that for a field containing objects differing widely in size, color, and shape, subjects performed better when they used color cues than when they used size or shape. Further, when provided with information about two or three target characteristics, subjects generally fixated objects on the basis of a single characteristic; namely, color, if provided.

One hypothesis that may account for these data is that the perception of the total field is determined by the target specifications or expectations. When, for example, a subject searches for a particular target, he may perceive objects with similar characteristics as relevant and view other objects as a somewhat irrelevant background. His task, then, involves scanning the different parts of the relevant pattern until he comes to the target.

The eye itself, of course, is continually moving in order to accumulate information and maintain a coherent image. When examining complex objects, the human eye fixates mainly on certain elements of these objects. Most visual fields contain different elements and the eye rests much longer on some of these than on others (some elements may even be ignored).

Analysis of the eye-movement records shows that the elements most actively scanned contained information assumed by the subject to be useful and essential for perception. Elements on which the eye does not fixate, either in fact or in the observer's opinion, do not contain such information (Yarbus, 1967).

Finally, we should note that, if the same stimulus is presented repeatedly, the response originally made tends to decrease or disappear; this change is known as habituation (Treisman, 1964). As the stimuli to which the subject is being habituated are repeated, they become less novel and bear less information; the focus of attention is then likely to shift to a richer information source.

Not only do environmental and information content affect human reception and response, but situational characteristics surrounding stimuli also have an effect. The context in which the stimulus is presented often plays a major role in determining the perception of the stimulus and the type of response that is elicited. In general, overly simple environments which fail to present sufficiently diverse and/or numerous dimensional units of information fail to stimulate the processes of perceptual accuracy (e.g., boredom, lapses of attention, etc.). On the other hand, overly complex environments which provide excessively diverse and/or numerous dimensional units of information produce similar effects but for different reasons (e.g., information overload, performance anxiety, etc.).

Particular attention has been given to variables of load, information diversity, and speed in visual displays. Load refers to the variety (in terms of type and/or number) of stimuli to which responses must be made. Thus, if a driver or pedestrian is exposed to several signs at the same time, the load on the visual system will be greater than if there were fewer signs. Speed, in this context, relates to the number of stimuli per unit of time or, conversely, to the time available to read each of the signs. Interestingly enough, in studies of load and speed, it has been found that the arithmetic product of these two variables typically results in a linear relationship with some types of performance.

Under conditions of stress or time pressure, the benefits to be gained by making the various stimuli distinct are substantial. McCormick (1964) states that, in many circumstances, the greater the distinction, the more likely is the distinction to be recognized quickly. Norman and Rumelhart (1970) indicate that we can maximize (or enhance) the likelihood of detecting a stimulus in three ways. The first is to increase the duration that the stimulus is available for inspection. This gives the perceptual system more time to identify the salient features of the stimuli and rehearse them. A second way is to decrease the number of stimulus items being presented or to be analyzed by the perceptual system at any moment. This increases the rate at which the stimulus material can be encoded. The third way is to decrease the number of possible stimulus items, or number of items or characteristics, that the subject expects to have presented to him. This decreases the number of features that the subject needs to consider in order to distinguish unambiguously among the possible stimulus items.

Consideration of stimulus context relates directly to the next element in the conceptual model, stimulus reception. As noted earlier, human sensory detectors (eye, ear, nose) cannot sense all values of all stimuli and they cannot resolve all degrees of magnitude. Two types of parameters account for reception characteristics: (1) operation of the receptor mechanism, and (2) a variety of intervening variables. In discussing these two parameters, emphasis will again be on the visual sense mode since it handles the majority of pedestrian and driver information input.

Looking straight ahead with both eyes, the typical adult has a 120° (left-right) field of view and between 160° and 180° field of view with peripheral vision from both eyes (Figure B-4). The eye performs several types of analyses on the data gathered from the visual field. Table B-3 lists functions particularly relevant to the intersection user. In addition, a number of variables affecting visual performance are given. All of the items in this table could occur at an intersection, but only those of particular importance to safety are considered further here.

Visual acuity refers to the ability to distinguish between physical features in several planes, as illustrated in Figure B-5. This capability becomes important for drivers when approaching an intersection and trying to ascertain the configuration, guidance, traffic control and conditions, and pedestrian activity. Acuity is primarily important for pedestrians in their ability to see written or symbolic messages across a roadway. Acuity in both situations is drastically affected by contrast and ambient illumination, as shown in Figure B-6. Extreme ambient light conditions alter acuity capability and must be avoided in any operational traffic setting. Conditions such as glare, either from headlights, bright (or direct setting) sun, or surrounding light sources, can make virtually any roadway feature, sign message, or signal light almost invisible. This is because the contrast ratio between object of interest and background moves toward zero. At the same time, extreme brightness diminishes or washes out color contrast.

From Figure B-6, the above discussion, and various studies of reverse contrast (light on a dark background), it is evident that night conditions pose a problem. Backlighted signs, symbols, or words adequately discriminable during the day may decrease in legibility because the backlighting is now too bright relative to the ambient brightness, resulting in halation.

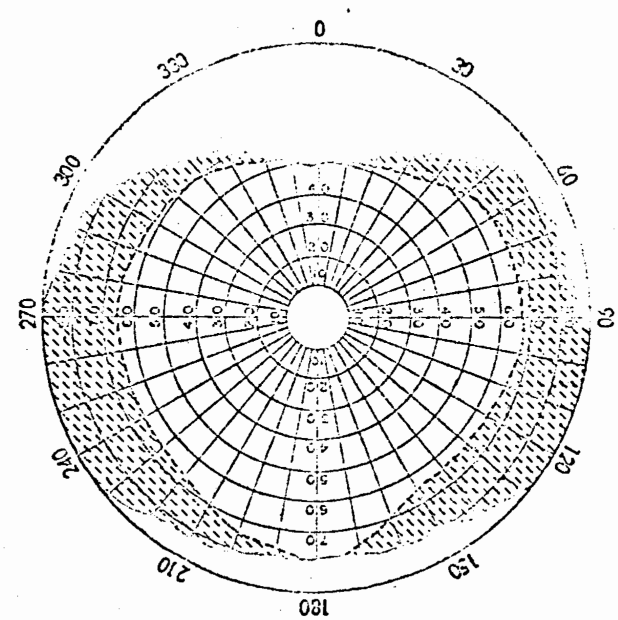


Figure B-4. Binocular Visual Field with Head and Eyes Fixed

This diagram shows the normal field of view of a pair of human eyes. The central white portion represents the region seen by both eyes. The checked portions, right and left, represent the regions seen by the right and left eyes, respectively. The cut-off by the brows, cheeks, and nose is shown by the white area. Head and eyes are motionless in this case.

Table B-3

Variables That Affect Principal Kinds of Visual Performance

Type of Visual Performance	Variables											
	Level of Illumination	Region of Retina Stimulated	Stimulus Size	Stimulus Color	Contrast Between Object and Background	Adaptive State of the Eye	Duration of Exposure	Distance	Number of Cues Available	Movement	Other Objects in Field	Stimulus Shape
Visual Acuity	X	X	(MV)*	X	X	X	X	X		X		X
Depth Discrimination	X		X	X	X	X	X	X	X	X	X	
Movement Discrimination	X	X	X	X	X	X	X	X		(MV)*	X	X
Flicker Discrimination	X	X	X	X	X	X	X					
Brightness Discrimination	X	X	X	X	(MV)*	X	X			X		X
Brightness Sensitivity		X	X	X	(MV)*	X	X			X		X
Color Discrimination	X	X	X	(MV)*	X	X	X	X	X		X	

*Variable being measured
(After Wulfeck et. al., 1956)

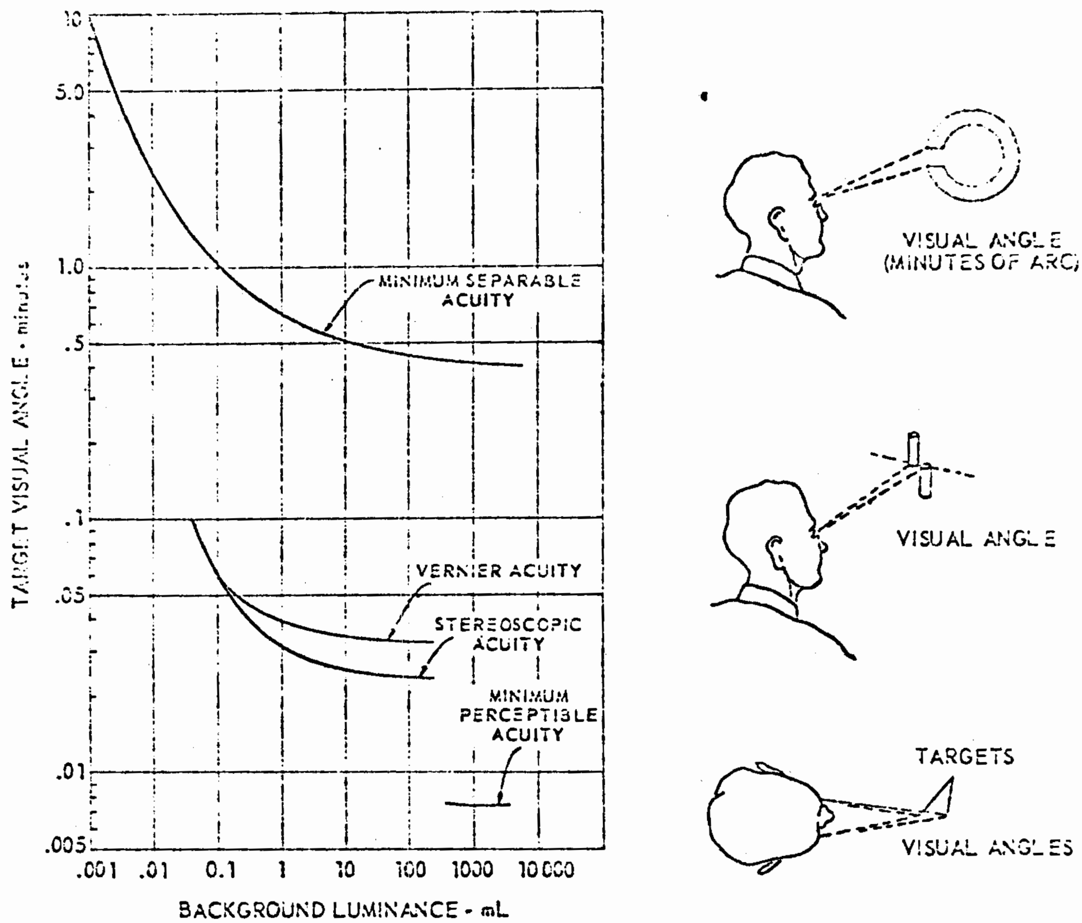


Figure B-5. Variation in Visual Acuity with Background Luminance

Above are variations in spatial acuity with background luminance for high contrast targets, considering the natural pupil and binocular vision. ***Minimum separable acuity*** defines the smallest space the eye can see between parts of a target. The relationship shown is for a black Landolt-ring on a white background. For white targets on black backgrounds, the relationship between acuity and luminance holds up to about 10 mL, above which acuity decreases because the white parts of the display blur. ***Vernier acuity*** is the minimum lateral displacement necessary for two portions of a line to be perceived as discontinuous. The thickness of the lines is of little importance. ***Stereoscopic acuity*** defines the just perceptible difference in binocular parallax of two objects or points. Parallactic angle is one of the cues used in judging depth. Beyond 2500 feet, one eye does as well as two for perceiving depth. ***Minimum perceptible acuity*** refers to the eye's ability to see small objects against a plain background. It is commonly tested with fine black wires or small spots (either darker or lighter) against illuminated backgrounds. For all practical purposes, these numbers represent the limits of visual acuity. Another type of acuity not shown in the graph is ***Minimum visible acuity***. This term refers to the detection by the eye of targets that affect the eye only in proportion to target intensity. There is no lower size limit for targets of this kind. For instance, the giant red star Aldebaran (magnitude l) can be seen even though it subtends an angle of 0.0003 minutes (0.056 sec) of arc at the eye. (The conditions under which these data were obtained were nearly optimal for a given level of illumination. Changes in contrast, retinal location, rapid changes in illumination, and vibration would decrease the resolution capabilities of the eye.) (After Roth, 1967.)

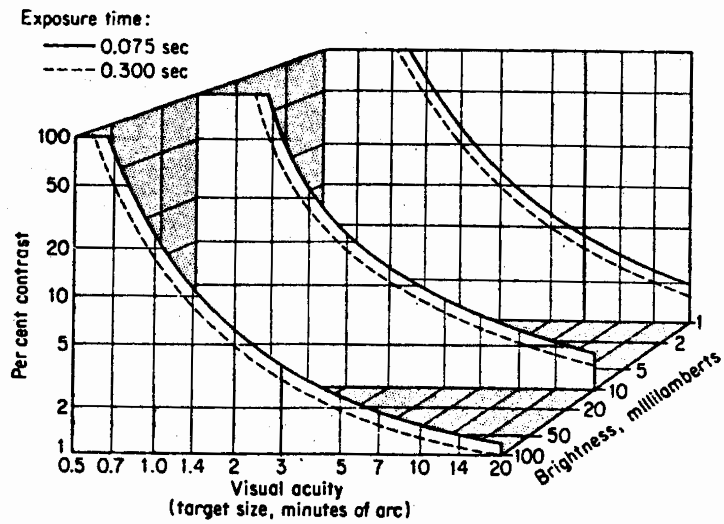


Figure B-6. Relation Between Brightness Contrast, Illumination (Brightness of Background), Exposure Time, and Visual Acuity. (From McCormick, 1964)

For drivers, there is another type of acuity which must be noted. Dynamic visual acuity (DVA) refers to the way visual acuity deteriorates as a function of increasing target speed (Goodson & Miller, 1959). Recent studies have shown that DVA is relatively independent of other visual measures and has a greater relationship to highway accident involvement than other types of acuity (Henderson & Burg, 1974). This has importance for the intersection designer to the extent that any symbology or feature to be discriminated by the driver must be seen far enough ahead so as to be identifiable before the car-target motion relationship exceeds 60^{o} per second; for acuity then rapidly deteriorates. The alternative is to use lettering or symbols large enough so motion will not affect discriminability.

Acuity is affected by sudden changes in light level. The eye is composed of two basic receptor types: rods, which are more sensitive to lower light levels; and cones, located primarily in the fovea, which are sensitive to higher light levels and color and able to resolve smaller visual angles. When going rapidly from light to dark illumination, the eye requires from several seconds to 30 to 40 minutes for the full shift to total rod vision. Going from dark to light adaption occurs very rapidly, i.e., from a few seconds to two minutes. The impact of this on intersection design is evident mainly at night. Sudden extreme changes in light level need to be avoided. For pedestrians, car headlights can be the source of the problem unless the sidewalk areas have a moderate level of illumination.

Depth and movement discrimination are usually considered separately; analytically, however, they are of interest in the intersection situation as a combined variable. As an example, simply knowing a car is 100 feet away is really not very useful to the pedestrian. Of far greater importance to his safety is the distance plus the velocity of the car's approach. The same is true for a driver. His concern is how rapidly he is closing on a pedestrian and how fast the pedestrian is progressing. In summarizing the state of knowledge on this type of sensing, Rockwell (1972) found few relevant studies. Those reviewed suggest that humans are very poor at judging closing rate straight ahead of them.

As the angle between the human and the target increases, the estimation of velocity improves. In terms of intersections, this means drivers must have sufficient sight distance to gage stopping distance, especially on high speed roads. In general, intersections and associated traffic or pedestrian controls should be arranged so that humans do not have to judge velocity or closing rate from a straight-on position.

Principal aspects of brightness were discussed under acuity, so we will proceed to color discrimination. As shown in Figure B-7, the eye is not equally sensitive to all wavelengths. Acuity is not affected by differences in wavelength (color) when there is a large brightness contrast. When luminance is reduced, acuity degrades similarly across wavelength (Roth, 1967). While detection will be discussed later, it should be noted that brightness or color contrast enhances conspicuity independent of acuity.

One consideration in using color is the fact that approximately six percent of the male population has a reduced ability to distinguish color difference. The disability is usually partial, being either a red-green or blue-green deficiency. Only .003 percent of the population are completely color blind. Baker and Grether (1967) list the colors (and definitive wavelengths) for use with the color-deficient (see Table B-4). Accommodating this type of deficiency means that a secondary means of identifying a color coded signal must be provided. A change in brightness and position, as in traffic lights, provides the needed redundancy.

The second major category of parameters affecting stimulus reception relates to individual differences across time and individuals. In the conceptual model, these are classed as intervening variables and, while they will be discussed now, they pervade information processing and response execution behavior.

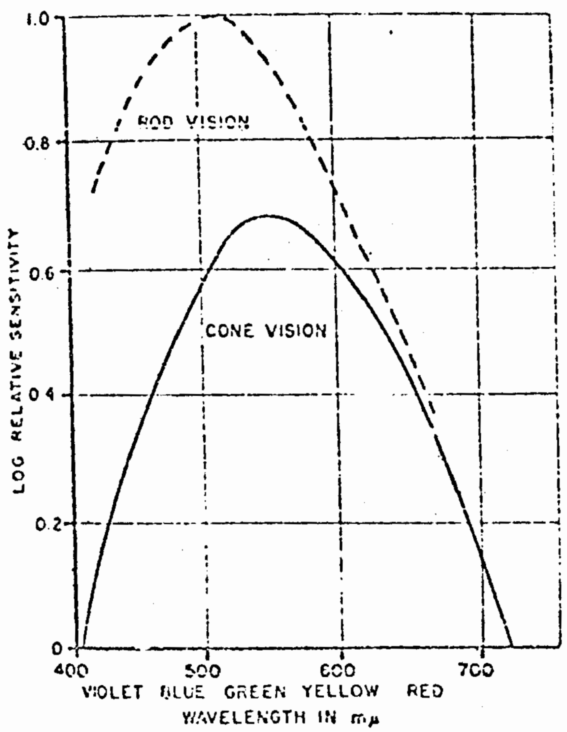


Figure B-7. Standard Luminosity Curves: Relative Sensitivity to Radiant Flux as a Function of Wavelength (From Roth, 1967)

Table B-4

Color Code Recommendations

		Ideal For Color-Blind Persons			
		Black	1770		
		White	1755		
		Yellow	1310		
		Blue	10B 7/6		
		For Use When More Colors Are Needed			
Red	1110	Blue	10B 7/6	White	1755
Orange	1210	Purple	2715	Black	1770
Yellow	1310	Gray	1625	Buff	1745

(After Baker and Grether, 1954)

The two extremes of age, young and old, result in differences in the human receptor (and processing) system which should be noted so that intersection design can accommodate them. With increasing age, there is a general decrease in sensitivity to the lower levels of light stimuli. At the same time, accommodation to very bright light, extreme contrast, and glare are impaired. Acuity often degrades with age. While corrective lenses are an aid, they are only directionally corrective; that is, peripheral vision is not improved and an important source of information for both driver and pedestrian is impaired. The human, being very adaptable, learns to compensate for such disabilities, usually by slowing down. The information input rate decreases and detection time increases.

Young children face the intersection situation with a lack of experience and, in the very young (under four years), incompletely developed perceptual capabilities. Colors are not always clearly distinguished, velocity and distance estimations may be less accurate than they are for an adult, messages cannot be read, and symbols do not have associated meanings. The young also tend toward more erratic, sudden changes in behavior, such as starting and stopping running or change in direction of movement.

Several transient conditions can affect an individual of any age. Fatigue results in a general impairment of sensory, motor and information processes. Attentional lapses and fluctuations are more frequent, resulting in missing of cues (e.g., movement of a child on a sidewalk) or traffic guidance (signs, signals). Research on visual behavior has shown the effect of fatigue on drivers to be a narrowing of the visual search pattern, or tunnel vision (Rockwell, 1972). Similar effects occur under other types of stress, e.g., emotional, information overload, and task complexity (Smith, 1972). Stress apparently has a common effect on information acquisition since the same types of performance deterioration were found in a variety of non-highway settings (for example, Gibbs, 1967).

Alcohol has been implicated in driver and pedestrian accidents. While effects vary with blood alcohol level (BAL), many of the effects on visual processes are similar to those associated with fatigue. The most dramatic change, and the one probably causative in accidents, is a shift in confidence in judgment. With increasing BAL, drivers overestimate their motor skills and are highly confident about decreasingly accurate distance and velocity estimates (Cohen & Preston, 1968). Similar degradation in pedestrian functions would lead to stepping out in front of cars much too close to stop, the inability to avoid a car, slowness in crossing an intersection, or ignoring pedestrian signals.

The study of the amount and type of information transmitted and processed is referred to under the rubric of attention. Several different stimulus characteristics including complexity, load, and brightness or color contrast have already been noted. Human reactions to these characteristics vary depending on several intervening variables. A stimulus which is relatively new in an individual's experience is likely to elicit an orienting response, vis-a-vis, the person looks at, moves toward or generally investigates the stimulus. The stronger the stimulus intensity, the more likely the response will occur up to a point. At higher intensities, the response changes character and evokes freezing, running, or, in general, a defensive response. Upon repeated presentations of the stimulus, the response diminishes (Berlyne, 1960).

In a similar manner, stimuli which create a conflict for the person will be attended. The problem facing intersection design is to provide stimuli which either stand out enough or contain such useful information that the pedestrian or driver will look and see it. On the other hand, very sudden, uncommon and intense stimuli are to be avoided so that road and crosswalk users are not distracted from more mundane but informationally more important stimulus sources, e.g., pedestrian signals.

Internal personal attributes which affect what we look at and see include perceptual defense (Bloomer, 1962) and perceptual style (Witkin, 1962; Barrett & Alexander, 1973). Studies of perceptual style have generally confirmed a significant relationship with accident experience (Barrett & Thornton, 1968; Harano, 1970; Williams, 1971). In terms of perceptual functioning, the field-dependent individual is not highly capable of separating stimulus cues from the overall stimulus context with which they appear. The field-independent person can separate and process stimuli relatively independently of competing or surrounding stimuli. For example Olson (1974), in a series of field experiments, showed that field-dependent drivers did not use information from vehicles beyond the car in front of them as well as field-independent drivers. Based on this data, Olson then hypothesized that field-dependent drivers would be overinvolved in rear-end collisions.

In terms of intersection design, differences in perceptual style affect behavior and lend further emphasis to the design goal of steady, smooth traffic flow. Another area of intersection design where perceptual style may be important is in the general visual environment. Smith and Faulconer (1971) compared interference in traffic flow and accidents to arterial street visual scenes. They found a direct relationship between color contrasts of focal points, dynamics of possible focal points, and naturalness of focal points with the criterion variables. A contributing factor could be that, faced with a complex visual scene, field-dependent individuals are not able to extract only the information required to move through the traffic stream witout incident, ignoring irrelevant cues.

Intersections themselves, perhaps more than any other type of highway facility, can become complex (e.g., special purpose lanes and signals, numerous route markers, heavy conflicting traffic, many pedestrians). When irrelevant additional light and sign stimuli form the visual backdrop, a field-dependent individual could experience considerable confusion and uncertainty as a result.

Another conceptualization related to the above is expectancy and uncertainty (Woods, 1971; Hurst, 1965). If a driver or pedestrian does not know what to expect in terms of traffic behavior, geometrics, or guidance, his behavior will reflect this uncertainty. Specifically, the behavior will tend to be either erratic and indecisive or incongruent with surrounding traffic behavior or expectations. The driver in this condition is taking a greater risk since he is more likely to perform a conflicting maneuver. The condition of uncertainty is nicely illustrated by the following: A driver is trying to turn a corner while a pedestrian is trying to cross the street. Each wants the other to go first and neither of them moves. Then they both proceed simultaneously, resulting in a conflict.

Based on this conceptualization, a primary intersection design consideration would be to clearly provide all the information necessary for either a driver or a pedestrian to proceed through the intersection with a minimum of questions concerning where to go (what direction to go; which lane to be in) and when to go. This design philosophy is implicit in the recently published statement on positive guidance (Alexander & Lunenfeld, 1975).

A final type of intervening variable relating to the physical world rather than the human internal world is visual obstructions. King and Sutro (1957) examined the visibility from a popular make sedan, noting the number of blind spots created by window posts, etc. Obstacles of this type hinder the driver's ability to see pedestrian movement. At the same time, roadside structures should not be allowed to hinder the pedestrian's view of approaching or turning vehicles.

Turning now from the intervening variables to the information processing characteristics of the conceptual model, we find problems with semantics. The five steps called out in information processing appear to be relatively independent. However, the state-of-the-art in understanding these processes does not allow clear operational distinctions. Also, the functions listed are evidently very interrelated. The impact of this situation is that the research conducted rarely deals with the most detailed level shown in the model and the terminology is often used interchangeably, i.e., "identification" is frequently used for "recognition" or "detection." Because of the lack of clarity, this review will consider the literature under two broad categories, recognition and decision making.

Detection is the first step in the recognition process. Conceptually, detection can be subdivided into search, or looking for information, and acquisition, or locating the appropriate stimuli. Studies of the search process on the highway generally involve eye movement measurement. Experienced drivers have similar search and scan patterns. They maintain a 2.5- to 3.5-second preview time which means they must focus relatively far in front of the car. There are no erratic or large jumps in the eyes, and fixations rarely occur on stimuli giving irrelevant or redundant information (Rockwell, 1972). Novice drivers, on the other hand, look about a great deal and tend to focus on objects or sections of the roadway much closer to the car (Mourant & Rockwell, 1970). The result, as shown in Figure B-8, is that the novice driver spends much of his time acquiring data for positioning the car, while the experienced driver spends most of his time looking for directional cues. This is not to imply that experienced drivers don't need positioning cues, rather that they obtain the information elsewhere. In fact, the information is gathered extra-foveally through peripheral vision. Most of the information obtained peripherally is processed and used to control lateral placement. However, there is evidence that some stimuli cue the driver to gather more detailed information. In this manner, peripheral cues partially plan eye movements (Mackworth, 1965; Sanders, 1966). In the earlier review of receptor characteristics, the lesser acuity capability and color sensitivity associated with peripheral vision was noted. Additionally, response time increases the farther a stimulus strikes from the fovea. Finally, the more complex the stimulus array, the greater the response time to peripherally detected stimuli (Bartlett, Bartz, & Wait, 1962).

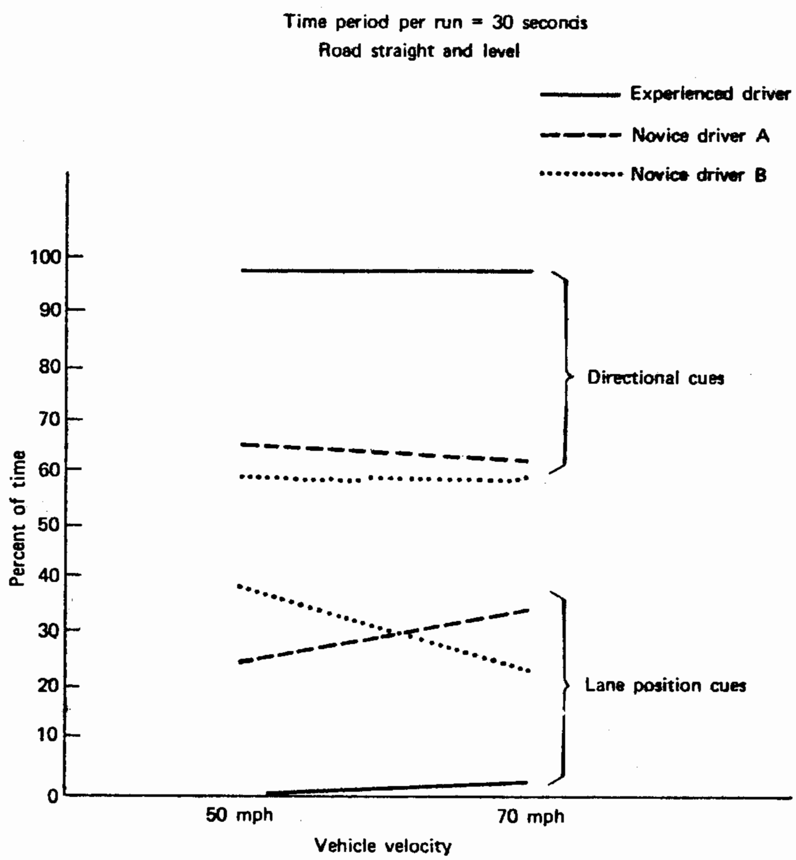


Figure B-8. Percent of Time Spent Sampling Directional and Lane Position Cues at Different Vehicle Velocities (After Rockwell, 1972)

Again, we must ask what relation this data has to pedestrian intersection safety. The large majority of drivers going through an intersection will be experienced, using peripheral information for positioning cues. To aid the driver, any markings or geometrics on the roadway should be clear and outstanding, not color-coded. Drivers should have their eyes on the dynamic traffic situation (including pedestrians) and traffic control devices. If the road is poorly marked or very rough (e.g., potholes), it will be necessary for drivers to employ foveal instead of peripheral search of the roadway, thereby greatly increasing the probability of missing a significant dynamic event. For pedestrians, it is necessary for intersection crosswalk design to align foveal vision with conflicting traffic as much as possible. While movement is probably the most sensitive peripheral cue and pedestrians often depend on it, foveal vision would provide far more positive pedestrian cueing.

While an individual searches and scans, he must detect stimuli that are relevant to the task at hand. Four basic variables have significant effects on detection: contrast, motion, color, and size. Experimentally, each of these variables can be isolated, varied singly, and studied. When combined, the effects are interactive (complicated) and, as yet, are neither well understood nor satisfactorily modeled.*

Detectability of a target can generally be increased by increasing any of the four variables, particularly where the others are of a low magnitude. If a pedestrian is walking at night and has neither good contrast, color contrast, nor size relative to other road objects, an increase in contrast will significantly improve his detectability. At intersections in urban areas, the major site of pedestrian accidents, the problem is the reverse; an overload of all four variables. It may be possible, for example, to optimize contrast and improve detectability. However, a more satisfactory solution, at least from a human factors viewpoint, may be to reduce the magnitude of the four variables in the visual surroundings of immediate importance to the driver. This is one effect of street lighting. Extreme contrasts as well as dark spots are reduced, giving the driver and pedestrian a more "even" visual field.

The highly urbanized intersection adds a fifth dimension to the detection problem: complexity. The number of elements in a visual field to be scanned is closely related to detection time (Egeth, Atkinson, Gilmore, & Marcus, 1973). This might suggest that the visual environment should be kept as simple as possible. Research indications (e.g., Cantilli & Fruin, 1972; Goldberg & Roby, 1963) are that too little stimulation results in boredom, vigilance decrement (missed signals), and distraction from the relevant task through attempts to gain additional stimulation. For design purposes, a varied, not too simple, but not overly competitive or complex stimulus environment appears optimum.

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*Voluminous research is available on target detection/pattern recognition and associated prediction models (e.g., Williams, 1966 or National Research Council, 1973); however, it generally deals with artificial situations such as scanning a CRT display involving small visual angles and abstract visual environments. The relationship between this research and full-scale highway applications has not been established.

Considerable interest exists currently as well as historically in the use of colored lights for communicating (Mashour, 1974). From the driver's perspective, the green-yellow-red signal light is standard and has almost universal meaning. The colors are readily distinguishable, are least distorted by weather factors, contrast sufficiently with most backgrounds, and are generally adequate from a human factors standpoint. To illustrate, the results of a study by Reynolds, White, and Hilgendorf (1972) found that response time was shortest for red, followed by green, yellow, and white. The number of errors in color naming was fewest for green, followed by red, yellow, and white. For specific situations, stimulus color, background, and amount of ambient illumination must all be considered. Correct detection and recognition of colors was most difficult under bright ambient illumination.

In an extensive review of the use of color in displays, Christ and Teichner (1973) found that color improved detection in many situations. There were, however, cases where negative effects were noted. A summary of these results are given in Table B-5. In general, "if the subject task is to identify some feature of a target, colors can be identified more accurately than sizes, brightness, familiar geometric shapes, and other shape or form parameters, but colors are identified less accurately than alphanumeric symbols" (Christ & Teichner, 1973, p. 44). There were no results reported which contraindicated the use of color in pedestrian (or traffic) signals.

Audition has received little attention thus far. For reasons indicated earlier, this has been intentional. There is, however, an interaction between audition and vision which could be beneficial should it prove usable. In a replicated experiment, Smith (1965a & 1965b) found that having another person vocalize what was visually perceived significantly reduced recognition errors. Should a system for facilitating visual signals with auditory commands be feasible, pedestrian recognition could be increased.

Decision-Making Processes

Once a stimulus is acquired and recognized, decisions must be made concerning the meaning of that stimulus and subsequent action requirements. The decision process is based on three types of input: incoming stimulus input, input from intervening variables, and memory or previous experience inputs.

Beginning with the last source, it has been well established (see any introductory psychology textbook) that incoming stimuli are interpreted in terms of past experience. From his experience base, each individual develops expectancies of what will happen next given certain stimulus configurations and sequences. Along with predictive expectancies, behavioral expectancies also develop and are stored in memory. Thus, people, because they have different past experiences and have developed a repertoire of behaviors appropriate to those particular experiences, may interpret the same situation differently. Operationally, this is seen among drivers in their assessment of the

Table B-5

Range of Percent Difference Scores for the Use of Color

	IDENTIFICATION TASK			SEARCH TASK		
	Minimum	Maximum	n	Minimum	Maximum	n
Unidimensional						
Brightness	+29	+ 32	2	+43	+43	1
Size	- 6	+111	6	+40	+40	1
Geometric Shape	-38	+ 33	11	+ 6	+42	5
Other Shapes	0	+118	6	+30	+63	2
Letters	-29	- 15	6	+10	+ 7	2
Digits	-48	+ 26	17	- 3	+42	4
Multidimensional						
Size	-10	+176	7			0
Geometric Shape	-28	+202	15	+50	+53	3
Other Shapes	- 2	+ 62	12	+41	+69	6
Letters	+ 4	+ 46	4			0
Digits	-51	+ 19	6			0
Interference						
Size	-29	0	14			0
Geometric Shape	-42	+ 1	4	- 8	- 8	1
Other Shapes	-43	- 17	4	-10	- 3	2
Digits	-14	+ 2	7			0
Complete Redundancy						
Size	+22	+ 60	3	+32	+32	1
Brightness	+24	+104	2	+32	+32	1
Geometric Shape			0	+21	+32	2
Letters			0	+53	+63	2
Digits	+ 2	+ 2	1	+60	+74	3
Partial Redundancy						
Digits			0	-23	+73	20
Maps	+ 1	+ 1	1			0
Static-Ground Photo	+29	+ 29	1	+32	+47	1
Static-Aerial Photo	+ 2	+ 2	1	+17	+17	1
Dynamic-Aerial Film	+ 3	+ 3	1			0
Dynamic-Aerial TV	+ 3	+ 3	1	- 3	- 3	1

Table B-5 (Continued)

Range of Percent Difference Scores for the Use of Color

A Guide for Design Decisions

Data in this table show the maximum and minimum gain (or loss) that has been reported using colors as target codes relative to the indicated achromatic coding dimensions. Minimum and maximum gain (or loss) are expressed in terms of the percent change relative to the achromatic codes shown in the first column. Positive scores indicate a gain; negative scores a loss with the use of color. These data are given separately for target identification tasks and for search tasks. Within each task, the data are further divided into five major categories based upon the use of color and the type of comparison used to derive the data:

1. The use of color as a nonredundant code; comparisons are made between unidimensional displays.

2. The use of color as a nonredundant code; comparisons are made within multidimensional displays.

3. The effects of nonredundant colors on the accuracy of identifying achromatic features of targets within multidimensional displays; comparisons are made between multidimensional displays and unidimensional displays.

4. The use of color as a completely redundant coding variable; comparisons are made between displays with completely redundant colors and achromatic displays.

5. The use of color as a partially redundant coding variable; comparisons are made between displays with partially redundant colors and monochromatic or achromatic displays. Studies using "natural" color representation in pictorial displays are included in this category.

The total number of comparisons (n) available in the literature is indicated for each range of effects listed in this Table. It should be noted that some of these data are based on only one or two comparative data points.

number and types of hazards present in various traffic situations. In reviewing studies using various traffic hazard recognition tests, not only did people differ in their ability to identify the hazards, but those who were more accurate tended to be accident-free (Pain, 1975).

Since people use their experience base in coping with current situations, one of the objectives of highway design is to sufficiently standardize the physical situations so that road users develop a common set of predictive and behavioral expectancies which will be valid anywhere in the system.

Considerable time has already been devoted to the acquisition and detection of stimuli. These form the major data base for the decision process, but their interpretation is affected by the past experience and expectancy input. Using the experience base and the needs of the perceived situation, various response or action alternatives will be identified. The final step, then, is determining which action to take.

Action selection is hypothesized to be a process of taking potential actions and applying a set of decision criteria which are, in turn, weighted by a series of intervening variables or weighting values. This sequence is shown in Figure B-9 (Whittenburg, Pain, McBride, & Amidei, 1972). Although the decision criteria have been tested with drivers, they appear equally applicable to pedestrians. Results of the study performed with the listed criteria suggest that drivers have consistent basic decision criteria, but that the relative weighting or profile of criteria vary. Among young male drivers (18-24 years), at least five clusters or profiles of decision criteria were identified (Whittenburg, Pain, McBride, & Amidei, 1972).

A critical implication of this model is that, while criteria may be generally consistent over time, the weighting of a given criteria can change dramatically as a result of a particular set of circumstances. Thus, a person who normally tries to minimize collision probability and normally chooses "safe" actions may adopt a minimized trip duration criteria if rushing to an emergency. His behavior would then resemble that of the person who normally values minimum duration and places little weight on the adherence to operational rules criteria.

The designer has relatively little control over the intervening variables affecting the decision process. At best, the design engineer can attempt to understand the criteria used in the decision process and then create system characteristics which accommodate, rather than conflict with the criteria.

ACTION ALTERNATIVES

1. Information-Seeking Actions

   1_1
   .
   .
   .
   1_n

2. Status Quo Actions

   2_1
   .
   .
   .
   2_n

3. New or Changes in Actions

   3_1
   .
   .
   .
   3_n

+

DECISION CRITERIA

a. Minimize Collision Probability
b. Minimize Collision Severity
c. Conserve Resources
d. Maximize Trip Comfort
e. Minimize Trip Distance
f. Minimize Trip Duration
g. Handle Vehicular Emergencies
h. Adhere to Operational Rules
i. Maintain Vehicular Readiness
j. Demonstrate Maneuvering Ability
k. Maximize Traffic Flow Efficiency
l. Maintain Control of Yourself

+

WEIGHTING VALUES

<u>Personal</u>

.Accurate assessment of own driving proficiency
.Positive attitude towards oneself (self-respect)
.Willingness to compensate for permanent or transient limitations on one's driving proficiency

<u>Social</u>

.Respect for laws
.Adoption of predetermined norms
.Concern for the rights of others
.Respect for property (including own car)

= ACTION(s) SELECTED

Figure B-9. The Action Selection Process

Response Execution

The human is able to perform a variety of movements with varying speeds. However, more and more concern attends the handicapped. A variety of disabilities and severities are included in this designation. The limitations most relevant to intersection design are:

- Visual impairment
- Walking speed
- Ability to negotiate curbs using aids, e.g., crutches, walker, wheelchair

The blind or otherwise handicapped are comparatively infrequent users of most intersections. This may be due to the relative hostility of the intersection physical plant. Accommodations such as ramps in curbs should become standard. Accommodating the blind pedestrian presents a more difficult problem. The blind also tend to fall into older age groups (see Figure B-10) and consequently, often have the mobility difficulties of the sighted elderly. Hulscher (1975) reviewed the state-of-the-art in pedestrian controls for the blind and determined that six basic functions must be provided in any type of signal for the blind, including:

- recognition of the facility
- orientation
- detection (of the signal and/or signal facility)
- provision of a starting signal
- indication of the clearance period
- guidance along the crossing.

Neither the audible nor tactile devices currently in use operationally or experimentally satisfactorily meet all of the above qualifications. A comprehensive analysis of the problem in the U.S. is currently being performed at the Georgia Institute of Technology under contract to the Federal Highway Administration.

The handicapped represent one extreme in response execution. At the other extreme is the child with fast reflexes and quick gait who anticipates the walk signal and moves quickly into the traffic stream.

A well established response characteristic for the entire spectrum of pedestrians (and drivers) is the increase in response time as a function of increasing stimulus information. Hyman (1953) experimentally demonstrated the phenomenon with young subjects. Given the general decrease in processing and response which accompanies advancing age, the effect probably becomes more pronounced for the fifty-year plus age group. The implication for intersections is that the amount of information being presented to the road user should be kept at a moderate level. This information, however, should be adequate for the user; otherwise decision and response time will be delayed. As Hammer and Ringel (1965) showed, "lack of confidence in their ability to make accurate decisions may cause some decision makers to delay taking action even when they are able to make an accurate decision on the basis of the information available." A more drastic reaction to high information load, stimulus complexity, and conflict or emergency situations is response blocking (Teichner, 1968). This could occur for either driver or pedestrian. The phenomenon was studied primarily in the 1930s and the actual frequency or likelihood in a highway setting has not been investigated.

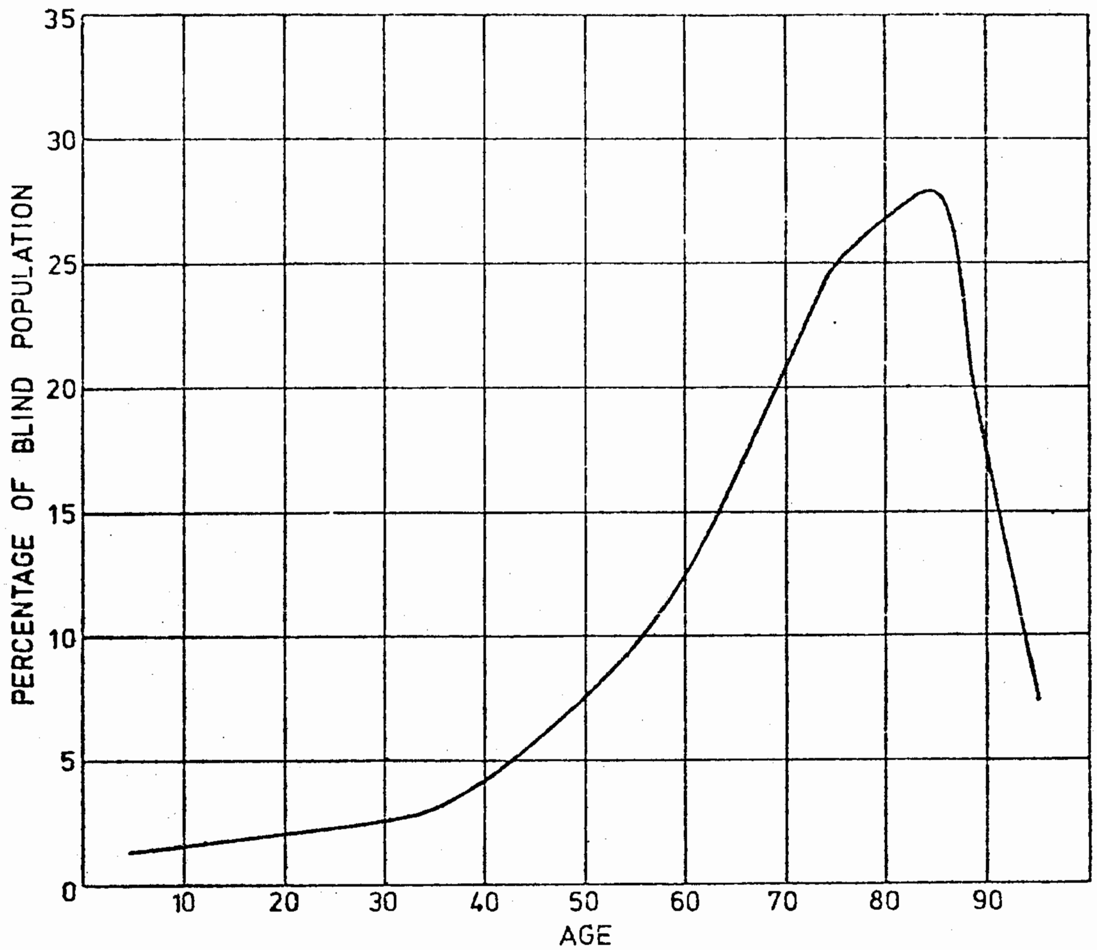

Figure B-10. Age Distribution of Blind in England and Wales
(From Hulscher, 1975)

In stimulus reception, recognition, decision making, and response execution, a common denominator has been the effect of information or task* load and complexity. Tangential support

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*Several studies by I.D. Brown (1965 or 1966) have shown the effects of information rate and complexity on driving skill.

for the importance of this class of variables is found in a study by Fergenson (1968). Time to process information was compared for accident/violation-free and -involved drivers. The accident-free group was significantly faster than the accident-involved group.

There appears to be abundant evidence that, from driver and pedestrian perspectives, intersection design should be particularly concerned with all aspects of information transmission and processing.

Research Concerning Pedestrians and Drivers at Intersections

The literature review in this section covers four areas: pedestrian behavior and characteristics, evaluation of safety countermeasures and controls at intersections, driver behavior at intersections, and driver control devices.

Pedestrian Behavior and Characteristics

Using our pedestrian conceptual model to organize this body of literature revealed no pedestrian-specific studies relating to stimulus receptor characteristics.

The data available for stimulus recognition come primarily from behavioral data gathered in the course of accident and evaluation studies. In a review of British accident studies, Older and Grayson (1972) found that over 70 percent of the adults struck by a vehicle reported not seeing it before impact. The same was true for 60 percent of the children. Elderly pedestrians involved in accidents looked more often but did not see the vehicle approaching. It is not clear from the report what proportion of these accidents occurred at intersections. However, Forsythe and Berger (1973) gathered scanning behavior of pedestrians while evaluating pedestrian accident countermeasures. The data were retabulated across countermeasures for this project. Table B-6 presents the mean proportion of scanning opportunities* *not* taken by pedestrians crossing intersections. There is some improvement in scanning behavior following countermeasure installation, but half the scanning opportunities still were not used. This is unusually clear evidence of the role of attention, particularly search and scan behavior, in pedestrian safety at intersections.

In the decision-making process, a major task of the pedestrian is gap acceptance. The studies of this behavior report results either in time intervals or feet. With car speeds of twenty miles per hour, the gap accepted by half the pedestrians was 84 feet. The overall distribution of gaps accepted is given in Figure B-11 (Sleight, 1972). Later studies differentiating pedestrians by age found that

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*A scanning opportunity refers to a data source which should have been looked at by the pedestrian but was not attended to before or during a crossing.

older children accept smaller gaps than younger children. However, the actual distance between the car and the older child at the point their paths cross is shorter. Younger children stand at the curb longer before starting the crossing (Grayson & Older, 1972). Overall gap acceptance for both age groups decreases when children are in groups.

Table B-6

Scanning Behavior of Pedestrians
(Mean Proportion of Scanning Opportunities *Not* Used)

Countermeasure Type	Before Countermeasure	After Countermeasure	Site
Stop Line Relocation	.43	.42	Intersections
Preventive Markings	.66	.46	Intersections
Crosswalk Setback	.48	N/A	Intersections
Bus Stop Relocation	.19	N/A	Intersections
Midblock Crosswalk	.77	.63	Midblock
Mean	.56	.51	

N/A = Not available

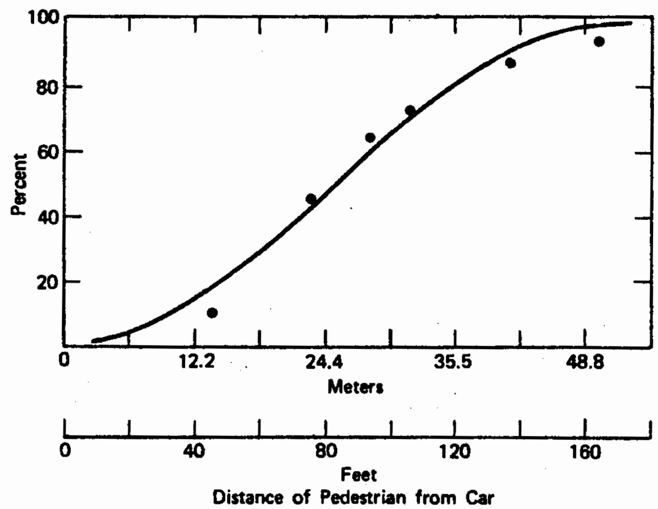

Figure B-11. Percent of Pedestrians Accepting Gaps of Given Size
(From Jacobs, 1968)

From the gap acceptance studies and other signal detection experiments, Grayson and Older (1972) concluded that both the elderly and young age groups do not process information as efficiently as the middle ages, and therefore require more time to reach a decision.

After considering pedestrian crossing hazards, Malo et al. (1971) determined that additional types of information could improve the driver and pedestrian decision-making process and lead to safer behavior. Signals were erected at several signalized and nonsignalized crosswalks to provide additional information. The signal told drivers of the presence of a pedestrian at the crosswalk. The pedestrian was advised to evaluate traffic before commencing his cross. This additional information was effective in increasing pedestrian use of the crosswalks and many more motorists braked, but overall vehicle speed distribution did not decrease.

The information which appears more useful to pedestrians is a clear indication of when to walk without interference from traffic and the amount of time available for the crossing. In evaluating the effect of pedestrian versus no pedestrian signals at intersections, Mortimer (1973) found that the pedestrian signal aided pedestrians in estimating the safe crossing time remaining. As a result, a significantly greater number of pedestrians crossed during the WALK interval compared to the green interval of the traffic signal. At the traffic signal, the highest pedestrian flow occurred during the amber interval, a potentially hazardous situation. In support of the need to know the status of traffic interference, Mortimer (1973) found that, "for every five safe crossings made at a walk or a run there was about one crossing that required evasive action" (by either the pedestrian or driver).

A similar conclusion was reached by a committee developing warrants for pedestrian signals. In summarizing the information that a pedestrian should be given, Leslie Sorenson wrote:

> The report also contains the committee's recommendation for circumstances under which pedestrian walk signals should be used. They are, (a) to identify an absolute free period for pedestrians, (b) to advise pedestrians as to the best time to cross, (c) to give the pedestrian information on when it is safe to cross which he would not otherwise discover from the signals, (d) to give pedestrians information at intersections where split signal heads are in use."

Outside the U.S., similar recommendations have been made. From a consideration of methods to separate pedestrians either in time or space, Youngman (1967) suggested an exclusive pedestrian crossing time. In a related vein, Retzko and Androsch (1974) found that traffic signal timing often encourages unsafe pedestrian behavior. This is usually the case when too much green time is given vehicle traffic with respect to its volume. Pedestrians are then more likely to cross against a red indication.

The role of decision criteria becomes evident in the above study. Pedestrians know the red should not be violated, yet other variables are given greater weighting than the added risk of going against the red indication. For example, Mortimer (1973) pointed out that pedestrians were more inclined to wait for correct signals in the spring than in the winter.

A question remains as to the weightings used by pedestrians in making decisions. Forsythe and Berger (1973) present the results of interviews with pedestrians crossing unsafely (not with a WALK or green indication). Table B-7 shows the results tabulated by general response category. The overriding factor is clearly time-related. A need to hurry or a desire to keep moving for some reason are prime movers behind disobeying pedestrian (or traffic) signals. The implication for intersection safety appears to be that, as with vehicles, the pedestrian stream must be kept flowing. W.P. Eno (taken from Siegel, 1961) reached the same conclusion in the late 1940s. "The science of highway traffic regulation consists in the knowledge of how to regulate the movement of vehicles and pedestrians so that they interfere with one another as little as possible and are enabled to go from point to point in the shortest time compatible with safety." The data reviewed here attest to the accurracy of his observation.

Table B-7

Reasons for Engaging in Unsafe Crossing Behavior

Category Title	Category Definition	Frequency	Percent
Personal conditions	Hurrying, convenience	168	69
Traffic conditions	Light traffic, cars stopped	27	11
Signal conditions	Pedestrian signal too short; vehicle light green	15	6
Social convention	No police around; others do it	3	1
Attention/sensory conditions	Didn't see or notice	24	10
Other	Bad weather miscellaneous	7	3
Total		244	100

Pedestrian response execution studies have focused on walking rates or crossing times. Different age groups walk at different rates, as shown in Figure B-12. Traditionally, a walking speed of four feet per second has been used for design purposes. A slower design speed would accommodate a larger portion of the population, particularly children and the elderly; that part of the population most frequently involved in pedestrian accidents. Within the adult category, Weiner (1968) found sex differences in walking speed. Women averaged 3.7 feet per second and men 4.22. Velocity changes as a function of pedestrian crowding or density. Figure B-13 gives the relationship for one-way movement. Speed will decrease more with two-way movement, as shown in Figure B-14.

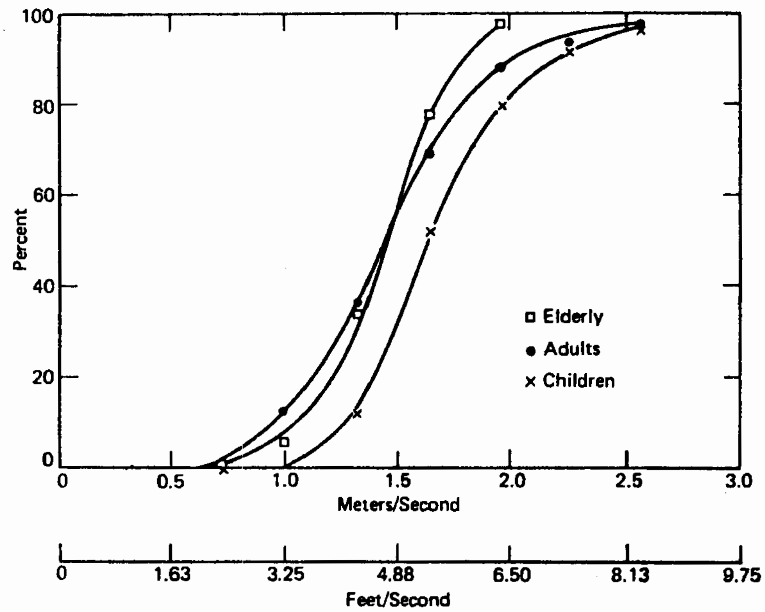

Figure B-12. Typical Speed of Pedestrian Movement at Crossings (From Sleight, 1972)

Another factor affecting crossing time is the number of conflicts with vehicular traffic. Velocity distributions decrease as a function of the number of conflicts. This decrease is greater for women than for men, mainly because women are involved in a greater number of conflicts (Henderson & Jenkins, 1974).

Finally, there is an interaction between street width, pedestrian crossing time, and vehicle capacity. Vuchic (1967) showed that pedestrian crossing time effectively limits the gain in vehicular flow as street width increases. Other measures must be undertaken to control this effect, e.g., grade separation, islands.

Evaluation of Safety Countermeasures and Controls at Intersections

A variety of pedestrian controls exist at intersections. Table B-8 summarizes the results of a survey which queried the usage of pedestrian signals. Since 1971, when the survey was conducted, pedestrian signal usage has continued to rise. The evaluations of pedestrian signals appear to warrant continued popularity, but recommendations for improvement have been forthcoming.

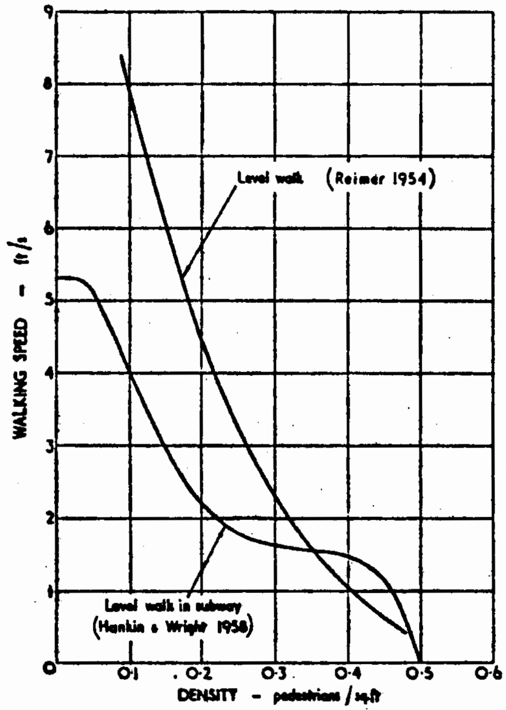

Figure B-13. Relation Between Pedestrian Density and Velocity (Movement in One Direction Only) (From Road Research Laboratory, 1965)

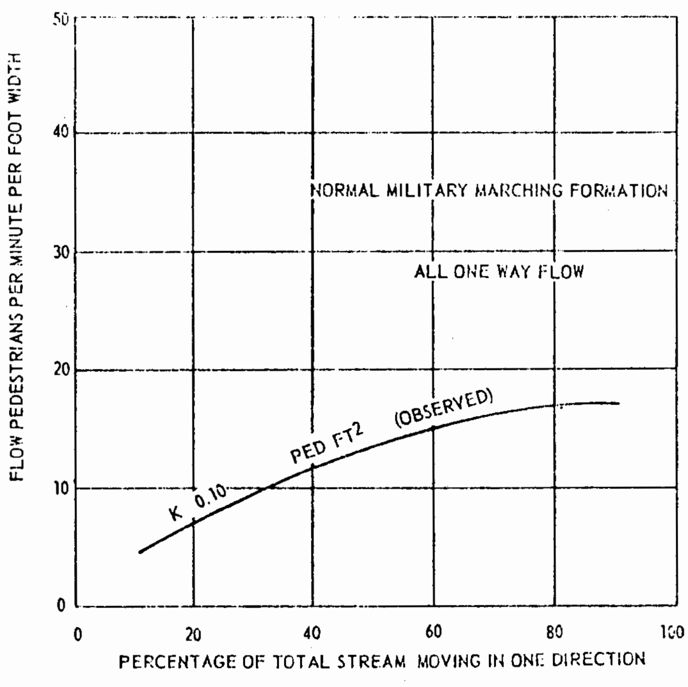

Figure B-14. Effect of Counter Flow on Total Flow (From Navin & Wheller, 1959)

Table B-8

Pedestrian Signal Usage in the United States

Summary of Survey Results

1. Most cities today use special pedestrian signals to supplement regular traffic control signals where such use is warranted by pedestrian and vehicular traffic volumes.

2. The most common wording used on special pedestrian signals is WALK and DONT WALK (85%) which is the national recommended standard. Some cities, however, still use the WAIT—WALK (14%) and DONT START—WALK (1%) indications.

3. There is great variance in the use of colors in special pedestrian signals, particularly in the WALK or "go" phase of the signal. GREEN—the generally accepted color for "go" movements is used in slightly less than half of all WALK signals (44%), while white is used in 48%.

4. The selection of the WALK signal color is directly related to the type of signal used. In gas-filled tubing signals, 64% use green WALK indications—with incandescent signals, only 25% use green.

5. Substantial uniformity exists in the DONT WALK signal color indication; 94% of all pedestrian signals use red or orange for the DONT WALK message (56% use red; 38% orange).

6. Only about 1 out of every 3 cities uses a flashing DONT WALK message during the clearance interval to warn pedestrians it is unsafe to begin crossing.

7. Most cities do not use any distinctly different WALK indication to distinguish pedestrian crossings where vehicle turning movements are not permitted.

8. Little or no experimentation or innovation in the development of special pedestrian signals was revealed through this survey. None of the cities used pedestrian symbols or silhouettes as is done in many European countries today.

(From AAA, 1971)

In 1959, John Kaiser found illegal pedestrian crossing behavior closely related to vehicular volume. After choosing sites with controlled volume, he observed the effects of pedestrian signals. The signals were effective in reducing the number of illegal crossings, but the reduction varied from 4 to 17 percent depending on vehicular volume. Recently, Mortimer (1973) compared the behavioral effects of signalized intersections with and without pedestrian signals. The overall results led to a conclusion that the pedestrian signals were effective. Table B-9 summarizes the findings.

Fleig and Duffy (1967) employed a before and after experimental design, but found no difference in pedestrian behavior or accidents. Unfortunately, no control intersections were included, so the result was compromised by not knowing if something else could have caused the change.

Table B-9

Behavioral Results From an Evaluation of Intersections With and Without Pedestrian Signals

With Pedestrian Signal	Without Pedestrian Signal
• 34.4% fewer illegal starts	
• 14.4% more successful corssings	
• 14.8% crossed against DONT WALK	• 24.8% crossed against red
• Proportion running increased when DONT WALK came on	• Twice as many ran during green as with WALK signal
• Pedestrian flow greatest on WALK	• Pedestrian flow highest on amber phase
• 27% reduction in pedestrian vehicle conflicts	
• Provided more useful information	

A particular aspect of the pedestrian signal has been of concern. As Sleight (1972) noted, the meaning of WALK signals are not always clear. In certain installations, WALK means that the pedestrian has exclusive use of the crosswalk and no traffic will interfere (see Welke, 1968 for an example); however, in the majority of situations traffic is not held. A pedestrian really has no way of knowing which type of control is in effect at a particular intersection. Obviously, the pedestrian who frequents semi-exclusive, controlled crosswalks builds a very different set of expectancies than the one who has to watch for traffic regardless of signal messages.

One way of providing more information is to use a flashing signal. A similar problem exists in that the WALK or DONT WALK signal may flash. Flashing may occur for one interval or only to indicate the last part of an interval. Again, pedestrians build expectancies which may be incorrect for other intersections, or, if they face different uses of flashing and cannot build an expectancy, they will tend to ignore the flashing.

The Institute of Traffic Engineers (1968) observed the behavior of 177 000 pedestrians at 15 intersections where a flashing signal was used. In eight locations, the before condition was a steady DONT WALK signal; the after and 30-day after conditions were a flashing DONT WALK. The remaining seven sites started with a flashing and changed to steady DONT WALK. Table B-10 gives the results which indicate that, in the long run, the steady signal was most effective.

An argument could be made that pedestrians were not educated about the meaning of the flashing signal. In a demonstration designed to show the effect of an education program in conjunction with the installation of flashing WALK signals, D'Angelo (1973) found no change in pedestrian behavior. In a similar study, Anderson (1973) found an increase in knowledge of the meaning of the flashing WALK signal after an education program. However, he did not measure behavioral changes.

Table B-10

Results of Change Between Steady and Flashing DONT WALK Pedestrian Signals

Conditions		Percent Proper Crossings		
Before	After	Before	After	30 Days After
Steady	Flashing	92	95	88
Flashing	Steady	93	92	95

In the specific situation of a major thoroughfare bounded by service roads, an additional set of pedestrian signals on the pedestrian islands had no effect on crossing behavior. Pedestrians still used the traffic signal and the presence of approaching traffic as a guide to crossing the service roads (Thakral, 1970; Thakral & Kraft, 1974).

The 3M Dynamic Pedestrian Signal (DPS) is a relatively recent innovation. Three evaluations have been conducted to date, and a fourth is in progress in San Diego, California.* All three studies found the DPS to be at least equivalent to conventional pedestrian signals. Understanding of the DPS (color, words, and indicated behavior) was superior to the conventional system; only one percent were confused by the DPS compared to 17 percent who were confused about the conventional signal. The number of aborted and wrong time crosses was reduced. All three authors (Edwards & Kelcey, 1974; Kyle, 1973; Stoddard, 1974) recommended the DPS system for longer crosswalks, divided roadways, and intersections frequented by the elderly, handicapped, or young.

In Europe, considerable experimentation with different signal colors and two- or three-light pedestrian signals took place in the 1960s. One commentator on these systems (von Stein, 1962) warned of the problems associated with red or green pedestrian signals if they were visible to a driver. The potential confusion of a driver faced with two signals, one green and the other red (or vice versa), could easily result in sudden and unexpected lead car stops and subsequent rear-end collisions.

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*Letter and work statement from the City of San Diego to the FHWA, April 12, 1974.

Overall, the pedestrian signal appears to have limited effectiveness. The major limitation is the uncertainty of information provided. However, it may not be practical to expect all of the "desirable" information features to be included in every pedestrian signal system. As Welke (1968) pointed out, the practical aspects of complicated signal systems, i.e., cost and maintenance, limit their use to heavily traveled intersections. Even if a complete information set cannot be provided in every signal application, considerable gain can result by standardizing the meaning of the information presented. If different amounts of information need to be given at various sites, a way must exist for the pedestrian to identify or be aware of the change.

Pedestrian signals are used only in conjunction with traffic signals, making methods of controlling pedestrian behavior important at nonsignalized intersections. A continuing evaluation of "zebra" marked crossings has been carried out in Britain. In 1961, Older and Basden presented data on their use together with a driver behavior courtesy index for one crosswalk. The driver behavior index, which had been gathered from 1948 to 1959, rose sharply in 1952 when the zebra markings were installed. The index dropped in 1955, but has since remained constant at a level twice that of the 1948 figure. Mackie (1962) determined the risk associated with using a zebra crossing versus crossing within 50 yards of the zebra crossing. Data from 21 sites indicated significantly less risk for pedestrians in the marked crossing. Continued monitoring of zebra crossings shows an increase in accidents since 1965, but this is partially due to increased vehicle volumes and a larger proportion of pedestrians using the crossings (Weaver, 1968).

With the introduction of the signalized panda crossings, comparisons with zebra crossings and fully signalized intersections soon appeared. The panda crossings resulted in excessive vehicular and pedestrian delays when volume was high, resulting in unsafe behaviors (Allen, 1963). Pedestrians crossed unprotected (against a signal) more frequently at panda and signal-controlled crosswalks than at zebra crossings. Pedestrians used the zebra more frequently when within 50 yards of it than they did signal-controlled crossings (Jacobs & Wilson, 1967). Driver behavior at panda crossings was less safe than at zebra or signal-controlled crossings (Mackie & Jacobs, 1965). A different type of signal-controlled crossing, the X-way, was tested in 1967. Pedestrian behavior was similar for this and other types of controlled crossings. Drivers were less observant of the cross stop signal, and intersection efficiency (delay) was less than at regular light-controlled intersections (Jacobs, Older, & Wilson, 1968).

The English experience is quite the reverse of U.S. results. Herms (1972) reported data on 400 intersections over a five-year period and found that approximately twice as many accidents occurred in marked as compared to unmarked crosswalks. Behaviorally, this was attributed to the pedestrians' false expectations about right-of-way and subsequent lack of caution.

A variety of unique crossing signs, e.g., "Dear Crossing," and marking systems have been documented but no evaluations have been reported (Anonymous, 1965; Chambliss, 1964; Grimm, 1960). The ultimate solution to pedestrian safety is complete vehicle-pedestrian separation. The criteria and design of such crossover programs are documented (Rotman, 1961; ITE Committee 4E-A, 1972; Roer, 1961). From a safety perspective, careful analysis of delay times and volumes are necessary to preclude creating a crossover that pedestrians do not really need or use.

In addition to engineering solutions to intersection control, behavioral control has also been recommended and attempted. Andrews (1973) argues that signing and crosswalk application have been minimized and they should now be fully standardized. The real task then is to enforce the right-of-way laws. This must be a community-wide effort, not an occasional "campaign." In attempting to improve behavior at an urban intersection, Cooper (1975) found that a reduction in violations took place only as long as a policeman was present and visible.

Enforcement may be of little value if appropriate laws are not enacted. Working from accident data, a recent study (Blomberg, Hale, & Kearney, 1974) developed nine model ordinances aimed at improving pedestrian safety. Three of these ordinances concern intersections. The first would require bus stops to be located on the far side of intersections, thereby eliminating the screening effect buses have when passengers disembark and cross in front of the bus. Second is an ordinance on parking near intersections. Vehicles would not be allowed to stand within 50 feet of a marked crosswalk or 60 feet of an unmarked crosswalk. The intent of this action is to improve pedestrian and driver sight distance. The third ordinance concerns vehicle overtaking, particularly at intersections. In essence, drivers would be required to yield to pedestrians in marked crosswalks. Any car stopped for a crosswalk could not be passed without a like stop and look at the crosswalk. To implement this law, any intersection with a designated crosswalk would have to be clearly marked and signed. After developing these ordinances, they were sent along with a questionnaire to various citizens and public officials. All three received strong support.

Through the application of behavioral modification techniques after public and small group educational efforts, Reading (1973) raised correct crossings by children from four to 12 percent to 65 to 85 percent. The long-range effects were not studied and application of the technique as outlined in this report would be very expensive on a large scale.

A more general point is implied by the above two studies. Intersection behavior can be modified by peer and social pressure, and that pressure can be applied through essentially educational means. Similarly, education is important when introducing and standardizing the purpose and meaning of traffic/pedestrian control devices.

Driver Characteristics at Intersections

While an enormous amount of research has been performed on drivers, only a minute proportion is devoted specifically to driver behavior at intersections. The studies reviewed here are organized according to the conceptual model.

For stimulus reception, the earlier discussion of brightness, contrast, and context are all applicable. A point rarely discussed but very important to intersection safety is pedestrian visibility. At signal-controlled or well-lighted intersections, this may not be a problem; however, at unlighted, painted crosswalks visibility is of importance. A study by Hazlett and Allen (1968) demonstrates how poor visibility becomes under certain night light conditions, and how reflective materials improve the situation (Table B-11). The implication for countermeasures is to provide illumination which will make pedestrians more visible.

Table B-11

Simulated Pedestrians Safely Visible at Distances
Greater Than Critical Visibility Distance
(In percent)

	Miles per Hour			
Simulated Pedestrians	*20*	*40*	*60*	*80*
Black	86.4	45.4	0	0
Grey	100	47.2	5.5	0
White	100	100	97.2	52.7
Reflectorized	100	100	100	100

(From Sleight, 1972)

This goal becomes particularly important when considered in the light of drivers' scanning behavior at intersections. When a traffic signal was present, almost no scanning was done by drivers. More scanning occurred if a stop sign was present. If a turn was to be made, most scans were in the direction opposite the turn (Anderson et al., 1968). Improving the scan behavior of drivers would be one method for increasing detection of pedestrians as well as other vehicles.

In the decision task, a continuing problem has been timing of the amber interval in traffic signals. Data collected on driver judgments about when drivers stop and when they go through an amber indication found consistent and relatively accurate performance. At the judgment thresholds at each speed, close peak vehicle braking was required in stopping. A third of the decisions at the threshold led to errors, hesitations, or change of mind. As a result of the study, the distance 95 percent of drivers used to stop successfully was recommended as a design parameter in calculating amber interval lengths (Crawford, 1962).

The fluctuation in importance of different decision criteria, depending on circumstances and situations, was clearly shown by Ebbesen and Haney (1973). In three studies, the effect of various types of audience on risk taking (gap accepted for turning at intersection) was examined. Being forced to wait in a line of cars before turning was the factor that increased risk. Cars present behind or beside the subject's car had no effect. As with pedestrians, the value of time (or negatively, the frustration of waiting) appears very high and evidently overrides safety considerations more frequently than other intervening variables.

Response execution of drivers suddenly faced with a pedestrian in their path was studied in a simulator. All subjects made some evasive action, usually braking. Only one driver tried to steer around the simulated pedestrian (Barrett et al., 1968). Driver response to emergency situations, e.g., braking technique and additional response options, could be improved through training.

Driver Control Devices

Control of the driver can be accomplished primarily by providing various types of information. This information is presented through signs, signals, markings, and roadway geometry. Extensive research has been devoted to these areas, as evidenced by the number of articles included on these subjects in the annotated bibliography. A review of this literature here would be redundant, as existing reviews adequately cover the topic (Berger & Hanscom, 1975; Street et al., 1970; Forbes, Snyder, & Pain, 1964).

The work on signs has concentrated on specific design parameters with much less attention paid to message content. Most studies use a laboratory- or highway-type field setting. Very few have used urban areas or intersections. In the 40 years of sign study, many parameters have been explored and design guides developed. The following list indicates these areas.

- Legibility
  - Contrast
  - Brightness
  - Color
  - Letter size, shape, spacing
  - Reflectorization
- Detectability
- Comprehension
- Color and form coding
- Relation of attention value
- Shape and contour
- Illumination

Onc aspect of signing of considerable interest is the use of symbology versus alphanumerics. A similar interest exists for pedestrian signals. The U.S. generally uses words and colored lights in pedestrian signals, but many European countries use standing man-walking man symbols with colored lights. Three major experiments compared word versus symbol signs. The results clearly favored the use of symbols for more accurate and consistent comprehension of meaning. There were no differences in speed of recognition (Plummer et al., 1964; Walker et al., 1965). When asked about preference, people heavily favored a combination of words and symbols (Dietrich & Markowitz, 1972). These findings suggest symbols should be considered for pedestrian signals, preferably combining words and symbols in some fashion.

Studies of signing at intersections are much less common. For certain parameters, such as attention value and stimulus complexity, findings are equally pertinent to highways or urban intersections. In terms of fulfilling the motorist's information needs, the intersection, especially in urban areas, is a special case. In a series of studies on developing information requirements and transmission techniques, King and Lunenfeld (1972) explored urban guide signing. They concluded the MUTCD did not fulfill urban motorists' information needs. The magnitude of the problem was illustrated when 50 percent of the 729 questionnaire respondents reported feeling lost at some point in their last trip into unfamiliar urban territory. The single greatest problem was signs that did not give the expected (or needed) information. Solutions to several of the identified problems were field tested. Advance arterial signing, arterial direction signs, and display of cartesian grid coordinates resulted in fewer errors and less uncertainty.

The importance of this type of design improvement from the human factors perspective is that, by providing adequate, needed information in a timely and detectable fashion, the last minute workload at the intersection is greatly reduced. The driver can then devote his attention to guiding the vehicle on the correct path (maintain an adequate space and time cushion), and have enough capacity left to scan for pedestrians. The effectiveness of this concept was illustrated by simply using diagrammatic signs at a complicated intersection – a Washington, D.C. traffic circle (Kraft, 1973).

The above discussion is equally applicable to traffic and pedestrian signals. For example, in Washington, D.C., various color right turn arrows were tried at an intersection (Flanakin, 1974). Correct driver observance data were: red arrow, 7.6 percent; yellow arrow, 18.6 percent; and green arrow, 73.8 percent. The red arrow gave two contradictory types of information: stop and go right. All aspects of intersection design, geometry, signing, signals, markings, and visual environment must be coordinated not just to contain information, but to transmit it so the user can readily recognize and process relevant information.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.