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16. Abstract

This document reports the findings and applications of research investigating the effectiveness of specially designed low pressure sodium luminaires to increase pedestrian safety at intersection crosswalks at night. It was found that the LPS systems had beneficial effects on the crossing environment, driver performance, and pedestrian behavior. Illumination intensity was increased as much as thirty-fold, resulting in an average of 9% increase of available time for drivers to respond. Pedestrians appeared to be more alert in crossing and make better use of the crosswalk. The driving environment has been improved by reduction in headlight glare effects. Local residents and business people expressed satisfaction with the system applications at all seven test sites.

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PRICES SUBJECT TO CHANGE

PREFACE

The investigations described in this report were conducted by the Transportation Sciences Laboratory of the Franklin Institute Research Laboratories (FIRL) under Federal Highway Administration (FHWA) Contract FH11-8034. Mr. Michael S. Janoff was the Principal Investigator for FIRL, Mr. Mark Freedman was the Co-Principal Investigator for FIRL, and Mr. Paul McMahan was the Contract Manager for FHWA.

This report summarizes work conducted during Phase I and Phase II, and describes work conducted during Phase III and Phase IV of the contract. Phase I work included a review of the state-of-the-art of crosswalk illumination; a review of literature on pedestrian safety and pedestrian nighttime accidents; an analysis of Philadelphia nighttime pedestrian accident data; the identification of potentially high nighttime crossing accident locations; the conduct of a series of "before" observational experiments at such "high" as well as "low" (control) accident sites; and an identification of the most promising illumination concepts. Phase II work included the installation of specialized crosswalk illumination at seven of the identified "high" crosswalks in Philadelphia, Pa.; the conduct of a series of photometric evaluations at these seven "high" and seven "low" accident crosswalks before and after installation of the supplemental illumination; the conduct of a series of "after" observational experiments at the seven "high" and seven "low" accident crosswalks; the conduct of a survey of pedestrians' and residents' attitudes toward the supplemental illumination; and the conduct of a detection experiment at one crosswalk, both with and without supplemental illumination. Phase III work included an analysis of specialized illumination costs; an analysis of the effectiveness of the implemented supplemental illumination with respect to pedestrian and driver behavioral changes and accident reduction potential; an analysis of the photometric effectiveness of such systems with respect to the promotion of a safer crossing environment; a review of accidents during the period in which the supplemental illumination was operational; benefit-cost analysis of the installations; the development of warrants and design criteria for the employment of such illumination; and the development of a method of assessing the priority of sites for special illumination installation which must compete with other safety improvements. Phase IV was the development of a users manual for the design, implementation and evaluation of specialized supplemental crosswalk illumination. The users manual is published separately.

The authors wish to thank the Philadelphia Police Department for its cooperation in conducting the experiments, the Philadelphia Department of Streets for providing assistance in obtaining permission and installing the supplemental lighting, and Dr. Alan Sockloff, Temple University, for assisting in all facets of the statistical analyses of observational data. We also wish to thank the personnel of W.V. Pangborne, our subcontractor, for the excellent service that they provided in installing the illumination.

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1. INTRODUCTION

The overall objective of this program was to develop an understanding of the critical parameters involved in pedestrian crossing behavior at night on city streets and of how the design and installation of specialized fixed-source illumination may be employed to increase the safety of pedestrians when crossing such streets.

The research was organized in four distinct Phases, which were:

- I - Critical Review
- II - Controlled Field Experiments
- III- Benefit-Cost Evaluation
- IV - Users Manual

The specific objectives of Phase I were as follows:

1. Review and evaluate available information on the design and operational effectiveness of specialized crosswalk illumination systems. Sources included the literature; architectural, engineering and visibility specialists; lighting and equipment manufacturers; and lighting engineering staffs in some states and major cities.
2. Based on the review of the literature, identify the critical factors that can be related to night pedestrian accidents, such as road geometry, vehicle and pedestrian density, vehicle speeds, type of traffic control, type of illumination and adjacent land use.
3. Employing the critical factors identified, analyze night pedestrian accidents in Philadelphia (and other areas if necessary) to determine the types of locations and factors which influence such accidents.
4. Select several sites from those identified as having a high potential for night pedestrian accidents; select a similar group of sites with low accident potential. Review the accident records for these sites to determine if there are specific pedestrian and/or driver behavioral patterns which might account for the accident experience at these sites.

5. Develop a detailed work plan for a series of observational studies at each of the sites to determine the frequency of specific behavioral factors which may be related to accident occurrence (e.g., pedestrian/driver maneuvers).

6. Conduct experiments at locations with both high and low accident potential, under day and night conditions and during dry and wet weather. Analyze results to determine how the behavior of pedestrians involved in accidents at night differs from the behavior of pedestrians using the same types of crosswalks who are not involved in accidents.

7. Determine the most promising pedestrian crosswalk illumination concepts based on their projected effectiveness in reducing dangerous behavior and accidents and prepare a preliminary benefit-cost analysis.

The specific objectives of Phase II were as follows:

1. Design and install specialized crosswalk illumination at seven crosswalks in Philadelphia, Pennsylvania with high potential for nighttime pedestrian accidents.

2. Determine the improvement in visibility that can be provided by specialized crosswalk illumination.

3. Determine the effect of specialized crosswalk illumination on driver detection of pedestrians.

4. Determine pedestrian, driver and local residents' attitudes toward special crosswalk illumination.

5. Determine the improvement in driver and pedestrian behavior under actual crossing situations by observational experiments (similar to those reported in Phase I).

The specific objectives of Phase III were as follows:

1. Determine the costs (initial, operational, and maintenance) for each of the pedestrian crosswalk illumination concepts identified in Phases I and II.

2. Determine the effectiveness of each illumination system in promoting safer pedestrian and driver behavior and the resulting projected accident reduction.

3. Develop warrants that indicate the traffic, geometric, pedestrian and environmental conditions under which specialized crosswalk illumination should be employed, based upon benefit-cost or similar econometric analysis.

4. Develop design procedures for the selection and development of specialized crosswalk illumination systems.

5. Develop a method for assessing priorities among competing projects and for evaluating the results of any changes in illumination systems. A pilot study was to be made to determine the adequacy of the evaluation procedures.

The specific objective of Phase IV was as follows:

1. Develop a Users Manual which explains the methodology proposed for deployment of specialized crosswalk illumination systems and for evaluating the methodology proposed. The manual would include:

    a. System descriptions, design specifications, and costs.

    b. Warrants based upon behavior and volume, geometry and environment, accident experience, and photometric measures.

    c. A selection procedure for determining optimal choices.

    d. A method for assigning priorities to proposed projects.

    e. A methodology for determining the effectiveness of such changes.

    f. Step-by-step procedure to be employed when budget constraints make it unfeasible to provide total system effectiveness in a short time frame.

2. SUMMARY OF PHASE I AND PHASE II RESEARCH

2.1 LITERATURE REVIEW

A literature review was performed with the objectives to a) determine the factors that predominate in nighttime pedestrian accidents at intersections, b) examine results of prior research related to the effects of illumination on pedestrian safety at intersections, and c) develop a categorization scheme of nighttime pedestrian accidents for use in analysis and the design of observational experiments.

Each of these objectives was performed to develop an initial understanding of the factors that are associated with both the behavior of pedestrians and drivers in accident situations, and the environment in which accidents occur. The results of this review would ultimately be used in conjunction with the results of experimentation to prepare the first general specifications of an illumination system designed especially for pedestrian crosswalks.

2.1.1 Predominant Factors Associated With Pedestrian Accidents

Three major factors which contribute to pedestrian accidents were identified: pedestrian and driver behavior failures, traffic operational factors, and environmental conditions.

The more common pedestrian and driver behavioral failures included *search and detection failures* and *alcohol*. Snyder, in a 1971 study of 2,157 pedestrian accidents in 13 major cities, identified the primary intersection accidents (day or night not specified) as *intersection dash* (8%), *multiple threat* (3.2%), *pedestrian waiting to cross* (0.6%), and *vehicle turn/merge with attention conflict* (6.4%)[1]. Three other studies reported that *alcohol* was found in the blood in 42 to 75% of pedestrian fatalities (not normalized by percentage of all pedestrians with alcohol in their blood).[2,3,4]

Traffic operational factors at intersections include *direction of traffic flow*, *crosswalk markings*, and *traffic control*. Conversion to one-way operations have been reported to reduce pedestrian accidents from 10 to 60%.[4,5,6] The presence of painted crosswalk markings has been found to produce inconsistent pedestrian safety effects. A study in San Diego reported that more pedestrian accidents occurred in crosswalks by a ratio of about 6:1, while the ratio of those crossing within the crosswalk to those outside of it was about 3:1, suggesting that approximately twice as many pedestrian accidents occur within the crosswalk, regardless of day or night.[7] A Vancouver study reported that pedestrian accidents increased by 86% at 55 intersections after crosswalk markings were provided.[5] Several studies report conflicting pedestrian accident experience at signalized intersections.[5]

Adverse weather, darkness and *geographical location* appear to be the most common accident precipitators. Urban areas are particularly hazardous: 39% of all urban fatalities were pedestrians; only 10% of rural deaths were pedestrians; 64% of all pedestrian fatalities occurred in urban areas.[8] One study reported that darkness increased the adult pedestrian casualties by a factor of 3, and adult fatalities by a factor of 6.[9] Another reported that the night to day pedestrian accident risk ratio is about 6:1.[10] Smeed found that darkness doubled pedestrian casualties, and that rainfall increased the risk to pedestrians by a factor of 9 at night.[11]

2.1.2 Categorization of Accidents

The literature review provided for the identification and inclusion of principal accident descriptors and precipitating factors. These were incorporated into a set of coding instructions and used for detailed accident analysis.

2.2 SPECIALIZED CROSSWALK ILLUMINATION

Manufacturers of highway lighting systems and officials in 24 cities, 9 states or provinces, and 10 foreign countries identified 8 specialized crosswalk illumination systems, located as follows:

- U.S.A: Detroit, Las Vegas
- Canada: Toronto, Winnipeg
- Europe: Copenhagen, Hanover (Lower Saxony), Switzerland (Basle, Bern, Olten, St. Gallen, Zurich and others), Holland (The Hague, Voorburg, Amsterdam), London.

2.2.1 Description of Systems

Las Vegas, Nevada has been using a sharp cutoff floodlighting system (originally high pressure sodium, now 400-watt mercury vapor) in locations where heavy pedestrian traffic has demanded crosswalk illumination that is even brighter that the highly illuminated major street. The luminaires are mounted on opposite sides of the street and on the median. The Las Vegas illumination system is complemented by enforcement of a crossing policy which provides the pedestrian priority in crossing non-signalized crosswalks.

Detroit, Michigan, with a grant from the National Highway Traffic Safety Administration, tested different combinations of lighted signs, lighted legends, better illumination, and pedestrian and/or vehicle actuated buzzing sound equipment at 13 pedestrian crosswalk sites in 1968 and 1969.[12] A public education and publicity program was conducted prior to the implementation of the specialized systems.

In 1958, Toronto introduced a pedestrian crossover program, which defined by law a set of rules providing the pedestrian the priority of crossing at such specially designated crossovers, of which 710 are presently in operation.[13,14] System illumination equipment has evolved to the presently used internally illuminated, translucent, 6 ft. (1.8m) CROSS X WALK fixture and a mercury luminaire with an "X" sign mounted on both sides of the fixture. Crossover operation depends both upon the lighting and the crossover policy.

Winnipeg, Manitoba implemented its "pedestrian corridor" concept in 1967, and through 1972, 78 such corridors were installed.[15,16] The lighting is provided by a dual purpose sign, which is internally illuminated by uniform white lighting showing a black "X" on a white background, and provides a sharply defined 10 ft. (3.0m) wide path of yellow (low pressure sodium) light at 20 horizontal fc (215 lux) in the central 24 ft. (7.2m) of the illuminated path. The lighting policy there is directed more at indicating the presence of a corridor than at illuminating the pedestrian.

In Copenhagen at each zebra crosswalk one or more 1000-watt quartz iodide lamps and flashing beacons are suspended over the crossing, with additional internally illuminated signs depicting a pedestrian on a zebra crossing.[17] The number of fixtures depends on the number of traffic lanes, number of directions of traffic and street width. Drivers must yield to pedestrians in the crosswalk.

At each zebra crosswalk in Hanover, one or more 200-watt, rod shaped low-pressure sodium vapor lamps with supplemental signs depicting a pedestrian on a zebra crossing are used, with the number of luminaires dependent on the number of lanes, directions of traffic, and street width.[18] Normally, one luminaire per direction of traffic is mounted upstream of the crosswalk with a sharply cutoff asymmetrical light distribution pattern. Drivers must yield to pedestrians in the crosswalk.

Various systems are in use throughout Switzerland.[19] In general, the number of fixtures is dependent on the number of directions of traffic, number of lanes, and road width. Light distributions are normally asymmetrical and sharply cutoff in the direction of the oncoming vehicle. Hardware in the various systems includes low pressure sodium vapor lamps with or without supplemental illuminated signs, which are frequently an integral part of the low pressure sodium vapor luminaire, but may also be side mounted. Drivers must yield to pedestrians wishing to cross.

Other systems are in operation on a limited scale in Holland, Cassel, Germany and Brazil.[20]

2.2.2 Effects of Specialized Illumination on Pedestrian Safety

Of the specialized crosswalk illumination systems identified - Detroit, Las Vegas, Toronto, Winnipeg, Copenhagen, Hanover and Switzerland - only the last two have developed detailed "before and after" data that can be used as a measure of the effectiveness of the lighting systems in reducing accidents. Winnipeg, Toronto, Detroit, Copenhagen and Israel, among others, have also reported varying effectiveness results.

A Winnipeg study reported that between 1968 and 1972 the average annual number of reported pedestrian accidents at signalized intersections increased from 0.33 to 0.43 per location; at locations where pedestrian corridors were installed in late 1967 the number of accidents increased from 0.14 to 0.33 per location, while there was no significant change at intersections with neither signal or corridors[15]. Accident frequencies were not normalized by changes in pedestrian volume.

A study of 170 pedestrian crossovers in Toronto revealed in a comparison of 7 months of accident data from 1959 and the same period from 1960 that a 12% increase in pedestrian accidents occurred during a 33% increase in pedestrian volume, resulting in a decrease in accident frequency.[13] More than 75% of the crossovers had no accidents.

Evaluations of the City of Detroit pedestrian safety program were made by traffic experts, paid driver and pedestrian subjects, and drivers and pedestrians in the general traffic stream.[12] Evaluation based on traffic engineering studies reported:

- Significantly greater relative use of crosswalk-especially during daylight-following installation of devices.
- Average speed of free-moving vehicles did not change.
- Significant increase in the number of motorists decelerating and braking at the sites following installation.
- Increased pedestrian use of push button actuated equipment at signalized locations.

Studies of the opinions of test subjects indicated that drivers were generally satisfied with the devices, but pedestrians were not satisfied with the drivers' responses. Drivers did not expect to have to decelerate or stop upon pedestrian actuation of the illumination system, while the expectation of the pedestrian was that the driver should stop (probably due to pedestrian familiarity with push button signal actuation systems), which caused a safety problem.

An evaluation of the statistics for the City of Hanover shows that the supplementary illumination at crosswalks decreased the number of accidents. Although the total number of accidents in Hanover as well as the number of accidents occurring at crosswalks during daylight within the period concerned increased steadily, the number of accidents during nighttime decreased considerably. Table 1 presents these data.

Table 1. Hanover Pedestrian Accident History Before and After Installation of Supplementary Illumination

	Before	After	%Change
Night accidents	51	19	-63
Day accidents	44	51	+14
Night accidents/crossing	0.33	0.12	
Day accidents/crossing	0.29	0.33	
Night fatalities	11	1	-91
Day fatalities	2	7	+250

The Swiss Bureau of Accident Prevention has collected statistics similar to Hanover's for 108 crossings in Switzerland.[19] Table 2 presents the data.

Table 2. Swiss Pedestrian Accident History Before and After Installation of Supplementary Illumination

	Before	After	%Change
Night accidents	34	15	-56
Day accidents	52	60	+15
Night accidents/crossing	0.31	0.14	
Day accidents/crossing	0.36	0.42	

There is a noticeable similarity between the German and Swiss data. The nighttime before and after changes were -63% and -56%, respectively, and the daytime before and after changes were +14% and +15%, respectively,

The before night accidents per crossing were 0.33 and 0.31 for Germany and Switzerland; the after night accidents per crossing were 0.12 and 0.14. Both reductions were in close agreement.* The reduction in night accidents was significant for both Germany and Switzerland.†

2.2.3 Warrants and Design Criteria for Specialized Crosswalk Illumination Systems.

Only a few of the systems described previously actually had warrants which were followed in selecting locations for supplementary illumination, placing luminaires, selecting illumination levels, etc. These systems were in Toronto, Winnipeg, Hanover and Switzerland.

*Analyses of Philadelphia accident data reveal 0.29 accidents per crossing (4 crossings per intersection) for a three-year period. The figures is in excellent agreement with the Hanover "before" figure of 0.33 accidents per crossing for a three-year period. (The Swiss figure is for a mixed before/after period but is also in agreement).

†Chi-square tests, 5% level.

In Toronto the minimum warrants are met if the following three conditions are satisfied:

1. The results of a pedestrian delay study, when plotted on the Graph for Pedestrian Crossover Evaluation (Figure 1), indicate a situation as being within the warranted zone. The term "Pedestrian Difficulty" as used in this graph is defined as a crossing in which the pedestrian is forced to wait longer than ten seconds.

2. There are at least 100 pedestrian crossings for an 8-hour study, except under special conditions such as where a substantial percentage of the pedestrians are senior citizens or school children.

3. The location is more than 700 ft (210m) from adjacent traffic control signals or pedestrian crossovers.

With the minimum warrants met, a pedestrian crossover is warranted upon judicial decision with due recognition of the following conditions:

1. The crossover should not be used on a roadway wider than four lanes.

2. A location at an offset intersection should be avoided.

3. The location should offer good visibility of the pedestrian.

4. A location is unsuitable for a crossover if advertising signs or other objects are overpowering distractions to the motorists.

5. A crossover should not be established where cross traffic or turning movements are excessive.

6. A crossover should not be considered for a road with a speed limit in excess of 40 mph (64 kph).

7. A crossover should not be located where consistent violation of the 30-ft (9.2m) NO STOPPING zone may be expected.

The subsequent paragraphs are excerpts from the Winnipeg warrants.

"The following minimum conditions will be required in order to justify the installation of a regular pedestrian corridor. The numerical values quoted below shall be based on the highest eight-hour period, not necessarily consecutive, in a normal weekday.

"1. A minimum of 300 pedestrians wishing to cross the streets, of which at least 100 will receive benefit from the installation. (Only those pedestrians waiting in excess of ten seconds will be considered as receiving benefit from the corridor).

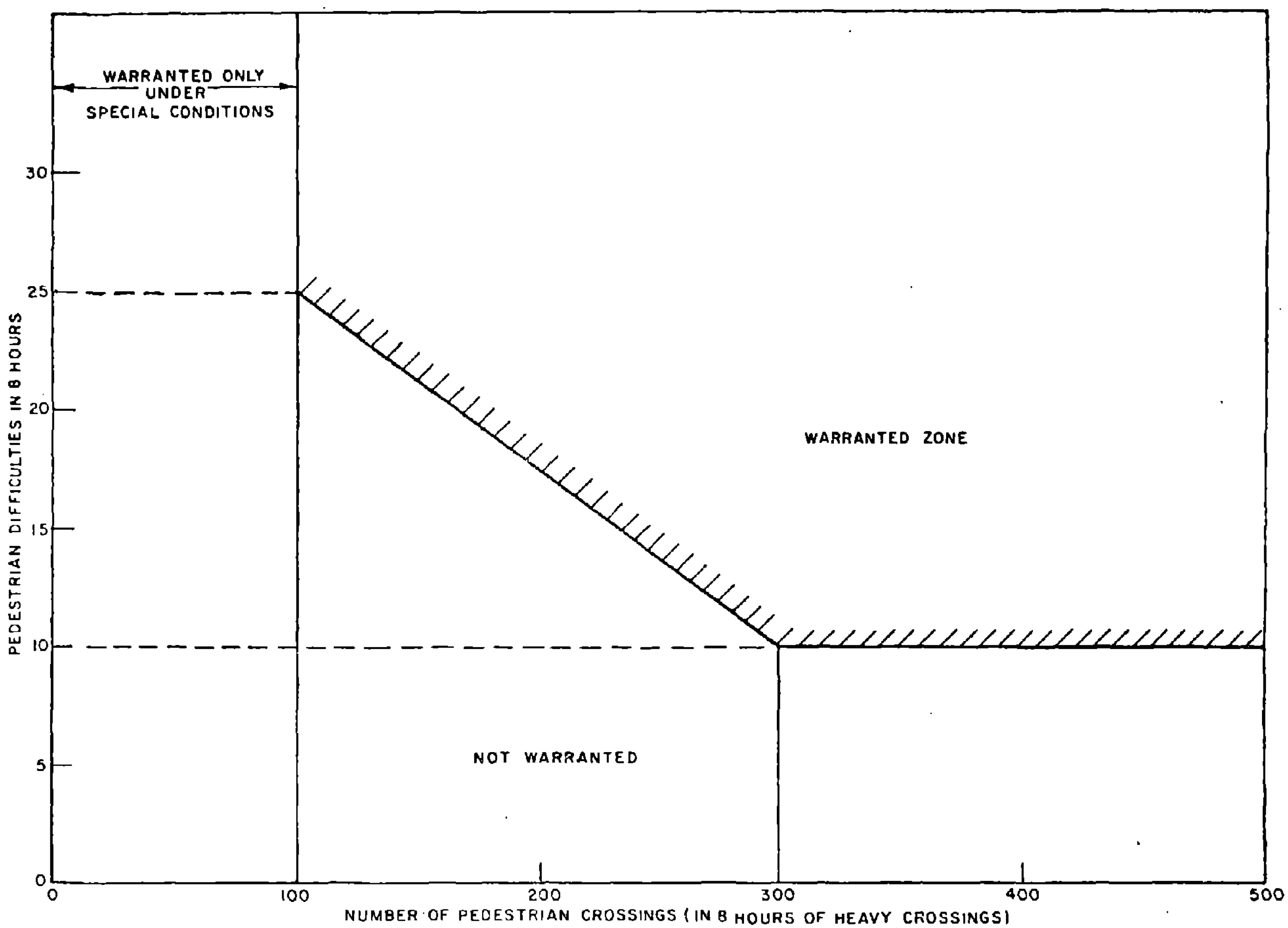

Figure 1. Graph for Pedestrian Crossover Evaluation
(Source Ref. 14)

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"2. If greater than 600 pedestrians are present, the corridor will be justified provided that vehicle volumes in peak hours exceed 200 and further that it does not conflict with any other provisions of the warrants.

"3. If fewer than 300 pedestrians are present, the benefit level must increase proportionately as illustrated in the attached drawings [Figure 2]. As indicated, corridors will not normally be justified if fewer than 200 pedestrians are present and, at this level, 100% of those wishing to cross the highway must receive benefit from the installation.

"4. A mid-block pedestrian crossing shall not be established unless all the requirements for the installation of a corridor are satisfied and the crossing shall then become a pedestrian corridor.

"5. Pedestrian corridors shall not be established less than 700 ft. from an existing pedestrian corridor.

"6. Before approval for a corridor in any jurisdiction is granted, the appropriate traffic authority must give a written undertaking to the Board that all previously marked crosswalks on the road system under their jurisdiction will be eliminated within a time period established by the Board. The only signed or marked crossings shall be at signalized intersections or at pedestrian corridor locations.

"7. Pedestrian corridors should be avoided at locations where heavy turning movements exist or where other traffic conditions would interfere with the safe operation of the corridor.

"8. No corridor shall be established at a location where it is impossible to effectively install control devices."

In addition to the foregoing provisions the city has warrants for special conditions such as school crossings and recreational areas and also recognizes other situations where corridors are to be avoided, including areas with extremely heavy turning movements, limited sight visibility, expressways and interchange ramps, and where other control devices are in use.

The following text has been translated from the German DIN Standard (No. 6753) in use in Hanover. This standard applies to the lighting of all zebra crossings.

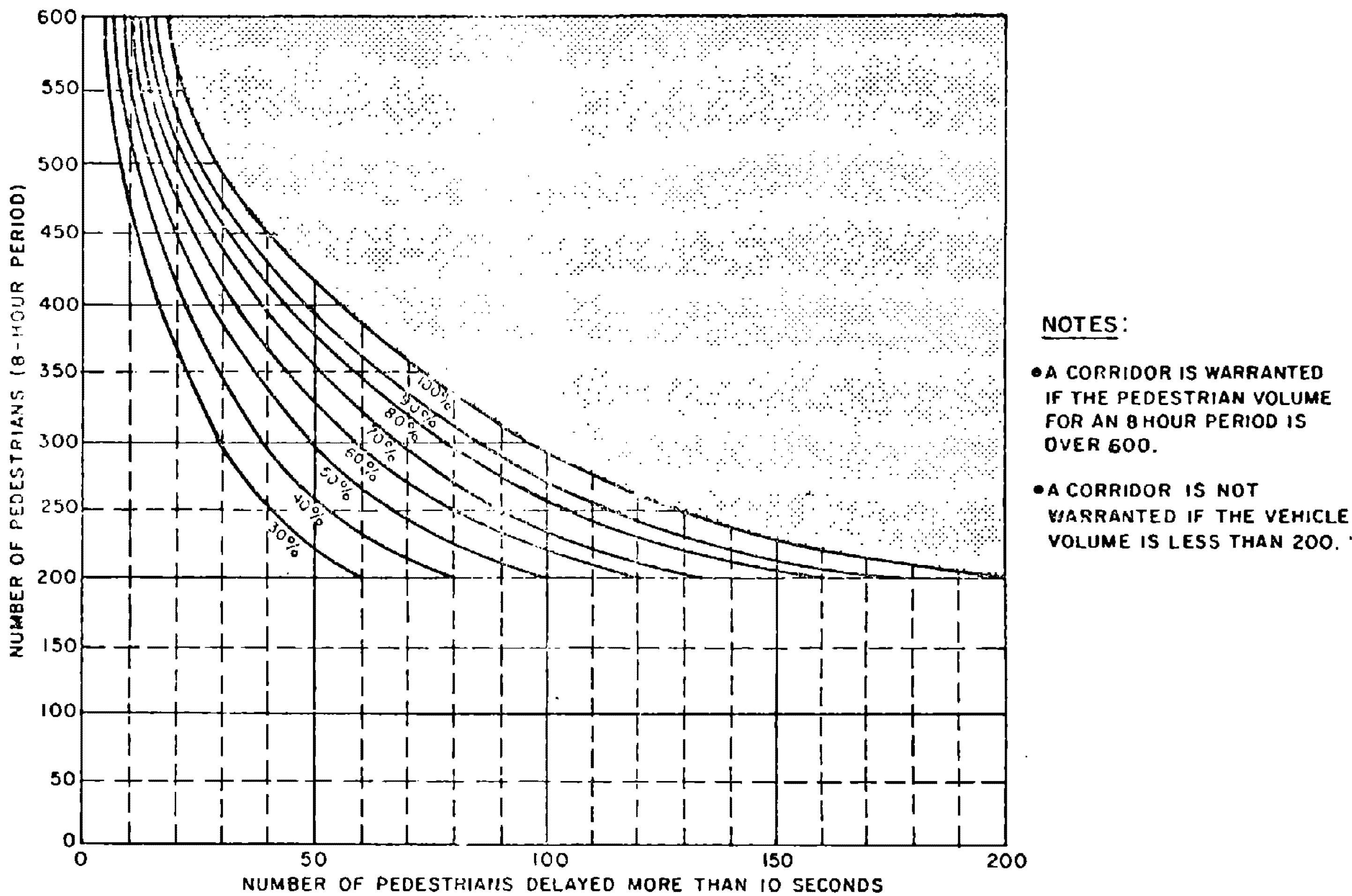

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Figure 2. Warrants for Regular Pedestrian Corridors
(Source Ref. 14)

"1. A supplementary lighting of pedestrian crossings may be unnecessary if the general street lighting provides for a horizontal light density of at least 40 lux on the pedestrian crossing. In addition the waiting zones of both sidewalks must be lit sufficiently, and be visible for the drivers at all times.

"2. If the requirements in paragraph 1 are not satisfied, supplementary lighting of the pedestrian crossing according to Figure 3 and 4 is necessary. In this case, the pedestrian must be illuminated from the traffic direction at high vertical light intensity so that he appears light against a dark background. The mean vertical light intensity, measured at a height of 1 m over street level in the center line of the pedestrian crossing (seen from the vehicle) should be generally five times that of the mean vertical light intensity of the road surface behind him, but not less than 40 lux. The ratio of the light height to the distance from the light to the center line of the pedestrian crossing should be about 1:0.7. This ratio may vary depending on the actual light distribution and the arrangement of the lights.

The distribution of light has to be such that both the pedestrian crossing and the waiting zones on both sidewalks are illuminated. Glare must be avoided (See DIN 5044).

The conspicuousness of the crossing can be increased by a light color different from that of the common street lighting. It is essential, however, that the colors of the traffic signs remain well distinguishable.

"3. If the specific local conditions do not permit the use of supplementary lighting of the pedestrian crossing according to paragraph 2, the pedestrian can be made more visible also by dark-light contrast, i.e., by setting him off dark against a light background. This is possible by a lighting arrangement according to Figure 4. This arrangement makes the' background appear light against the pedestrian. To make the pedestrian crossing more conspicuous without disturbing the continuity of the lighting. The longitudinal distances should be made shorter, or the number of lamps should be increased so that the light intensity is markedly increased in such zones.

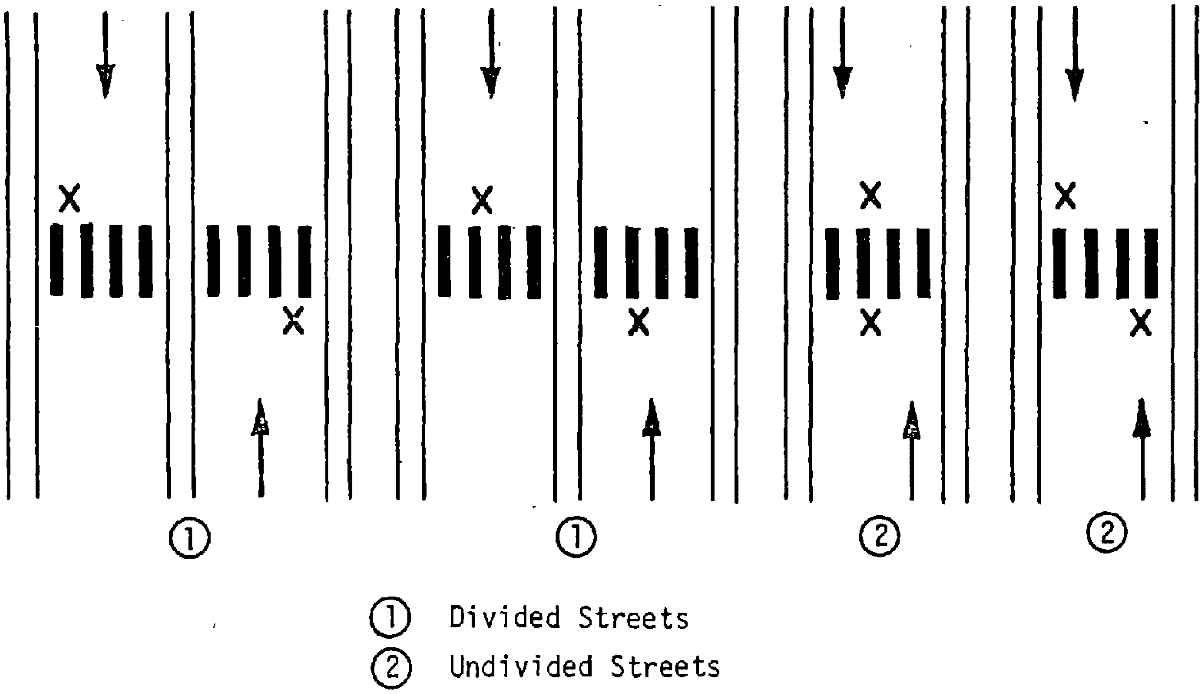

Figure 3. Examples of the Arrangement of Lights for the Supplementary Lighting of Pedestrian Crossings.
(Source Ref. Supplement to DIN 5044)

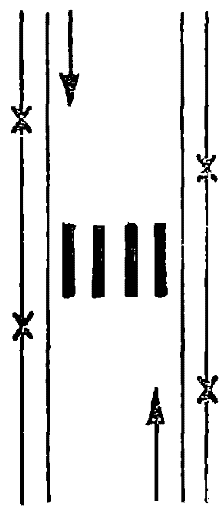

Figure 4. Example of the Arrangement of Lights in Undivided Two-Way Streets, Permitting Improved Visibility of the Pedestrian From the Traffic Direction as a Dark Object Against a Light Background.
(Source Ref. Supplement to DIN 5044)

The warrant for illumination of zebra crossings in Switzerland is similar to the German standard.

Walthert[22] has recommended additional design criteria for the German/Swiss warrants, based upon his research findings. These additions are the following:

1. Lighting Requirements: See Table 3.
2. Light Color: To obtain a warning effect, either low-pressure or high-pressure sodium vapor lamps should be used; high-pressure lamps should be used in streets with low-pressure lighting.
3. Glare Control: The luminaires should be in compliance with the CIE class "cut-off" (I_{80}<30cd/1000 lm). It is absolutely necessary that the pedestrian not be hindered by glare.

> "Cut-off" designation = 25 candlepower (max) (2 1/2%) per 1000 lamp lumens @ vert $\sphericalangle$ = 90° above nadir and 100 candlepower (10%) @ vert $\sphericalangle$ = 80° above nadir by IES standards.
>
> $I_{90°}$ = 25cp/1000 lm
>
> $I_{80°}$ = 100cp/1000 lm

2.3 ACCIDENT ANALYSIS

2.3.1 Objectives and Background

The accident analysis phase of the study was divided into three major subtasks:

1. Determination of pedestrian and driver behavioral patterns from police reports and data from previous studies.

2. Development of computer programs for accident analysis of police reports.

3. Final analysis of data to determine high accident locations and the predominating factors in pedestrian accidents at intersections in Philadelphia.

Table 3. Lighting Requirements According to Walthert

Street Lighting	Illumination of Zebra Crossing		
	Arrangement of Luminaires	Light Intensity	
		Horizontal	Vertical
None	One-half of light source height before the zebra (in direction of traffic flow)		$\bar{E}_V \simeq$ 3.6fc (40 lx) $E_{V_{min}} \geq$ 1.4fc (15 lx)
$L_m <$ 0.4fl (1.5 cd/m^2)	Over the zebra	$\bar{E}_H \simeq$ 18 fc (200 lx) $E_{H_{min}} \geq$ (9fc) (100 lx)	
$L_m >$ 0.4fl (1.5 cd/m^2)	One half of light source height before the zebra (in direction of traffic flow)		$\bar{E}_V \simeq$ 7.2fc (80 lx) $E_{V_{min}} \geq$ 2.7fc (30 lx)

Source: Ref. 22

During the course of our study, the Philadelphia Police Department's Accident Investigation Division (AID) reports were examined, but most of the data were gleaned from standard police reports from January 1, 1970 to December 31, 1972. In addition to these reports, Operations Research, Inc. (ORI) data for Philadelphia were analyzed to determine behavioral patterns associated with pedestrian accidents[1]. Finally, to develop an overall picture of pedestrian accidents in Philadelphia, files from the Streets Department dealing with land use, signalization, curb-to-curb widths, etc., were reviewed and compared to a national data sample, supplied by Biotechnology, Incorporated.

All data gathered from the standard police reports and Streets Department files were coded using the format described in the Phase I, Interim Report[21]. After coding, a computer analysis was performed to determine predominant factors in Philadelphia pedestrian accidents and to isolate high accident locations.

2.3.2 Analysis of Behavioral Patterns from Police Accident Reports and ORI Data.

In general, only limited information on behavior was available from the standard police accident reports and a random sample of approximately 20 AID pedestrian accident reports. These included (1) driver vs pedestrian responsibility for an accident, (2) nature of the violations involved, (3) a *general* description of pedestrian and driver behavior at the time of the accident, (4) the physical condition of the pedestrian and (5) driver and pedestrian age. Information was completely lacking concerning locations and use of pedestrian crosswalks, street lights, pedestrian speed and crossing path, reasons for inattentiveness, color of clothing, etc. For these reasons, it was determined that further examination of these police reports solely to extract behavioral patterns was not warranted.

Very little specific information concerning differences in pedestrian and driver behavioral patterns under daylight vs nighttime lighting conditions could be derived from ORI's Philadelphia pedestrian data. ORI's data were not applicable in our study because of (1) the sparsity of data in most of the classifications, (2) the hybrid classification scheme used by Dunlap and Associates to combine ORI's original data, (3) the tendency for much of the data to be classified as "other," (4) the fact that only about 40% of the accident data was derived from interviews and the remainder was derived from police accident reports, (5) the fact that in some analyses ORI made no distinction between intersection and mid-block accidents, and (6) the small sample size of 292 pedestrian accidents (58 nighttime of which 23 were at intersections).

2.3.3 Data Input

Nighttime intersection pedestrian accidents for the period January 1, 1972 through December 31, 1972, were coded for computer analysis. To compare accident locations, factors, trends, etc., 1972 day intersection pedestrian accidents were also coded using the police reports only. The sample sizes were as follows:

1972 day accidents	816
1972 night accidents	726
1971 night accidents	640
1970 night accidents	804
Total night accidents	2170
Total day accidents	816
Total	2986

Based on available data, city-wide statistics were developed for items such as illumination, widths of streets and percent of time that rain falls. This information was used to normalize our accident factors and to determine which were critical.

2.3.4 Data Analysis - Computer Programs

A series of interrelated computer programs was developed to facilitate an efficient and selective means of reviewing and analyzing night intersection pedestrian accidents. The first of the accident analysis programs utilizes a large number of counters to accumulate aggregate numbers of accidents. These numbers are presented in matrix form on printed output. A second-generation version of this program decodes and prints out the entire accident description as found on the data cards. The net output is a list of decoded accident locations, each containing a complete description of the pedestrian, driver and environmental factors that were present at the time of the accident.

2.3.5 Results - FIRL Data

Fifty-one locations were identified as high accident sites (i.e., three or more night accidents in the 3-year reporting period). These 51 sites were then re-analyzed. Tables 4 and 5 present a comparison of the three classifications of accidents (daylight, 3-year night and 51 locations (night)). Table 5 also shows city-wide data as a comparison.

Table 4. General Accident Data

Source of Data	Number of Intersections	Number of Accidents
City-wide	25,000	4,500 (per year)
1972 Day	586 (excluding night accidents)	816
3-year Night	1,903	2,170
51 Locations (night only)	51	211

Table 5. General Accident Data - Percent of Accident by Condition*

Condition	Source of Data			
	City-Wide	1972 Day	3-Year Night	51 Locations (Night Only)
Traffic Control				
Signals	13	40	53	88
Stop-Sign Intersection	60	13	13	3
No-Control Intersection	27	45	30	7
Unknown	--	2	4	2
Traffic Flow				
One-way	38	--	33.3	16.9
Two-way	55	--	66.7	83.1
Unknown	7	100	--	--
Land Use				
CBD	--	--	1	3
Industrial	--	--	9	4
OBD-Comm.	--	--	43	66
Row Homes	--	--	15	5
Semidetached	--	--	3	0
Single Homes	--	--	5	3
Apartments	--	--	6	5
Parking Lots, Playgrounds, Schools	--	--	18	14
Unknown	100	100	--	--
Street Width (ft)				
Less than 20	23	--	1.4	0
20 to 29	30	--	29.2	7.7
30 to 39	30	--	21.8	13.8
40 to 49	0.5	--	19.3	23.1
50 to 59	9.5	--	8.4	15.4
60 to 69	5	--	14.5	32.3
70 to 79	.5	--	1.3	0
80 and Above	2	--	4.1	7.7
Unknown	--	100	--	--
Pedestrian Location				
First-half Crossing				
Approach	Data	28	22	20
Exit	Not	23	24	30
Total		51	46	50
Second-half Crossing	Available			
Approach		14	12	12
Exit		14	15	17
Total		28	27	29
Unknown		21	27	21
Vehicle Movement				
Right-turn approach		1	1	1
Thru Approach		44	37	35
Left-turn Approach	Data	1	2	1
Total Approach	Not	46	40	37
Right-turn Exit	Available	5	4	5
Thru Exit		29	30	35
Left-turn Exit		8	10	10
Total Exit		42	44	50
Unknown		12	16	13
Weather (Percent of time)†				
Clear (no precipitation)	69.1	66.3	72.7	72.0
Rain/Drizzle	8.9	12.8	23.4	24.6
Freezing Rain	0.2	--	--	--
Snow/Sleet	1.9	0.4	1.7	1.9
Fog‡	19.4	0.1	0.3	0.5

*1972 night data only have been used to determine percent of accidents by street width, traffic flow, and land use.

†City-wide data from Naval Weather Service Command, Willow Grove, Pa.

‡NWSC has a different definition of fog than that normally used by police.

Several interesting conclusions emerge from these comparisons:

1. Two-way streets appear to be more hazardous than one-way streets. This statement agrees with the results of several other studies.[1,2]

2. The proportion of accidents occurring during rain is greater than the proportion of time in which rain was recorded. Several researchers have drawn the same conclusion.[3,4,6]

3. Most nighttime accidents occur in commercial areas.

4. No conclusions can be drawn about street width since the distribution of accidents at high accident locations was seriously affected by Broad Street, which is 60 to 90 ft wide. Broad Street is a heavily travelled (by both pedestrian and vehicles) commercial street, and the city-wide street-width data could not be normalized by volume.

5. Pedestrians are more prone to have an accident while in the first half of the street crossing. The location of the pedestrian does not appear to vary significantly for daytime or nighttime collisions.

Table 6 summarizes a "typical" nighttime intersection accident, a "typical" daytime accident, and a "typical" accident at a high nighttime accident location.

2.3.6 Results - FIRL Data Compared with Biotechnology, Inc. Data

A large amount of pedestrian accident data, derived primarily from recent police accident reports on file with the Philadelphia Police Department were compared with similar but independently collected data derived from police records in other metropolitan areas in an attempt to demonstrate a satisfactory level of representativeness in the Philadelphia data. The compared pedestrian accident data was obtained from Biotechnology, Inc., of Falls Church, Virigina. These data include a

Table 6. Typical Pedestrian Accident Summary

Variable	3-year Night Data	1972 Day Data	High-Accident-Location Data (night only)
1. Day of week	Friday or Saturday	Thursday or Friday	Friday or Saturday
2. Time of day	Between 6 and 8 p.m.	Between 3 and 4 p.m.	Between 5 and 8 p.m.
3. Age of driver	25-34	25-34	25-34
4. Age of pedestrian	5-9	5-9	20-24 or 35-44
5. Location of pedestrian	First half of crossing	First half of crossing	First half of crossing
6. Vehicle direction and location	Through vehicle at approach to intersection	Through vehicle at approach to intersection	Through vehicle at approach to or exit from intersection
7. Driver action	Not stated	Not stated	Not stated
8. Pedestrian action	Crossing with signal	Crossing with no signal	Crossing against signal
9. Weather and road surface	Clear and dry	Clear and dry	Clear and dry
10. Driver condition	Normal	Normal	Normal
11. Pedestrian condition	Normal	Normal	Normal
12. Parking	Not a factor	Not a factor	Not a factor
13. Intersection	Signalized, crosswalk painting unknown	No control, crosswalk painting unknown	Signalized, crosswalk painting unknown
14. Land use	Commercial	Unknown	Commercial
15. Traffic flow	Two-way	Unknown	Two-way
16. Width of street	20'-29'	Unknown	60'-69' or 40'-49'
17. Speed limit	25 mph	Unknown	25 mph
18. Volume of accident street	0-2.5K or 10-20K	Unknown	10-20K

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compilation of the key factors involved in the pedestrian accidents in five major United States cities.

The following 16 principal accident factors were found to be of sufficient similarity to justify comparisons between the FIRL and Bio-technology, Inc., data. Some of these comparisons were very straight-forward; others required deletions and combinations of sub-categories.

(1) Day of week on which accident occurred
(2) Time of day at which accident occurred
(3) Age of pedestrian accident victim
(4) Age of driver striking pedestrian
(5) Type of roadway at scene of accident
(6) Width of accident street
(7) Predominant type of land use surrounding accident location
(8) Weather conditions at time of accident
(9) Road surface conditions at time of accident
(10) Type of traffic control device in use at accident scene
(11) Direction of vehicle movement at time of accident
(12) Driver parking maneuver as an accident causative factor
(13) Primary pedestrian action just prior to accident
(14) Primary driver action just prior to accident
(15) Primary pedestrian physical condition
(16) Primary driver physical conditon

In general, the order in which these factors are listed indicates the degree of similarity between the sets of sub-categories within each factor. Thus, the higher up the list a factor appears, the more confidence one can place in it.

As a further check on the FIRL data, the 16 comparisons were made for both daylight and nighttime data (since FIRL was primarily interested in nighttime pedestrian accidents). Also, the nighttime comparisons probably have a slightly higher degree of validity than the daytime data, since the large sample sizes were for night accidents. Examination of the distributions of percentages under the sub-categories within each of the 16 major factors indicates that half of the comparisons had very similar results. These were:

Number	Factor
(1)	Day of week on which accident occurred
(2)	Time of day at which accident occurred
(3)	Age of pedestrian accident victim

Number	Factor
(4)	Age of driver striking pedestrian
(8)	Weather conditions at time of accident
(9)	Road surface conditions at time of accident
(11)	Direction of vehicle movement at time of accident
(13)	Primary pedestrian action just prior to accident

The remaining eight factors were found to have at least one major dissimilar sub-category. The degree of dissimilarity varied considerably across factors, depending largely on the degree of similarity between the original (un-altered) sub-categories. The results of these comparisons revealed the following discrepancies in accident frequency between FIRL and Biotechnology data shown in Table 7.

Table 7. Differences in Accident Frequencies Reported by FIRL and Biotechnology Inc.

Number	Factor	Subcategory	Discrepancy in Percent of Accidents Found by FIRL
(5)	Type of roadway	One-way	FIRL 13% more
(6)	Width of accident street	Three-lane	FIRL 15% more
		four-lane	FIRL 12% fewer
(7)	Predominant land use	Residential	FIRL 16% fewer
		Commercial	FIRL 5% fewer
		School	FIRL 15% more
(10)	Traffic control device	Signalized intersections	FIRL 26% more
		Signed intersections	FIRL 5% more
		No signals present	FIRL 31% fewer
(12)	Driver parking as factor	Parking involved in accident	FIRL 14% more
(14)	Primary driver action	Improper driving	FIRL 15% more
		Speed too fast	FIRL 10% more
		Failed to yield ROW or turning maneuver involved	FIRL 35% more
		Other	FIRL 23% fewer
(15)	Primary pedestrian condition	Normal appearance	FIRL 16% fewer
		Other	FIRL 17% more
(16)	Primary driver Condition	Normal appearance	FIRL 14% fewer
		Other	FIRL 9% more

With the possible exception of variable (12), "parking as a factor," all discrepancies may easily be accounted for on the basis of incomparable categorization schemes. The reason for the difference in the parking variable is unknown at this time.

In conclusion, FIRL believes that the pedestrian accident data derived from the Philadelphia Police Department records is probably representative of urban pedestrian accidents in the United States today.

Detailed breakdowns of the 16 comparisons can be found in the Phase I, Interim Report, Appendix B[21].

2.3.7 Illumination Data

City-wide route illumination data were not available. An approximation of design illumination based on street width and functional classification of city streets was obtained and is presented in Table 8.

Table 8. City Route Illumination Data

Footcandles (lux)	% City-Wide	% CBD
<0.3 (<3.2)	0	0
0.3 (3.2)	23	23
0.6 (6.4)	30	23
0.9 (9.7)	10	9
1.2 (12.9)	3.5	8
3-4 (32-43)	3.5	37

Actual intersection illumination data were obtained for specific sites during the observational experiments and are discussed subsequently.

2.4 OBSERVATIONAL EXPERIMENTS

A series of observational experiments was conducted at crosswalks with both high accident and low or no accident history to determine the frequency of occurrence of the specific factors that were found to be related to pedestrian accidents in the review of literature and the analysis of accident data. This was done by observing non-accident involved pedestrian crossings according to the experimental assumption that certain of the factors related to accidents would be more prevalent for all crossings at the high accident sites, and similarly, factors related to safer crossings would be more prevalent at low accident sites. These factors included: pedestrian and driver behavior; physical descriptors of pedestrians, vehicles and the environment; traffic and geometric factors; and illumination factors. These factors were then compared under the following conditions.

1. Sites with high and low accident potential.
2. Day and night conditions.
3. Wet and dry road conditions.
4. Sites with signalized and unsignalized crossings.

The observational experiments were conducted and analyzed on a "before-after" basis. That is, observations and analyses were performed at sites where conditions were unchanged from the time when the accidents occurred ("before"). The experiments were later conducted following the implementation of special crosswalk illumination ("after").

2.4.1 Experimental Design

Observational experiments of pedestrian crossing behavior and pedestrian/vehicular interaction were specifically designed to determine how the behavior of pedestrians involved in accidents differs from the behavior of pedestrians who are not involved in accidents. The basic experimental postulate was that by observing and recording measures of pedestrian and driver behavior, we could discern generalized differences at low accident history or "safe" sites (those with no or infrequent night pedestrian accidents) and high accident history or "unsafe" sites (those with three or more night pedestrian accidents in a 3-year period).

The definition of observational measures or variables sought to identify the relevant descriptors of the pedestrian's crossing behavior at intersections, his interaction with vehicles, and his immediate environment.

The pedestrian variables included descriptors of intersection origin and destination, walking speed, exposure time and gap, volume and density, search behavior and search time, measures of decisiveness, action taken, motivation, distraction, erratic or inappropriate behavior and crossing location as "active" measures. "Passive" measures included pedestrian age, physical condition, physical impediment, visual obstruction, apparent clothing brightness and the presence of an approaching vehicle within 500 ft. A combined measure "conflict potential" was also used as one of the twenty-nine measures.

The driver variables included measures of vehicular type, condition, speed, density, volume, direction and location, and measures of driver actions, motivation, distraction, performance, visual obstructions and physical characteristics. Seventeen driver variables were identified.

Two classifications of driver observations were conducted. The first, observations of potentially conflicting vehicles, was designed to relate specifically to individually observed pedestrian crossings. The second, observations of free or nonconflicting drivers, collected the same kinds of information to provide a basis for comparison and analysis of purely driver and purely pedestrian-sensitive variables.

Non-constant environmental conditions were described by seventeen variables dealing with illumination, weather, pavement condition, and background illumination and activity.

Constant environmental variables provided information describing main street and cross street width, parking condition, traffic flow direction, intersection geometry, crosswalk paint, paving conditions, and neighborhood description.

Constant traffic condition variables indicated type of traffic control device, timing of vehicular and pedestrian signals if applicable, and speed limit on the main and cross streets. Visual obstructions were considered in the identification of type of obstruction, the estimated percent field of vision blocked, and the adequacy of sight distance for all vehicular movements that coincided with the crosswalk location. The estimated average free speed of vehicles passing the crosswalk was recorded as observed.

The formalized experimental design was one in which observational data were aggregated by study population, wet versus dry weather, high versus low accident history, day versus night conditions, and signalized versus unsignalized intersections. The frequency distribution of each variable of one population was compared to the corresponding frequency distribution of each variable in the comparison population. The generalized null hypothesis was that there is no difference between pedestrian behavior, as measured by a particular variable, from one population to another, or that the samples come from the same population.

An experimental methodology was developed to enable the collection of data specified in the experimental design. The generalized procedure was determined in a two-stage pilot study. Equipment, study team composition, data collection forms, and data processing techniques evolved during the pilot studies.

Pilot studies were conducted at the intersections of 20th and Chestnut, 8th and Chestnut and 10th and Chestnut Streets in Center City Philadelphia, following several hours of pedestrian and driver observations at scattered CBD intersections. It was determined that behavioral data could be satisfactorily described as coded while traffic volume information could be recorded on a separate form.

A team of three people was formed to collect observational data. One member was responsible for pedestrian observations, another for driver observations, and the third member maintained the traffic count. All three participated in gathering environmental information. The data from each observation period was consolidated and traffic count information was added to the coding forms, which were then keypunched on 80-column IBM type data cards.

2.4.2 Site Selection

Evaluation of accident reports indicated a wide variation in accident location and accident history. The selection of study sites was based on accident history, metropolitan area location, accident location at the intersection, availability of control locations similar enough to provide comparison, ease of data collection and safety of the data collection crew. Table 9 is a summary of the study sites, characteristics and conditions for the "before" experiments.

2.4.3 Data Collection

Data collection for the "before" behavioral observations was continued from October 1973 through February 1974. Approximately 3,200 pedestrian crossing observations were recorded during that period.

Non-conflicting driver observations were conducted at one signalized location (Kensington and Torresdale) and at all non-signalized locations.

2.4.4 Data Analysis

Two computer programs were developed to assist in the analysis of the "before" observational study data. The first program provided a summary matrix printout of frequency counts and percentages of each category of each pedestrian and driver observation, the second performed a chi-square analysis of variance on each variable of compared data sets.

The statistical analysis was designed to facilitate the examination of all behavioral variables so that any which appeared to be insignificant could be removed from further analysis.

The chi-square test for non-parametric data was the basis for primary statistical analysis. Study data for individual study sites and

Table 9. Chi-Square Analyses

Run No.	Location	Basic Conditions	Compared Samples
1	All signalized	Day+Night, Wet+Dry	High vs Control
2	All signalized	Day+Night, High+Control	Dry vs Wet
3	All non-signalized	Day+Night, Dry	High vs Control
4	Castor & Fanshawe + Paul & Torresdale, All non-signalized		All signalized vs non-signalized
5	Castor & Fanshawe + Paul & Torresdale, All signalized	All	Signalized vs non-signalized
6	All signalized and non-signalized	All	Signalized vs non-signalized
7	All signalized and non-signalized	Wet+Dry, High+Control	Dark vs Light
8	All signalized	High+Control, Wet+Dry	Dark vs Light
9	All non-signalized	High+Control, Dry	Dark vs Light
10	13th & Market - North & West combined	High, Night	Dry vs Wet
11	13th & Market - North & West combined	High, Dry	Day vs Night
12	13th & Market - Northwest, 12th & Market-West & South	Night, Dry	High vs Control
13	13th & Market - West, 12th & Market - West	Night, Dry	High vs Control
14	13th & Market - North, 12th & Market-South	Night, Dry	High vs Control
15	13th & Market - West	High, Dry	Day vs Night
16	13th & Market - North	High, Dry	Day vs Night
17	5th & Lindley - North, South	Night, Dry	High vs Control
18	5th & Lindley - North	High, Dry	Day vs Night
19	5th & Lindley - North	Night, High	Dry vs Wet
20	Kensington & Torresdale - East, West	Night, Dry	High vs Control
21	Germantown & Chelten - West, East	Night, Dry	High vs Control
22	19th & Moyamensing - North, South	Dark, Dry	High vs Control
23	J & Erie - East, West	Dark, Dry	High vs Control
24	Paul & Torresdale - South, North	Dark, Dry	High vs Control
25	Paul & Torresdale - South	High, Dry	AM Dark vs PM Dark
26	Paul & Torresdale - South	High, Dry	AM+PM Dark vs Light
27	Castor & Fanshawe - South, North	Dark, Dry	High vs Control
28	Castor & Fanshawe - South	High, Dry	AM Dark vs PM Dark
29	Castor & Fanshawe - South	High, Dry	AM+PM Dark vs Light
30	All non-conflict drivers	High, Control, Dry	Signalized vs non-signalized
31	All non-conflict drivers	Dark, Dry, High, Control	Signalized vs non-signalized
32	All non-conflict drivers	Light, Dry, High, Control	Conflict vs non-conflict
33	19th & Moyamensing - combined	Light, Dry, High, Control	Conflict vs non-conflict
34	19th & Moyamensing - combined	Dark, Dry, High, Control	Conflict vs non-conflict
35	Frankford & Montgomery - combined	Dark, Dry, High, Control	Conflict vs non-conflict
36	Frankford & Montgomery - combined	Light, Dry, High, Control	Conflict vs non-conflict
37	Kensington & Torresdale - West	Dark, Dry, Control	Conflict vs non-conflict
38	Paul & Torresdale - South, combined	Dark, Dry, High, Control	Conflict vs non-conflict
39	5th & Ruscomb - combined	Dark, Dry, High, Control	Conflict vs non-conflict
40	Castor & Fanshawe - combined	Light, Dry, High, Control	Conflict vs non-conflict
41	Caster & Fanshawe - combined	Dark, Dry, High, Control	Conflict vs non-conflict
42	J & Erie - East, combined	Dark, Dry, High, Control	Conflict vs non-conflict
43	5th & Ruscomb - combined	Light, Dry, High, Control	Conflict vs non-conflict

conditions were grouped into samples based on basic conditions of signalized or unsignalized sites. Then, analyses were performed on the high-accident-history sites vs control sites, dry vs wet conditions, and day vs night conditions. Further, all signalized data were compared to all non-signalized data for night-day conditions, and all signalized and unsignalized data were combined and analyzed for day vs night conditions. In similar tests, different sets of conditions at each intersection were compared to check for behavioral differences, assuming the same population with the same geometric conditions. Table 9 lists the analyses that were performed.

2.4.5 Results of "Before" Data Analysis

The non-parametric analysis of variance using a chi-square test of the hypothesis that the samples compared come from the same or similar populations (i.e., no difference) indicated the significance of several dependent behavioral variables. Table 10 is a summary of the significant variables.

The most meaningful results were found in the comparison of high accident history versus control locations. Twenty-five of the 41 behavioral variables were found to be sensitive at alpha = 0.01 to the behavioral differences at high vs control sites. Of those twenty-five variables twenty-three (13 pedestrian and 10 driver) were judged to be appropriate for further analysis in more complex statistical tests. The 13 pedestrian variables were:

- approach direction
- exit direction
- density of arrival
- approach search behavior
- first half of crossing search behavior
- second half of crossing search behavior
- decisiveness
- action taken in crossing
- motivation
- distraction
- crossing location
- erratic or inappropriate behavior
- brightness of significant portion of the pedestrian

Table 10. Significant Variables

	#	VARIABLE	SIGNALIZED HIGH VS CONTROL	NON-SIGNALIZED HIGH VS CONTROL	SIGNALIZED DRY VS WET	SIGNALIZED AND NON-SIGNALIZED DAY VS NIGHT	SIGNALIZED DAY VS NIGHT	NON-SIGNALIZED DAY VS NIGHT	SIGNALIZED VS NON-SIGNALIZED
PEDESTRIAN VARIABLES	1	CONFLICT POTENTIAL	●			X		●	●
	2	APPROACH DIRECTION	●	X		●	X	●	●
	3	EXIT DIRECTION	●			●	●		●
	4	APPROACH WALKING SPEED			●	●	X	●	●
	5	1st 1/2 SPEED	●		●		●	●	●
	6	2nd 1/2 SPEED	●		●	●	●	X	●
	7	ARRIVAL DENSITY	●		X	●	●		●
	8	APPROACH SEARCH	●		●	●	●	●	●
	9	APPROACH SEARCH TIME	●			●	●	●	●
	10	1st 1/2 SEARCH	●			●	●	●	●
	11	1st 1/2 SEARCH TIME	●		●		X	●	●
	12	2nd 1/2 SEARCH	●				●		●
	13	2nd 1/2 SEARCH TIME	●		●	●	●		●
	14	DECISION TYPE		●					X
	15	ACTION TAKEN	●			●	●	●	●
	16	PEDESTRIAN AGE				●	●	●	●
	17	PHYSICAL CONDITION				●	X		X
	18	MOTIVATION			●	X			
	19	DISTRACTION			●		●		●
	20	CROSSING LOCATION	●	●			●		●
	21	ERRATIC-INAPPROPRIATE BEHAVIOR	●		●	●	●	●	●
	22	IMPEDIMENT	●			●	●	X	
	23	VISUAL OBSTRUCTION		●		●	X	●	●
	24	CLOTHING BRIGHTNESS	●			●	●	X	X
	25	APPROACH VEHICLE IN 500 FT.	●			●		●	●
DRIVER VARIABLES	26	APPROACH SPEED				●			●
	27	ARRIVAL DENSITY	●		●	●	●		●
	28	VEHICLE DIRECTION	●		●	●	●		●
	29	APPROACH LOCATION				●			●
	30	DRIVER ACTION	X						
	31	TRAFFIC CONTROL DEVICE	●					X	X
	32	DRIVER AGE	●		●	●	●	●	
	33	DISTRACTION			●				
	34	MOTIVATION							
	35	ACTION LEGALITY							
	36	APPROACH LANE USE							
	37	VEHICLE TYPE			X	X	●		
	38	VEHICLE LIGHTS	●	X	●	●	●	●	●
	39	VISUAL OBSTRUCTION	●			●	●	X	
	40	WINDSHIELD CONDITION	●		●				
	41	DRIVER PHYSICAL CONDITION						X	

● SIGNIFICANT at $\alpha = 0.01$
X SIGNIFICANT at $\alpha = 0.05$

The ten driver variables were:

- approach speed
- density of arrival
- vehicle direction
- vehicle approach location
- driver age
- reliance on traffic control device
- vehicle type
- vehicle lights
- presence of visual obstruction
- windshield condition

The precise definitions of these variables are presented in the Phase I Interim Report[21].

The results of the observational experiments, combined with the findings of the accident analyses, literature review and state-of-the-art review, constituted the input to the first formalization of those characteristics that would be desirable for a specially designed crosswalk illumination system. It was postulated that a special illumination system should include as many of the following qualities as possible:

1. Provide advance warning to drivers that a hazardous pedestrian crossing was located ahead. This may serve to reduce the consequences of conflict between pedestrians and vehicles.
2. Produce an illuminated crossing path that includes the sidewalk or street sections that constitute the pedestrian's approach and exit.
3. Provide an improvement in visibility that will enable the driver to respond to the presence of pedestrians just entering the crosswalk to reduce dart-out type accidents and accidents involving intoxicated pedestrians or children playing in street.
4. Provide illumination that will not distract the pedestrian, nor induce a false sense of security in the crossing so that signal indications are disregarded.
5. Provide illumination that will not produce a glare source for motorists, nor create a condition in which the difficulties experienced by motorists in seeing at night are compounded.

It was determined that the comparative analysis of "before" data using Chi Square statistical methods could not provide a basis for generalizations regarding the reasons for behavioral differences at different crosswalks, and their relationship to lighting and safety. A factor analysis, which can relate many behavioral variables to form patterns, and a multivariate analysis of variance (MANOVA), were used for complete analysis of the "before" data.

2.4.6 Factor Analysis of "Before" Data

The factor analysis identified five principal factors which were each composed of weighted components of the thirteen pedestrian and/or ten driver dependent variables. Only the components that contributed most heavily to each factor were considered for further analysis in the MANOVA, and are listed in Table 11.

Table 11. Principal Factors and Components

FACTOR	COMPONENTS
1. Search Behavior	a. approach crossing search
	b. 1st half crossing search
	c. 2nd half crossing search
2. Crossing Path	a. approach path
	b. exit path
3. Concentration	a. motivation
	b. distraction
	c. crossing location
4. Erratic-Inappropriate Behavior (one component)	
5. Apparent Clothing Brightness (one component)	

The factor which was identified as "Search Behavior" was composed of the original observational variables "Approach crossing search", "1st half crossing search", and "2nd half crossing search". Each of these variables provided a measure of whether or not the pedestrian was giving attention to appropriate environmental stimuli, such as signal indications, vehicular traffic, or the crosswalk path ahead, for each portion of the crossing. The "Search Behavior" factor reflected the combined effects of these three variables on the pedestrian's searching behavior exhibited in each full crossing.

The factor identified as "Crossing Path" was composed of the observational variables "approach path" and "exit path". Approach path indicated the direction from which the pedestrian was coming (right or left turn from another crosswalk or sidewalk, or straight ahead from the sidewalk) and similarly for exit path, the direction that the pedestrian chose upon completing the crossing.

The factor called "Concentration," composed of the original observational variables "motivation" and "distraction", expressed the strength of external stimuli which tended to compete for pedestrian attention to more appropriate attentional demands. Such competing forces as distraction by loud noises or other pedestrians in a platooned arrival, or motivation to catch a bus were commonly observed.

"Erratic - Inappropriate Behavior" was a factor contributed to most strongly by the observational variable of the same name. It indicated the presence of pedestrian actions that were either in defiance of or oblivious to general safe crossing behavior. Drunken staggering or horseplay are examples of erratic or inappropriate behavior.

"Apparent Clothing Brightness" was another factor contributed to most heavily by the single pedestrian observational variable of the same name. It expresses the observer's perception of the brightness of a significant portion of the pedestrian (e.g., a coat, trousers, large package).

It was found that there were no significant independent driver factors.

2.4.7 Results of MANOVA of "Before" Data

A four way (16 cell) analysis of variance was used for the MANOVA as follows:

high accident history	X	with conflict	X	signalized	X	day
low accident history		without conflict		non-signalized		dark

Using this design a pooled group of data was formed for each of the sixteen cells which were then compared in statistical tests for differences between cells. These differences (called effects in statistical terminology) were then interpreted for their relationship to pedestrian safety.

This analysis indicated several important relationships between pedestrian behavior, accident history, light and conflict. Perceived clothing brightness was nearly always darker at high accident locations, as was the tendency to cross outside of a crosswalk or cut a crosswalk corner. Further, erratic or inappropriate crossing behavior was more likely to occur in general during darkness, at high accident locations, and in conflict situations. This suggested that the presence of pedestrian crosswalk illumination may have an effect on these variables, and could be tested for significance in the analysis of data collected after the implementation of special crosswalk illumination.

2.4.8 Implementation of Experimental Special Crosswalk Illumination

Based on the results of Phase I, the most promising illumination systems were identified as those used in Switzerland (various designs), Hanover, (Hellux/Osram), Winnipeg (Marv-Eon) and Copenhagen (Phillips).

After a review of recommendations and warrants pertaining to crosswalk illumination, research pertaining to the design of crosswalk illumination, and the availability of the hardware, the following systems were dropped from consideration.

Hanover - not available in U.S.
Copenhagen - does not provide a contrasting color
Winnipeg - insufficient intensity of illumination.

The Swiss System met all the recommendations (Walthert)[22] and warrants (German, Swiss)[22] and one of the fixtures was available from a local agent, North American Phillips.

The source of illumination is a 90 watt low pressure sodium (LPS) lamp, hence it provides a contrasting color (yellow) on streets illuminated by either incandescent, fluorescent, mercury or high pressure sodium (HPS). A sample fixture is illustrated in Figure 5. This fixture is available with either a symmetric or asymmetric light distribution.

A sample asymmetric fixture was obtained from N.A. Phillips and installed in Philadelphia on an existing pole using a 12 foot davit arm.

Illumination and luminance measurements were taken at 21 points on the crosswalk. The improvement in horizontal illumination (Hfc) was above 12:1; target luminance (L_t) about 10:1; vertical illumination on the target (Vfc) 10:1 (calculated from L_t); minimum horizontal illumination about 6:1 and minimum vertical illumination about 8:1.

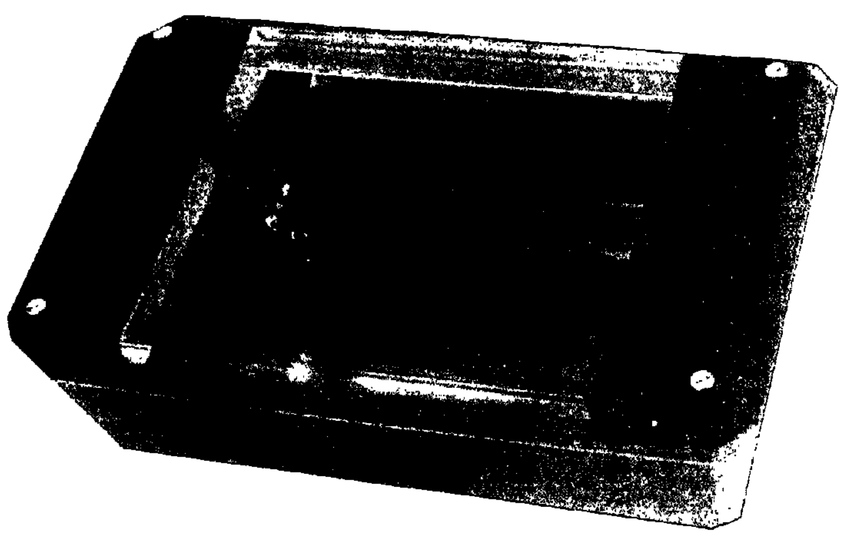

Figure 5. Picture of Crosswalk Fixture

The pilot system met the design criteria for average illumination intensity, maximum intensity, contrasting color and glare prevention, established by Walthert. German and Swiss standards for uniformity were also met.

Seven of the high accident sites identified in Phase I research were selected for supplemental illumination. These are illustrated in Table 12.

Table 12. Crosswalks Selected for Supplemental Illumination

Location/Crosswalk	Characteristic	Signalized/ Non Signalized	Geometry
Paul & Torresdale/Paul - south	Residential	N	2 directions/2 lanes
5th & Ruscomb/5th - north	Residential	N	2 directions/4 lanes (including 2 parking)
5th & Lindley/5th - north	Residential	S	2 directions/4 lanes (Including 2 parking)
5th & Cayuga/5th - north*	Residential	S	2 directions/4 lanes (inlcuding 2 parking)
A & Allegheny/Allegheny-- east*	Residential	S	2 directions/4 lanes plus 2 parking lanes
Kensington & Allegheny/ Allegheny - west*	OBD	S	2 directions/4 lanes plus 2 parking lanes
Kensington & Torresdale/ Torresdale - east	OBD	S	2 directions/4 lanes plus 2 parking lanes

*For these three sites, the before observational experiments were conducted during Phase II, and were not included in original twelve sites. Acually four sites were selected from the original twelve and three additional were selected from the original list of 51 sites.

A supplemental illumination system was designed for each of the seven crosswalks in Table 12. At Paul and Torresdale one symmetric fixture was employed. At the remaining 6 sites, 2 or 4 asymmetric fixtures were used. Table 13 summarizes the system descriptions.

Table 13. System Descriptions

Location	No. of Fixtures	Light Distribution	Mounting Height	Description
Paul & Torresdale	1	Symmetric	16 ft(5m)	Span wire mounted
5th & Ruscomb	2	Asymmetric	16 ft(5m)	From arms on poles
5th & Lindley	2	Asymmetric	16 ft(5m)	From arms on poles
5th & Cayuga	2	Asymmetric	16 ft(5m)	From arms on poles
A & Allegheny	2	Asymmetric	16 ft(5m)	From arms on poles
Kensington & Allegheny	4	Asymmetric	16 ft(5m)	From arms on Subway Elevated structure
Kensington & Allegheny	4	Asymmetric	16 ft(5m)	From arms on Subway Elevated structure

Each system (crosswalk) is controlled by a photocell which energizes the circuit at sundown and turns it off at sunrise. In addition there are control boxes at each crosswalk which allowed the experimenter to override the photocell control. At sites with asymmetric fixtures, the arrangement is designed to preclude any glare for all oncoming cars. This is illustrated in Figure 6. For the one symmetric installation, the fixture is suspended over the center of the crosswalk.

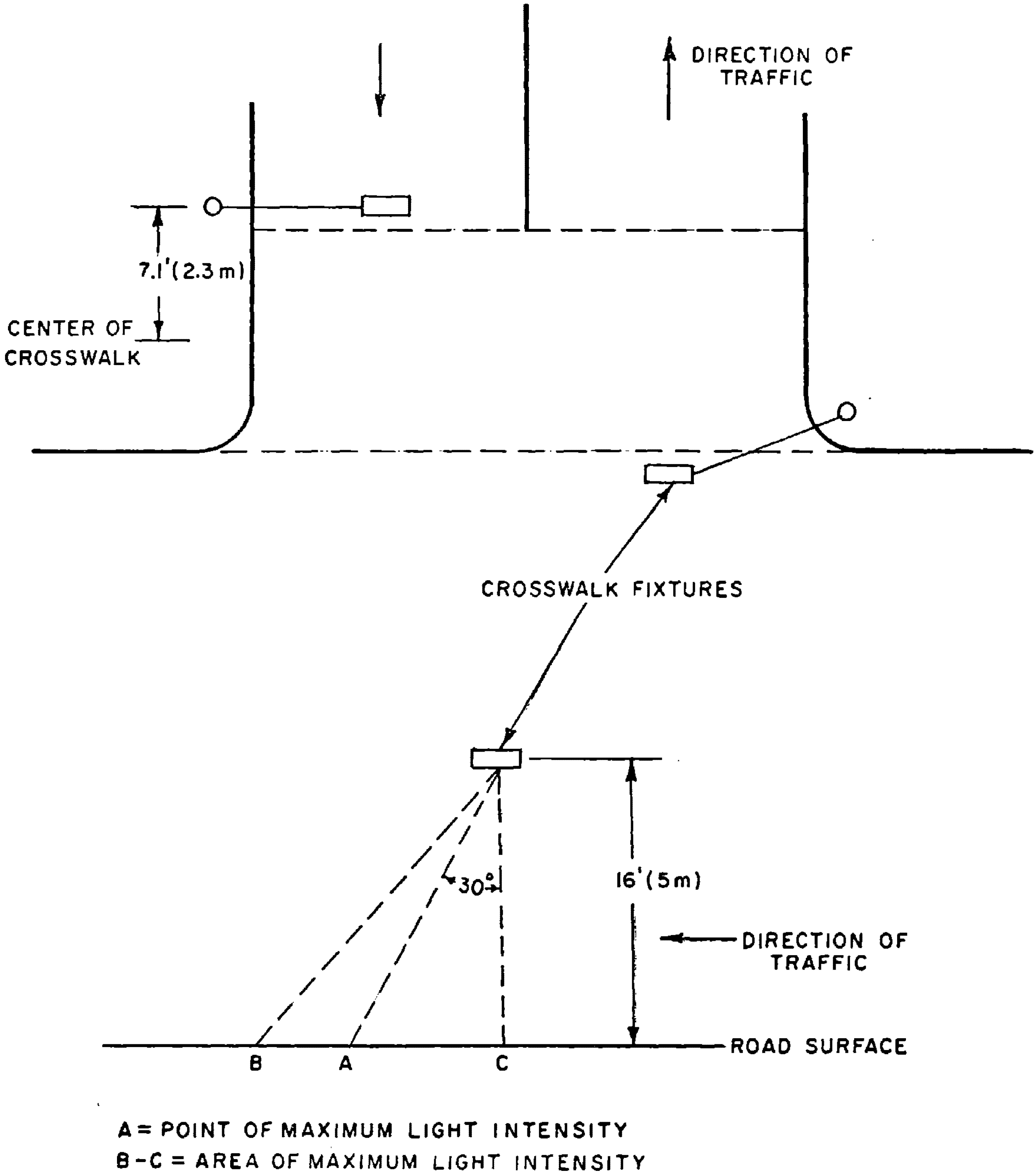

Figure 6. Light Distribution of Crosswalk Fixture

2.4.9 Summary of "After" Experiments

"After" observational experiments were conducted at night at seven high accident and seven control crosswalks corresponding to the seven intersections found in earlier statistical analysis[21] to be most suited for specialized crosswalk lighting. Only the high accident crosswalks were provided with specialized crosswalk illumination. A total of 728 observations of pedestrians, and 191 of independent drivers were recorded.

2.4.10 Statistical Analyses of "Before" - "After" Data

Chi Square Test

A Chi Square Test was performed which compared the before-lighting observational data to the after-lighting observational data. These comparisons were made between blocks of data representative of similar site characteristics of accident history and conflict potential at each of the seven control crosswalks.

Of the thirteen originally most significant pedestrian variables (Phase I, Interim Report, May 1974)[21] ten were found to be significant at the .05 level or better in at least 8 of 28 comparisons (about 30%). They were:

1. Approach direction
2. Exit direction
3. Approach search pattern
4. First half of crossing search pattern
5. Second half of crossing search pattern
6. Decision behavior
7. Motivation
8. Distraction
9. Crossing location
10. Clothing Brightness

Of the variables cited above, the following most strongly indicated a change toward *safer* pedestrian crossing behavior as determined through the Chi Square analysis of Pre-Post lighting conditions.

Approach search pattern
First half of crossing search pattern
Second half of crossing search pattern
First half search time
Second half search time
Clothing brightness

Analysis of Variance

A multivariate analysis of variance (MANOVA) was used to assess the behavioral changes in pedestrians and drivers due to the new illumination systems. The statistical design and results are fully described in Section 4., Effectiveness of Pedestrian Lighting, later in this report.

2.5 PHOTOMETRIC EXPERIMENTS

A series of "Before-After" photometric experiments was conducted to determine the improvement in visibility provided by supplemental crosswalk illumination. These experiments were designed to evaluate changes in target luminance (brightness), surrounding background luminance, and a visibility metric, all of which were expected to change due to the addition of the crosswalk illumination. The metric used to quantify visibility was the Visibility Index (VI) developed by Gallagher[23]. VI is calculated according to the formula:

$$VI = |C| \cdot RCS_{Lb} \cdot DGF$$

$|C|$ = Target contrast (absolute value)

$$|C| = \frac{L_t - L_b}{L_b}$$

L_t = Target luminance (in fL)

L_b = Background luminance (in fL)

RCS_{Lb} = Relative Contrast Sensitivity of observers adapted to a luminance level equivalent to a measured L_b[26].

DGF = Disability glare factor

This expression uses physical contrast as its principal component. Physical contrast is the luminous relationship that an object has with the background against which it is seen, and is fundamental to the description of visual quality[24]. It has been shown[25] that physical contrast alone strongly correlates with a driver's ability to detect objects in a roadway. This correlation has been shown[23,24,25] to be independent of whether the contrast is negative (so-called silhouette seeing) or positive (so-called reverse silhouette seeing or direct seeing) and for this reason, the absolute value of contrast is used in the VI formula. The RCS_{Lb} term is used in this expression because of an interesting feature of the visual mechanism which causes the ability of the eye to detect objects which are near threshold (i,e., objects which are very difficult to see) to improve as the overall adaptation level of the retina increases. This phenomenon is called Contrast Sensitivity. The term Relative Contrast Sensitivity (RCS_{Lb}) is used as a mathematical factor to take this physiological factor into account[26]. The Disability Glare Factor (DGF) is an adjustment to the Visibility Index formula to account for the effects of any high intensity light source within the driver's field of view[27,28].

The experimental hypothesis was that the specialized crosswalk illumination would increase contrast or VI and result in better driver performance and fewer nighttime pedestrian accidents.

2.5.1 Apparatus and Methodology

The complete instrumentation utilized in the measurement of field data consisted of a portable, self-powered system contained within a van type truck. This system was composed of a battery and inverter power supply, two Spectra Pritchard Photomultiplier Photometers to measure target luminance (L_t) and background luminance (L_b), computing circuitry to calculate contrast (C), and an eight channel chart recorder.

Figure 7 presents a schematic of the field operations employed to measure target and background luminances at the Kensington and Torresdale, Kensington and Allegheny, Paul and Torresdale, and A and

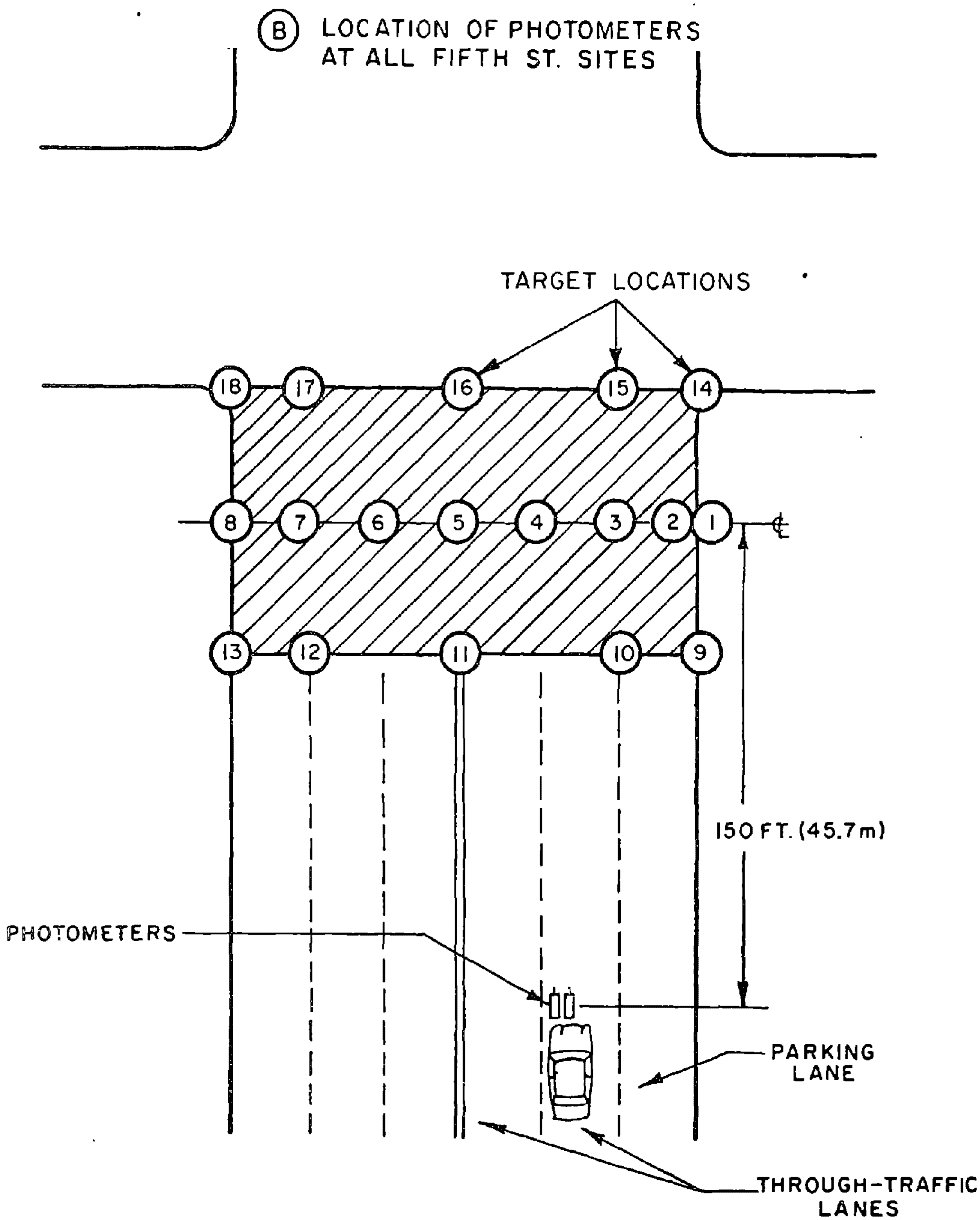

Figure 7. Schematic of Geometric Layout of Field Operations

Allegheny study sites. At all Fifth Street sites, the location of the photometers was at point B in Figure 7. At all sites, the photometers were located to approximate the viewing position and direction of approaching vehicles associated with pedestrian accidents.

The selection of the target to be used in the experiments was based upon the premise that the reflectivity of the target should be similar to that of the average (or perhaps 15th percentile) pedestrian. Since the early data of Goldman[39] was judged not to be representative of modern clothing and therfore not suitable for our needs, more than 100 subjects were photometered at FIRL. Clothing reflectance calculations from these measurements are summarized in Table 14, and compared to the Goldman data in Figure 8.

Table 14. FIRL Clothing Reflectance Data (%)

SAMPLE SIZE	MEAN	STANDARD DEVIATION	15TH PERCENTILE
Men 76	34.58	17.57	16.31
Women 27	28.78	23.33	4.53
Total 103	33.06	19.95	13.35

The target utilized throughout the field photometric measurements was a standard rubber traffic cone, truncated at a height of 18 in. (45.7 cm), and covered with red velour paper possessing a diffuse reflectance coefficient of 8%. This target was chosen for its simple three-dimensional shape, its lack of internal contrast, and for its crash-survival and safety properties.

During the photometric data collection, care was taken to prevent contamination of the luminance and contrast signals resulting from interposing vehicles in the path between the photometers and the target. On the data records the experimenter indicated the passage of vehicles through the crosswalk by placing an indicator mark on the chart recorder paper. Complete vehicular and pedestrian traffic volume counts were also made.

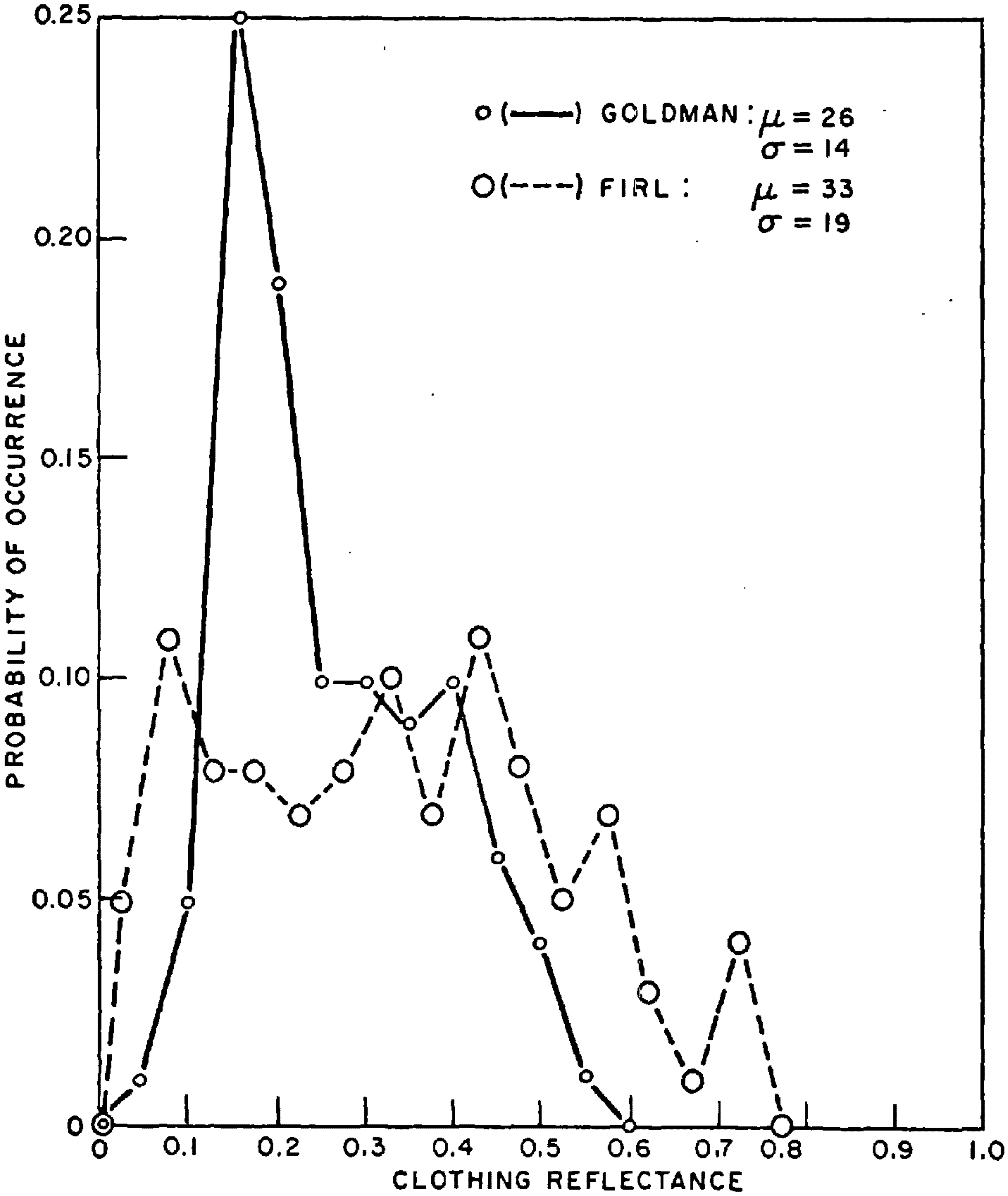

Figure 8. FIRL and Goldman Clothing Reflectance Data

The experimental independent variables under which photometric measurements were made are summarized in Table 15. Measurements were thus made at all seven study sites in each of the following three conditions: BEFORE-LOW, BEFORE-HIGH, and AFTER-HIGH.

Table 15. Experimental Independent Variables

	Time of Measurement Relative to Installation of Specialized Crosswalk Illumination	
Pedestrian Accident Experience	BEFORE	AFTER
HIGH	All sites	All sites
LOW	All sites	Not tested

2.5.2 Results

Illumination

Table 16 presents average horizontal foot-candles illumination for each study site and study condition crosswalk. Measurements at each target position in individual study sites are presented in the Phase II Interim Report of this research[27]. LOW accident history crosswalks at all sites but Paul and Torresdale and Kensington and Allegheny exhibited higher mean illumination than corresponding HIGH accident history crosswalks before the installation of the special LPS luminaires. After the pedestrian crosswalk illumination was installed, all HIGH crosswalks yielded higher mean illumination than LOW crosswalks. The increases over BEFORE-HIGH mean illumination ranged from 383% (Kensington and Allegheny) to 3267% (Fifth and Cayuga).

Ambient Visibility

Ambient visibility refers to those visibility conditions during which vehicular headlighting effects are absent, i.e., when target visibility is determined solely by fixed overhead lighting and environmental illumination, when vehicles are not operating in the vicinity of the crosswalk. The portions of the contrast records representing ambient visibility conditions were identified by relatively low and

Table 16. Average Horizontal Foot-Candles Illumination for Each Study Site and Study Condition Crosswalk.

	Study Condition		
Study Site	BEFORE-HIGH	AFTER-HIGH	BEFORE-LOW
Paul & Torresdale	0.74	7.41	0.45
A & Allegheny	0.23	7.14	0.61
5th & Ruscomb	0.42	8.30	1.01
5th & Lindley	0.25	8.30	1.01
5th & Cayuga	0.21	7.07	0.99
Kensington & Allegheny	2.75	13.34	1.13
Kensington & Torresdale	0.58	10.98	0.69
Mean over sites	0.74	8.93	0.86

stable contrast levels, and the absence of vehicle indicator marks.

The mean values of ambient Visibility Index (VI_{amb}) are presented for the three study conditions and three target reflectances in Table 17. Measurements of the 13% and 33% reflectant targets were derived by using the standard target and manipulating the target luminance (L_t) signals in the contrast computing circuitry.

The mean values of VIamb therefore point to improved ambient visibility conditions at high pedestrian accident crosswalks after the installation of the specialized LPS luminaires. For the 33% reflectant target, this improvement is also statistically significant (beyond .005).

Dynamic Visibility

Dynamic visibility refers here specifically to those portions of the dynamic contrast records which were not classified as ambient visibility conditions. A more extensive analysis was required to deal with the time-varying and probabilistic nature of the non-ambient visibility records, the details of which are presented in the Phase II Interim Report[27]. The results of the analysis are Dynamic Visibility Index (DVI) probability density distributions showing the frequency of occurrence of DVI levels. To describe these distributions, the 50th percentile (median) DVI values were determined. The 50th percentile DVI represents the dynamic visibility below which 50% of the DVI distribution occurs. Conceptually this means that the 50th percentile DVI quantifies the maximum visibility condition during 50% of the cumulative time when vehicles are in the vicinity of the study crosswalk area.

The mean values of 50th percentile DVI for each study condition were tested with a randomized block factorial 2-way analysis of variance (ANOVA). Whereas no significant differences between the BEFORE-HIGH and BEFORE-LOW DVI means were disclosed, the AFTER-HIGH mean was significantly greater (beyond .10, approaches .05) than the BEFORE-HIGH mean. This difference indicates that the addition of LPS luminaires to HIGH pedestrian accident crosswalks has significantly improved the visibility for drivers entering the study crosswalk area.

Table 17. VIamb Means for All Study Conditions and Three Target Reflectances

	Target Reflectance		
Condition	8%	13%	33%
BEFORE-HIGH	1.41	1.06	1.69
AFTER-HIGH	2.01	1.66	4.40
BEFORE-LOW	1.53	1.18	1.15

To examine the extent of dynamic visibility effects due to vehicular headlighting, a new variable for analysis was created by normalizing the DVI distributions by traffic volume counts. Using DVI data from six of the seven study sites, the resulting variable describes the duration of non-ambient visibility condition caused by each vehicle passing through the crosswalk areas. A randomized block factorial ANOVA test of the means of overall response time for all study conditions disclosed no significant differences between BEFORE condition means but a significantly smaller (beyond .025) response time mean for the AFTER-HIGH condition. Since traffic volumes were unchanged during the course of the photometric experiments, this result indicates that the addition of specialized crosswalk illumination has decreased the difference between peak DVI due to headlighting effects and the ambient VI condition. Because of this change:

1. Ambient visibility conditions prevail for longer periods of time, i.e., the effects of headlighted vehicles on DVI are apparent only when vehicles are closer to the crosswalk area;
2. Motorists can rely less upon their own vehicle's headlighting and relatively more upon environmental lighting, which may therefore decrease adverse effects of poorly aimed or dirty headlamps;
3. The lighted "visible space" ahead of the motorist has increased in size; and
4. Disability glare effects on visibility due to the presence of oncoming vehicular headlamps within the driver's visual field have diminished.

An additional measure that combined both ambient visibility (VI_{amb}) and dynamic visibility (50th percentile DVI) was developed to provide an integrated description of the crosswalk visibility that exists over extended periods of time. This measure is called Weighted-mean Dynamic Visibility Index (WDVI), and represents the mean of the ambient and non-ambient visibility measures weighted by the proportional time during the data collection periods that each measure occurred. A complete description of the calculations performed to generate WDVI is presented in the Phase II Interim Report[27].

WDVI means for each study site and study condition are presented in Table 18. Using the same ANOVA, overall means were tested for differences. Although no differences between BEFORE conditions were significant, the AFTER-HIGH mean WDVI is significantly greater (beyond .10, approaches .05) than the BEFORE-HIGH WDVI mean.

Table 18. WDVI Means for all Study Sites and Study Conditions

Study Site	Study Condition		
	Before-High	After-High	Before-Low
5th & Ruscomb	1.15	1.46	1.06
5th & Lindley	1.22	1.20	1.45
5th & Cayuga	0.97	0.99	1.51
A & Allegheny	1.06	1.15	0.98
Kensington & Allegheny	2.23	3.46	2.23
Kensington & Torresdale	1.10	2.72	1.09
Paul & Torresdale	0.64	1.25	1.40
Weighted Means	1.33	2.03	1.38

When WDVI means for individual study sites were grouped according to (1) signalization/no signalization present, (2) area type (OBD/residential), (3) increments of perpendicular street width, and then tested with a Kruskal-Wallis ANOVA by ranks test, the following results were disclosed:

1. WDVI means were greater at signalized study sites (significant beyond .05);
2. WDVI means were greater at OBD class study sites (significant beyond .05);

and

3. WDVI means were ordered as a function of street width, i.e., WDVI increased with street width (significant beyond .10, approaches .05).

WDVI has thus been demonstrated to increase with the implementation of LPS luminaires at HIGH Pedestrian accident crosswalks. In addition, wide signalized study sites in outlying commercial areas exhibited the highest visibility, possibly resulting from the generally higher levels of illumination at these sites.

Generalizations concerning the relationships between the results of these photometric experiments and improvements in pedestrian safety are discussed in Section 4, Effectiveness of Pedestrian Lighting.

2.6 DETECTION EXPERIMENT

A threshold detection experiment was designed and conducted at one specially illuminated crosswalk (Paul & Torresdale) to determine the improvement in threshold detection provided by the supplemental illumination.

2.6.1 Method

The experiment required the subjects to identify the orientation of a cone shaped target similar to the one in the photometric experiments, positioned in the exact center of the crosswalk and directly beneath the luminaire. Four target orientations were utilized, i.e., pointing up, down, to the left, and to the right.

The duration of exposure to each target orientation stimulus was constant over subjects and conditions at 0.2 seconds. This control was achieved through the use of a Vision Interruption Apparatus (VIA), developed by Senders and utilized in several FIRL research projects[29,30]

2.6.2 Results

Inasmuch as this study addressed the quantification of recognition performance rather than detection performance, the obtained mean percent correct identification scores over all subjects can be utilized to determine the recognition threshold distances that were provided under the crosswalk illumination with and without the low-pressure sodium luminaire.

This recognition threshold is defined as the observation distance at which subjects correctly identify the cone target orientation in 50% of the presentation exposures. With the luminaire on, the threshold occurred beyond the range of observation distances tested due to space limitations at the test site, and was therefore extrapolated from the relatively linear performance vs. distance curve (Figure 9) to be about 587 feet (178.9 m). With the luminaire off, the threshold occurred within the range of observation distances tested: interpolation on the performance vs. observation distance curve (Figure 9) yielded 245 feet, (74.7m) as the recognition threshold. The low-pressure sodium luminaire installation over the "high" crosswalk at the intersection of Paul St. and Torresdale Ave. thus improved the recognition threshold of the cone target by almost 140%.

2.6.3 Pedestrian Photometrics

A FIRL technician wearing a lab coat covered with the red velour paper (reflectance coefficient = 8.3%) used for the cone target was positioned in the crosswalk directly under the LPS luminaire. Photometric measurements of the lab coat were made to relate pedestrian visibility to visibility assessments of the recognition target cone. Background luminance (L_b) was measured using a larger aperture (2 degrees) than for previous photometric experiments, corresponding to the field of view required to surround the six-foot pedestrian. This larger aperture resulted in exaggerated L_b measurements due to an increased depth of field, which encompassed all fixed illumination over roughly two blocks of Paul St. north of Torresdale Ave. This effectively increased the task contrast as well as the RCS_{Lb} factor in the VI calculations. Values of VI representing the simulated pedestrian were thus much greater in magnitude under both "light on" and "light off" conditions and far beyond the range of VI noted for the cone target orientations. The pedestrian was more visible under illumination from the specialized crosswalk luminaire (VI = 14.9) than without (VI = 6.0), but the large differences in measured L_b and the variability in the pedestrian target itself (due to internal contrast

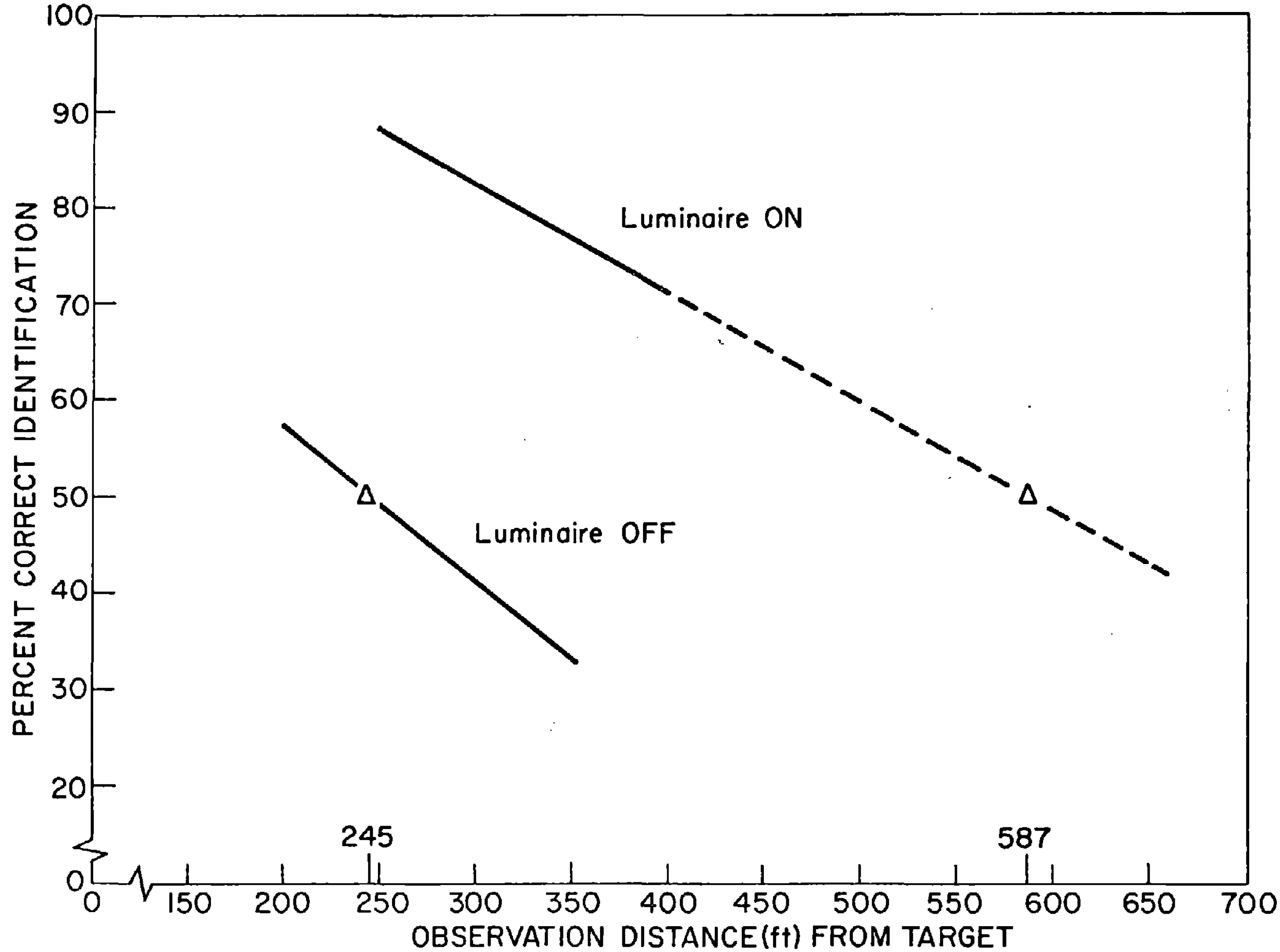

Figure 9. Percent Correct Identification Performance As a Function of Observation Distance, for Luminaire "ON and "OFF"

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of the coat resulting from variable angles relative to the luminaire) lend little confidence to these measurements.

2.7 ATTITUDINAL SURVEY

An interview type survey of pedestrians, local residents and local business personnel was designed and conducted to determine personal attitudes toward the specialized illumination systems. A summary of the results is shown in Figure 10.

The majority of interview responses indicated a positive reaction toward LPS illumination at high-accident history crosswalks, relative to increased pedestrian visibility and a greater sense of safety and comfort while crossing. Residents and neighborhood commercial establishments also reacted positively, citing reasons of customer safety as well as increased potential for police surveillance. An overwhelming number of respondents felt that the lighting yielded a definite improvement over normal unlighted crosswalks.

Total Sample Interviewed: 101

1.1	Do you live in this area?	YES (74.3%)		NO (25.7%)
1.2	How often do you cross at this intersection?	(57.4%) NIGHTLY	(23.8%) WEEKLY	(18.8%) SELDOM
1.3	How often do you cross in this Xwalk?	(57.4%) NIGHTLY	(23.8%) WEEKLY	(18.8%) SELDOM
1.4	How often at night?	(57.4%) NIGHTLY	(23.8%) WEEKLY	(18.8%) SELDOM
2.2	Did you notice anything different about this Xwalk?	YES (100.0%)		NO (0.0%)
3.1	How comfortable/safe do you feel in this Xwalk?	SAFE (77.2%) DON'T CARE (19.8%) UNCOMFORTABLE (2.0%) DANGEROUS (1.0%)		
3.2	Do you think this Xwalk is an improvement over normal un-lighted Xwalks?	YES (97.0%)		NO (3.0%)
4.1	Is it easy/difficult to see traffic while in this Xwalk?	(91.1%) EASY	(8.9%) NEITHER	(0.0%) DIFFICULT
4.2	Do you think cars can see you better or worse in this Xwalk as compared to other unlighted Xwalks?	(82.2%) BETTER	(16.8%) SAME	(1.0%) WORSE
5.1	Are you a driver?	YES (49.5%)		NO (50.5%)
5.2	How easy would it be for you, as a driver, to see pedestrians in this Xwalk compared to normal unlighted Xwalks?	(92.0%) EASIER	(8.0%) SAME	(0.0%) HARDER

Figure 10. Summary Survey Results

3. SPECIAL ILLUMINATION SYSTEM COSTS

3.1 COSTS OF CROSSWALK ILLUMINATION IN OTHER CITIES

The following is a summary of the costs of the specialized illumination systems previously described in Section 2.2. Costs include initial costs of material and labor, maintenance (including relamping, cleaning painting, signing) and power.

The Las Vegas System uses standard MFB-4 lamps on side-mounted poles. Las Vegas officials did not have exact costs documented, but they noted that the costs of such fixtures would be almost the same as for standard, 400-watt mercury vapor lamps on standard poles. We contacted the Philadelphia Street Lighting Department to obtain costs for comparable equipment.

The Detroit costs were obtained from the report describing the Detroit study and from the manufacturer of the crosswalk lighting (Steel Art, Toronto). No annual or initial labor costs were available from Detroit.

Toronto costs were obtained from the Traffic Department of the Municipality of Toronto. The fixtures have been supplied by a number of different firms since 1958.

Costs for the Winnipeg system were developed by Mr. Lowell Campbell, Traffic Engineer, Municipality of Winnipeg. They included installation (material and labor), electric energy, maintenance, and damage replacement.

Costs for the Copenhagen System were obtained through Mr. Frederiksen of the Danish Illuminating Laboratory. Initial equipment costs were provided by Phillips (the manufacturer); installation and annual costs were developed by the City of Copenhagen.

Costs for the Swiss system were developed by Mr. H. Gloor, Basle Electric Company. These costs apply to the Basle system only, and hence may be different for other areas of Switzerland.

Costs for the Hanover system were supplied by Osram, Hanover (lamps and starters) and Hellux, Hanover (luminaires). Costs were not available for items such as poles or for labor, and only initial costs were supplied.

The summarized costs of specialized illuminated crosswalks were updated to June, 1975 (Table 19). All foreign costs were updated using the current international exchange rate and the average consumer price index. Domestic costs were also updated using the average consumer price index (June, 1975 = 1.62). The initial costs include expenses for material and labor and the annual costs comprise the expenses for power and maintenance. We were unable to obtain actual man-hours of effort required for installation and maintenance except for Las Vegas and Winnipeg.

Table 19. Summary of Reported and Updated Costs

SYSTEM	REPORTED INITIAL COST/SYSTEM	UPDATED INITIAL COST/SYSTEM	ANNUAL COST/SYSTEM
Las Vegas	$2000	$2340	$165
Detroit (1)	$1415	$1655	----
Toronto	$2000	$2340	$362
Winnepeg	$2000	$2340	$386
Copenhagen	$1869	$2675	$428
Switzerland	$1467	$2275	$332
Hanover (2)	$173	$237	----
Average	$1561	$2394	$335

(1) No installation or annual costs available - not used in average calculation.
(2) Luminaire, lamp and starter only - not used in average calculation

3.2 PHILADELPHIA SYSTEM COSTS

The purchase price of the seven crosswalk lighting in Philadelphia was obtained from the manufacturer of the crosswalk luminaires (N.A. Phillips, Hightstown, N.J.). The lighting contractor (W.V. Pangborne, Bala Cynwyd, Pa.) supplied all the costs associated with the installation and maintenance. Energy costs ($0.04 per kwh.) and yearly power consumption (369 kwh per unit) were provided by Mr. D. Floor of the Philadelphia Electric Company. These costs are summarized in Table 20.

Table 20. Average FIRL Project Costs

ITEM	INITIAL	ANNUAL
Phillips SGC 226 Pedestrian Luminaire	$330/unit	---
Installation and Maintenance	$3203/system	$50/unit
Power	--- ---	$20/unit

Although the installation contractor could not provide a more detailed construction cost on an individual crosswalk basis, our own records of construction labor and equipment enabled us to modify the reported average cost to reflect the differences between installations at the seven sites. These total costs for the installation and operation for each of the seven systems in Philadelphia are listed in Table 21.

Table 21. Estimated FIRL Costs/Intersection

INTERSECTION	LUMINAIRES	COSTS			
		AMORTIZED			
		INITIAL	ANNUAL+	ANNUAL*	TOTAL ANNUAL
5th & Ruscomb	2	$3863	$454	$140	$594
5th & Cayuga	2	$3863	$454	$140	$594
5th & Lindley	2	$3863	$454	$140	$594
A & Allegheny	2	$3863	$454	$140	$594
Kensington & Allegheny	4	$4820	$566	$280	$846
Kensington & Torresdale	4	$4820	$566	$280	$846
Paul and Torresdale	1	$2939	$345	$70	$415

+ Capital Recovery, 20 years, 10% compound interest rate, c.r.f. = .11746
* Includes power, maintenance and relamping.

3.3 BULK COST ESTIMATION

Budget contract price estimates for the installation of the FIRL pedestrian lighting system were furnished by Mr. Al Thier of Pangborne, Inc. and the cost estimates for the N.A. Phillips SGC-226 type luminaire were provided by Mr. Richard Klapper of Area Lighting and Mr. Robert Lewis of N.A. Phillips (Table 22).

Table 22. Estimates for Contract Installation

SYSTEM	LUMINAIRES*	INSTALLATION	TOTAL INITIAL COST
1	$660 ($330/unit)	$4000 ($4000/system)	$4660
25	$13,600 ($272/unit)	$87,500 ($3500/system)	$101,100
50	$24,750 ($247.50/unit)	$165,000 ($3300/system)	$189,750
100	$45,000 ($225/unit)	$310,000 ($3100/system)	$355,000

*Based on two luminaires per system

3.4 ANNUAL COST COMPARISON

Installation and annual costs were available for only five of the seven pedestrian lighting systems studied. Table 23 compares the average annual costs of the Philadelphia system with the five other lighting systems.

Table 23. Comparisons of Average Annual Cost Per System

SYSTEM	TOTAL INITIAL COSTS	ANNUAL CAPITAL* RECOVERY COST	ANNUAL OPERATION & MAINTENANCE	TOTAL ANNUAL COSTS OF PEDESTRIAN LIGHTING/SYSTEM
Philadelphia	$3863	$454	$140	$594
Las Vegas	$2350	$276	$165	$441
Switzerland	$2275	$267	$332	$599
Toronto	$2340	$275	$362	$637
Winnipeg	$2340	$275	$386	$661
Copenhagen	$2675	$315	$428	$743

* Includes depreciation of installation and luminaires over 20 years at 10%.

It is important to note that the total initial cost of the Philadelphia system is much higher than any of the system costs reported by other cities, even where adjusted for cost of living increases. This was probably due to the effects of installing a prototype system for research purposes by a contractor who was not familiar with the luminaires or their mounting requirements. Once a more standardized bracket and davit arm (which the contractor was forced to specially fabricate) are adopted for more widespread use, and contractors become familiar with the system, it is expected that system costs could be reduced by as much as 40%. The installation of two standard mercury vapor luminaries on wooden poles costs about $2400, and the basic differences between the LPS system and the mercury vapor system are in the luminaire, davit arm, and power distribution wiring.

4. EFFECTIVENESS OF PEDESTRIAN LIGHTING

4.1 OBJECTIVES

The objectives of this task were to determine the effectiveness of the special low pressure sodium (LPS) illumination systems installed at the seven test crosswalks. This evaluation utilized the considerations of behavioral changes (determined through observational experiments and statistical analysis), photometric changes and photometrically derived information (Visibility Index (VI)[29,30], Dynamic Visibility Index (DVI)[27], Weighted Dynamic Visibility Index (WDVI), and Time to Target (TTT)[29,30], and changes in accident patterns and frequency.

The results of this task were used as input to the benefit-cost analysis of the system, development of other measures of effectiveness, and the development of warrants, design specifications, and evaluation criteria for future system implementation.

4.2 BEHAVIORAL EFFECTIVENESS

The objectives of this sub task were to determine the effectiveness of the special LPS illumination systems in promoting safer crossing behavior and to predict, if possible, the potential reduction in nighttime pedestrian accidents as a result of the improved behavior.

Two methods of analysis were used to determine the effectiveness of the experimental systems. The first, which was used to assess the behavior changes in pedestrians and drivers due to the new illumination systems, was based upon the comparison of before and after behavioral data by means of Chi Square Tests, factor analysis, and multivariate analysis of variance (MANOVA).

The second, which was used in an attempt to predict the potential reduction in nighttime accidents, was based on the methods of analysis of concordance and multivariate analysis of variance.

The determination of the modifications of pedestrian behavior was conducted so that the descriptors of "after" behavior were first checked to ensure that they were the same as the "before" descriptors by using a Factor Analysis of the after data, then analyzed in a multivariate analysis of variance utilizing a four way design as follows:

Before	X	without conflict	X	low acc. hist.	X	non-signalized
After		with conflict		high acc. hist.		signalized.

4.2.1 Methods of Analysis

Factor Derived Variables

The analysis used the ten pedestrian variables which through factor analysis were previously found to comprise five principal FACTORS or composite descriptors of pedestrian behavior[27] (Table 24). These factors became the five Variables examined in the MANOVA.

Table 24. Principal Factors of Pedestrian Crossing Behavior

VARIABLE	FACTOR
1. Approach search pattern	1. SEARCH
2. 1st half crossing search pattern	1. SEARCH
3. 2nd half crossing search pattern	1. SEARCH
4. Approach direction	2. PATH
5. Exit direction	2. PATH
6. Crossing location	2. PATH
7. Motivation	3. CONCENTRATION
8. Distraction	3. CONCENTRATION
9. Erratic-inappropriate behavior	4. ABNORMAL BEHAVIOR
10. Perceived clothing brightness	5. CLOTHING BRIGHTNESS

In order to ensure conservatism in the interpretation of the MANOVA, Bartlett tests of homogeneity of variance and Spearman Rank order correlation tests were performed on the MANOVA results to determine the applicability and sensitivity of any comparisons that could be made among the cells of the four way design (e.g., one comparison could be before-with conflict, high accident history, signalized versus after - with conflict, high accident history, signalized intersections for the SEARCH Variable). These tests indicated whether a .05 or a .01 level of significance for Scheffé F Tests was required to conservatively judge whether statistically significant differences existed between compared cells for particular Variables. Table 25 indicates the results of the Bartlett and Spearman tests.

Table 25. Summary of Bartlett and Spearman Tests for Required Significance Levels of Before-After Comparisons of Factor Derived Variables

FACTOR DERIVED VARIABLE	BARTLETT CHI SQUARE VALUE	SPEARMAN RANK ORDER CORRELATION COEFFICIENT	REQUIRED SIGNIFICANCE LEVEL
Search	85.85	+.4801	.05 for slightly higher
Path	105.24	-.0777	.05 or less
Concentration	19.46	not needed	.05 or slightly higher
Abnormal Behavior	55.45	-.3580	.01 or slightly higher
Clothing Brightness	32.23	+.4700	.05 or less

Twenty-three Scheffé tests for statistically significant differences between two cells or cell combinations for each of the five Variables were performed.

The interpretation of the Scheffé test results compared the individual cell mean values to the composite cell grand mean values of each tested pair, which provided for the evaluation of the direction of changes in behavior.

Analysis of Potential Accident Reduction

The thirteen pedestrian and ten driver variables which had been found to be good behavioral descriptors in earlier analysis were used in modified form as a composite safety score (CSS) for each observation. The CSS was analyzed in the same manner as were the five Factor Analysis Variables using a 2x2x2x2 MANOVA.

The CSS was developed through the use of expert opinion provided by members of the Transportation Sciences Laboratory at FIRL and analysis of concordance, as follows. First, respondents were asked to rank a list of thirteen pedestrian and ten driver variables from most to least important with respect to safety. Next, each of the variables were rated, or assigned a maximum possible score which could range from 1 to 10. The most important variable would receive a score of 10. Other variables would receive scores which lay between 1 and 10. Additional categories of each variable would be scored with values lying between the variable's highest and lowest value, and would reflect the intermediate categories' relative safety within the range of categories. The relative importance of pedestrian versus driver variables was also noted. In order to ensure reasonable agreement among responses, a Kendall W test for concordance was performed. The results of that test indicated general agreement for both ranking and rating (scoring) of variables and variable categories. It was determined that respondents agreed that pedestrian actions were twice as important as driver actions. This would require that about 2/3 of the total score be derived from pedestrian variables, and 1/3 from driver variables.

The final step in the development of the CSS employed scaling the scores so that the safest and least safe *Pedestrian* score (sum of scores of pedestrian variables) would be +65 and -65, respectively. Similarly, the maximum or sum of driver scores ranged from +35 to -35. The total CSS could therefore range from +100 to -100 for safest and least safe observations of a pedestrian crossing in the presence of a potentially conflicting vehicle (with-conflict crossing). Figure 11 summarizes the CSS variables, categories and scores.

PEDESTRIAN DESCRIPTORS

RANK*	DESCRIPTOR	RATING**	CATEGORIES***					
12	APPROACH DIRECTION	2	① PARALLEL TO X WALK +2	② TURN FROM OTHER X WALK −2	③ TURN FROM BUILDING SIDE +1	④ UNKNOWN 0		
13	EXIT DIRECTION	2	① " +2	② " −2	③ " +1	④ " 0		
11	NATURE OF ARRIVAL	2	① ISOLATED −2	② LIGHT TO MODERATE STEADY STREAM +1	③ IN GROUPS OR PLATOONS −1	④ HEAVY CONTINUOUS STEADY FLOW +1		
1	APPROACH SEARCH BEHAVIOR	9	① ALL DIRECTIONS +9	② VEHICULAR TRAFFIC ONLY +7	③ PATH AHEAD ONLY 0	④ SIGNAL ONLY −7	⑤ NO PURPOSEFUL LOOK −9	
4	1st HALF CROSSING SEARCH	7	① " +7	② " +4	③ " 0	④ " −4	⑤ " −7	
7	2nd HALF CROSSING SEARCH	5	① " +5	② " +3	③ " 0	④ " −3	⑤ " −5	
10	DECISION BEHAVIOR	2	① DECISIVE +2	② INDECISIVE −2	③ HESITANT CAUTIONARY 0			
3	ACTION TAKEN	7	① LEGALLY CROSS WITH CLEARANCE +7	② LEGALLY CROSS WITHOUT CLEARANCE −7	③ WAIT +3	④ CROSS ILLEGALLY WITH CLEARANCE +1	⑤ CROSS ILLEGALLY WITHOUT CLEARANCE −7	
9	MOTIVATION	1	① NO SPECIAL +4	② SUSPECTED 0	③ DISTINCT - DESCRIBE −4			
5	DISTRACTION	6	① NO SPECIAL +6	② MODERATE −2	③ DISTINCT-DESCRIBE −6			
6	CROSSING LOCATION	5	① IN MARKED CROSSWALK OR WHERE IT WOULD BE IF MARKED +5	② WITHIN 10' OF PROPER LOCATION 0	③ 10' TO WITHIN 25' OF PROPER LOCATION −5	④ BEYOND 25' −3	⑤ DIAGONAL −5	⑥ CUT CORNER −3
2	ERRATIC OR INAPPROPRIATE BEHAVIOR	7	① NONE +7	② HORSE PLAY −2	③ DARING TRAFFIC OR WALKING IN TRAFFIC STREAM −5	④ STAGGER −7	⑤ CROSS AGAINST SIGNAL 0	⑥ INATTENTIVE −7
8	BRIGHTNESS OF SIGNIFICANT PORTION OF CLOTHING	5	① VERY DARK OR BLACK 5	② DARK −3	③ DULL OR GRAY 0	④ LIGHT +3	⑤ VERY BRIGHT OR WHITE +5	
		65						

RELATIVE IMPORTANCE

2

DRIVER/VEHICLE DESCRIPTORS

RANK*	DESCRIPTOR	RATING**	CATEGORIES***					
1	APPROACH SPEED (mph)	8	① 0-9 +8	② 10-19 +4	③ 20-29 0	④ 30-39 −2	⑤ 40-49 −6	⑥ 50+ −8
4	NATURE OF ARRIVAL	4	① ISOLATED +4	② LIGHT TO MODERATE STEADY STREAM +2	③ IN PLATOONS −2	④ HEAVY STEADY STREAM CONGESTED −4		
5	VEHICLE DIRECTION	3	① PROCEED THRU +1	② TURN LEFT −3	③ TURN RIGHT −2	④ STOP WAIT FOR GREEN LIGHT OR CLEARANCE +3		
7	VEHICLE APPROACH LOCATION	2	① PARALLEL TO PED PATH −2	② CROSSING PED PATH +2				
9	DRIVER AGE	1	① UP TO 30 −1	② 30-50 +1	③ 50-65 0	④ OVER 65 −1	⑤ UNKNOWN - DON'T USE IF POSSIBLE 0	
2	RELIANCE ON TRAFFIC CONTROL DEVICE	6	① COMPLETE-DO JUST WHAT INDICATION SAYS WITHOUT ANY SUPPLEMENTAL CAUTIONARY MOVES −6	② MINOR CAUTIONARY ACTIONS DISPLAYED.(SLOW DOWN, LOOK AROUND) +2	③ FULL STOP EVEN THOUGH WITH RIGHT OF WAY +6			
10	VEHICLE TYPE	1	① PASSENGER CAR +1	② LIGHT TRUCK (SINGLE REAR AXLE) 0	③ HEAVY TRUCK, BUS SEMI TRAILER −1			
6	VEHICLE LIGHTS	3	① LOW BEAMS +3	② OFF −3	③ PARKING LIGHTS ONLY −2	④ HIGH BEAMS ON +2	⑤ ONE HEADLIGHT OUT −1	
3	OBVIOUS VISUAL OBSTRUCTION IN VEHICLE, ON ROAD, CURB, BROKEN VEHICLE GLASS	5	① NONE +5	② TO LEFT −3	③ TO RIGHT −4	④ STRAIGHT AHEAD −5		
8	WINDSHIELD COND.	2	① CLEAN OR NOT STRIKINGLY DIRTY +2	② OBVIOUSLY DIRTY, FOGGED, ETC. −2				
		35						

RELATIVE IMPORTANCE

1

*WRITE THE CHOSEN RANK IN THIS COLUMN

**WRITE THE CHOSEN RATING IN THIS COLUMN

***WRITE THE CHOSEN SCORES RIGHT IN THE CATEGORY BOXES

Figure 11. Summary of the Composite Safety Scores

4.2.2 Findings

Before - After Behavioral Variables

Twenty three before-after analyses of the mean values of each of the five Factor derived Variables were conducted using Scheffé F Tests for statistical significance at the levels specified by the Bartlett and Spearman tests for homogeniety of variance. These twenty three sets of tests were chosen because they examined the differences between the mean values of the five Variables under specific combinations of conditions of time (before - after), conflict potential (with - without), accident history (high - low) and intersection control (signalized or non-signalized) for which interpretation would be most enlightening with respect to improvements in safety. The results of the Scheffe´ test indicated which of the comparisons should be further interpreted by examining both the magnitude and direction of the differences between mean values. These differences in magnitude and direction were ultimately used to describe the nature of changes in behavior due to the implementation of special crosswalk illumination. Table 26 is a summary of those mean values of the compared sets of conditions found to exhibit statistical differences.

The most striking difference was found in the examination of Variable 5: Perceived Clothing Brightness. Every comparison of the before versus after, high accident history, signalized locations, under either with or without conflict conditions showed an increase in perceived clothing brightness after the installation of the special illumination system. This increase in perceived subject luminance is especially meaningful because it relates the measurable luminance quantity to a subjective assessment. That is, observers, searching the street in a more directed but similar fashion as drivers, perceived the general appearance of pedestrians as brighter.

Non-signalized locations with the same accident and conflict conditions showed no perceptible difference between before and after stratification. Further, the low accident (control) locations did not show

Table 26. Summary of Mean Values of Indicated Variables and Results of Scheffe Tests for Significant Behavioral Differences

TEST NO.		MEAN VALUES OF CELLS FOUND TO BE STATISTICALLY SIGNIFICANT				
		SEARCH VARIABLE	PATH VARIABLE	CONCEN-TRATION VARIABLE	ABNORMAL BEHAVIOR VARIABLE	CLOTHING BRIGHTNESS VARIABLE
1.	Before-W+W/O,H+L,S+N/S After-W,H+L,S+N/S			.9083 1.2690		.2390 -.0541
2.	Before-W,H+L,S+N/S After-W,H+L,S+N/S			.8232 1.2283		.2524 -.0512
3.	Before-W/O,H+L,S+N/S After-W/O,H+L,S+N/S	1.0366 1.3329		.9550 1.3082		.2191 -.0558
4.	Before-W+W/O,H,S+N/S After-W+W/O,H,S+N/S			.9227 1.2275		.2048 -.1520
5.	Before-W+W/O,L,S+N/S After-W+W/O,L,S+N/S			.8942 1.3233		.2565 .0741
6.	Before-W+W/O,H+L,S After-W+W/O,H+L,S	1.3082 1.5515		.8864 1.0778		.2199 -.0609
7.	Before-W+W/O,H+L,N/S After-W+W/O,H+L,N/S					
8.	Before-W,H,S+N/S After-W,H,S+N/S					.2534 -.1510
9.	Before-W,L,S+N/S After-W,L,S+N/S					
10.	Before-W/O,H,S+N/S After-W/O,H,S+N/S	1.0910 1.4431				.1712 -.1529
11.	Before-W/O,L,S+N/S After-W/O,L,S+N/S					
12.	Before-W,H,S After-W,H,S					.2660 -.1160
13.	Before-W/O,H,S After-W/O,H,S		-.9190 -.3270	.9090 1.3180		.1690 -.1830
14.	Before-W,L,S After-W,L,S			.7170 1.3520		
15.	Before-W/O,L,S After-W/O,L,S			.9050 1.3410		
16.	Before-W,H,N/S After-W,H,N/S					
17.	Before-W/O,H,N/S After-W/O,H,N/S					
18.	Before-W,L,N/S After-W,L,N/S					
19.	Before-W/O,L,N/S After-W/O,L,N/S					
20.	Before-W,L,S After-W,H,S					.2740 -.1160
21.	Before-W/O,L,S After-W/O,L,S			.9050 1.3180	.3600 .7160	.2190 .1830
22.	Before-W,L,N/S After-W,H,N/S					
23.	Before-W/O,L,N/S After-W/O,L,N/S	.2550 1.2360				

Empty cells indicate no significance
* W = with conflict; W/O = without conflict
S = signalized; N/S = non-signalized
H = high accident history; L = low accident history
( ) = indicates marginal significance; .10> α >.05

differences between before and after stratification in any third or fourth order interaction comparisons.*

The importance of this analysis of low (control) sites is that it suggests that the differences were not due to observer bias, but to actual site conditions. This examination of observer bias is fundamental to the task of determining the behavioral changes directly due to the implementation of specialized crosswalk illumination.

Variable 3, Concentration, composed of the measures of Motivation and Distraction, was the second most frequently different Variable. Analysis of fourth order interactions showed more direction concentration (less distraction or distracting motivation) at signalized locations in the after condition with and without conflict at both high and low accident locations. Although this finding is somewhat confounding, it suggests that the presence of illumination system was in general conducive to better concentration since the control sites were in close proximity to the high accident crosswalks.

Variable 1, Search Behavior, composed of the Measures of Approach Search, First Half of Crossing Search and Second Half of Crossing Search patterns, generally showed improvement under all condtions in after observations. The difference showed in second, third and fourth order interaction comparisons and indicated that more pedestrians were looking at either the vehicular traffic or all stimuli that are important to safe crossing. It is significant that distraction was reduced. That is, the presence of the LPS system did not create a distractive stimulus to pedestrians that was apparent to observers. This improvement was apparent at both signalized and non-signalized locations under without conflict situations. It may also have been apparent at non-signalized locations under with conflict conditions, but the sample size for such

*A typical third order interaction would be [*before, with and without conflict, low, non-signalized*] versus [*after, with and without conflict, low, non-signalized*] while a fourth order interaction would remove one of the conflict categories from both the before and after cell combinations.

situations was small compared to others. This hinders the determination of significance in the conservative Scheffe´ test.

Variable 2, Crossing Path, composed of Approach Direction, Exit Direction, and Crossing Location, showed marginal improvement in only one comparison of fourth order interactions (before-without conflict-high-signalized versus after-without-high-signalized).

Variable 4, Abnormal Behavior, composed of the Erratic or Inappropriate Behavior Variable showed marginal improvement in only one comparison of before-low versus after-high (fourth order interaction of non signalized, without conflict conditions). The importance of this comparison is that it indicates that high accident locations of the type described which formerly had *greater* Abnormal Behavior than their control sites had now shifted to *less* Abnormal Behavior than their control sites.

Before - After Composite Safety Score

Several analyses of the CSS were conducted by means of univariate and multivariate analysis of variance. The first analysis attempted to find significant differences between before-after (B), high accident and control (A) locations by using the individual site as the unit of analysis. That is, a mean CSS, derived from the averaged pedestrian, driver, and pedestrian plus driver scores for each site was computed. Additional analyses attempted to perform analysis of variance using the individual observation as the unit of analysis, similar to the analysis of behavioral data. These analyses were further refined by covarying out the effects of signalization. A final analysis of variance using a 2x2x2x2 design (before-after x conflict x accident history x signalization - abbreviated as BxCxAxS) was performed on driver scores only. It was this last analysis that provided the most useful results.

No analysis except for that of the driver CSS indicated statistically significant results that were interpretable. Each analysis did indicate some significant differences, however, which indicates that the CSS was a reliable measure of composite safety. (If there were no indications significant differences, then one would have to conclude that either differences really did not exist or that the CSS was not a reliable measure of safety.)

The analysis of driver CSS provided information indicating that significant differences in scores did exist for the main effects of before - after (B), conflict potential (C), and accident history (A), at a .001 level for the F test. Further, the interactions of C-A and C-S also were significant at .017 and .007 levels, respectively.

The interpretation of the analysis of the CSS privides some insight into both the changes in safety and the perception of safety by drivers and pedestrians under the study conditions. The comparison of pooled data, stratified into two groups or a main effect (before and after) indicated that drivers at crosswalks that had special crosswalk illumination achieved higher mean scores, or exibited safer driving behavior than drivers at those same crosswalks before the installation of the LPS system. Pooled data stratified into a with conflict group and a without conflict group demonstrated that drivers exhibited safer behavior in without conflict situations. Surprisingly, when driver data were divided into a high accident history group and a low accident history group, it was found that drivers at high accident history sites had higher (safer) scores than drivers at low accident history sites, although this difference was not as pronounced as those of the before - after comparison and the with - without conflict potential comparison. Table 27 is a summary of the mean CSS scores of these comparisons.

Table 27. Mean CSS Scores for Significant Main Effects

CONDITIONS COMPARED	DRIVER SCORE	INTERPRETATION
Before	21.19	less safe
After	27.07	more safe
With conflict	17.86	less safe
Without conflict	27.39	more safe
High acc. history	25.25	more safe
Low acc. history	22.48	less safe

4.2.3 Summary of Results

The analysis of pedestrian behavior as measured by the five Factor Analysis derived Variables indicated the following conditions which showed significant improvements.

1. Improved Perceived Clothing Brightness
   - After - High Accident - Signalized - With conflict
   - After - High Accident - Signalized - Without conflict
2. Improved Concentration (Reduced Motivation and Distraction)
   - After - High Accident - Signalized - With conflict
   - After - High Accident - Signalized - Without conflict
   - After - Low Accident - Signalized - With conflict
   - After - Low Accident - Signalized - Without conflict
3. Improved Search Behavior (Approach, First Half and Second Half Crossing Search Pattern)
   - After - High Accident - Signalized - With conflict
   - After - High Accident - Signalized - Without conflict
   - After - High Accident - Non-Signalized - With conflict
   - After - High Accident - Non-Signalized - Without conflict
   - After - Low Accident - Signalized - With conflict
   - After - Low Accident - Signalized - Without conflict
   - After - Low Accident - Non-Signalized - With conflict
   - After - Low Accident - Non-Signalized - Without conflict

Although the following results were not statistically significant, in general, improved safety was noted for pedestrians in after conditions under all combinations of accident history (A) and conflict potential (C). Driver safety was unchanged in all combinations of A and C except for with conflict, low accident sites, where driver safety was lower in the after condition. Combined Pedestrian and Driver Scores were higher in the after condition for all combinations of A and C.

These results have a useful interpretation with respect to traffic engineering concepts. Although analytical relationships cannot be devised due to the nature of the data, generalized inferences can be made which provide a notion of how traffic (pedestrian and vehicular) operations can be modified.

More pedestrians appear to pay attention to the aspects of the crossing environment that are most important to a safe crossing. They use a larger portion of the time of their crossing by watching the vehicular traffic, traffic signals, and the roadway ahead. Prior to the implementation of the crosswalk illumination, fewer pedestrians were this attentive in crossing. A smaller proportion of the pedestrians are adversely influenced by distractions in the crossing environment. Also, proportionately fewer show a hazardous motivation or inadvertant disregard of what could be important environmental information while crossing. Common motivation, such as running to catch a bus, may be somewhat relieved because the pedestrian feels that he is more prominantly seen in the crosswalk by the driver of the bus. Abnormal behavior, such as horseplay or walking in the traffic stream has become less frequent, perhaps again because of a feeling of increased visibility (or being "spotlighted") to both motorists and other pedestrians. Perhaps a feeling of the special hazard at the crosswalk may cause the offender to shy away from such activities. The greater frequency of pedestrians who appear to be brighter (more easily seen) is probably the key element of these behavioral improvements.

Drivers are apparently made more aware that a hazardous crosswalk is in their path. Their actions at high accident sites which have been provided with special illumination show a significant improvement, which probably has a basis in the distinctive color of illumination, and the increased level of illumination and increased pavement luminance of the crosswalk, as discussed in the following section.

4.3 PHOTOMETRIC EFFECTIVENESS

The analysis of photometric measurements, discussed in Section 2.5 of this report and in detail of the Phase II research report[27], was re-examined in an attempt to determine how the addition of specialized LPS crosswalk illumination has affected pedestrian safety, especially in terms of potential accident reduction and improved driver performance. Measures of illumination and visibility are considered in this evaluation of effectiveness.

4.3.1 Illumination Evaluation

It was found that average horizontal illumination in the AFTER crosswalk had increased 3.9 to 32.7 times the BEFORE levels with a mean increase of 11.1 times the BEFORE levels. LPS crosswalk luminaires provided clearly delineated crossing zones, which have been recognized by pedestrians as being safer than normal unlighted crosswalks, due in part to the yellow color of the light which symbolized caution to the majority of pedestrians surveyed. Almost all pedestrians surveyed believed that they were more visible to drivers while crossing at these sites. Few respondents reacted negatively towards the LPS luminaires; most were able to see traffic adequately while crossing, indicating the absence of adverse glare effects from these luminaires.

4.3.2 BEFORE-AFTER Visibility Evaluation

To determine the effectiveness of specialized LPS crosswalk illumination toward promoting a safer pedestrian crossing environment a transformation of Weighted-mean Dynamic Visibility Index (WDVI) was performed. WDVI represents an integrated measure of visibility in the crosswalk area during ambient and non-ambient traffic conditions, and has been shown to increase significantly (beyond .10, approaches .05) after the addition of the specialized crosswalk illumination. The transformation of WDVI values utilized the results of Gallagher[23], who determined the relationship between driver responses to a target ahead and the visibility (VI_{amb}) of the target. Figure 12 presents Gallagher's driver response measure, Time-to-Target (TTT, in seconds), as a function of VI. Transforming the mean WDVI for each study site and study condition (Table 18, Section 2.5) yields the TTT values presented in Table 28. These TTT values can be interpreted as signifying the amount of response time provided the motorist in which an object

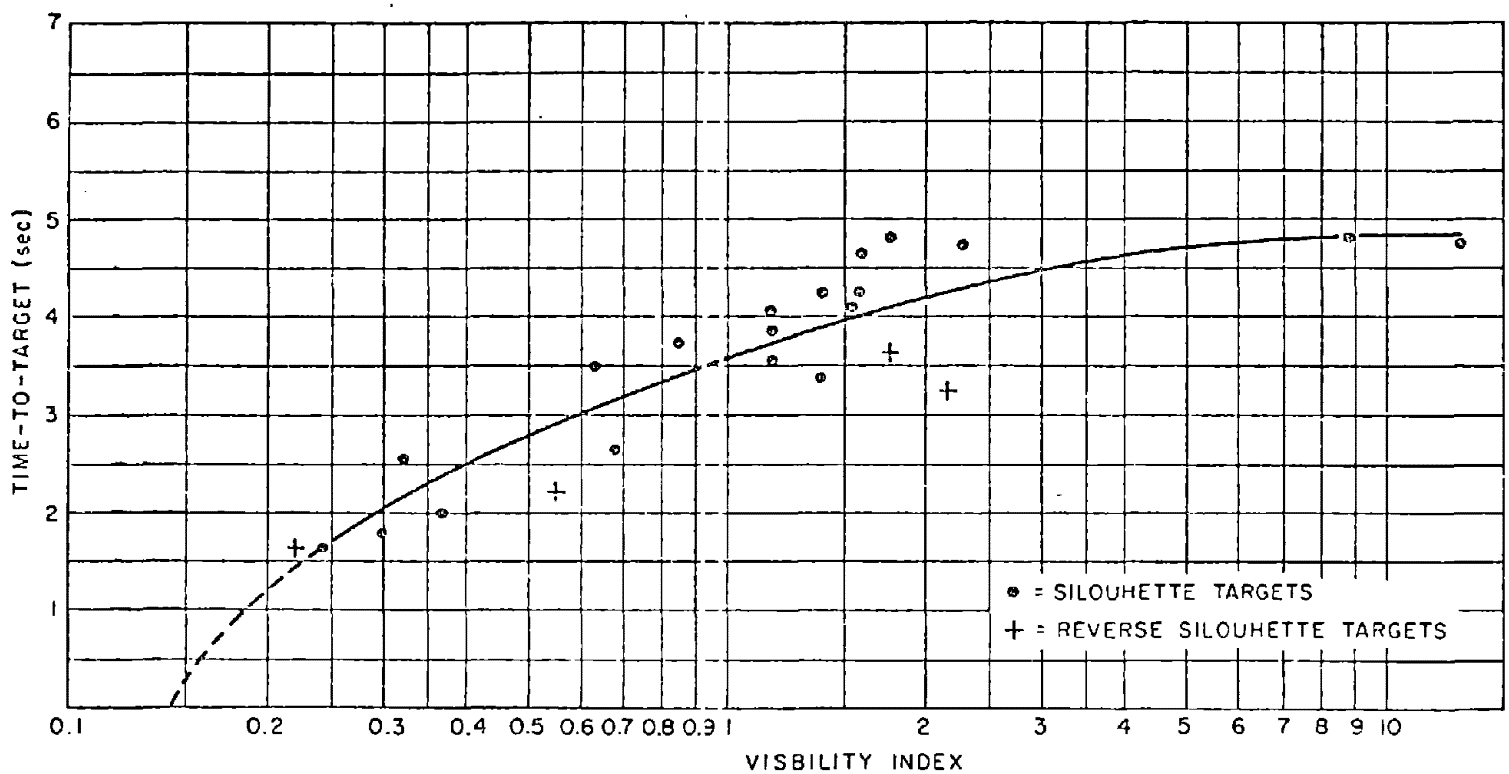

Figure 12. Regression Line for Mean Driver Responses (Raw Data) and Visibility Index

F-C3658

Table 28. TTT (seconds) Based on Mean WDVI for All Study Sites and Conditions.

Site	Condition Before-High	 After-High	 Before-Low
Paul & Torresdale	3.13	3.85	3.95
5th & Ruscomb	3.77	4.00	3.67
5th & Lindley	3.83	3.79	3.84
5th & Cayuga	3.60	3.62	4.02
A & Allegheny	3.67	3.77	3.60
Kensington & Torres.	3.70	4.48	3.69
Kensington & Allegh.	4.30	4.67	4.30
Mean	3.87	4.22	3.91

Note: These TTT values have been derived directly from the WDVI values presented in Table 18, Section 2.5. Since the TTT vs. VI Relationship is non-linear and the transformation of WDVI to TTT is also subject to interpretive errors, "Mean" values above represent the direct transformation of the "Weighted Mean" WDVI values in Table 18 and are not the arithmetic average of TTT for each individual site.

ahead must be detected, the proper vehicle control maneuver must be selected to avoid the target, the maneuver must be executed, and the vehicle must respond appropriately. TTT values determine the time available for responses dependent only upon the visibility of the target. Other driver and vehicle performance factors are not considered.

Table 28 indicates an overall mean TTT for the BEFORE-HIGH condition of 3.87 seconds, and an overall mean TTT for the AFTER-HIGH condition of 4.22 seconds. The increase in TTT resulting from visibility conditions provided by the specialized crosswalk illumination is thus 0.35 seconds, an increase of 9% over the BEFORE-HIGH condition. The consequences for pedestrian crossing safety of this increase in driver responding time can be realized in terms of increased driver stopping sight distance, increased safe driving speed, or simply increased potential visual task performance.

Because of the increased time potential for driver responses provided by the specialized crosswalk illumination, the driver also has available to him more advance knowledge about possible pedestrian conflict in a much larger "visible space" ahead. At an urban roadway design speed of 25 mph (40 kph), the 0.35 second increased responding time yields an increase in stopping sight distance of 12.8 ft. (3.9 m), which could make the crucial difference between striking a crossing pedestrian or stopping short of the crosswalk.

Gallagher[23] has presented minimum roadway visibility requirements for a 50th percentile (median) driver, assuming uniform vehicle deceleration capabilities at a rate of 11 fps^2 (3.35 mps^2) and taking into account safe stopping distances. These requirements are reproduced in Figure 13. The WDVI means transformed to the overall TTT means presented above correspond to minimum visibility requirements for 43 mph (69.2 kph) and 47 mph (75.6 kph) for the BEFORE-HIGH and AFTER-HIGH conditions respectively. Although these safe driving speeds are greater than the design (posted) speed limit at the seven study sites they are not outside of the range of vehicle speeds observed at these sites. The increased TTT resulting from the specialized crosswalk illumination

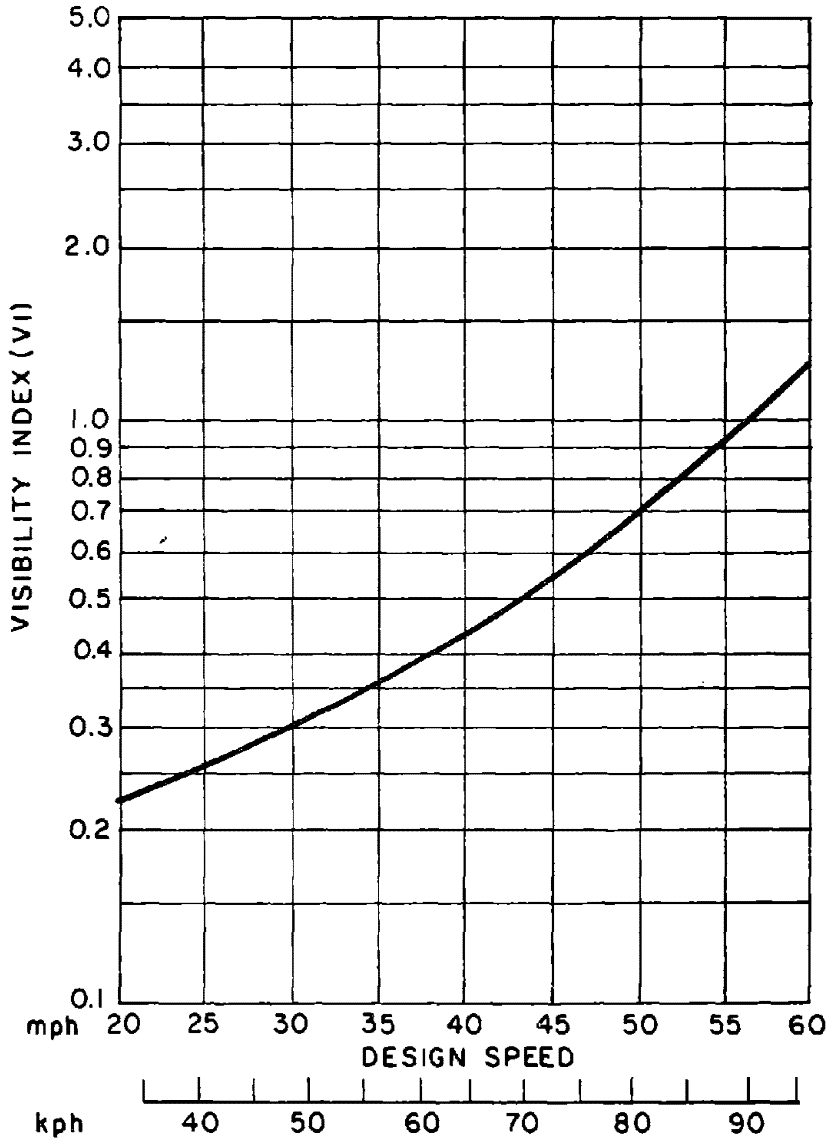

Figure 13. Relationship Between Visibility Requirements and Design Speed for 50th Percentile Driver and Assumed Deceleration of 11 fps^2.

can thus be interpreted as providing for an increase in safe vehicle operating speed of 4 mph (6.4 kph) or 9.3%. While our purpose here is not to advocate higher driving speeds, this increase can be viewed as a practical and effective speed margin for safety.

The third interpretation of the 0.35 second increase in TTT provided by the specialized crosswalk illumination results from an examination of the asymptotic portion of the TTT vs. VI curve in Figure 12. This portion of the relationship between visibility and driver responding time indicates that the maximum possible performance to be expected from visibility increases is a TTT of approximately 5.0 seconds[31]. Assuming this maximum TTT of 5.0 seconds and considering the additional 0.35 seconds available for driver responses results in an increase in potential maximum visual task performance of 7% (.35/5.0).

The only method to infer consequences for pedestrian safety due to increased visibility in the crosswalk area must be based upon the increased driver responding time. In the absence of identified causal relationships between visibility and pedestrian accidents and the lack of accident statistics for the AFTER illumination condition, more definitive conclusions regarding pedestrian crossing safety cannot be made.

4.4 ACCIDENT REDUCTION EFFECTIVENESS

A review of pertinent pedestrian accident data was conducted to determine the effectiveness of pedestrian crosswalk illumination in reducing nighttime pedestrian accidents.

As reported in Phase I research report,[21] and discussed in Section 2.2.2 of this report, specialized crosswalk illumination systems of the type studied in this research resulted in pedestrian accident reduction of between 33% (Copenhagen) and about 60% (Hanover and Switzerland).

In order to determine the system's effectiveness in reducing accidents locally, Philadelphia traffic accident records from July, 1974 to July, 1975 were obtained for the seven intersections installed with FIRL's specialized illumination system. This was done to update our earlier examination of night pedestrian accidents at these seven, and all other accident sites, over a previous three year period. Only three additional night accidents were discovered at our seven test intersections. Table 29 gives a summary of the updated (four year) accident history at the seven test sites.

Table 29. Pedestrian Night Accidents Prior to Operation and Subsequent to Removal of Special Illumination at FIRL Test Sites

INTERSECTION	NUMBER OF ACCIDENTS				
	Treated Crosswalk			Total for Other Crosswalks	Grand Total
	Before Operation	After Removal	Total		
5th & Lineley	4	2	6	2	8
5th & Ruscomb	3	0	3	1	4
5th & Cayuga	2	0	2	0	2
Paul & Torresdale	2	0	2	0	2
Kensington & Torresdale	4	0	4	1	5
Kensington & Allegheny	4	0	4	5	9
A & Allegheny	2	1	3	2	5

Since the completion of the seven illuminated crosswalk systems in March 1975, no pedestrian night accidents have been recorded at any of the seven intersections. Data was available from the City of Philadelphia Traffic Engineering Division only to May 5, 1975 and correspondence was made with the Police Commissioners Office to obtain accident records up to July 14, 1975 when the lighting systems were temporarily suspended.

Table 30 summarizes the before and after accident rates and the accident reduction experience of Philadelphia and three other cities with special LPS crosswalk illumination similar to the Philadelphia system. Since no night pedestrian accidents were reported to have occurred at the test sites during the period in which the experimental systems were in operation, no record of accident reduction can be reported. However, it is believed that because of the similarities in the system configurations, and the similarities in the average annual night accident rates, similar reductions ranging from 33% to 60% should be realized.

Table 30. Summary of Accident Rates/Crossing and Accident Reduction in Cities Using LPS Crosswalk Illumination.

LOCATION	BEFORE SYSTEM INSTALLATION	AFTER SYSTEM INSTALLATION	ACCIDENT REDUCTION
Hanover	0.33	0.12	64%
Switzerland	0.31	0.14	55%
Copenhagen	not reported	not reported	33% reported
Philadelphia (1)	0.31	(2)	unknown
Philadelphia (3)	0.34	no reported change	no reported change
Philadelphia (4)	0.86	(2)	unknown

(1) Rates shown are an updated four year average for all four crosswalks at the intersections at which special crosswalk illumination was installed.

(2) There were no accidents reported in any of the crosswalks during the period of operation of the systems.

(3) Average of all four crosswalks at locations having at least three night pedestrian accidents in a period of three years.

(4) Average of updated four year accident history in the seven high accident crosswalks which were subsequently treated with special crosswalk illumination.

5. COST OF PEDESTRIAN ACCIDENTS

5.1 OBJECTIVE

A review of previous findings and subsequent literature concerning the cost of nighttime pedestrian accidents was performed to provide up-dated information to be used in benefit-cost analysis.

5.2 FINDINGS

The cost associated with pedestrian accidents was addressed by three studies. The first study conducted by Wilbur Smith and Associates[32] computed only the direct costs which included the present value of loss of future earnings and funeral expenses. For the year of April 1, 1964 to March 31, 1965 the average cost of a pedestrian accident was $1425. Adjusting this value to June 1975 according to the consumer price index brings the costs to $2444 per accident.

Another study conducted by Burke and McFarland[33] analyzed both the direct as well as the indirect costs and found an average cost of $5100 per accident in 1969. Adjusting this figure to June 1975 yields a value of $7457 for a pedestrian accident.

Mr. R. J. Peszek of the National Safety Council Statistics Division supplied further information on both the direct and indirect costs of pedestrian accidents. Since NSC classifies all accidents in terms of fatal vs. non-fatal costs, analysis of pedestrian accident costs was determined by a ratio of fatal to non-fatal accidents. The calculable costs of pedestrian accidents are wage loss, medical expense and insurance administrative costs.

In 1973, pedestrian fatalities accounted for 9% of all pedestrian accidents and the calculable cost obtained from NSC for a fatality was $90,000. The average cost for a pedestrian non-fatality was $5000.

Computing the cost of a pedestrian accident in 1973 according to a ratio of fatal to non-fatal accidents, yields a value of $12,650 per pedestrian accident.

6. BENEFIT-COST ANALYSIS

6.1 BENEFITS OF SPECIAL CROSSWALK ILLUMINATION

Although benefits of special crosswalk illumination have been discussed in Section 4 in terms of the effectiveness of such systems, a measure of benefit that is quantifiable in dollars is needed for benefit-cost analysis. The most direct measure of benefit is the accident reduction potential of the LPS system. This benefit is calculated for any individual site by multiplying the known average annual night pedestrian accident history at that site by the percent reduction in accidents expected from the implementation of crosswalk illumination and multiplying that product by an appropriate accident cost.

6.2 BENEFIT COST ANALYSIS

Our benefit cost analysis of installations in Philadelphia utilized the average cost of a pedestrian accident as reported by Burk and McFarland[33], updated to 1975 dollars. This cost ($7457) seemed to be a reasonable median value between the Wilbur Smith[32] estimate ($2444; 1975) and NCS ($12,650; 1975). The four year accident data for the seven installation sites in Philadelphia were used. The potential reduction in accidents was derived from the reported accident reduction in Copenhagen (33%) and Hanover-Switzerland (about 60%). Precise information was not available on the annual cost of the Copenhagen system. Table 31 shows a comparison of benefit-cost analyses of various accident rates in Switzerland and Philadelphia. Three accident rates in Philadelphia are presented in the table. The first considers the total number of accidents in all four crosswalks at each of the seven study sites, and is identical to the reported Swiss rate. The second shows the accident rate for all high accident Philadelphia intersections and again considers all four crosswalks at each. The third considers only the treated crosswalk at each of the study sites, and is probably the most informative indicator of the benefit-cost relationship possible through implementation of special crosswalk illumination.

Table 31. Comparison of Benefit-Cost Ratios for Generalized Swiss and Philadelphia Data

LOCATION	ANNUAL ACCIDENT RATE	ANNUAL ACCIDENT COST ($)	60% REDUCTION BENEFIT ($)	33% REDUCTION BENEFIT ($)	ANNUAL COST PER SYSTEM ($)	60% BENEFIT-COST RATIO	33% BENEFIT-COST RATIO
Switzerland	0.31	2312	1387	763	599	2.32	1.27
Philadelphia(1)	0.31	2312	1387	763	594	2.34	1.28
Philadelphia(2)	0.34	2535	1521	837	594	2.56	1.41
Philadelphia(3)	0.86	6413	3848	2116	594	6.48	3.56

(1) Rate includes accidents at all four crosswalks at each of the seven test sites intersections.

(2) Average rate for all intersections having three or more accidents in a period of three years.

(3) Average rate for high accident crosswalks only at seven test site intersections.

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Table 32 is a summary of the benefit-cost analysis for the individual treated crosswalks in Philadelphia. Annual system costs are based upon the costs reported by the installation contractor, as discussed in Section 3.

It is felt that the 33% reduction is a reasonable estimate of the accident reduction potential of specialized crosswalk illumination. It would be much better, however, to have several years of accident data from operational installation sites in Philadelphia so that local (American) drivers and pedestrians would be the basis for the reduction figures.

6.3 OTHER MEASURES OF EFFECTIVENESS

It is desirable to have a means of economic analysis that does not depend entirely on a generalized predictor of accident reduction. Other measures of effectiveness that relate more directly to individual system and proposed site characteristics could be used for comparison of alternative systems and alternative sites. These measures can include such concepts as an achieved level of safety, satisfaction of informational needs, remediation of particular operational problems, improvement of behavioral patterns, public acceptance, and others. Each of these measures can be at least subjectively assessed for different systems and different sites, and related to a system of weights that are related to the relative importance of the objectives and goals of particular communities. The objective assessment of these measures requires a basis in data that relates them to measurable quantities such as illumination, Visibility Index (VI), Time-To-Target (TTT), traffic volume, Combined Safety Score (CSS), and others. The evaluation of special crosswalk illumination systems in terms of these measures, or cost-effectiveness analysis, was not within the scope of this research. However, in the interest of providing a background for attempts at such analysis, several of the measured concepts that relate to measures of effectiveness are presented.

Table 32. Benefit-Cost Analysis Based on Accident Reduction

STUDY SITE	4 YEAR ACCIDENT HISTORY	ANNUAL ACCIDENT COST ($)	60% REDUCTION ($)	33% REDUCTION ($)	ANNUAL COST OF SYSTEM ($)	60% BENEFIT-COST RATIO	33% BENEFIT-COST RATIO
Paul & Torresdale	2	3,729	2,237	1,230	461	4.85	2.67
5th & Ruscomb	3	5,593	3,356	1,846	531	6.32	3.48
5th & Lindley	6	11,186	6,711	3,691	531	12.64	6.95
5th & Cayuga	2	3,729	2,237	1,230	531	4.21	2.32
Kensington & Torresdale	4	7,457	4,474	2,461	750	5.97	3.28
Kensington & Allegheny	5	9,593	5,593	3,076	750	7.46	4.10
A & Allegheny	3	5,593	3,356	1,846	531	6.32	3.48

6.3.1 Photometric Effectiveness

It is suggested that the measures of effectiveness that deal with satisfaction of informational needs, safety, and improvement of traffic operations are strongly related to the various measures derived from photometric data. These data include average horizontal illumination in the crosswalk and TTT (derived from WDVI), discussed in Sections 2 and 4.

Because the accident reduction potential of specially illuminated crosswalks could not be predicted through any relationship with photometric data, two other measures were considered. The first, illumination effectiveness, is simply the average horizontal illumination within the crosswalk divided by the annual cost of the illumination system. It is a straightforward indication of "how much light" one gets for each dollar invested. The second measure is based upon the WDVI derived concept of TTT. It relates the annual change in TTT to the annual cost of a system. In doing so, the effectiveness measure relates the product of annual nighttime vehicular traffic volume and visibility in terms of TTT to annual cost.

Illumination Effectiveness

The illumination effectiveness for each special crosswalk lighting installation in Philadelphia is presented in Table 33. By this measure, the relatively complex installation (4 luminaires suspended by davit arms from an overhead elevated railroad structure) is the most effective.

TTT Effectiveness

The VI derived measure, based upon TTT, used the change in the annual number of TTT seconds resulting from the implementation of special illumination systems for all vehicles. This measure of effectiveness was derived by multiplying the average annual night traffic volume at each intersection by the TTT change at each intersection, as derived from WDVI and the TTT vs. VI curve (Figure 12, page 79). Table 34 is a summary of this effectiveness measure. It

Table 33. Illumination Effectiveness

STUDY SITE	AVG. ILLUMINATION (fc)	ANNUAL COST	EFFECTIVENESS
Paul & Torresdale	7.41	$461.	.016fc/$
A & Allegheny	7.14	$531.	.013fc/$
5th & Ruscomb	8.30	$531.	.016fc/$
5th & Lindley	8.30	$531.	.016fc/$
5th & Cayuga	7.07	$531.	.013fc/$
Kensington & Allegheny	13.34	$750.	.018fc/$
Kensington & Torresdale	10.98	$750.	.015fc/$
Mean over Sites	8.93	$584.	.015fc/$

Table 34. TTT Effectiveness

STUDY SITE	ANNUAL NIGHT VOL (veh)	TTT (sec/veh) DIFFERENCE	ANNUAL TTT (sec) DIFFERENCE	ANNUAL COST ($)	EFFECTIVENESS (sec/$)
Paul & Torresdale	62000	+.72	+44,640	461	+96.8
5th & Ruscomb	831000	+.23	+191,130	531	+359.9
5th & Lindley	838000	-.04	-33,520	531	-63.1
5th & Cayuga	720000	+.02	+14,400	531	+27.1
Kensington & Torresdale	621000	+.78	+484,380	750	+645.8
Kensington & Allegheny	621000	+.37	+229,770	750	+306.3
A & Allegheny	621000	+.10	+62,100	531	+117.0

should be noted that under this evaluation method, the installation at 5th and Lindley is not warranted, while the Kensington and Torresdale installation is highly effective.

The value of this measure is that it deals with a safety related concept, which predicts the change in response time that a driver would experience, to both vehicular traffic volume and cost. Unfortunately, until better methods are available to either measure or predict VI, most traffic or lighting engineering offices would not be able to apply this procedure of evaluation.

6.3.2 Behavioral Effectiveness

The analyses of behavioral data that was collected in this research cannot be used to address the various effectiveness measures at individual sites for two reasons. First, the method of analysis distinguished between conditions (before-after, conflict potential, accident history, and intersection control), not between individual sites. Second, the nature of the behavioral data and CSS data is at best interval, with no true zero point, preventing mathematical comparisons of the data. However, the CSS analysis results can be used to provide subjectively derived weightings to the various measures of effectiveness when installation sites are grouped according to the aforementioned conditions. It was found that CSS values showed significant differences in comparisons of Before and After, with and without conflict, and High and Low Accident History. Therefore, the consideration of driver CSS in the safety effectiveness measure would create a heavier weighting for installations at high accident sites, and at sites where potential conflict (perhaps due to particular kinds of land use, commercial activity or area location, and pedestrian and/or vehicular volume) is judged through examination of accident reports and site visits to be closely related to pedestrian safety.

6.3.3 Pedestrian and Vehicular Volume Related Effectiveness

Although traffic volume is not a measure of effectiveness of special crosswalk illumination, it can be used to assist in the analysis of priorities for the selection of sites to receive such improvements. That is, consideration of the volume of pedestrians and vehicles that are affected by an installation provides a measure of the need for an individual system. For example, if one had to choose between two proposed installation sites that had the same level of need (expressed in terms of accident rate (accidents per year) community goals, or others), it would be reasonable to select the one that would provide the greatest benefit per pedestrian, driver, or both. Similarly, one could use volume to normalize the benefit-cost evaluation, or other effectiveness measures, of all alternative sites even though those measures were not equal. This normalization would provide a further indication of the need for improvement at each site, particularly when it is conceptualized as a normalizer for accident rate, as in accidents per pedestrian per year.

Through examination of City of Philadelphia traffic count records, it was determined that a good estimate of the nighttime vehicular volume on most arterial streets is about 17% of the daily total. Nighttime is here defined as the ten hour period from about 7:00 P.M until 5:00 A.M. Of course, this varies with time of year, but for an annual estimate, that time period was satisfactory. If actual nighttime counts are desired, they should be taken during the actual hours of darkness for the particular time of year on typical traffic days (Tuesday, Wednesday or Thursday). The pedestrian volumes are (and should be) actual counts from at least 7:00 P.M until midnight, and until 5:00 A.M. if pedestrian activity is great enough past midnight. Average annual nighttime pedestrian and vehicular volumes are shown in Table 35. The benefit-cost analyses of individual sites were recalculated using night pedestrian volume, and combined night pedestrian and vehicular volume. These calculations are summarized in Table 36 and Table 37.

Table 35. Average Annual Nighttime Pedestrian and Vehicular Volumes

STUDY SITE	ANNUAL NIGHT PED. VOL(PEDS/YR)	ANNUAL NIGHT VEH.VOL(VEH/YR)
Paul & Torresdale	19,000	62,000
5th & Ruscomb	14,000	831,000
5th & Lindley	42,000	838,000
5th & Cayuga	19,000	720,000
Kensington & Torresdale	160,000	621,000
Kensington & Allegheny	241,000	621,000
A & Allegheny	30,000	621,000

Table 36. Pedestrian Volume Normalized Accident Reduction Benefit-Cost Analysis

STUDY SITE	NORMALIZED ANNUAL ACCIDENT COST ($)*	60% REDUCTION ($)	33% REDUCTION ($)	ANNUAL SYSTEM COST ($)	60% EFFECTIVENESS	33% EFFECTIVENESS
Paul & Torresdale	196	117	65	461	0.25	0.14
5th & Ruscomb	400	240	132	531	0.45	0.25
5th & Lindley	266	160	88	531	0.30	0.17
5th & Cayuga	196	118	65	531	0.22	0.12
Kensington & Torresdale	47	28	15	750	0.04	0.02
Kensington & Allegheny	39	23	13	750	0.03	0.02
A & Allegheny	186	112	62	531	0.21	0.11

* Normalized annual accident cost = $\dfrac{\left(\dfrac{\text{annual accident cost}}{\text{annual night ped. vol.}}\right)}{1000}$

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Table 37. Total Volume Normalized Accident Reduction Benefit-Cost Analysis

STUDY SITE	NORMALIZED ANNUAL ACCIDENT COST($)*	60% REDUCTION($)	33% REDUCTION($)	ANNUAL SYSTEM COST($)	60% EFFECT-IVENESS	33% EFFECT-IVENESS
Paul & Torresdale	3166	1899	1044	461	4.12	2.26
5th & Ruscomb	481	289	159	531	0.54	0.03
5th & Lindley	318	191	105	531	0.36	0.20
5th & Cayuga	273	164	90	531	0.31	0.17
Kensington & Torresdale	75	45	25	750	0.06	0.03
Kensington & Allegheny	62	37	20	750	0.05	0.03
A & Allegheny	300	180	100	531	0.34	0.19

$$* \text{ Normalized annual accident cost} = \frac{(\text{annual accident cost})}{\dfrac{(\text{annual night ped. vol.})}{1000} \times \dfrac{(\text{annual night veh. vol.})}{1{,}000{,}000}}$$

7. WARRANTS AND DESIGN CRITERIA

7.1 BACKGROUND

The objectives of this portion of the research were to develop, through the results of all previous research within this study, the warrants that indicate the traffic, geometric, pedestrian and environmental conditions under which special supplementary crosswalk illumination should be employed, and to develop design criteria for the selection and implementation of crosswalk illumination.

To accomplish these objectives, the literature was re-examined, behavioral information was utilized, and photometric considerations were employed. In addition, what we consider to be sound transportation engineering judgement was applied to the use of such information in considering the applicability of all warrants and design criteria. We felt that warrants based upon concepts not yet fully developed nor understandable to traffic engineering personnel would serve no useful purpose at this time.

7.1.1 Literature Review

A review of published material dealing with warrants for roadway lighting indicated the following:

Existing warrants for locations utilizing "Crossover" programs were in general not applicable to the type of crosswalk improvements studied in this research. Those warrants are principally based upon a high degree of cooperation between pedestrians and drivers with the purpose of improving safety *and reducing delay*. Through this reduction in delay, pedestrian and vehicular volumes are considered for warranting conditions. The fixed illumination studied in this research is considered passive. That is, no extraordinary cooperation between pedestrian and motorist is required, thus improvement in safety rather than reduction of delay is the goal.

AASHTO has declined to specify warrants for illumination for streets and highways other than freeways[34]. They do report several general warranting considerations, however.

> In general, lighting is considered to be warranted for those locations where the respective governmental agencies concur that lighting will contribute substantially to the efficiency, safety, and comfort of vehicular and pedestrian traffic. Lighting should be provided for all major arterials in urbanized areas and for locations or sections of streets and highways where the ratio of night to day accident rates is high (say higher than the statewise average for all similar locations) and a study indicates that lighting may be expected to significantly reduce the high accident rate. . .Lighting also should be considered at locations where abnormal or unusual weather conditions exist, such as the frequent occurrence of fog, ice or snow. In other situations, lighting may be warranted where studies indicate that the resulting benefits, both tangible and intangible, are in the interest of the general public.

Design criteria have been suggested by AASHTO for both illumination in average horizontal foot candles and uniformity, as shown in Table 38. Other AASHTO considerations for design are as follows:

> There are many locations where very high levels of illumination are provided for streets in the central business district. The reason for the increased illumination, sometimes amounting to ten or more footcandles, is basically a commercial consideration and directed toward making the downtown business area more appealing to shoppers. Illumination of these higher magnitudes is not considered necessary solely for the safe and efficient flow of pedestrian and vehicular traffic.

IES has provided neither specific nor general warrants for roadway illumination. It has prefaced the American National Standard Practice for Roadway Lighting[35] with general information concerning the need for lighting, and the benefits derived from lighting, as follows:

Table 38. AASHTO Recommendations for Average Maintained Illumination for Streets and Highways Other than Freeways.

ROADWAY CLASSIFICATION	AVERAGE MAINTAINED HORIZONTAL FOOTCANDLES*(uniformity) AREA CLASSIFICATION		
	DOWNTOWN	INTERMEDIATE	OUTLYING AND RURAL
Major**	2.0(3:1 to 4:1)	1.4(3:1 to 4:1)	1.0(3:1 to 4:1)
Collector	1.2(3:1 to 4:1)	0.9(3:1 to 4:1)	0.6(3:1 to 4:1)
Local or Minor	0.9(3:1 to 4:1)	0.6(3:1 to 4:1)	0.2***(6:1)

*Average illumination on the traveled way or on the pavement area between curblines of curbed roadways, when the illuminating source is at its lowest output and when the luminaire is in its dirtiest condition.
**Includes expressways with partial control of access. Expressways with full control of access are covered in the section on freeways.
***Includes residential streets.

Source: Ref. 34.

Nightfall brings increased hazards to users of streets and highways because of limited visibility distances. The fatal accident mileage rate at night is more than three times greater than the daytime rate, based on night travel research findings. There are added night factors which account for this high rate increase. These are:

1. Reduced visibility
2. Distraction of extraneous background lighting.
3. Lack of environmental clues (or recognition clues).
4. Defective, inadequate, improperly maintained, or misused vehicle lights.
5. Increased fog, rain, and snow (decreased atmospheric transmussivity).
6. Increased driver fatigue.
7. Increased influence of alcohol and drugs.
8. Different composition of traffic.
9. Different drivers' attitudes and visual capabilities.
10. Declining visual capabilities of people with increasing age (perception, adaptation, accommodation, glare tolerance).

The addition of special crosswalk illumination has been shown to have positive effects on most of these factors. Visibility, as measured in terms of VI and TTT can be improved. Distraction of pedestrian attention has been reduced. A distinct hazardous area recognition clue has been provided to both motorists and pedestrians by the distinctive color, high intensity (measured in both horizontal illumination and background luminance), and sharp definition of the crosswalk illumination. It is possible that increased reaction time may reduce the accident probability of drivers under the influence of drugs or alcohol, but this improvement could be negated by the increased visual inputs to the already overloaded sensory system of such drivers. Although driver fatigue cannot be reduced, the stimulus provided by the increased illumination, luminance, and color of illumination of a special crosswalk system may interrupt the effects of fatigue. Visual capabilities associated with adaptation and glare have been shown to be improved.

IES has further stated:

> The most urgent element that underlies this American National Standard Practice is the provision of proper lighting where it adds to safety and comfort of the vehicular driver, safety of pedestrians, and facilitates traffic flow.

Finally:

> . . .the proper use of roadway lighting as an operative tool provides economic and social benefits to the public including:
>
> 1. Reduction in night accidents, attendant human misery, and economic loss.
> 2. Preventive of crime and aid to police protection.
> 3. Facilitation of traffic flow.
> 4. Promotion of business and industry during night hours.
> 5. Inspiration for community spirit and growth.

In consideration of special situations, IES has indicated design criteria for grade intersections, some of which are recognized as being complicated by pedestrian traffic as well as vehicular traffic. It is specified that the illumination level for these areas should be the summation of the levels of the intersecting roads. Table 39 is a summary of the recommended illumination for the individual roadways.

More recently, IES has proposed recommendations for illumination on sidewalks and pedestrian walkways[36]. In particular, it is recommended that crosswalks at street intersections be provided with additional illumination producing from 1.5 to 2 times the normal roadway lighting level. It should be noted that if roadway intersection illumination is designed to provide the sum of the recommended values for each of the individual roadways, then the crosswalk illumination would be as much as four times the illumination of the individual roadway. Proposed recommended walkway illumination specifications are shown in Table 40.

Table 39. IES Recommendations for Average Maintained Horizontal Illumination.

Roadway and Walkway Classification	Area Classification					
	Commercial		Intermediate		Residential	
	Footcandle	Lux	Footcandle	Lux	Footcandle	Lux
Vehicular Roadways						
Freeway	0.6	6	0.6	6	0.6	6
Major Expressway	2.0	22	1.4	15	1.0	11
Collector	1.2	13	0.9	10	0.6	6
Local	0.9	10	0.6	6	0.4	4
Alleys	0.6	6	0.4	4	0.2	2
Pedestrian Walkways						
Sidewalks	0.9	10	0.6	6	0.2	2
Pedestrian ways	2.0	22	1.0	11	0.5	5

Source Ref. 35.

Table 40. Proposed Recommendation for Average Maintained Horizontal Illumination for Walkways.

Walkway Classification	Horizontal Illumination (Footcandles) Mounting Heights 9' to 15'	Mounting Heights 15' to 30'	Mounting Heights Over 30'
Sidewalks:			
Residential or industrial areas	0.4	0.8	-
Commercial areas	2.0	4.0	5.0
Institutional areas	1.0	2.0	2.5
Pedestrian Ways:			
Park walkways	0.6	1.0	-
Pedestrian tunnels	5.0	-	-
Pedestrian overpasses	0.4	-	-
Pedestrian stairways	0.8	-	-
Roadway crosswalks	**	**	**

** Crosswalks traversing roadways in the middle of long blocks and at street intersections should be provided with additional illumination producing from 1.5 to 2 times the normal roadway lighting level.

Source: Ref. 36

7.1.2 Warrants for Similar Systems

The most relevant warrants and specifications for special crosswalk illumination are found in the German DIN Standard No. 6753[21]. These specifications constitute a supplement to DIN 5044 "Strassenbeleuchtung" (Street Lighting), and are summarized in Section 2.2.3, earlier in this report.

7.1.3 Behavioral Considerations

The analysis of pedestrian and driver observational data indicated that the following conditions were relevant to the development of warrants.

Factor Derived Variables

- In general, significant behavioral improvements occured at *signalized* locations. *Non-signalized* locations did not demonstrate a significant change.
- Only the SEARCH BEHAVIOR variable showed limited significant improvement at non-signalized sites. This finding should be considered in warranting special crosswalk illumination at non-signalized intersections where search and detection failures were found to contribute to the cause of accidents.

Combined Safety Score (CSS)

- Driver scores improved at high accident sites and under all "after" conditions.

Pedestrian Observational Variables

- In general, "after" conditions showed improvement over "before" conditions in High accident crosswalks for the following variables:

  Approach Search Pattern
  First Half of Crossing Search Pattern
  Second Half of Crossing Search Pattern
  Approcah Search Time
  First Half Search Time
  Second Half Search Time
  Clothing Brightness

7.1.4 Other Considerations

Benefit-cost analysis and other measures of effectiveness indicated that for the measures used, the simple, non-signalized intersections had high effectiveness values for illumination, TTT, and combined pedestrian and vehicle volume normalized accident reduction. They had low effectiveness when system cost was divided by pedestrian volume, however.

7.2 WARRANTS

Through consideration of the contributions of the literature, existing warrants, behavioral information, photometrics, and cost-benefit analysis, and based upon experience in field data collection and engineering judgement, the following warrants are suggested for application to specialized crosswalk illumination. The satisfaction of any one of these warrants is considered sufficient to justify the implementation of special crosswalk illumination.

7.2.1 Volume Warrant

Special crosswalk illumination shall be warranted if the following minimum average of at least three nights of traffic counts of pedestrian and vehicular volumes are present during the night time period of 10 hour duration from the beginning of darkness until dawn, on nights representative of normal traffic patterns, according to the following area-roadway classification.

		ROADWAY CLASSIFICATION		
		MAJOR ARTERIAL	COLLECTOR DISTRIBUTOR	LOCAL
AREA	CBD - (COMMERCIAL)	*	500 veh/night 100 ped/night	200 veh/night 50 ped/night
AREA	FRINGE (INTERMEDIATE)	1000 veh/night 100 ped/night	500 veh/night 100 ped/night	200 veh/night 50 ped/night
AREA	OBD (INTERMED-COMM)	1000 veh/night 100 ped/night	500 veh/night 100 ped/night	200 veh/night 50 ped/night
AREA	RESIDENTIAL	1000 veh/night 50 ped/night	500 veh/night 50 ped/night	200 veh/night 50 ped/night

*Because of the generally high volume of pedestrian and vehicular traffic at these types of locations, it is recommended that other warrants be examined for justification of special lighting.

Figure 14. Warranting Conditions According to Volume

The pedestrian and vehicular traffic volumes shown for each roadway-area classification were derived through experience in data collection (traffic counts and pedestrian observations), pedestrian accident reports, and benefit-cost analysis. The actual volumes shown in the table are the minimum average volumes, rounded to the nearest 100 vehicles and nearest 50 pedestrians, of the accident sites that were both evaluated in our initial study of pedestrian accidents in Philadelphia, and visited during the observational experiments. Theoretically, the minimum warranting volumes should be those that result in a benefit-cost ratio of exactly 1.0, assuming that accident production is related to volume and environment in a predictable way. In actuality, the lowest benefit-cost ratio calculated for the observed sites, based upon a 33% accident reduction potential, was 2.32:1. However, in the interest of conservatism in predicting accident reduction potential, and to prevent the initiative to install special crosswalk illumination solely on the basis of traffic volumes, the tabular values are suggested for the minimum warranting volume conditions. This warrant applies when it is determined that conventional illumination systems designed to provide the crosswalk illumination levels recommended by IES will not reduce pedestrian accident potential. This determination should be made by comparing environmental and traffic conditions at other sites which have been improved to the illumination levels recommended by IES to the site under consideration for special crosswalk illumination, and relating this comparison to the accident reduction experienced at those other sites. A measure that is useful for comparison is the difference between the ratio of night-to-day accidents both before and after the improvement to IES recommendations at those other sites. However, engineering judgement must be used to relate the differences between improved sites and the site under consideration to the accident reduction potential, because neither IES nor other sources have reported the effect of the recommended conventional lighting improvement on pedestrian safety.

Pedestrians volume during that time period is defined as the total volume of pedestrians crossing the roadway in the subject crosswalk during the ten (10) hour period for all area classifications except residential. For residential areas, the pedestrian volume may be taken as the total number of pedestrian crossing in all crosswalks which traverse the roadway in the direction of the subject crosswalks. Vehicular volume during that time period is the total number of vehicles which pass across the subject crosswalk, by either through or turning movements. Measurement of the subject pedestrian and vehicular volumes should be avoided during periods of atypical activity, such as Christmas shopping season in the CBD.

Special attention is recommended for locations at which pedestrian traffic is not uniform throughout the evening. Where this traffic is frequently heavy (at least 10 times each night) for short periods of time (in which arriving pedestrians are platooned), at such locations as major transit stops, schools, hospitals and large industrial operations, crosswalk illumination shall be warranted if the sum of the volumes recorded for the peak five minutes of five separate platooned arrivals is equal to the warranting volumes shown in Figure 14.

For locations at which heavy pedestrian activity exists for a single period of short duration each night (e.g., early evening in summer) or is highly seasonal, permanently installed special crosswalk illumination is not warranted.

7.2.2 Accident Warrant

Special crosswalk illumination shall be warranted provided a study of four consecutive years of night time accidents indicates a minimum of three (3) pedestrian accidents in the subject crosswalk which may be partially or wholly attributed to poor visibility of the pedestrian and which condition can be remedied by illumination.

To determine whether or not pedestrian accidents may be attributed to visibility factors that may be remedied by crosswalk illumination, the engineer should make a complete investigation of several sources of information. They are:

1. Accident records and/or interviews with victims:

- Did accidents occur at night?
- Were drivers able to see the pedestrian?
- Were drivers aware of the presence of the crosswalks?
- Was glare produced by other vehicles a factor?
- Would the provision of increased reaction time have prevented the accidents?
- Was driver fatigue a factor?
- Was the pedestrian distracted by environmental stimuli?
- Was the pedestrian attentive to vehicular traffic and signal indications?

2. Accident site visit
   - Do physical obstructions exist which block the view of drivers?
   - Do background glare sources exist which may affect the driver?

3. Observations of random pedestrian crossings (minimum of 100 per accident crosswalk over a period of at least 3 nights)
   - Record total volume of vehicles traversing the crosswalk
   - Record total volume of pedestrians using the crosswalk(s)
   - Record the frequency of pedestrians exhibiting behavioral characteristics shown in Figure 15. If the frequency of occurrance of any one of these characteristics is found to be 5% of the total, then a visibility-behavior deficiency will be established.

Although the benefit-cost ratio of reduction in annual accident costs to illumination cost is greater than 1 for a reduction of 33% at an intersection with only one accident in four years, it is reasonable to require a four year history of at least three accidents to ensure that the pattern of accidents suggests inadequate visibility due to poor lighting. However, if it is obvious after only one accident (or none) that a lighting-visibility problem exists, and would continue to exist at illumination levels recommended by IES for crosswalks, crosswalk illumination shall be warranted.

7.2.3 Adverse Geometry and Environment Warrant

Special crosswalk illumination shall be warranted when roadway geometry, local structures, and/or environmental conditions such as the prevalance of fog, etc. cause reduced pedestrian visibility in the presence of conventional intersection illumination which may be improved by the application of special crosswalk illumination.

1. Did the pedestrian cross the street outside of the crosswalk, but within 25 feet of the crosswalk, during any portion of the crossing?

2. Was the direction of travel of the pedestrian approach (prior to entering) the crosswalk from any direction other than parallel to the crosswalk (did he turn into the crosswalk)?

3. Was the direction of travel of the pedestrian exiting the crosswalk toward any direction other than parallel to the crosswalk?

Was pedestrian attention directed other than toward vehicular traffic or traffic signals -

4. in his approach to the crosswalk?

5. in the first half of the crossing?

6. in the second half of the crossing?

7. Was the pedestrian motivated to hurry the crossing or run in the crossing for a bus, taxi cab, etc.?

8. Was the pedestrian distracted by noise, street activity, bright lights, other pedestrians, etc?

9. Did the pedestrian exhibit any erratic or inappropriate crossing behavior such as crossing against the signal, horseplay, daring traffic, walking in the traffic strea, inattention to traffic or signals, or staggering?

10. Did the brightness of the overall appearance of the pedestrian seem to be dark, very dark, or black?

Figure 15. Checklist for Pedestrian Characteristics to Determine Visibility - Behavior Deficiency

Such illumination shall be warranted if the visibility of pedestrians by approaching motorists is limited by adverse geometry, local structures or environmental conditions to the extent that pedestrians cannot be seen until the motorists is within the normal safe stopping distance to the crosswalk*. Such reductions in visibility may be the result of horizontal or vertical curvature, or the presence of physical obstructions in the motorist's field of view of the portions of the crosswalk. Further, special crosswalk illumination will be warranted in locations where it is determined that the presence of background and/or surrounding lighting for advertisement, etc., will distract the motorist so that the effect of conventional illumination is negated.

Special attention should be given to this warrant for proposed installations in CBD and OBD areas because of the relatively high frequency of sites in which such adverse geometry and environment exist.

This warrant has been established in accordance with the concept that the distinctive color of illumination of the specially designed system will serve as a visual clue to drivers and pedestrians that a hazardous area is ahead.

7.2.4 Photometric Warrant

Special crosswalk illumination shall be warranted when the existing illumination at the subject crosswalk is less than 1.5 times the prescribed roadway illumination level of the intersection, not to exceed 4.0 fc (40 lux), *and* the ACCIDENT WARRANT is satisfied to 2/3 of what warranting criterion.

This warrant is established in the spirit of compliance with proposed IES recommendations for intersection crosswalk illumination[36] and in consideration of cost-benefit analysis. It should be realized that compliance with the proposed IES recommendations for illumination

* Safe stopping distance to the crosswalk is defined by the formula

$$Sd = 1.47\ Vt + \frac{V^2}{30\ (f \pm g)}$$

V = velocity in miles per hour
f = coefficient of friction
g = the percent grade divided by 100
t = the perception-reaction time in seconds.

at intersection crosswalks may be sufficient to reduce pedestrian accident potential in crosswalks by conventional means at a much lower cost than the application of special crosswalk illumination, when such recommendations have not been met.

A photometric warrant based upon the concept of VI is here proposed as follows:

Special crosswalk illumination shall be warranted if the Weighted Dynamic Visibility Index (WDVI), as discussed in Section 2 and Section 4, is found to be less than the prescribed value, read from Figure 9 (page 82), for the particular design speed at the crosswalk under consideration.

It is recommended at this time that the VI warrant be further investigated and verified because of the infancy of the concept. Further, since very few organizations possess the instruments to measure target luminance and background luminance in the manner necessary to calculate VI or WDVI, it is recommended that this warrant be deferred from inclusion in the user's manual.

7.2.5 Pedestrian Behavior Warrant

Special crosswalk illumination shall be warranted when it is determined that a minimum proportion equal to 5% of observed pedestrians using the subject crosswalk are demonstrating inadequate search and detection behavior, show dangerous distraction to surrounding stimuli, or demonstrate erratic or inappropriate crossing behavior as discussed in the ACCIDENT WARRANT, and the VOLUME WARRANT is satisfied to 2/3 of the prescribed level. It is recommended that the behavioral characteristics shown in Figure 15 be used for observational measures, and that observations of pedestrian crossings be conducted as prescribed in the ACCIDENT WARRANT.

7.2.6 Combined Warrant

Special crosswalk illumination may be warranted if any two of the above warrants are met to 2/3 of the prescribed levels, or responsible traffic engineering and illumination engineering judgement along with local governmental concurrence indicates the advisability and desirability of such special crosswalk illumination.

7.3 DESIGN CRITERIA

7.3.1 Luminance and Visibility Index

If it is within the capability of the design agency, special crosswalk illumination should be designed to produce a luminance level of objects (pedestrians) in the crosswalk (L_t) and in combination with fixed and dynamic (vehicular) illumination sources in the background, a background luminance (L_b) in such proportion to produce luminance contrast (C) that will provide the prescribed VI based upon WDVI for the desired design speed. This relationship between VI and speed is shown in Figure 9 (page 82), and the formula for C and VI are the following:

$$C = \frac{L_t - L_b}{L_b}$$

$$VI = |C| \times RCS_{Lb} \times DGF$$

These relationships are discussed in Section 2.5 and are fully developed by Gallagher[23]. The procedure for calculating Weighted Dynamic Visibility Index* (WDVI), is fully discussed in the Phase II Interim Report[27]. A summary of values of VI for particular design speeds based upon a 50th percentile driver and 11fps^2 deceleration is shown in Table 41.

Table 41. Common Values of Design Speed and VI

DESIGN SPEED (mph)	PRESCRIBED VI
20	0.23
25	0.25
30	0.30
35	0.35
40	0.43
45	0.54
50	0.70
55	0.94

*WDVI is an integrated measure of the Visibility Index as it is affected by the presence of vehicular traffic over time, under operating conditions

7.3.2 Illumination

If luminance measurement and WDVI calculation are not within the capability of the design agency, the design of specialized crosswalk systems should provide an average illumination level within the crosswalk area of at least 7.0 horizontal foot candles (75 lux). This area should extend onto the adjacent sidewalk area at least as far as the area that pedestrians use for waiting.

Color of illumination should be distinctive, yet not distracting. Low pressure sodium lamps, which produce characteristic monochromatic yellow light are best suited for this purpose. These lamps should not be used where it is required to distinguish colors, however. It is for that reason that low pressure sodium lamps are not recommended for *continuous* lighting on streets carrying both vehicular and pedestrian traffic, but they are recommended for special purpose *local* lighting, such as specially illuminated crosswalks[37].

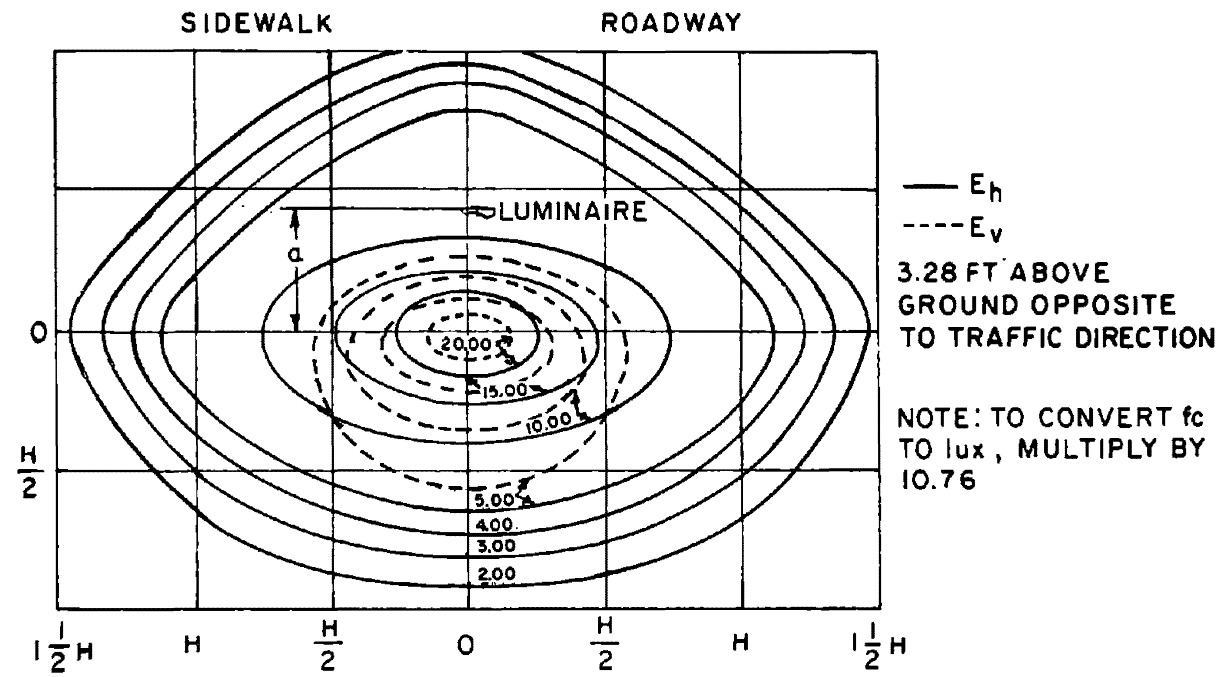
The distribution of illumination within the crosswalk should be designed so that the crosswalk area is clearly defined by a contrasting color band of light on the pavement surface. Figure 16 shows a desirable illumination distribution pattern for special crosswalk luminaires suspended at a mounting height of 16 feet (5 m). Table 42 lists factors to be applied to the illumination values of Figure 16 for other mounting heights.

The illumination uniformity (average to minimum) should be no greater than 4:1.

Glare produced by the crosswalk illumination must be minimized. This is best accomplished by means of a luminaire design which is asymmetrical and conforms to the full IES "cutoff" specification for luminaires*.

---

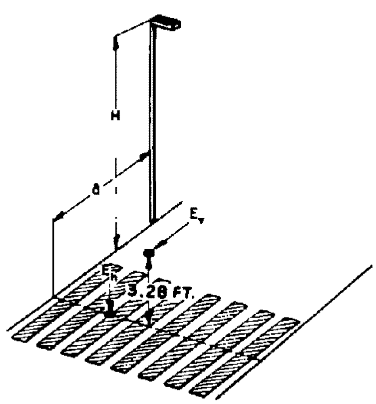
* A luminaire light distribution is designated by IES as cutoff when the candlepower per 1000 lamp lumens does not numerically exceeed 25 (2-1/2 percent) at an angle of 90 degrees above nadir (horizontal); and 100 (10 percent) at a vertical angle of 80 degrees above nadir. This applies to any lateral angle around the luminaire.



Source Ref. 39 (original table shown in lux)

Figure 16. Distribution of Illumination Values (fc) for a Mounting Height of 16 ft. (5m)

Table 42. Dimensions of Street Relative to Mounting Height.



H(ft)	a(ft)	FACTOR for E_h	FACTOR for E_v
13.12	5.67	1.560	0.780
16.40	7.54	1.000	1.000
19.68	9.45	0.695	0.640
22.96	11.35	0.510	0.440
24.60	12.33	0.447	0.380
26.24	13.25	0.391	0.327
29.52	15.12	0.309	0.250
32.80	16.99	0.250	0.197

E_h = horizontal illumination

E_v = vertical illumination

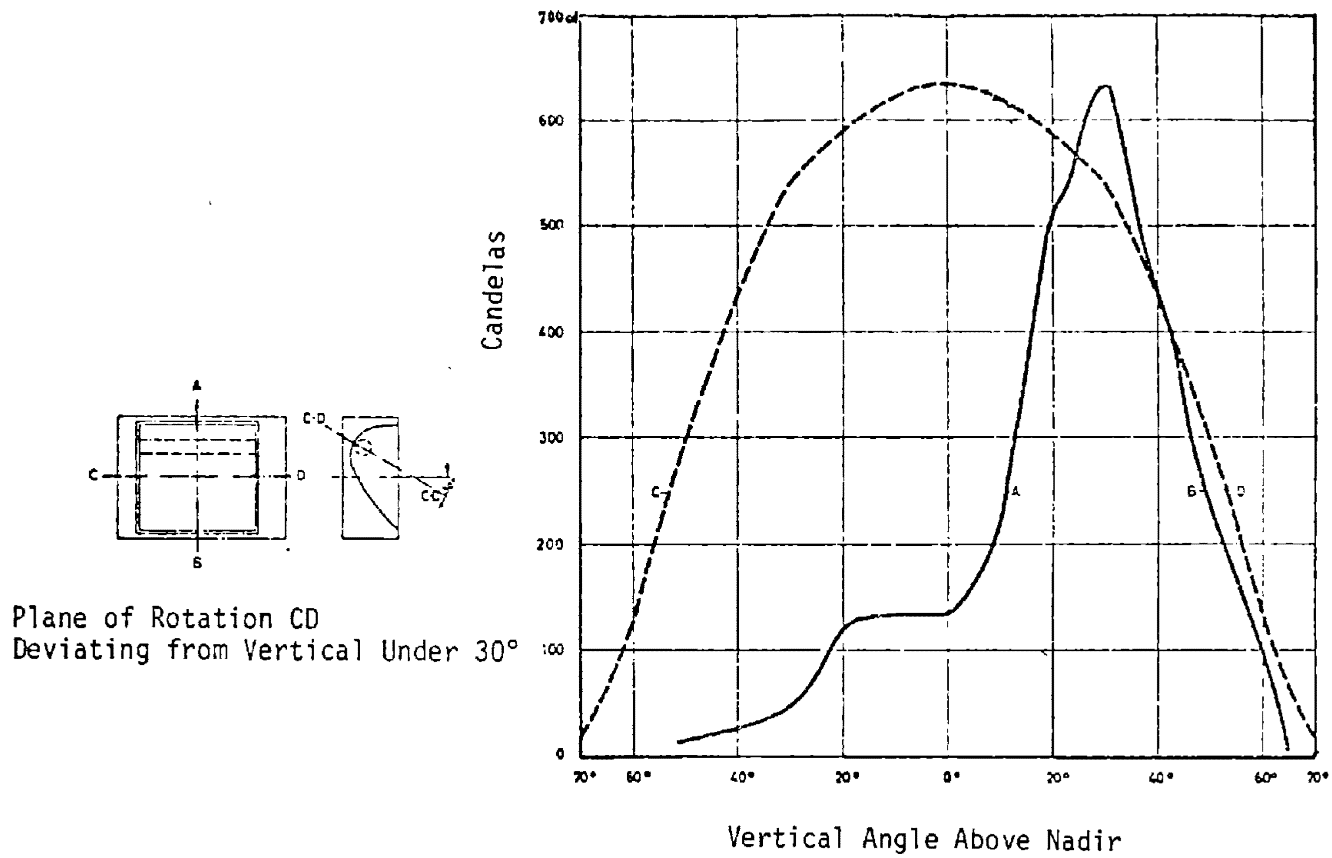
A suggested luminaire candela distribution is depicted in Figure 17.

7.3.3 Installation Specifications

Luminaires should be located to take maximum advantage of their asymmetrical, anti-glare design. For a mounting height of 16 feet (5m), each luminaire should be placed 7.1 feet (2.3m) from the centerline of the crosswalk in the direction which is opposite to the flow of traffic in the lanes over which the luminaire is suspended. Figure 18 depicts this mounting location for two way streets. Each luminaire should be responsible for illuminating a distance of no more than 30 feet (9.2m) on the roadway in the direction perpendicular to the flow of traffic. The luminaires on either side of the street closest to the curb should therefore be mounted not more than 15 feet (4.6m) out from the curb line, or less when portions of the sidewalk are to be illuminated.

The luminaires may be suspended over the crosswalk by means of span wires, davit arms, or mast arms. Where overhead clearance is restricted, such as locations having overhead trolley wires, etc, span wire mounting is not advised. Light weight davit arms, cantilevered from wooden or metal poles and stayed with steel cables to the pole when necessary is a relatively inexpensive mounting methods. Cantilevered mast arms provide a clean, uncluttered mounting method, but may be inordinately expensive. Figure 19 depicts these three mounting methods. Either symmetrical or asymmetrical luminaires may be used, depending upon the location of the span wire, mast arm or davit arm with respect to the center line of the crosswalk.

The luminaires must be mounted so that the refractor base is parallel to the crosswalk surface to ensure the most uniform distribution of light in the crosswalk. When asymmetrical luminaires are used, the side of the fixture toward which the lamp is offset must be toward the *upstream* traffic side of the crosswalk.



Source: Reference 38

Figure 17. Candela Distribution for Asymmetrical (Anti-Glare) Luminaire

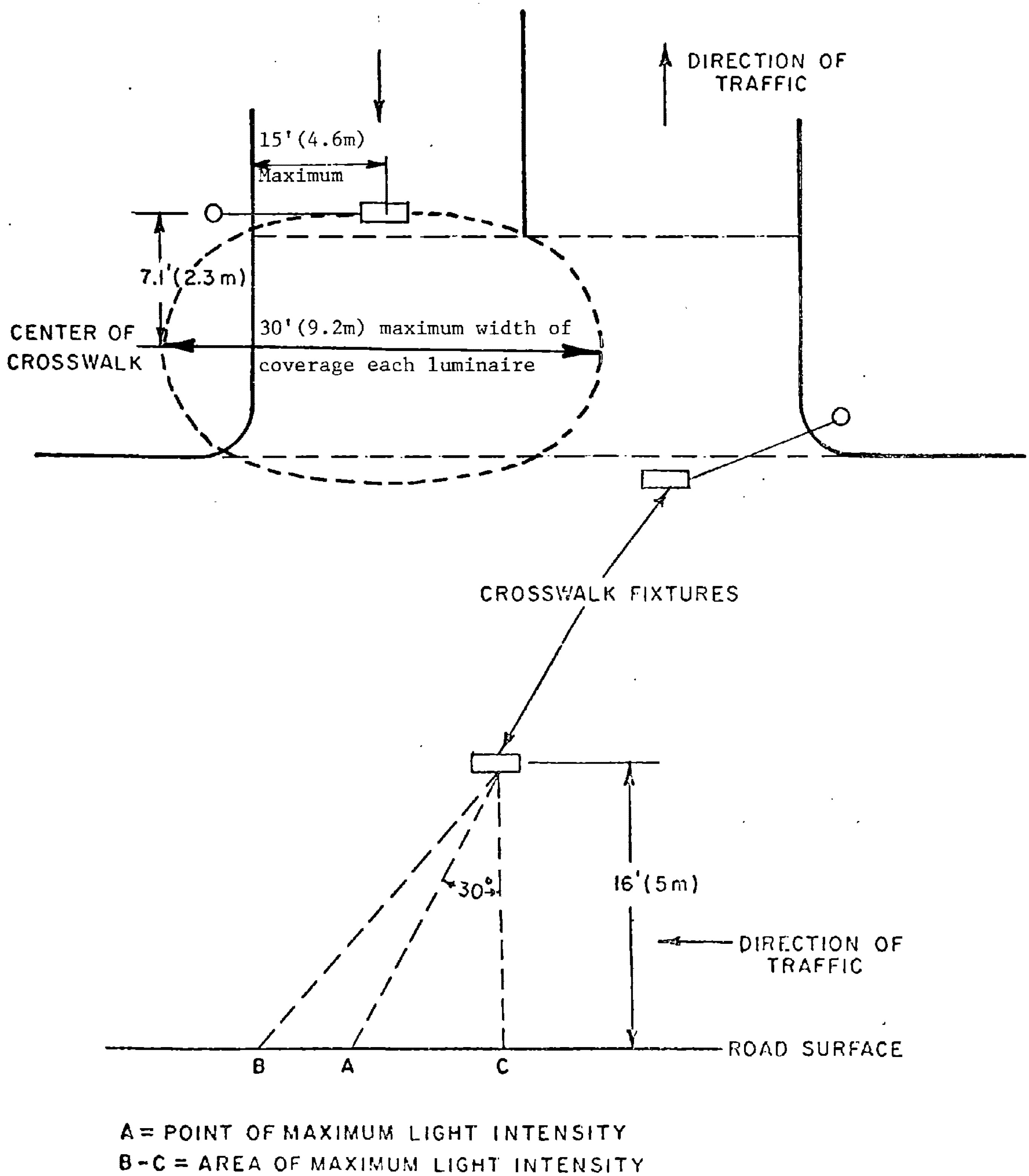


Figure 18. Light Distribution of Crosswalk Fixture

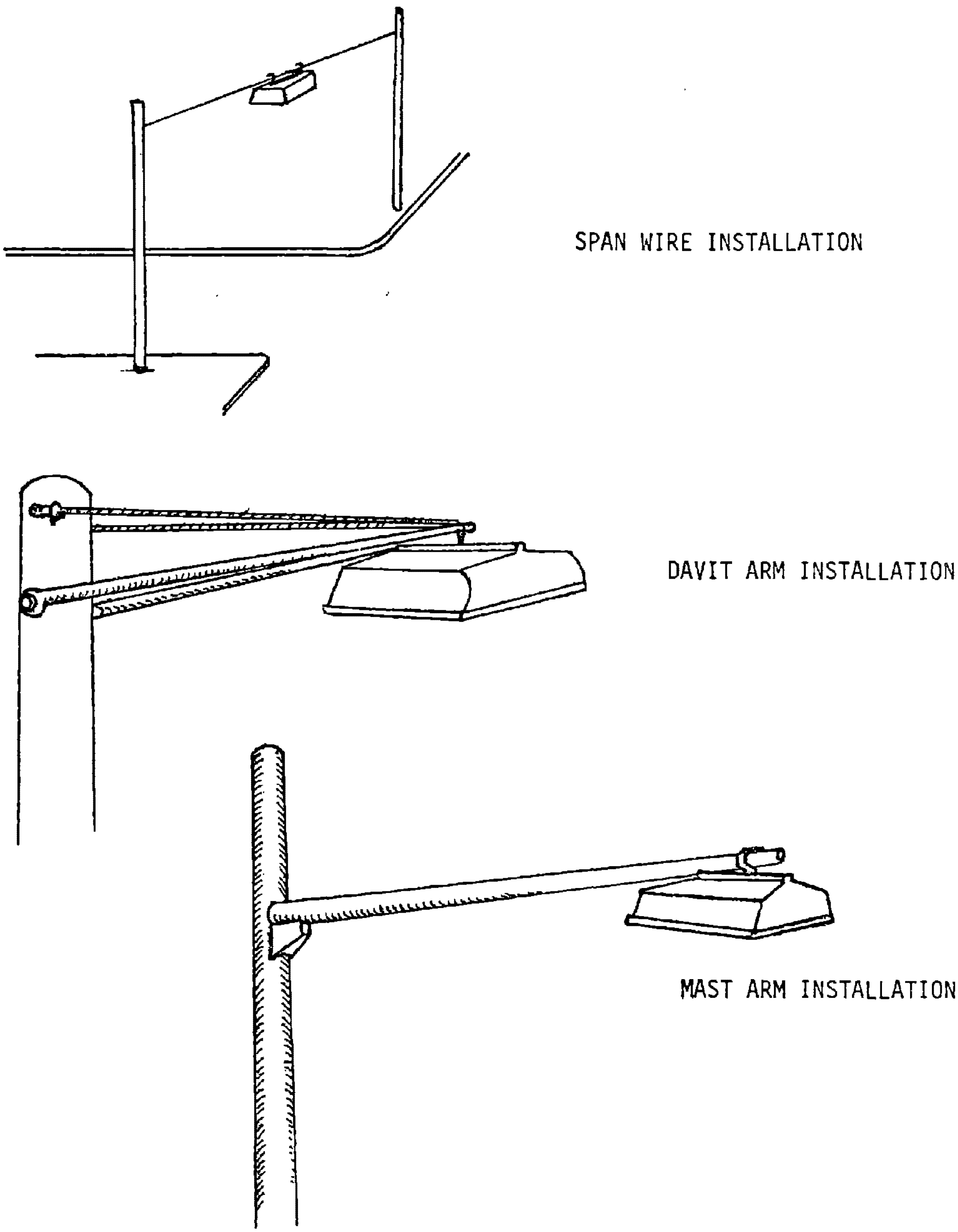


Figure 19. Alternative Methods of Mounting Crosswalk Luminaires

7.3.4 Intersection Geometry and Environment

Specialized LPS crosswalk illumination can be installed in locations where the visibility of pedestrians by approaching motorists is limited by adverse geometry, local structures or environmental conditions to the extent that pedestrians cannot be seen until the motorist is within normal safe stopping distance of the crosswalk.

The most important design criteria for the consideration of adverse geometry and environment is the provision of sharply defined illumination of contrasting color in the crosswalk. This will provide a distinct visual clue to both motorists and pedestrians that special hazard exists in that location. The motorist should become aware of this hazard when he sees the color and intensity of the luminous flux, even though his vision of the crosswalk may be blocked.

Such visibility reductions may be the result of horizontal or vertical curvature, or the presence of physical obstructions in the motorist's field of view of the crosswalk. When such conditions are found, means should be sought to remove, to the extent possible, any such obstructions. For example, trees and/or shrubbery may be trimmed, movable obstructions, such as newspaper stands, etc. may be relocated, bus stops can be made "far side" rather than "near side", and others. A strictly enforced policy of no parking within at least 30 ft. (9.2m) of the crosswalk should be considered if parking creates visibility restrictions.

7.4 ASSESSMENT OF PRIORITIES

7.4.1 Objectives

If supplemental crosswalk illumination is to find application in this country, the relatively expensive installations will immediately compete for funding with other intersection improvement alternatives, as well as affect whatever lighting program exists in the area in which the special illumination is considered. This competition for limited funds will require judicious decision making on the part of those parties involved with the planning and implementation of such systems. To assist in this potential problem, the objective of this portion of the research was to develop the means by which the prospective user of the research results could determine how to select sites for crosswalk illumination. Two specific questions were addressed:

1. What will be the criteria for selection of sites?
2. How will the user select these sites given competing projects?

To illustrate the developed methodology, an analytical pilot study, or sample problem using actual field data, was conducted.

7.4.2 Selection Criteria

The prospective user of the research results should make use of as many of the following selection criteria as possible:

Accidents:

As discussed in the Warrants, night pedestrian accident history should be examined over at least a four year period. Each accident should be examined in detail to determine whether or not supplemental illumination is an appropriate treatment to improve pedestrian safety. For example, a location may have a history of accidents in which vehicles negotiating turns ran into pedestrians, indicating a right of way conflict which may be better treated by a traffic signal with a separate pedestrian phase. Or, intersection dash or dart out accidents may be avoidable via increased time to target that can result from supplemental crosswalk illumination. For the selection of sites to be improved by illumination, only the accidents that may be effectively treated by such illumination should be compiled and considered for comparative evaluation.

Visibility:

Problems associated with visibility must also be considered with respect to their treatability via special illumination. Physical or environmental factors which cause reduced visibility may be independent of illumination, such as severe horizontal or vertical curvature, or structures which block vision. Site visits are necessary to assess the extent to which illumination can improve conditions. Ultimately, an evaluation utilizing a visibility metric, such as VI and the associated TTT, conducted by means of appropriate photometric equipment and anlaysis, should be conducted if possible.

Traffic Volumes:

Pedestrian and vehicular volume must be considered in site selection. Evaluation techniques based upon such data may give different priority results, depending upon engineering and community values. For example, a site with a high accident frequency history and very high pedestrian volumes would yield a high priority based on frequency of accidents, yet a low priority based on accident rate. Conversely, a very low volume intersection with few accidents could produce the opposite analysis conclusions. Community values and engineering judgement must be applied in the establishment of priorities, based upon goals. If the goal is to accomplish the reduction of the greatest number of accidents, then frequency would establish priority. Alternatively, priority may be established by accident rate. Consideration of cost-benefit analysis normalized by traffic volume can help to sort out such apparently conflicting conclusions.

Community Values:

The goals and values of the local community are of considerable importance in establishing the priority of crosswalks to be treated.

For example, a *stated* goal may be that the very young and elderly should be considered first. In that case, locations with low or no accident history, but whose potential for accidents causes considerable community concern, may receive first priority.

Funds:

It is quite rare that a community has unlimited funds that can be used to implement all desired improvement projects. It is therefore necessary to consider the budgetary framework within which improvements are to be planned. Alternative projects, alternative sites, and alternative improvements at sites always compete for available funding. It may be necessary to consider *staging* improvements. That is, improved illumination for intersection crosswalks having substandard lighting (according to IES Recommendations) may first be brought up to a minimum standard at a substantially lower cost than special illumination. After a period of time, if it is determined that sufficient improvement has taken place, no additional lighting may be necessary. Or, special illumination may be installed at a later date. In either case, the initial decision to incrementally improve the site illumination would allow the available funds to be used for improvements at other sites.

7.4.3 Proposed Methodology

The prospective user of the research results should utilize the following framework for the selection of sites for supplemental illumination, given competing projects.

- Examine accident history over a four year period to determine the number of accidents at each site that may be treated by supplemental illumination. Visit the accident sites.
- List the sites by rank according to treatable accident frequency.
- Calculate the accident rate at each site based upon pedestrian and vehicular volumes.
- Examine public opinion and governmental desires. Identify community goals.
- Consider other sites independent of accident history, but based upon community goals.

- Examine warrants for special crosswalk illumination and compare to site conditions. Eliminate unwarranted sites.
- Prepare a list of warranted sites for preliminary design and comparison - perform preliminary designs and prepare cost alternatives for each site.
- Apply selection criteria based upon accidents, visibility traffic volumes, community values and economic considerations.
- Establish preliminary priority of sites by ranking locations according to the application of selection criteria - a separate ranking should be performed for each criterion. Apply community values and engineering judgement to the separate priority list of sites and their associated improvements. Each of the selection criteria should be evaluated with respect to its relative importance to the others. For example, it may be decided that the accident frequency criterion is twice as important as accident rate, which is three times as important as community values, which is twice as important as cost considerations. Then the scale factors in this example would be as follows:

  accident frequency: 1

  accident rate : 2

  community values: 6

  cost: 12

  Each community must specify its own judgement of the relative importance of selection criteria, based upon its goals. If five alternatives, representing 3 sites, of which 2 have alternative designs, were being considered and their individual criterion rankings were shown in Table 43, then their composite priority would be determined by multiplying each criterion ranking by its appropriate scale factor, and ranking the resulting scores with the lowest number representing the highest priority, as shown in Table 44.

- Select the alternative for each site receiving the highest priority and then assign a priority to each site.
- Compare the budget constraints to the costs of improvements. Select the sites according to priority which fit within the budget or revise the site designs (utilizing a staged plan of implementation, if possible) so that more sites may be necessary following design changes.

Table 43. Individual Criterion Rankings for Sites A, B and C.

	ACCIDENT FREQUENCY	ACCIDENT RATE	COMMUNITY VALUES	COST
High Rank (1)	A_1	A_2	B_1	A_2
(2)	A_2	A_1	A_1	A_1
(3)	B_1	C	A_2	C
(4)	B_2	B_2	C	B_2
Low Rank (5)	C	B_1	B_2	B_1

Table 44. Composite Priority Calculation

SITE OR ALTERNATIVE	ACCIDENT FREQUENCY	+	ACCIDENT RATE	+	COMMUNITY VALUES	+	COST	TOTAL SCORE	PRIORITY
A_1	1 x 1		2 x 2		2 x 6		2 x 12	41	2
A_2	2 x 1		1 x 2		3 x 6		1 x 12	34	1
B_1	3 x 1		5 x 2		1 x 6		5 x 12	79	4
B_2	4 x 1		4 x 2		5 x 6		4 x 12	90	5
C	5 x 1		3 x 2		4 x 6		3 x 12	71	3

7.4.4 Analytical Pilot Study

The following sample analytical study of 3 crosswalks demonstrates the utility of the site selection, design, and evaluation process. Actual data from Philadelphia streets are used.

SITE A. 5TH AND LINDLEY AVENUE

Area Type: OBD-Residential (intermediate)

Accident Street Type: Major - Arterial

Accident Location: North X-walk on 5th Street

Street Width: 50ft.

Traffic: ADT (vehicular) = 13500 veh/day - night = 2295 veh/night

Average Night Pedestrian Traffic = 115 (north X-walk)

Traffic Control: Signalized

Existing Illumination: HP Sodium, S.W. corner, 30ft. (9m) MH
Average illumination in X-walk:
.25 fc (2.5 Lux)

Accident History: 6 illumination treatable accidents in 4 years.
No fatalities.

Special Considerations: Overhead power lines

SITE B. 5TH STREET AND RUSCOMB STREET

Area Type: Residential

Accident Street Type: Major - Arterial

Accident Location: North X-walk on 5th Street

Street Width: 50 ft. (15m)

Traffic: ADT = 13400 veh/day night - 2278 veh/night
Average Night Pedestrian Traffic: 38 (North Crosswalk)
42 (South Crosswalk)

Traffic Control: Stop Sign on East- West St. (Ruscomb)

Existing Illumination: HP Sodium, S.W. Corner, 30 ft. (9m) MH
Average illumination in X-Walk:
.42 fc (4.2 Lux)

Accident History: 3 illumination treatable accidents in North X-walk. No fatalities.

Special Considerations: Overhead power lines

SITE C. 5TH STREET AND CAYUGA AVENUE

Area Type: Residential

Accident Street Type: Collector-Distributor

Accident Location: North X-Walk on 5th Street

Street Width: 52ft. (15.8m)

Traffic: ADT (vehicular) = 11,600 night = 1972
Average Night Pedestrian Traffic = 52 (North X-Walk)

Traffic Control: Signalized

Existing Illumination: HP Sodium, S.W. Corner, 30ft. (9M) MH
Average illumination in X-Walk:
.21 fc (2.1 Lux)

Accident HIstory: 2 illumination treatable accidents in North X-Walk, no fatalities

Special Considerations: Overhead Trolley Lines

CONSTRAINING PARAMETERS

Budget: Funds Available = $10,000.00 total for all sites to pay for initial capital outlay

Assessment of Community Values:

a) Cost considerations are most constraining. However, cost-benefit and other measures of effectiveness rather than least total cost will be the criteria, as long as projects stay within the budgeted amount.

b) Reduction of accidents is the next most important consideration. Community pressure is emphasising maximum accidents reduction, suggesting that evaluations which use accident rates measured in terms other than frequency should receive lower priority than the evaluation of frequency.

c) Community values also place high emphasis on the protection of the elderly and school age children. There are two schools located to Site C, and a church and school at Site A.

Engineering Capability:

Advanced photometric equipment is not available, however cosine and color corrected illumination meters are available to the traffic engineering and illuminating engineering personnel.

DESIGN AND EVALUATION

Step 1. Examination of accident data from 1971, 1972, 1973 and 1974 indicate that Site A experienced 5 accidents suitable for treatment, Site B had 3 such accidents and Site C has 2 such accidents.

Step 2. Ranking the sites by total accidents

1. 5th & Lindley
2. 5th & Ruscomb
3. 5th & Cayuga

Step 3. Accident Rates:

	SITE A	SITE B	SITE C
Time Rate (frequency)	$\frac{6acc}{4\ years} = \frac{1.50acc}{yr}$	$\frac{3acc}{4\ years} = \frac{.75acc}{yr}$	$\frac{2acc}{4\ years} = \frac{.50acc}{yr}$
Ped. Volume Rate	$\frac{1.50acc/yr}{42000ped/yr} = \frac{.036acc}{1000\ peds}$	$\frac{.75acc/yr}{1400\ ped/yr} = \frac{.054acc}{1000\ peds}$	$\frac{.50acc/yr}{19000ped/yr} = \frac{.026acc}{1000}$
Veh. Volume Rate	$\frac{1.5acc/yr}{838000veh/yr} = \frac{.18acc}{100000\ veh}$	$\frac{.75acc/yr}{720000\ veh/yr} = \frac{.10acc}{100000\ veh.}$	$\frac{.50acc/yr}{831000veh/yr} = \frac{.06acc}{1000\ veh}$

Step 4. Ranking by Accident Rate

SITE	RANK BY FREQUENCY	RANK BY PED. VOL. RATE	RANK BY VEH. VOL. RATE
A	1	2	1
B	2	1	2
C	3	3	3

Step 5. Public opinion and community goals are as indicated under constraining parameters. They suggest that rating by frequency be most heavily weighted. The presence of school children at sites A and C would also require heavy weighting.

Step 6. No other sites have been suggested for consideration.

Step 7. All sites are warranted for special crosswalk illumination as follows:

Site A: Accident warrant and volume warrant met. Photometric warrant met (.25 fc existing, 2.70 required).

Site B: Accident warrant and volume warrant met. Photometric warrant met (.42 fc existing, 1.5 required).

Site C: Volume warrant met. Photometric warrant met (.21 fc existing 1.2 required).

Step 8. Preliminary Design Alternatives

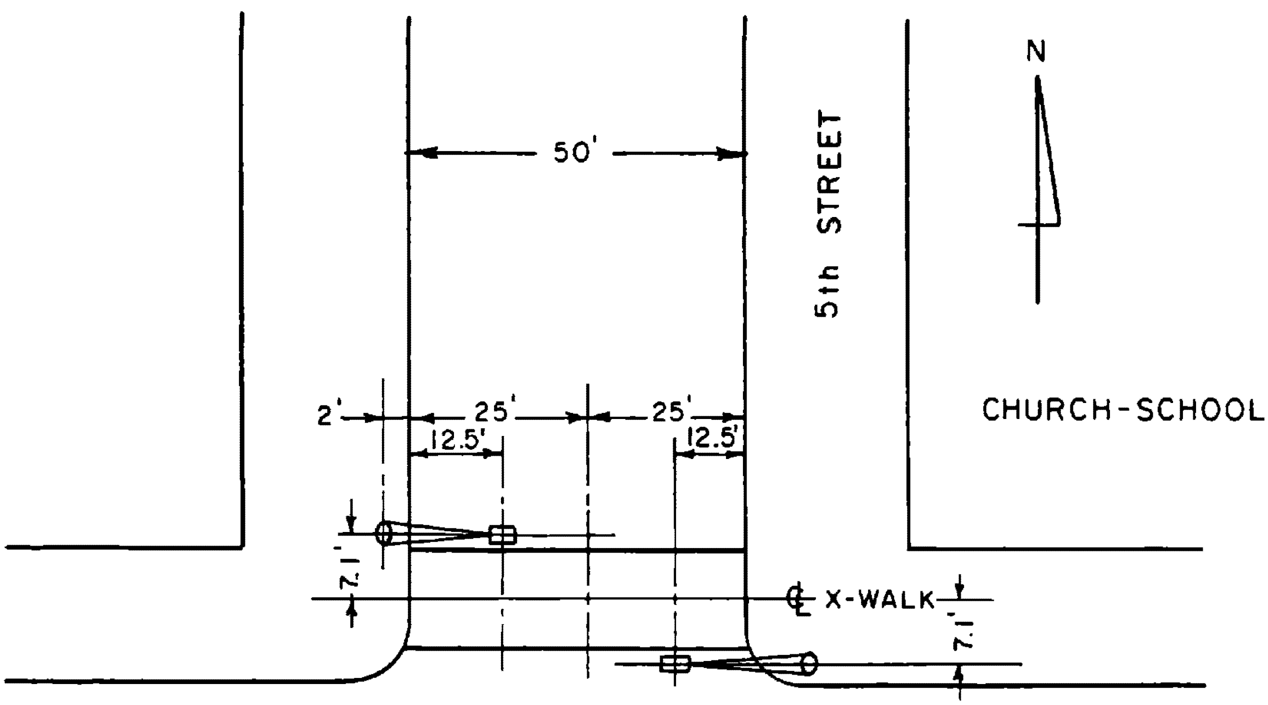
Site A: 5th and Lindley

Alternatives: (1) increased conventional illumination

(2) special crosswalk illumination.

Because of the high accident history, community pressure will not allow Alternative 1 to be considered.

Alternative (2)



Davit Arm Mounting to Wooden Poles
Mounting Height = 16 ft. to Refractor Face
Assymetrical Luminaires offset 7.1' and oriented toward crosswalk

Cost: (limited quantity cost figures used)

fixtures: 2 at $330.00 each	$660.00
installation at $3203.00 per system	$3203.00
	$3863.00
annual maintenance at $50.00/unit	$100.00
annual power cost at $20.00/unit	$40.00

Annual Cost at 10% interest rate and 20 year life

Capital Recovery Factor (crf) = .11746

(.11746) ($3863.00)	=	$454.00/year
	+	$100.00
	+	$40.00
		$594.00/year

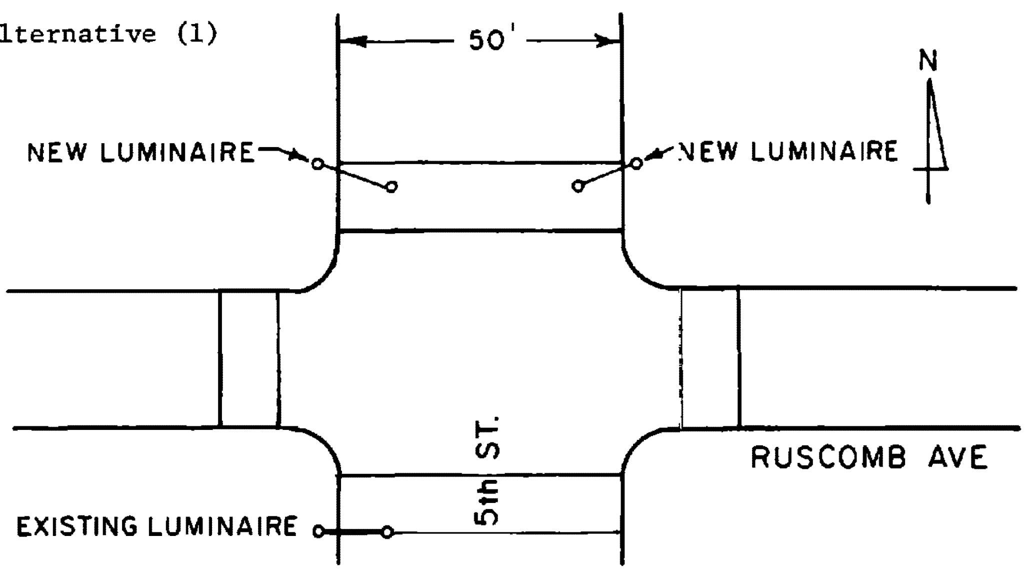
Site B: 5th and Ruscomb

Alternatives: (1) increased conventional illumination

(2) special crosswalk illumination

(3) install signalization

Alternative (1)



Cost: (cost figures supplied by City of Philadelphia)

HP Sodium lamp luminaire with aluminum pole mounting

luminaire, pole and installation at $605.00 per pole	$1210.00
annual maintenance at $20.00/unit	$40.00
annual power cost at $87.00/unit	$174.00

Annual cost at 10% interest rate and 20 year life

(.11746) $1210.00) = $142.00
+ $40.00
+ $174.00
$356.00/year

Alternative (2)

Same as Site A - annual cost = $594.00/year

Alternative (3) - intersection does not meet signalization warrant.

Site C: 5th and Cayuga

Alternatives: (1) increased conventional illumination
(2) special crosswalk illumination.

Because of the location of schools at the intersection, Alternative 1 is *not* to be considered.

Alternative (2)

Same as Site A - annual cost = $594.00/year

Step 9: Application of selection criteria; benefit-cost

a) Accidents - Because insufficient data are available to predict the accident reduction capability of improvements in conventional illumination, an estimate of 15% will be used. This is approximately one-half of "low" accident reduction potential reported for specialized crosswalk illumination as proposed for improvements at the three sites. An average accident cost of $7457 will be used for evaluation.

SITE	AVG. ANN. ACC.COST.	15% REDUCTION	33% REDUCTION	ANN. COST	BENEFIT-COST RATIO	RANK
A	$11,186.	-----	$3691.	$594	6.21	1
B_1	$ 5,593.	$839.	----	$356	2.36	3
B_2	$ 5,593.	----	$1846.	$594	3.11	2
C	$3,729.	----	$1230.	$594	2.07	4

b) Visibility - Because advanced photometric equipment is not available, analysis involving V.I. or luminance is not possible. Measurement and prediction of average horizontal illumination ($\bar{E}_h$) is possible, and yields:

SITE	$\bar{E}_h$ existing (fc)	$\bar{E}_h$ proposed(fc)	$\Delta \bar{E}_h$(fc)	ANN.COST	EFFECTIVENESS	RANK
A	.25	8.0	7.75	$594.	.013fc/$	1
B_1	.42	2.0	1.58	$356.	.004fc/$	3
B_2	.42	8.0	7.58	$594.	.013fc/$	2
C	.21	7.0	6.79	$594.	.011fc/$	4

c) Traffic Volume - Ranking by accident frequency, pedestrian volume accident rate and vehicular volume accident rate has been done in Step 4. However, a more meaningful comparison is accomplished by normalizing *costs* by these traffic volume measures.

SITE	AVG. ANN. ACC. COST PER 1000 NIGHT PEDESTRIANS	15% REDUCTION	33% REDUCTION	ANNUAL COST	EFFECTIVENESS acc. cost reduction / cost	RANK
A	$266.	----	$ 88.	$594	.148	3
B_1	$400.	$60.	-----	$356	.169	2
B_2	$400.	----	$132.	$594	.222	1
C	$196.	----	$ 65.	$594.	.109	4

SITE	AVG. ANN. ACC COST PER 1000 NIGHT PEDESTRIANS	15% REDUCTION	33% REDUCTION	ANNUAL COST	EFFECTIVENESS acc. cost reduction / cost	RANK
A	$1335.	----	[illegible]	[illegible]	.742	1
B_1	$ 777.	$117.	----	[illegible]	.329	3
B_2	$ 777.	----	[illegible]	[illegible]	.431	2
C	$ 449.	----	[illegible]	[illegible]	.249	4

d) Community Values - Analysis of community values suggest that a reasonable comparison of criteria result in the following weightings.

(1) Accident Frequency Cost Benefit Analysis : 1

(2) Presence of Schools : 2

Rank by presence of school children yields
Site A - 2
Site B - 3
Site C - 1 (two schools)

(3) Pedestrian Volume Effectiveness: 2

(4) Vehicle Volume Effectiveness: 3

(5) Photometric Effectiveness: 5

Step 10. Site ranking summary by criteria and application of scale factor

SITE	ACC.FREQ. COST-BENEFIT	+ PRESENCE OF SCHOOLS	+PED. VOL EF-FECTIVENESS	+VEH. VOL. EFFECTIVENESS	+PHOTOMETRIC EFFECTIVENESS	= TOTAL	RANK
A	1 x 1	2 x 2	3 x 2	1 x 3	1 x 5	19	1
B_1	3 x 1	3-1/2 x 2	2 x 2	3 x 3	3 x 5	38	3
B_2	2 x 1	3-1/2 x 2	1 x 2	2 x 3	2 x 5	27	2
C	4 x 1	1 x 2	4 x 2	4 x 3	4 x 5	46	4

Step 11. Comparison of Budgetary Constraints

Funds available : $10,000.00 (capital)

Cost of Alternatives:

A - $3863.00

B_1 - $1210.00

B_2 - $3863.00

C - $3863.00

Analysis: Although the composite ranking indicates that the most desirable solution would be a A,B_2, and C, this combination would cost $11,589.00 to implement, which is beyond the budgetary means. The combination of A, B_1, and C would cost $8936.00, which is within budgetary means and will be effective in improving safety at the crosswalks considered, as well as satisfying community desires.

REFERENCES

1. Snyder, M. B. et al., *Pedestrian Safety: The Identification of Precipitating Factors and Possible Countermeasures*, Vol. 1, Operations Research, Inc., NHTSA: DOT HS-800 403, 1971.
2. American Automobile Association, *Manual on Pedestrian Safety*, American Automobile Association, Washington, D.C., 1964.
3. Davis, R. A. and Huelke, D. F., *Pedestrian Fatalities*, Highway Safety Research Institute, University of Michigan, 1969.
4. Haddon, W., et al., "A Controlled Investigation of the Characteristics of Adult Pedestrians Fatally Injured by Motor Vehicles in Manhattan," *Traffic Safety Research Review*, Vol. 7, No. 2, June 1963.
5. Mueller, E. A. and Rankin, W.W., *Traffic Control and Roadway Element-Their Relationship to Highway Safety*, Revised, Chapter 8, "Pedestrian," Highway Users Federation for Safety and Mobility, 1970.
6. Bruce, J. A., "One-Way Major Arterial Streets," Special Report 93, *Improved Street Utilization Through Traffic Engineering*, Highway Research Board, 1967.
7. Herms, B. F., "Pedestrian Crosswalk Study: Accidents in Painted and Unpainted Crosswalks," *Highway Research Board Record 406*, 1972.
8. National Safety Council, *Accident Facts*, 1972 Edition, Chicago, Illinois.
9. Harris, A. H. and Christie, A. W., "Research on Two Aspects of Street Lighting," *Public Lighting*, Vol. 19, No. 83, 1954.
10. Cameron, M. H., "Nature and Value of Present Pedestrian Protection Measures," *Proceedings of Australian Safety Week on Road Safety Practices*, Institute of Engineering, Australia, 1967.
11. Smeed, R. J., "Some Aspects of Pedestrian Safety," *Journal of Transport Economics and Policy*, September 1968, pp. 225-279.
12. Malo, A. F., et al., "An Innovative Pedestrian Crosswalk Safety Device Demonstration," City of Detroit and the University of Michigan Highway Safety Research Institute, HSRI Report No. TrS-8.
13. "Effectiveness of the Pedestrian Crossover Program in the City of Toronto, "Department of Public Works, Traffic Division, City of Toronto, 1960.
14. "Criteria for the Installation of Traffic Control Devices," The Municipality of Metropolitan Toronto, Department of Roads and Traffic, 1970.

15. Burns, H. R., "The Pedestrian Corridor - A Study of Pedestrian Accommodation in the City of Winnipeg," Transportation Division, City of Winnipeg, 1972.

16. "Specification for Pedestrian Corridor Fixtures," The City of Winnipeg (Central Council), Transportation Division, 1972.

17. Jorgensen, N. O., et al., "Fodgaengeres Sikkerhed i og ved fogeangerovergange," Radet for Trafiksikkerhedsforskning, Rapport 7, Kobenhavn, 1971.

18. Jaster, K., "Influence of Crosswalk Lighting Upon Accidents on Zebra Crossings in Hanover," *Lichttechnik*, January 25, 1973, pp. 183-186.

19. Borel, P., "The Accidents Occurring on Pedestrian Crossings During Daytime and Nighttime," *SKS Journee Technique*, 1973.

20. Schreuder, D. A., "Marking and Lighting of Pedestrian Crossings," Lighting Laboratory, Philips, Eindhoven, Netherlands.

21. Janoff, M.S. et al., "Fixed Illumination for Pedestrian Protection", Phase I Interim Report, FHWA Contract FH-11-8037.

22. Walthert, R., "Supplementary Illumination of Pedestrian Crossings: Requirements and Technical Means" (in French).

23. Gallagher, V.P., Koth, B.W., and Freedman, M., "Specification of Streetlighting Needs," *Final Report C3660*, The Franklin Institute Research Laboratories, November 1975.

24. Blackwell, H.R., "Contrast Thresholds of the Human Eye," *Journal of the Optical Society of America*, 35, (11), 1946.

25. Gallagher, V.P., and Meguire, P.G., "Contrast Requirements of Urban Driving," *Special Report 156*, Transportation Research Board, 1975.

26. Committee E-142 on Visual Performance (CIE), "Recommended Method for Evaluating Visual Performance Aspects of Lighting", *C.I.E. Report No. 19*, 1971.

27. Janoff, M.S. et al., "*Fixed Illumination for Pedestrian Protection,*" Phase II, July 1975.

28. Fry, G.A., Pritchard, B.S., and Blackwell, H.R., "Design and Calibration of a Disability Glare Lens," *Illuminating Engineering*, No. 58, 1963.

29. Gallagher, V.P. and Meguire, P., "The Specification of Lighting Needs," Phase I Interim Report, FHWA Contract FH-11-8037.

30. Gallagher, V.P. and Koth, B.W., "The Specification of Lighting Needs", *Interim Report 11-C3660*, The Franklin Institute Research Laboratories, Philadelphia, Pennsylvania, January 1974, p. I-4-4.

31. Committee T.C. 3.1 - "Visual Performance (C.I.E.) "Implementation Procedures for Evaluating Visual Performance Aspects of Light," (Second Draft of Proposed 1977 C.I.E. Publication, June 1974.

32. Smith, Wilbur and Associates, "Motor Vehicle Accident Costs," Washington Metropolitan Area, 1966.

33. Burke, Donald and McFarland, W. Frank, "Accident Costs: Some Estimates for Use in Engineering Economy Studies," *Highway Research Board Record 467*, 1973.

34. AASHO (now AASHTO) *An Informational Guide for Roadway Lighiting*, Com. on Plng. and Des. Policies, AASHO, March 1969.

35. *American National Standard Practice for Roadway Lighting*, RP-8, IES, 1972.

36. *Draft* "4. Pedestrian Walkways", Roadway Lighting Subcommittee, IES, 3/17/75.

37. *Lighting Manual*, staff of N.V. Phillips Gloeilampenfabrieken, Lighting Design and Engineering Centre, Eidhoven, the Netherlands, May 1975.

38. "Special Lantern for Lighting of Pedestrian Crossings", Technical Information paper SG-P1, Phillips, 1971.

39. Goldman, H., *Bull. ASE*, Vol. 56, No. 891 (1956).

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