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16. Abstract

This users' manual represents the practical recommendations and guidelines for implementation of special crosswalk illumination systems. It contains information describing the illumination systems, specifications, installation recommendations and design information. Warrants for crosswalk illumination are presented. Site selection procedures are recommended. Methods of evaluation of system effectiveness and a step-by-step procedure for development of an implementation program are reported.

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PRICES SUBJECT TO CHANGE

PREFACE

This manual for users and prospective users of specially designed crosswalk illumination systems has been prepared by members of the Transportation Sciences Laboratory of The Franklin Institute Research Laboratories, under Federal Highway Administration Contract FH11-8034.

The manual is intended for use by those persons involved with transportation engineering, lighting engineering, public planning and decision making. It contains the necessary information for the design and evaluation of such special crosswalk illumination systems for the purpose of improving pedestrian safety at intersections at night.

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I. INTRODUCTION

This document provides persons interested in special pedestrian crosswalk illumination systems a complete description of one such system, including photographs, specifications and system costs, and the warrants that are recommended for implementation of such systems. The manual also includes recommended means of selecting sites and assessing the priority for improvement of sites, as well as a methodology for evaluating system effectiveness. Procedures are recommended for establishing an implementation program that considers budget constraints and competing improvements at one or many sites.

The user's manual has been developed through the results of research sponsored by the Federal Highway Administration. For full documentation of the research study, the reader is encouraged to obtain a copy of the report, "Fixed Illumination for Pedestrian Protection" Final Report*. This research sought to identify the characteristics of special illumination systems that could be used to improve pedestrian crossing safety at night on city streets, implement such a system at various locations in an urban environment, and evaluate the effectiveness of the system. During the course of research several thousand observations of pedestrian crossings, at both high accident and low or accident-free crosswalks, both with and without the supplementary crosswalk illumination, were conducted and analyzed. It was found that certain characteristics of pedestrian and driver behavior and performance which are related to the safety of pedestrian crossings could be improved with the use of the system. These characteristics included pedestrian search and detection patterns, perceived clothing brightness, crosswalk utilization and the drivers' time to respond to a pedestrian in the crosswalk. Through this process, warrants, design criteria and evaluation procedures were developed, applied and found to be useful. The manual represents the guide to application of the

* Available from National Technical Information Service, Springfield, Va. 22151.

research findings.

The manual has been prepared so that it will be useful to a range of professionals who are concerned with improving the safety of pedestrians crossing city streets at night. It is therefore of interest to traffic and transportation engineers, street lighting designers and manufacturers, public policy makers and legislators who deal with the design, implementation, funding and legal aspects of traffic safety programs.

One section is devoted to a complete description of the illumination system. Included are photographs of the luminaire and installations at seven experimental sites in Philadelphia, Pennsylvania. This section also contains the lighting system specifications, which include system diagrams, suggested mounting methods, a luminaire candlepower distribution table and an isofootcandle diagram.

Another section is devoted to the statement and discussion of warrants for crosswalk illumination applications. This section is particularly useful to traffic engineering personnel and public policy makers.

A section is devoted to the procedure for selecting the appropriate sites to be considered for system implementation. Alternative methods of site selection are suggested based upon traffic engineering practice and community goals.

A separate section suggests procedures for evaluating the effectiveness of proposed implementations of the crosswalk illumination. Methods and criteria for benefit-cost analysis and analysis based on other measures of effectiveness are presented.

The last procedural section of the manual offers a step-by-step method for developing an implementation program to be employed where budget constraints make it unfeasible to provide total system effectiveness in a short time period.

It is the overall purpose of this manual to familiarize the user with the characteristics and implementation requirements of a relatively new concept in illumination practices. It is also expected that the installations suggested in this manual will be modified to suit local needs. The spirit of the information in this manual is therefore advisory, and is intended to provide the design information and implementation guidance necessary for familiarization with the specially designed illumination system concept for crosswalks.

II. CROSSWALK ILLUMINATION SYSTEMS

A. Description

The crosswalk illumination system is composed of one or more 90 watt low pressure sodium luminaires, suspended from either a span wire, davit arm or mast arm at a height sufficient to both produce a sharply defined band of light of contrasting color on the pavement surface and provide overhead clearance for traffic passing beneath the installation (Figure 1.)

The luminaire is designed to be light-weight and self-contained. It incorporates an asymmetrical mirror reflector which eliminates glare by projecting the plane of maximum light intensity at an angle of 30° from vertical while maintaining a horizontal luminaire orientation. Each luminaire uses a 90 watt low pressure sodium (LPS) lamp to provide light that will provide sufficient color contrast on streets illuminated by incandescent, fluorescent, mercury vapor, or high pressure sodium (HPS) systems. The luminaire refractor is clear acrylic to minimize weight and reduce the hazard of glass fragments from breakage due to accidents or vandalism. The housing is made of glass-fibre-reinforced polyester for weight reduction and strength. It incorporates an inner frame made from galvanized steel and an equipment tray to secure both electrical connections and a standard 90 watt LPS ballast. Mounting hardware composed of suspension hooks for span wire installation or brackets for mast arm/davit arm installation connect to slotted steel channels on top of the housing to allow proper positioning of the luminaire.

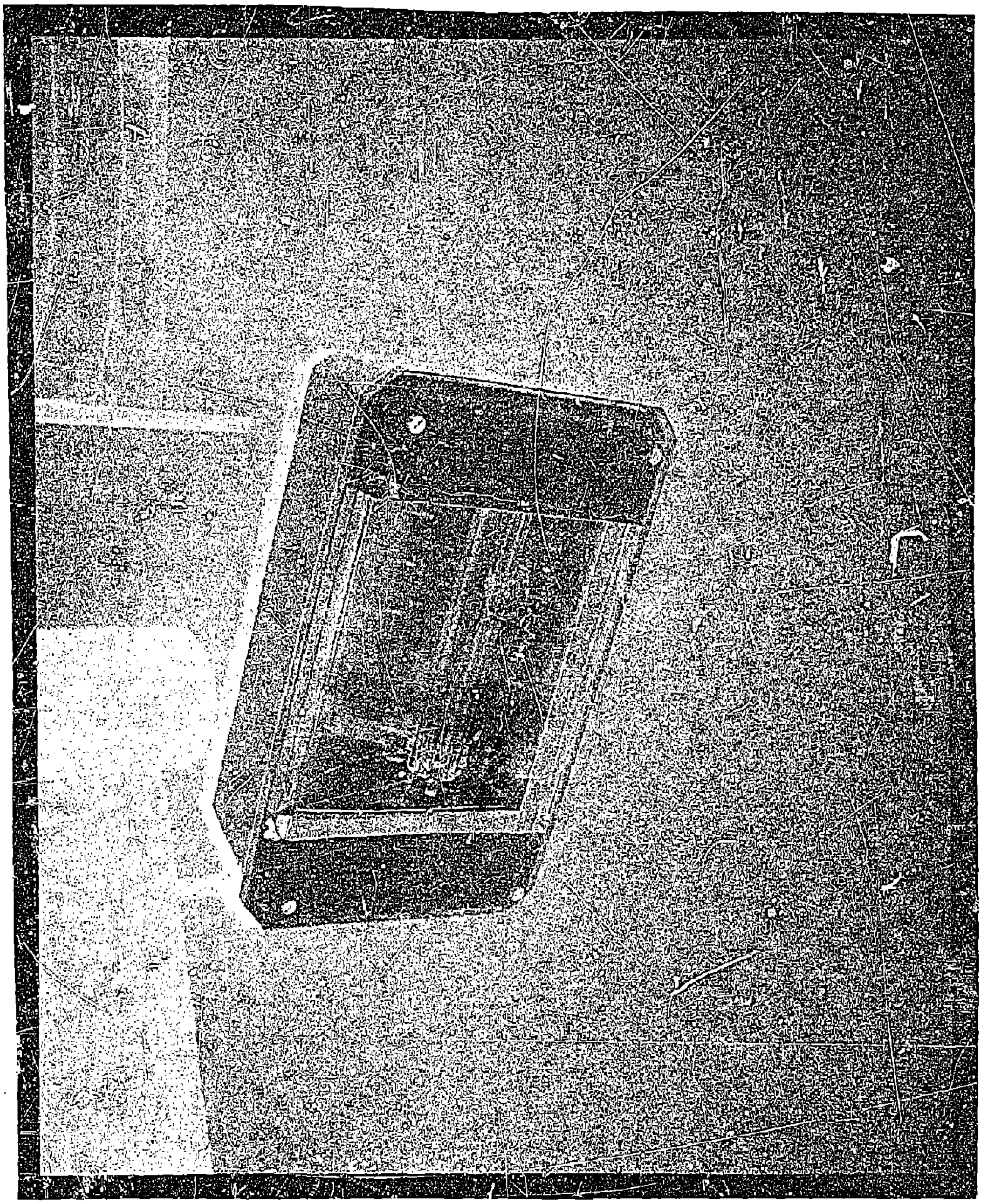


Figure 1. Picture of Crosswalk Fixture

The mast arm, davit arm or span wire may be connected to wooden or metal poles. A standard curved street light davit arm may be used on a short metal pole (such as the type used for pedestal mounted traffic signals) with an extension to provide the proper mounting height. Figure 2, Figure 3 and Figure 4 illustrate these installations. Systems have been installed utilizing existing structures as well. At one location, an overhead elevated rail structure was used to mount short brackets which held the luminaires in place (Figure 5).

The system may be controlled by means of a photocell, timer, or combination photocell-timer so that energy may be saved during hours when there is no pedestrian activity.

B. Design Criteria and Installation Specifications

Special crosswalk illumination should conform to the following design criteria.

1. The system should provide an average illumination level within the crosswalk area of at least 7.0 horizontal footcandles (75 lux).

2. The color of illumination should be distinctive so that sufficient color contrast is provided on the roadway to clearly designate the crosswalk.

3. Illumination uniformity (average to minimum) should be no greater than 4:1.

4. The luminaires should be mounted so that the refractor face is at least 16 ft (5m) above the roadway to provide adequate overhead clearance.

5. The distribution of illumination for a mounting height of 16 ft (5m) should be at least as great as shown in Figure 6. Factors for vertical illumination (E_v) and horizontal illumination (E_h) for other mounting heights are shown in Table 1.

6. The candlepower distribution through the plane of maximum candlepower (30° from vertical) for asymmetrical luminaires should be similar to the distribution shown in Figure 7.

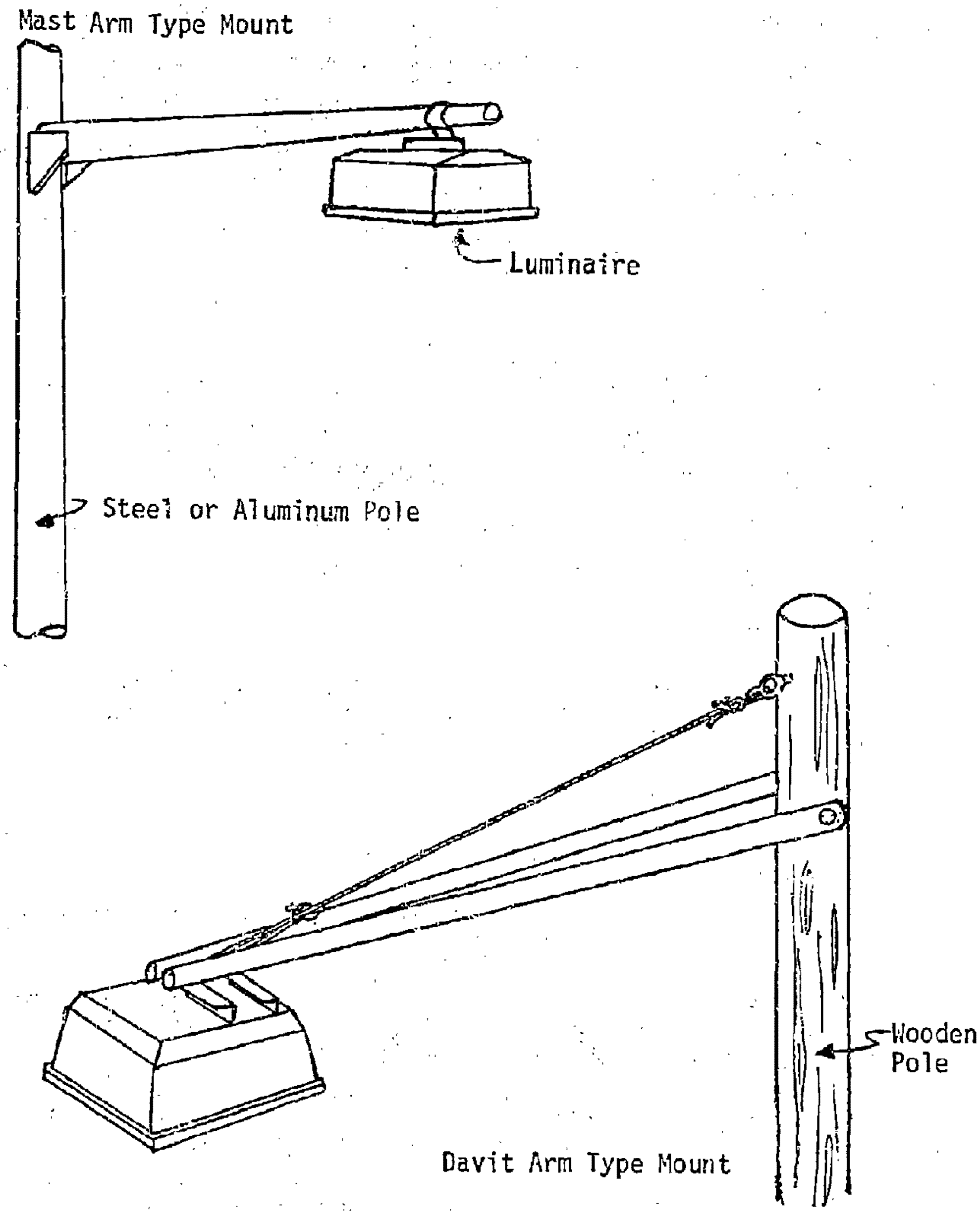
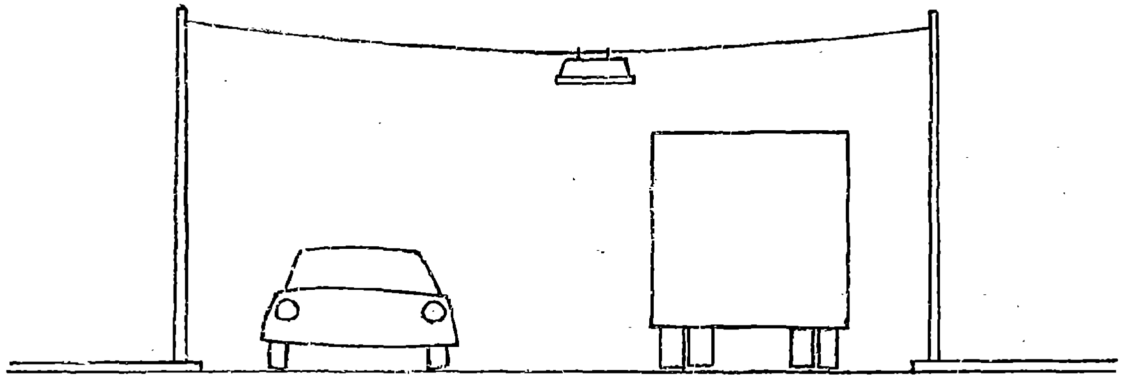
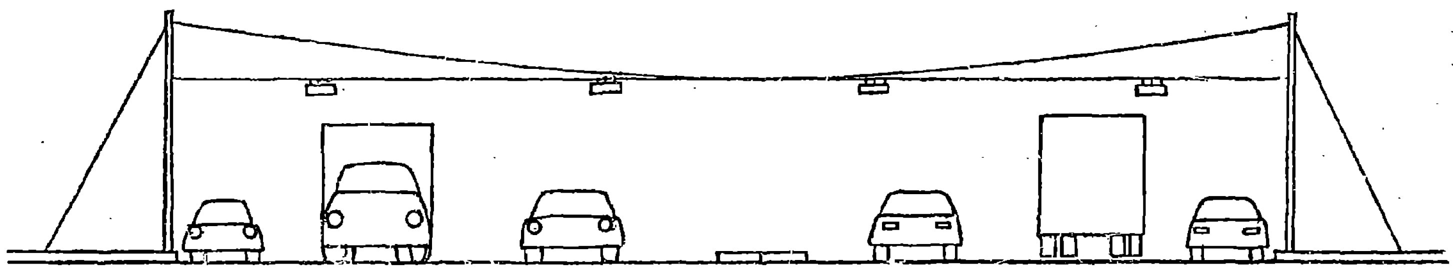


Figure 2. Mast Arm and Davit Arm Type Mount



Span Wire Mount for Narrow Streets



Span Wire Mount for Wide Streets

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Figure 3. Span Wire Type Mounts

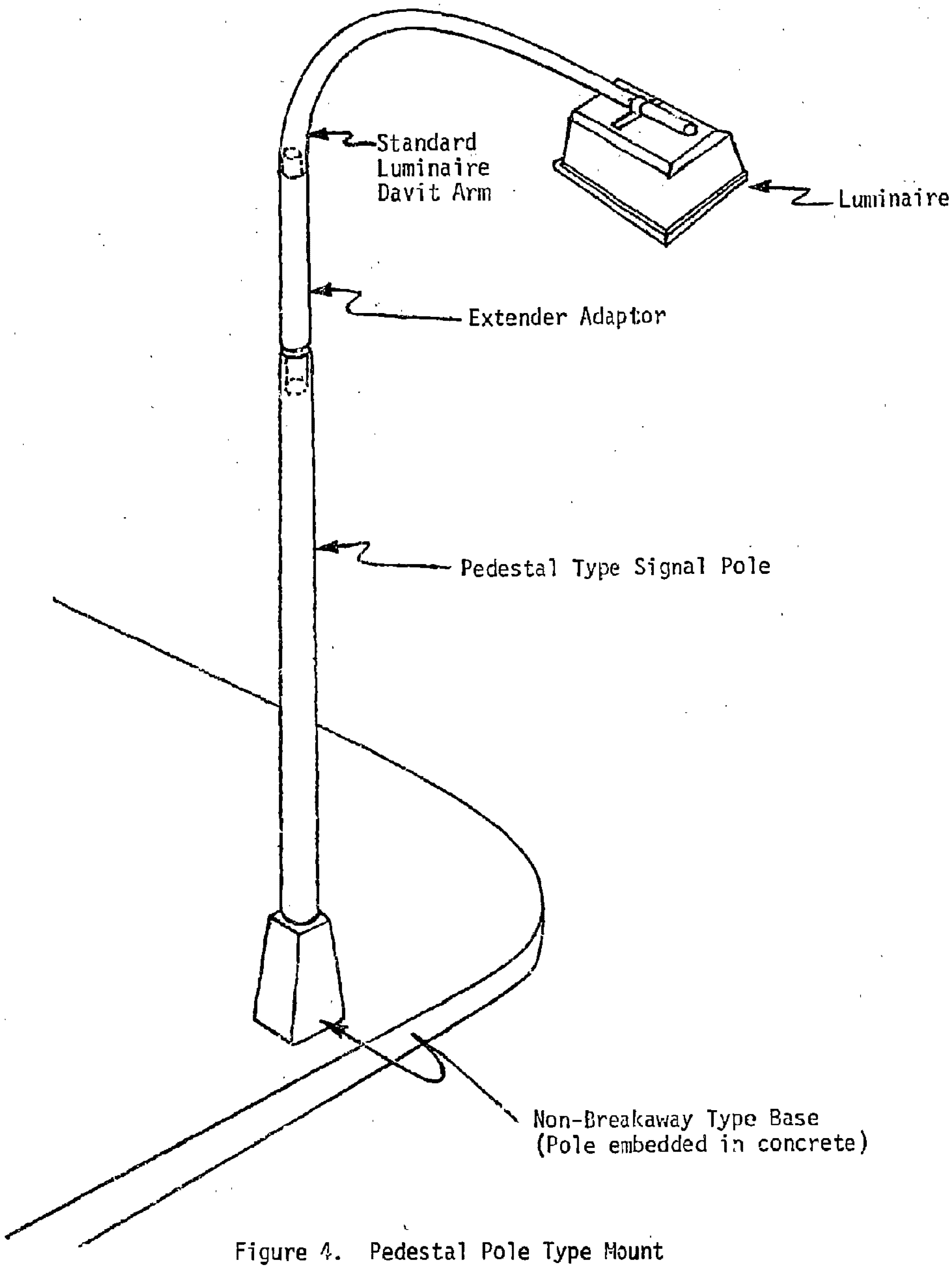


Figure 4. Pedestal Pole Type Mount

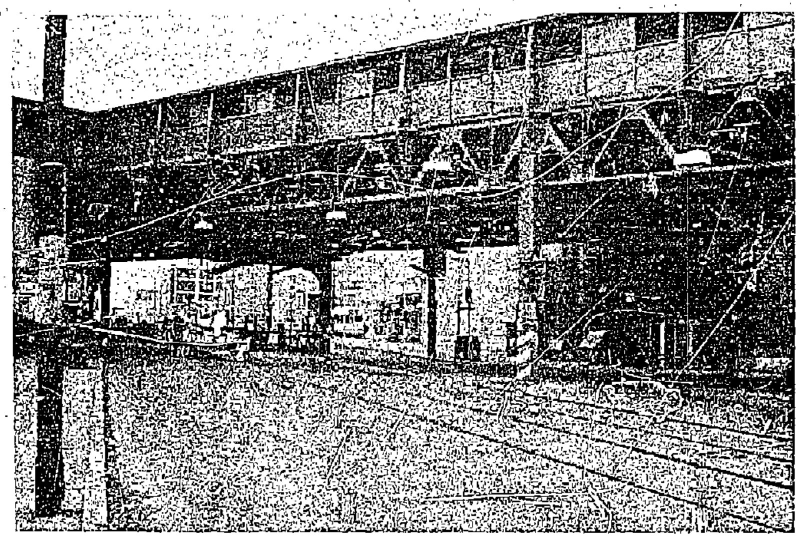


Figure 5. Luminaire Bracketed from Overhead Structure

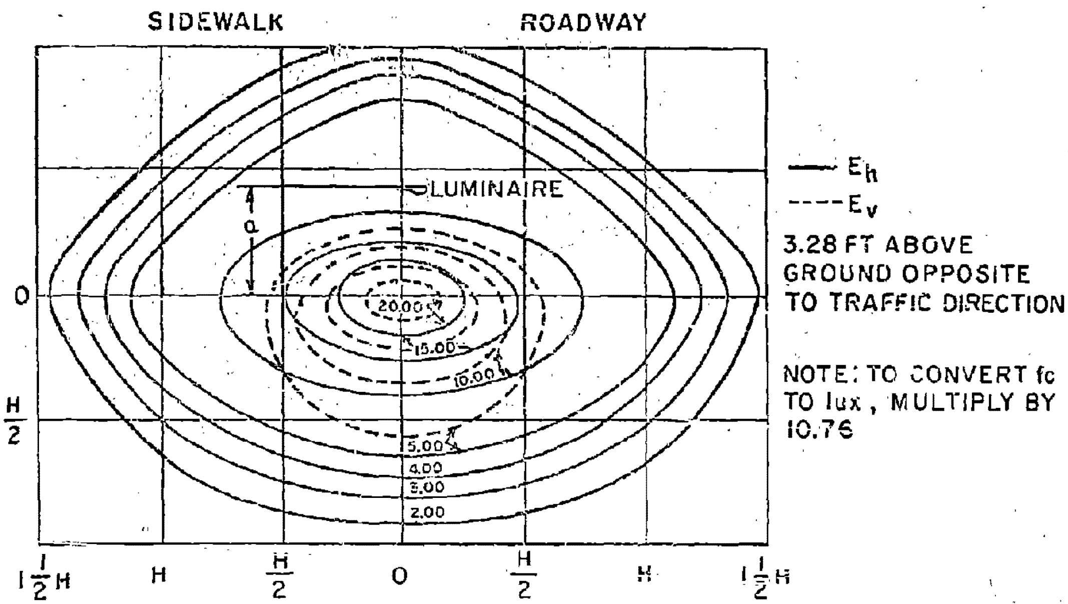
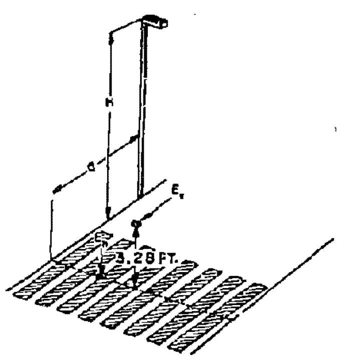


Figure 6. Distribution of Illumination Values (fc) for a Mounting Height of 16 ft (5m)

Table 1. Dimensions of Street Relative to Mounting Height.

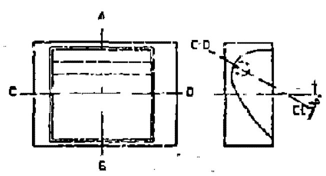


H(ft)	a(ft)	FACTOR for E_h	FACTOR for E_v
13.12	5.67	1.560	0.780
16.40	7.54	1.000	1.000
19.68	9.45	0.695	0.640
22.96	11.35	0.510	0.440
24.60	12.33	0.447	0.380
26.24	13.25	0.391	0.327
29.52	15.12	0.309	0.250
32.80	16.99	0.250	0.197

E_h = horizontal illumination

E_v = vertical illumination

Candlepower (cd) Distribution in Plane CD



Plane of Rotation CD
Deviating from Vertical Under 30°

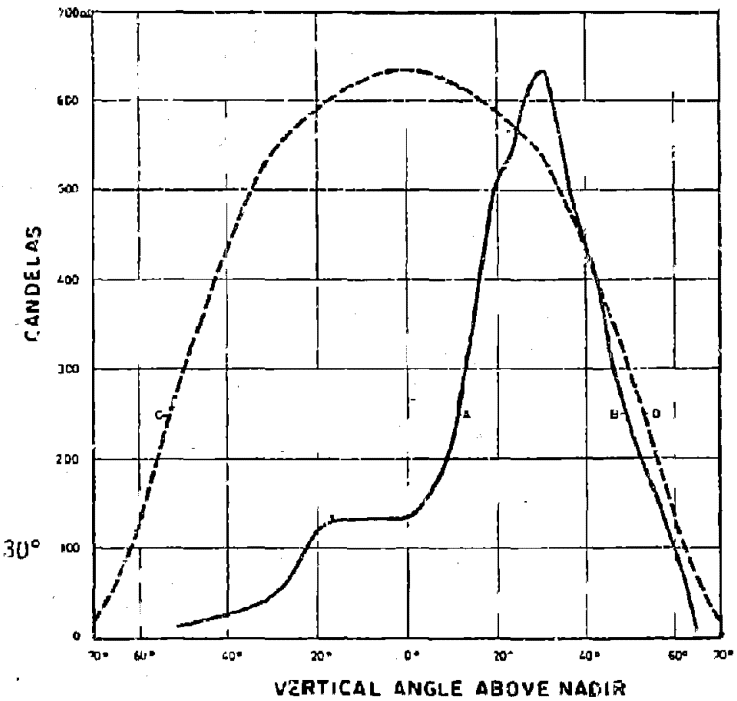


Figure 7. Candlepower Distribution for Asymmetrical Luminaires

7. Luminaires should be mounted to take maximum advantage of their asymmetrical, anti-glare design. For a mounting height of 16 ft (5m) each luminaire should be offset 7.1 ft (2.3m) from the centerline of the crosswalk in the direction opposite to the flow of traffic (upstream) in the lanes over which the luminaire is suspended. Figure 8 depicts this mounting location for two-way streets. Table 1 indicates factors for vertical and horizontal illumination, and offsets, for mounting heights other than 16 ft.

8. In order to ensure proper illumination and uniformity, each luminaire should be located so that it is responsible for no more than 30 ft (9.2m) of the crosswalk length, for a mounting height of 16 ft (5m), as shown in Figure 6.

9. 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.

10. When specialized LPS crosswalk illumination is installed in locations where the visibility of pedestrians by approaching motorists is limited by adverse geometry, local structure or environmental conditions, means should be sought to remove, to the extent possible, any such obstructions. 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. 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. Relocating the crosswalk, using physical barriers to prevent crossing at the undesirable location. should be considered if the restriction cannot be removed.

III. WARRANTS FOR CROSSWALK ILLUMINATION

A. Introduction and Background

Six warrants are suggested for consideration in the planning for special crosswalk illumination. These warrants have been developed in the spirit that they indicate the minimum warranting conditions necessary for implementation, based

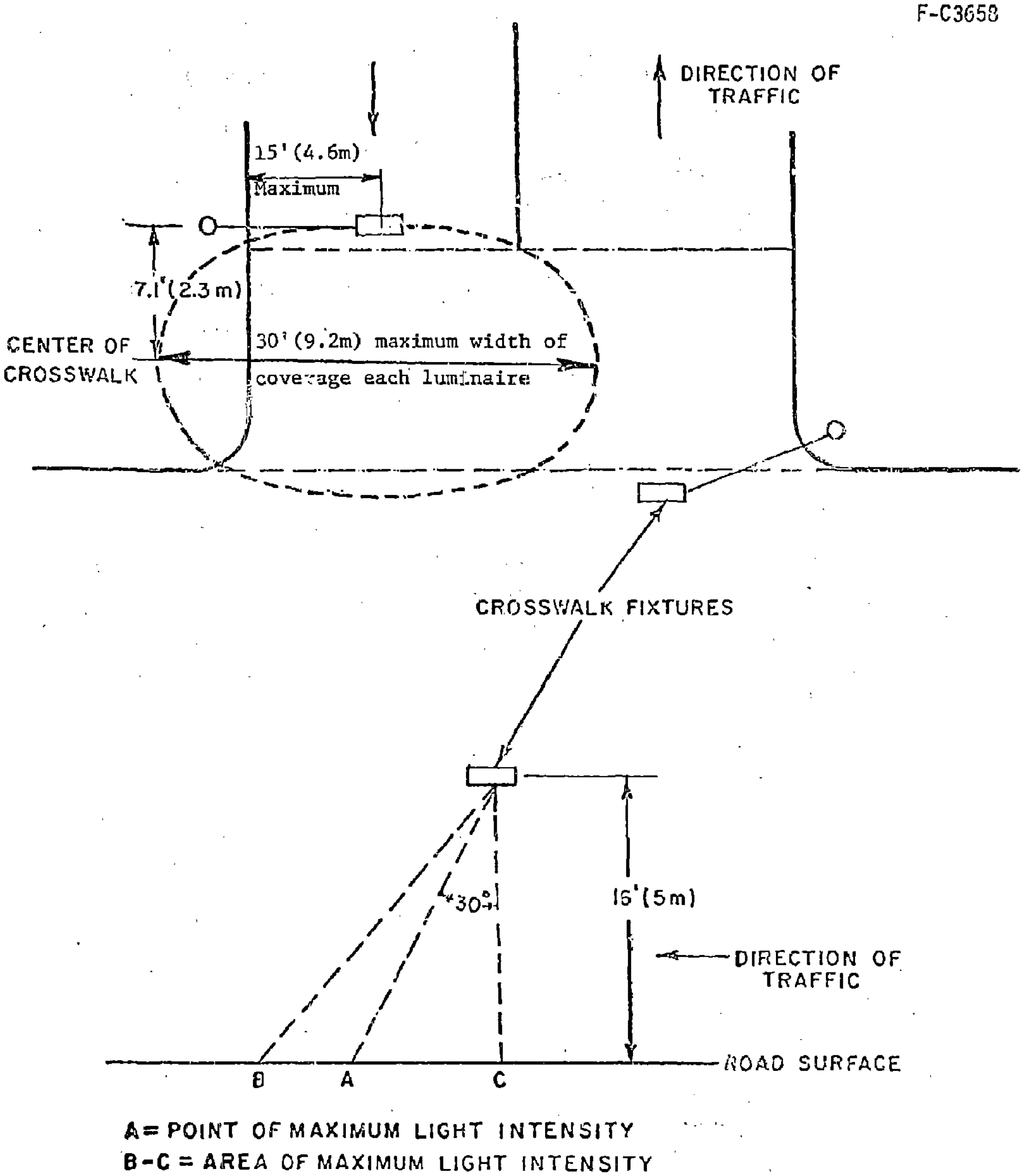


Figure 8. Light Distribution of Crosswalk Fixture

upon photometric analysis, engineering judgement, field application, benefit-cost and effectiveness considerations. The satisfaction of any one of the warrants is considered ample justification for the implementation of special crosswalk illumination. However, if a community feels that the need for special crosswalk illumination exists, and that the benefits to be derived from such illumination outweigh economic considerations, the illumination systems may be installed without satisfaction of any warrant, provided the specifications and design criteria are followed.

B. Warrants and Discussion

1. Special crosswalk illumination shall be warranted if the following vehicular and pedestrian volumes are exceeded by the average of at least three nights of traffic counts during the nighttime period of approximately 10 hour duration from the beginning of darkness until dawn on nights representative of normal traffic patterns according to the area-roadway classification shown in Table 2.

Table 2. Warranting Conditions According to Volume/Roadway Classification.

		MAJOR ARTERIAL	COLLECTOR DISTRIBUTOR	LOCAL
AREA	CBD - (COMMERCIAL)	*	500 veh/night 100 ped/night	200 veh/night 50 ped/night
	FRINGE (INTERMEDIATE)	1000 veh/night 100 ped/night	500 veh/night 100 ped/night	200 veh/night 50 ped/night
	OBD (INTERMED-COMM)	1000 veh/night 100 ped/night	500 veh/night 100 ped/night	200 veh/night 50 ped/night
	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 locations, it is recommended that other warrants be examined for justification of special crosswalk illumination at this type of location.

Discussion

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. These recommendations are shown in Table 3. Special attention should be given to the proposed (IES) modification of this table for intersection improvements, shown in the note beneath the table.

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 experience 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.

Pedestrian 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 crossings in all crosswalks which traverse the roadway in the direction of the subject crosswalk. This is recommended because of the relatively low pedestrian volumes at these locations, and the arbitrary choice of crosswalk found to be exhibited by pedestrians in residential locations. Vehicular volume during

Table 3. IES Recommendation 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

*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.

that time period is the total number of vehicles which pass across the subject crosswalk, by either through or turning movements.

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, hospital and large industrial operations, crosswalk illumination shall be warranted if the sum of the volumes recorded for the *peak five minutes* of ten of the platooned arrivals is equal to the warranting volumes as shown in Table 2, (Page 14).

2. Accident Warrant

Special crosswalk illumination shall be warranted provided a study of four consecutive years of nighttime 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.

The accident warrant may be considered satisfied if it is determined that the potential for a nighttime pedestrian accident due to poor pedestrian visibility is high. This potential should be determined by an examination of pedestrian crossings and their interactions with vehicular traffic at the subject intersection. A minimum of fifty (50) pedestrian crossings should be observed and evaluated in each crosswalk under consideration.

Discussion

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
   - o did accidents occur at night
   - o were drivers able to see the pedestrian
   - o were drivers aware of the presence of crosswalks
   - o was glare produced by other vehicles a factor
   - o would the provision of increased reaction time have prevented the accidents
   - o was driver fatigue a factor
   - o was the pedestrian distracted by environmental stimuli
   - o was the pedestrian attentive to vehicular traffic and signal indications

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

3. Observations of random pedestrian crossings (minimum of 50 per accident crosswalk over a period of at least 3 nights)
   - o record total volume of vehicles traversing the crosswalk
   - o record total volume of pedestrians using the crosswalk(s)
   - o record the frequency of pedestrians exhibiting behavioral characteristics shown in Figure 9. If the frequency of occurrence of any one of these characteristics is found to be 5% of the total, then a visibility — behavior deficiency will have been 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

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 stream, 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 9. Checklist for Pedestrian Characteristics to Determine Visibility - Behavior Deficiency

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 light-visibility problem exists, and would continue to exist at illumination levels recommended by IES for crosswalks, special crosswalk illumination shall be warranted.

3. Adverse Geometry and Environment Warrant

Special crosswalk 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 motorist 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 portions of the crosswalk. Furthermore, 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 the conventional illumination is negated.

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

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

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

where

Sd = minimum stopping sight distance
V = velocity in miles per hour
f = coefficient of friction
g = gradient

Discussion

This warrant has a basis in the concept that the sharply defined high level of luminous flux of contrasting yellow color produced by the crosswalk illumination will serve as a visual clue to both motorists and pedestrians that a hazardous area is ahead. Although the motorist's vision of pedestrians in the crosswalk may be obstructed, the distinctive nature of the lighting will stimulate his attention.

4. Photometric Warrant

Special crosswalk illumination shall be warranted when the existing illumination at the subject crosswalk is less than 1.5 times the IES prescribed roadway illumination level of the intersection and a minimum of two night pedestrian accidents in four years has occurred.

Discussion

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

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.

Discussion

It is recommended that the behavioral characteristics listed in Figure 9 be used for observational measures, and that observations of pedestrian crossings be conducted as prescribed in the ACCIDENT WARRANT.

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.

IV. SITE SELECTION PROCEDURE

A. Introduction

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 the lighting program that 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, this portion of the manual presents the means by which the traffic engineer and planner can determine how to select sites for crosswalk illumination. Two specific questions are addressed:

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

B. Selection Criteria

The prospective user of special crosswalk illumination systems should make use of as many of the following selection criteria as possible:

1. 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. Intersection dash or dart out accidents may be avoidable via increased driver response time that can result from supplemental crosswalk illumination. Only the accidents that may be effectively treated by such illumination should be compiled and considered for comparative evaluation.

2. 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 structues which block vision. Site visits are necessary to assess the extent to which illumination can improve conditions.

3. Traffic Volumes:

   Pedestrian and vehicular volume are of great importance in establishing the priority of sites to be considered for special crosswalk illumination. These can be examined in two ways. First, the volume of pedestrians or vehicles is often related to the land use in the crosswalk area. Major transit stops, commercial and manufacturing areas in cities are typified by locations on arterial streets where both pedestrian and vehicular volumes are high. These locations tend to have the greatest frequency of night pedestrian accidents, and are often the sites where special crosswalk illumination will affect the greatest number of people, or have the highest "payoff". Second, accident rate, expressed as the annual number of accidents per volume measure, is usually a good indicator of the need for improvement. By comparing accident rates, which can be a function of pedestrian volume, vehicular volume, or both, the relative priority of the need for improvement at a number of sites undergoing comparison for the implementation of crosswalk illumination can be determined.

4. 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, locations with low or no accident history, but whose potential for accidents cause considerable community concern, may receive first priority.

5. 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.

C. Methodology

The prospective user of special crosswalk illumination systems 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 each site to determine the extent to which visibility may be a factor in each accident.
- 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 compare; 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 would be as follows:

accident frequency :	1
accident rate :	2
community values:	6
cost:	12

If five alternatives, representing 3 sites, of which 2 have alternative designs, were being considered and their individual criterion rankings were as shown in Table 4, 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 5.

- o Select the alternative for each site receiving the highest priority and then assign a priority to each site.
- o 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 treated within the budget. A revised priority analysis may be necessary following design changes.

V. EVALUATION OF SYSTEM EFFECTIVENESS

A. Introduction

Methods of benefit-cost analysis and cost-effectiveness analysis have been used to assess the justification of public works improvements, and are generally well understood. The application of these methods to use with special crosswalk illumination is direct, requiring brief elaboration of system costs and projected benefits or measures of effectiveness that will be derived from their use.

Table 4. 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	B_2	C	B_2
(4)	B_2	B_2	C	B_2
Low Rank (5)	C	B_1	B_2	B_1

Table 5. 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

B. System Costs

Table 6 summarizes the costs of a variety of system installations. The costs shown are in terms of 1975 dollars, and represent single unit (rather than bulk installation contract) costs.

The installation costs of the prototype systems installed in Philadelphia are high in comparison with similar systems in Europe. It is expected, however, that installation costs could be reduced by as much as 40% once contractors become familar with installation requirements, and when standardized hardware, including the davit arm and connnection bracket, become available.

The manufacturer of luminaires has indicated that a cost reduction of about 20% can be realized for orders of 50 to 99 luminaires, 25% for 100 to 199 luminaires, and 30% on orders for more than 200 luminaires. Installation costs may be reduced by 10% to 20% for contract installation of 25 to 100 or more systems.

C. System Benefits and Measures of Effectiveness

1. Accident Reduction Measure

The most basic benefit of the special crosswalk illumination systems is the reduction of nighttime pedestrian accidents. Applications of illumination systems similar to the one described in this manual have resulted in annual accident reductions between 33% and 60%*.

The cost of a pedestrian accident has been reported to vary between $2444** and $12650*** in terms of 1975

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

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

*** Personal Contact with the National Safety Council

Table 6. Crosswalk Illumination System Costs for Individual Site Improvements***

DESCRIPTION	NO. OF LUMINAIRES	COST OF LUMINAIRES	COST OF INSTALLATION	AMORTIZED ANNUAL COST*	ANNUAL P&M**	TOTAL AMOUNT
Single Symmetrical, Span wire mount, 2 wood poles	1	$330	$2609	$345	$70	$415
Double Asymmetrical Two davit arm Mounts, Wooden Poles	2	$660	$3203	$454	$140	$594
Four Asymmetrical Two Davit Arm on Wooden Poles, Two Bracketed from Overhead Structure	4	$1320	$3500	$566	$280	$846

*Capital Recovery, 20 years, 10% compound interest rate
**Includes power, maintenance, and relamping.
***Based on installation costs at seven crosswalks in Philadelphia, Pennsylvania during February, 1974.

dollars. A median cost of $7457* appears to be a reasonable estimate useful in evaluation. Of course, local records of cost may be used for analysis of benefits. The accident reduction benefit of special crosswalk illumination can therefore be projected in terms of 1975 dollars by multiplying the annual accident history of a site by the accident reduction potential and multiplying this product by the cost of a pedestrian accident. This value represents the net value of the annual reduction in nighttime pedestrian accidents. Assuming a 33% reduction, and $7457 as the unit accident cost, a net annual benefit of $2461 can be realized for each annual accident at an intersection following implementation of special crosswalk illumination. If the 60% reduction figure is used, this annual benefit becomes $4474 per annual accident.

2. Photometric Measure

   Although benefit-cost analysis cannot be performed using photometric measures of effectiveness, analysis of effectiveness can. The most direct measure of photometric effectiveness is the average horizontal illumination, measured in footcandles (fc) in the crosswalk. This measure can be predicted by using Figure 6 and Table 1. The effectiveness measure is then the annual cost of an installation divided by the average horizontal illumination produced in the crosswalk by that installation.

3. Volume Measures

   Measures that are not strictly indicators of effectiveness but that relate to the volume of pedestrians and/or vehicles passing over a crosswalk are desirable because they identify the numbers of

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

users of the system or people/vehicles affected by the system. These normalizing measures can be formed by dividing the annual cost of a system by the annual *night* vehicular and/or pedestrian traffic volume.

4. Combined Volume and Accident Reduction

   A measure of effectiveness which uses the projected reduction in annual accident cost divided by annual nighttime pedestrian or vehicular volume provides a means of relating accident rate to accident cost. The rate is expressed in terms of accidents per pedestrian crossing, or accidents per vehicular crossing. The volumes may be expressed by multiples of thousands or hundred-thousands of crossings in order to express the rates in more workable terms. The rate is multiplied by the cost of an accident to provide the measure of accident cost per crossing. This measure may be used without modification to establish the priority of the need for improvement at the site, or may be used as the denominator by which the proposed installation cost is divided as a cost-benefit measure.

5. Other Measures

   Other measures of effectiveness which are not quantifiable can be considered and used in the analysis of need and establishment of priorities for site improvements. These subjective measures may include comfort, security, ability to indicate the presence of hazard, ability to interrupt driver fatigue, and others. They can be applied as scale factors or weightings (whose magnitude are chosen by the emphasis that community values and engineering judgement place on them) to modify other quantifiable measures.

VI. BUDGET CONSTRAINED IMPLEMENTATION PROCEDURES

A. Introduction

As previously mentioned, an ongoing problem in the implementation of public works improvements is that it is rare that sufficient funds are available to implement *all* programs at the time that the need for those improvements is recognized. In the case of special crosswalk illumination as one type of safety improvement at intersections, one must consider competing (in the sense of competing for funding) programs such as signalization at that site, as well as recommended improvements of all types at other sites. It is possible to simply assess the priority of each of the programs at each site as discussed in Section IV, and implement only the highest priority sites to the limit of available funds until additional capital is available. This method does nothing to satisfy the recognized need for improvement at other locations, however.

An alternative to that method is the development of a staged implementation program, based both upon priority assessment and maximization of effectiveness. For example, if five sites have been identified as requiring improvements, the engineer might consider implementing various combinations of illumination and signalization programs. Alternatives to be considered for each site may include:

- o special crosswalk illumination
- o signalization (implementation or improvement)
- o geometric improvement (treatment of curb radius, islands, etc.)
- o upgrading standard illumination.

B. Procedure

The procedure for "local-optimization" of the benefits of improvement can be handled as follows.

1. Specify constraining parameters - e.g., all sites must receive some treatment, funds are limited to X thousands of dollars, no site may receive more than Y thousands of dollars, etc.

2. Prepare preliminary design alternatives for each improvement at each site - these may be very sketchy and indicate only the type of improvement and rough estimate of cost.
3. Evaluate the effectiveness of the alternative site improvements according to the methods suggested in Section IV, or other methods.
4. Prepare lists of alternative improvement programs for all sites considered - incorporate the constraining parameters and determine the total effectiveness of each set of alternatives.
5. Select the program that maximizes the total effectiveness.

Two major considerations must be handled in this procedure.

First, the specification of constraining parameters must be as detailed and inclusive as possible. It may contain fixed dollar limits, and/or statements related to community goals or priorities.

Second, timing or staging of implementation must be considered. By evaluating a program over an extended period, such as five years, the improvements may be upgraded incrementally and re-evaluated. In this way, locations that have indicated the greatest need may be fully treated, while others can receive some improvement immediately. Later, when funding becomes available again, the locations that received marginal improvement can be re-examined and upgraded if necessary. The staging and re-examination process must exercise care in considering that partial systems can only be credited with partial effectiveness.

VII. SAMPLE PROBLEM

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)

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 North X-walk, no fatalities.

Traffic Control: Signalized

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: 53 ft. (15.8m)

Traffic: ADT (Vehicular) = 11,600 veh/day - night = 1972 veh/night
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 cost-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 emphasizing maximum accident 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 schools located at Site C, and a church and a school at Site A.

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

DESIGN AND EVALUATION

Step 1. Examination of accident data from 1971, 1972, 1973 and 1974 indicate that Site A experienced 6 accidents suitable for treatment, Site B had 3 such accidents and Site C had 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)	6acc / 4 years = 1.50acc / yr	3acc / 4 years = .75acc / yr	2acc / 4 years = .50acc / yr
Ped. Volume Rate	1.50acc/yr / 42000ped/yr = .036acc / 1000 peds	.75acc/yr / 1400 ped/yr + .054acc / 1000 peds	.50acc/yr / 19000ped/yr = .026acc / 1000
Veh. Volume Rate	1.5acc/yr / 838000veh/yr = .18acc / 100000 veh	.75acc/yr / 720000 veh/yr = .10acc / 100000 veh.	.50acc/yr / 831000veh/yr = .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

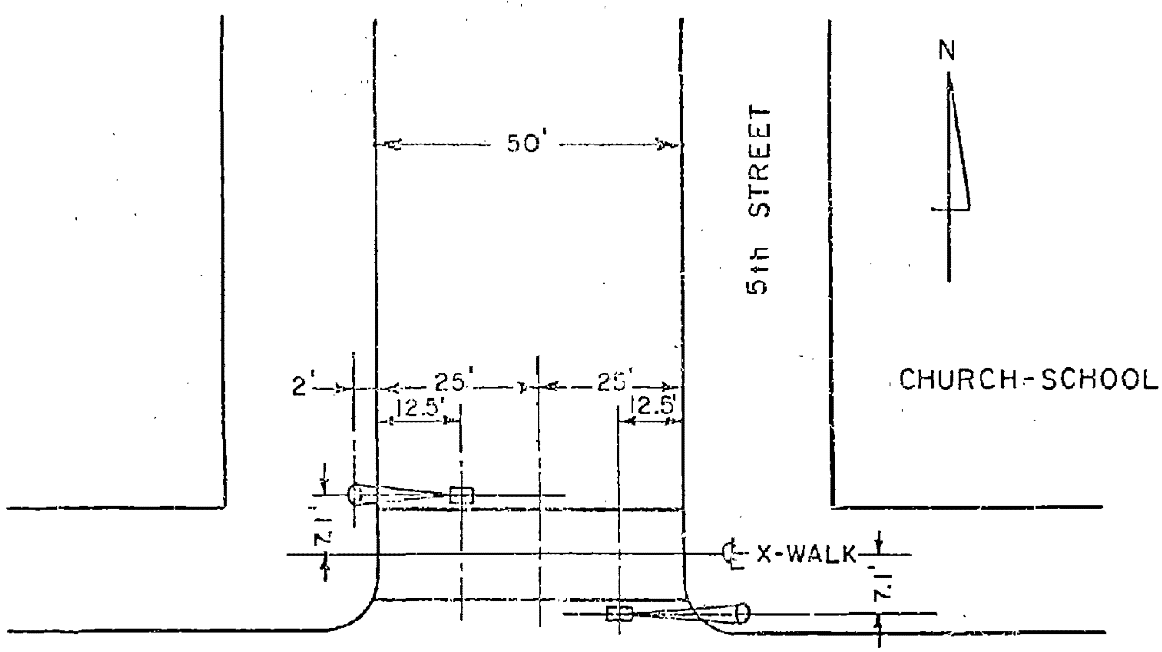
Site A: 5th and Lindley

Alternatives: (1) increased conventional illumination at the intersection.

(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

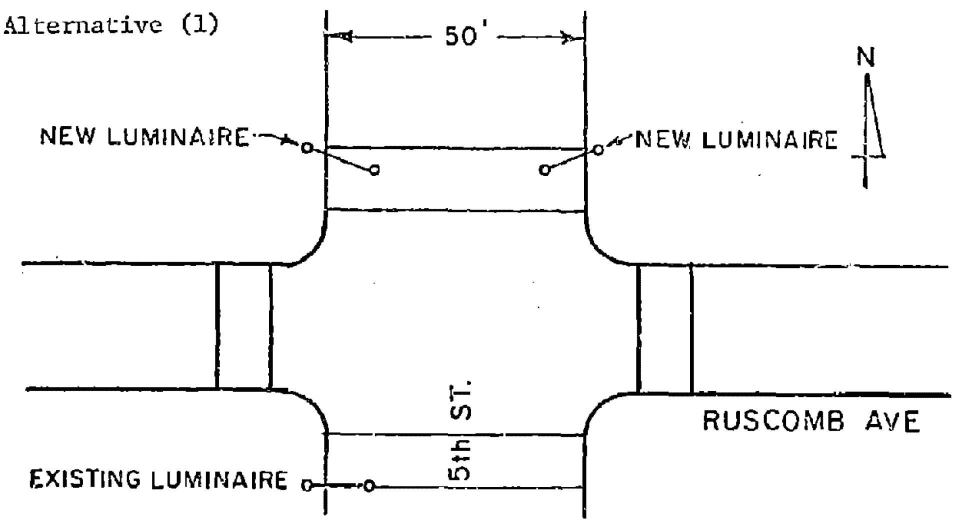
Site B: 5th and Ruscomb

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 is 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 the "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 - Measurement and preduction of average horizontal illumination ($\overline{E}_h$) yields:

SITE	$\overline{E}_h$ existing (fc)	$\overline{E}_h$ proposed (fc)	ΔE_h (fc)	ANN. COST	EFFEC-TIVENESS	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	$594	.11fc/$	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 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.	----	$441.	$594.	.742	1
B_1	$ 777.	$117.	-----	$356.	.329	3
B_2	$ 777.	----	$256.	$594.	.431	2
C	$ 449.	----	$148.	$594.	.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	+PHOTOMETRIC EFFECTIVENESS	+ PED. VOL. EFFECTIVENESS	+ VEH. VOL. EFFECTIVENESS	+ PRESENCE OF SCHOOLS	= TOTAL	RANK
A	1 x 1	1 x 5	3 x 2	1 x 3	2 x 2	19	1
B_1	3 x 1	3 x 5	2 x 2	3 x 3	3-1/2 x 2	38	3
B_2	2 x 1	2 x 5	1 x 2	2 x 3	3-1/2 x 2	27	2
C	4 x 1	4 x 5	4 x 2	4 x 3	1 x 2	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: The procedure for local optimization is continued as follows:

From the analysis of constraints and community goals (Step 5), and the development of alternatives (Step 8), it is not possible to consider the upgrading of conventional illumination as staged alternatives at the Lindley Street or Cayuga Street site. The only possible remaining alternative programs are the following:

1. Special crosswalk illumination at all sites.
2. Special crosswalk illumination at the Lindley Street and Cayuga Street sites, and upgraded conventional illumination at one crosswalk on Ruscomb Street.
3. Same as 2 but install special crosswalk illumination one year later at Ruscomb Street when more funds are available.

Alternative 1 is not possible within present funding constraints. Alternatives 2 and 3 are possible, and provide the following benefits over one year and twenty year periods.

Alternative 2: The average annual accident costs for the three sites total $20,508 for one year (Step 9). The expected annual reduction in accidents yields a savings of $5760, while the annual cost of the alternative is $1544, producing a benefit-cost ratio of 3.73:1 each year, throughout the system's economic life.

Alternative 3: The expected annual reduction in accident cost is $5760 in the first year, and $6767 for each year following implementation of special crosswalk illumination at all three sites. Assuming a 20 year economic life, the total accident reduction benefits would be $7560 + 19 x ($6767) = $134,333, while the amortized cost of the system would be $1544 + (19 x $2138) = $42,166, yielding a 20 year benefit cost ratio of 3.17:1, if the upgraded conventional illumination was left in place at Ruscomb Street. If it is removed upon installation of special crosswalk illumination and re-used at another site, then 20-year annual cost becomes $1544 + (19 x $1782) = $35,402. This cost yields a benefit ratio of 3.79:1.

Conclusions:

The highest benefit-cost ratio is produced by a program that implements two special crosswalk illumination systems and upgrades one conventional illumination system during the first year, then replaces the latter with special crosswalk illumination the folloiwng year when funding is available.