A REVIEW

of the

ISSUES IN STREET LIGHTING AND CRIME

prepared for the

NATIONAL INSTITUTE OF LAW ENFORCEMENT AND CRIMINAL JUSTICE

LAW ENFORCEMENT ASSISTANCE ADMINISTRATION

UNITED STATES DEPARTMENT OF JUSTICE

by

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PREFACE

On April 23, 1976, Public Systems Evaluation, Inc. (PSE) was awarded a one-year, National Evaluation Program grant by the National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration, United States Department of Justice, to conduct a "Phase I Evaluation of Street Lighting Projects." In brief, the purpose of the grant is to assess the present state of knowledge regarding the impact of street lighting on crime and the fear of crime. To this end, PSE has undertaken a brief but encompassing review of the literature and an initial survey of individuals who have developed expertise in the area.

This report is based on work performed during the first three months evaluation of the effort and contains the findings of the initial review activity. As such, the report should be regarded as *preliminary* and as a benchmark of progress to date. The purpose of the report is to review major issues in street lighting, and, in particular, the impact of street lighting on crime. The review serves as a basis for discussion and as a framework for formally conducting a Phase I evaluation of street lighting projects. The status of each of the issues identified in this report will be assessed through a systemic and comparative analysis of past and on-going street lighting projects. The assessment will determine the range of performance and effectiveness of various street lighting projects; the accuracy and reliability of available data in the street lighting area; the factors that seem most likely to influence the success or failure of projects; and the cost of implementing and maintaining alternative types of street lighting projects/systems. Utilizing this information, PSE expects to identify gaps in the present knowledge base and make recommendations concerning future research and evaluation activities which should be undertaken to fill those gaps.

The contents of this report should also be of interest to *criminal justice administrators and planners* who are contemplating street lighting projects. As the report emphasizes, street lighting serves a variety of objectives, and crime prevention needs to be viewed in context with the other objectives of pedestrian safety; community character and vitality; and traffic orientation and identification. The criminal justice specialist, in order to work effectively with street lighting engineers and utility companies, must also be familiar with the basic technical facts about light and street lighting hardware. The report presents these facts in a succinct and purposeful manner. Additionally, the report relates the experiences of past street lighting projects, including an identification of their strengths and weaknesses, successes and failures. Thus, the report can serve as a *reference and guide* to the criminal justice specialist who is interested in street lighting.

ACKNOWLEDGMENTS

Although the street lighting evaluation effort has just begun, many individuals have already been contacted either by telephone or in person, and they have collectively contributed to the knowledge base that is reflected in this report. Exhibit A.3 in Appendix A contains a list of those individuals whose contribution to date the authors would like to acknowledge--it is hoped that they will continue to contribute to this important evaluation effort.

The authors have also been assisted by Dr. Thomas A. Reppetto, Dr. Saul I. Gass and Mr. Goodall Shapiro, all of whom are consultants to Public Systems Evaluation, Inc. (PSE) and a part of the project team. Other members of the PSE project team include Dr. Richard C. Larson, Mr. Gilbert C. Larson, and Dr. Kent W. Colton.

Finally, the authors would like to acknowledge the guidance and support provided by Ms. Jan J. Trueworthy, the government project monitor.

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1 INTRODUCTION

Is street lighting an effective approach in the reduction and deterrence of crime? In 1967, the President's Crime Commission stated that

> There is no conclusive evidence that improved lighting will have lasting or significant impact on crime rates, although there are strong intuitive reasons to believe that it will be helpful....Improved street lighting may reduce some types of crime in some areas....With information on past, present and projected crime rates, it may be possible to assess better the impact of lighting on crime.*

The passage of the Omnibus Crime Control and Safe Street Act of 1968 has accelerated the development and testing of anti-crime strategies, including improved street lighting programs to reduce the threat of street-related, nighttime crimes in urban environments. While methodological problems render the results of these programs statistically questionable, the proliferation of encouraging reports does seem, in itself, significant. However, as cautioned by the National Advisory Commission in 1973,

> ...these statistics cannot be interpreted as proof of the efficacy of lighting programs in reducing crime...additional scrutiny of these results is necessary. Such study will have to take into account the effects of such variables as police patrol levels, displacement of

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* President's Commission on Law Enforcement and Administration of Justice, Task Force Report: Science and Technology. Washington, D.C., U.S. Government Printing Office, 1967.

> criminal activity to other times and places, and seasonal changes in crime patterns. Until all evidence is sifted, it should be assumed that lighting is only one of the factors that help reduce crime.*

In more recent months, the Law Enforcement Assistance Administration (LEAA) has been subjected to considerable criticism for promoting hardware--including street lighting--and for not being able to show that it has contributed to any reduction in crime.** The critics have also complained that even though elaborate evaluation requirements are built in at every level of the LEAA program, evaluations have been geared more to justifying past projects than to identifying problems.

The National Institute of Law Enforcement and Criminal Justice, the research arm of the LEAA, is undertaking several evaluation efforts which address these doubts and criticisms. Among these is the National Evaluation Program, which is providing the grant to conduct this "Phase I Evaluation of Street Lighting Projects." In brief, the purpose of the grant is to assess the present state of knowledge regarding the impact of street lighting on crime and the fear of crime. To this end, a brief but encompassing review of the literature and an initial survey of individuals who have developed expertise in the area have been undertaken.

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* National Advisory Commission on Criminal Justice Standards and Goals, Community Crime Prevention, Washington, D.C., 1973, p. 199.

** See, for example, "Law Enforcement: The Federal Role" (produced by a Twentieth Century Fund task force) and "Law and Disorder" (written by Sarah Carey for the Center for National Security Studies).

This report is based on work performed during the first three months of this Phase I Evaluation effort and contains the findings of the initial review activity. As such, the report should be regarded as *preliminary* and as a benchmark of progress to date. The purpose of the report is to review major issues in street lighting, and, in particular, the impact of street lighting on crime. The status of each of the issues identified in this report will be assessed through a systemic and comparative analysis of past and on-going street lighting projects. The assessment will determine the range of performance and effectiveness of various street lighting projects; the accuracy and reliability of available data in the street lighting area; the factors that seem most likely to influence the success or failure of projects; and the cost of implementing and maintaining alternative types of street lighting projects/systems. Utilizing this information, gaps in the present knowledge base will be identified and recommendations concerning future research and evaluation activities to fill those gaps will be made.

As part of this introductory section, Section 1.1 briefly traces the historical development of street lighting, while section 1.2 summarizes the approach being undertaken by this evaluation effort, and Section 1.3 outlines the scope of the report.

1.1 HISTORICAL BACKGROUND

Archaeologists have dated outdoor lighting to 3,000 B.C. [A.1-38]*. After discovering and mastering fire, prehistoric man used earthen

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* For convenience, all references in this report are coded and identified in square brackets; i.e., "[ ]". Full details of the references are given in Appendix A.

jars to contain the fire which lit his cave inside and out. However, *street lighting systems* are a relatively new phenomena, dating back to 1558 when the city of Paris installed pitch-burning lanterns on some of its main streets. Street lanterns were just one part of the city's attempt to light up the streets. An ordinance was also passed requiring all citizens to keep lights burning in windows that fronted the streets. It is interesting to note that the lighting of the streets in Paris was motivated by the belief that street lighting would rid the streets of nighttime robbers, who had practically taken over the city after nightfall.

Historically, the motivation for street lighting began with security and safety considerations; then became integrated with the community's needs for character identity and vitality; and finally, following the advent of the automobile, contributed to traffic orientation and identification requirements. Exhibit 1.1 summarizes principal street lighting objectives, which have remained unchanged for several decades. What has changed over time has been the emphasis placed on the different objectives: for example, security considerations are again high on the list of priorities of urban administrators and planners. Section 4.1 further discusses these objectives in the context of evaluation.

Exhibit 1.2 traces the historical development of street lighting systems in terms of the locales where the various lighting innovations were installed. Exhibit 1.3 contains an historical development of the various electric lamps. It is seen that the efficacy (i.e., lumens per watt) of the lamps has been increasing. In fact, if the exhibit were to be updated, high pressure sodium vapor would be included with an efficacy rating of over one hundred lumens per watt.

EXHIBIT 1.1

Street Lighting Objectives

Security and Safety

- Prevent Crime
- Alleviate Fear of Crime
- Prevent Traffic (Vehicular and Pedestrian) Accidents

Community Character and Vitality

- Promote Social Interaction
- Promote Business and Industry
- Contribute to a Positive Nighttime Visual Image
- Provide a Pleasing Daytime Appearance
- Provide Inspiration for Community Spirit and Growth

Traffic Orientation and Identification

- Provide Visual Information for Vehicular and Pedestrian Traffic
- Facilitate and Direct Vehicular and Pedestrian Traffic Flow

EXHIBIT 1.2

Historical Development of Street Lighting Systems

Year	Place	Light Source
1558	Paris, France	Pitch-burning lanterns, followed by candle lanterns
1690	Boston, Mass.	Fire baskets
1807	London, England	Gaslights
1879	Cleveland, Ohio	Brush arc lamps
1905	Los Angeles, Ca.	Incandescent
1935	Philadelphia, Pa.	Mercury vapor
1937	San Francisco, Ca.	Low pressure sodium
1952	Detroit, Michigan	Fluorescent
1967	Several U.S. cities	High pressure sodium

EXHIBIT 1.3

Historical Development of Electric Lamp for Street Lighting

Lamp Description	Date	Rated Life for Street Lighting Service	Initial Lumens Per Watt
Arc			
Open carbon-arc	1879	Daily trimming	-
Enclosed arc	1893	Weekly trimming	4-7
Flaming arc			
Open	..	12 hours	8.5 (d-c multiple)
Enclosed	..	100 hours	19 (a-c series)
Magnetite (d-c series "luminous arc")	1904	100-350 hours	10-20
Filament			
Carbonized bamboo	1879	...	2
Carbonized cellulose	1891	...	3
Metallized (gem)	1905	...	4
Tantalum (d-c multiple circuit)	..	...	5
Tungsten (brittle)	1907	...	-
Drawn tungsten	1911	...	9
	1913	...	10
Mazda C (gas-filled)	1930	...	14-20 (varies with lamp size)
	1915	1,350 hours	10-20
	1950	2,000 hours	16-21
		3,000 hours	16-20
Mercury Vapor			
Cooper-Hewitt	1901	Indefinite	13
H25DE	1951	1,500 hours	35
H25DE	1952	6,000 hours	38
H25DE	1963	7,000 hours	39
H33-1CD/E	1947	3,000 hours	50
H33-1CD/E	1952	5,000 hours	50
H33-1CD/E	1966	16,000 hours	51
H35-18NA	1959	7,000 hours	52
H35-18NA	1966	16,000 hours	53
H34-12GV	1959	6,000 hours	54.5
H34-12GV	1966	16,000 hours	55
H36-15GV	1966	16,000 hours	56.5
Sodium Vapor			
NA 4 (10,000 lumen)	1934	1,350 hours	50
NA 9 (10,000 lumen)	1935	2,000 hours	56
	1952	4,000 hours	58
Fluorescent			
F100T12/CW/RS	1952	7,500 hours	66
F100T12/CW/RS	1966	10,000 hours	71
F72PG17/CW	1966	14,000 hours	68
F72T10/CW	1966	9,000 hours	63

Source: [A.2-24]

It is also seen from these two exhibits that the time between major innovations has become increasingly shorter--a "future shock" phenomenon. In fact, it is probably safe to say that another major innovation will occur in the very near future, and will most likely be based on a high intensity discharge lamp containing vapors of more than one chemical element. In comparison with present-day high-pressure sodium vapor lamps, the next generation will achieve higher efficiency and smaller lamp size (for better optical properties) and will use multi-vapors which will fill in and perhaps extend the frequency spectrum that characterizes the current single vapor lamps.* Historically, the properties determining the acceptability of new lamp types have been overall output, efficacy, lifetime, ease of maintenance, ease of optical control, color rendition and initial cost.

1.2 PROPOSED APPROACH

In carrying out the mandate of the National Evaluation Program (NEP) in connection with the "Phase I Evaluation of Street Lighting Projects," an evaluation approach has been proposed. The approach is detailed in Exhibit 1.4: it contains essentially seven tasks, each of which is

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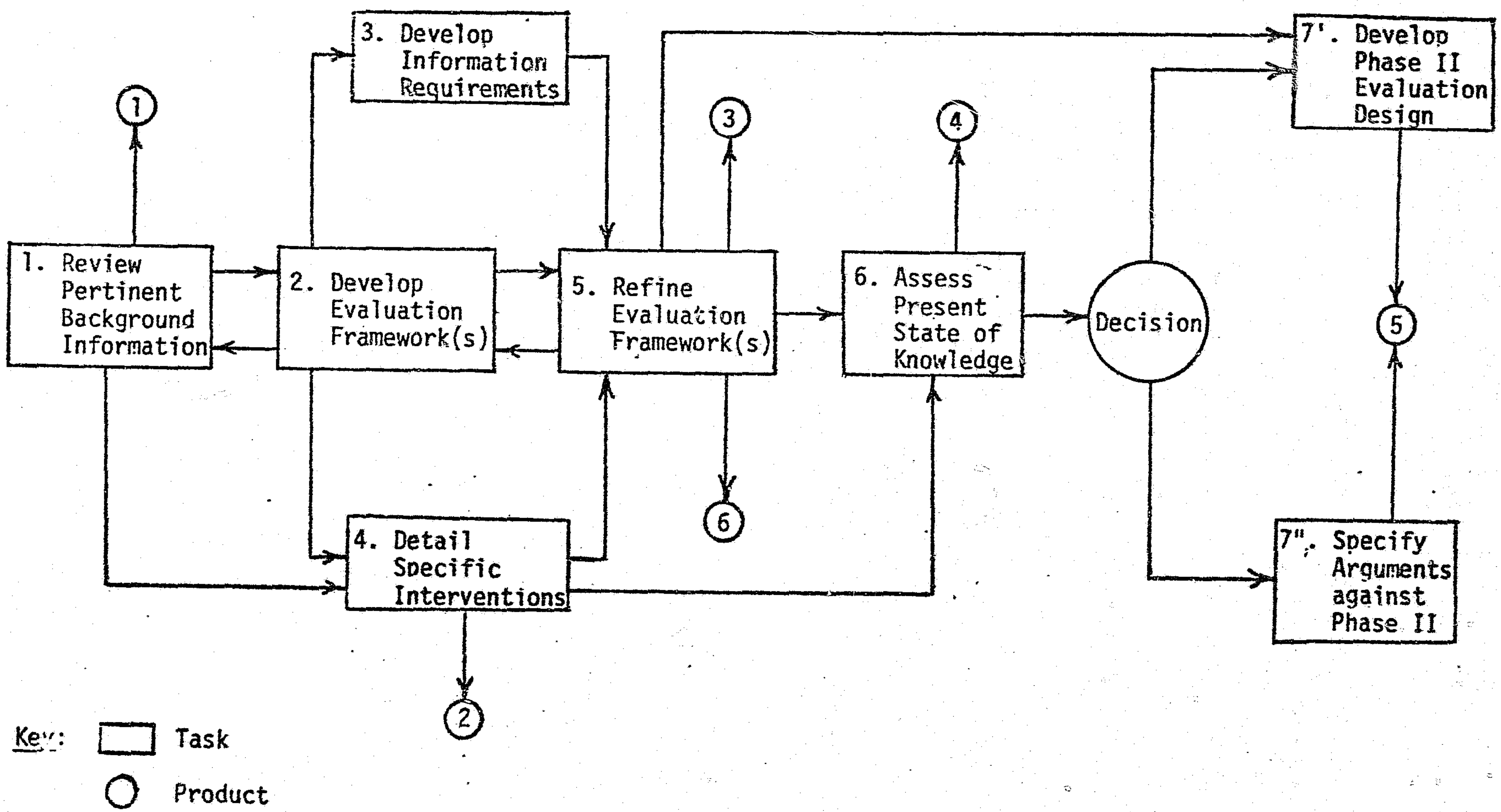
* The non-technical reader should peruse Appendix B, which contains an abbreviated, technical discussion of light measures. In any discussion of street lighting, especially in the development and evaluation of street lighting, it is important to have at least a minimum level of technical understanding of street light design and measurement.

EXHIBIT 1.4

Phase I Evaluation Approach



briefly discussed below. At this time, only the first task has been completed--this report being the product of the task.

TASK 1: REVIEW PERTINENT BACKGROUND INFORMATION

Based primarily on a literature search, this task has assimilated and reviewed past research findings, evaluation studies, and project descriptions; opinions of users, implementors, and experts; and other related background material. The literature search included identifying LEAA-sponsored lighting projects; using the NCJRS and NTIS reference services; and culling through trade journals and professional society publications. In addition, brief telephone interviews have been conducted with experts in the area. The assimilated knowledge base, as contained in this report, includes quantitative, qualitative and engineering data.

As illustrated in Exhibit 1.4, the review of background material will also provide the necessary input for developing a robust and flexible evaluation framework. In turn, the development of the framework will impact the review task, providing guidance on the type of additional material that should be culled and reviewed, assuming that the material is available. The development of an evaluation framework is discussed next.

TASK 2: DEVELOP EVALUATION FRAMEWORK(S)

As indicated in Exhibit 1.4, the establishment of an evaluation framework is the result of a series of identical steps, each involving a development and refinement cycle. In general, an evaluation framework is a multi-dimensional, systemic structure used to represent the impact of an experiment or project. However, a Phase I evaluation framework must also serve an additional purpose: that of comparing similar projects so as to test the validity of the various assumptions or hypotheses. "Similar" projects refer to those projects that have common input elements. For example, street lighting projects that are implemented in commercial areas may not be similar to those that are implemented in residential areas. For this reason, more than one evaluation framework may be required for conducting a general Phase I evaluation. On the other hand, the Phase I evaluation is strengthened if a more robust and flexible evaluation framework can be developed. Such an evaluation framework is already taking shape: Section 2.3 presents street lighting and crime hypotheses in the context of a systematic and viable structure.

TASK 3: DEVELOP INFORMATION REQUIREMENTS

In accordance with NEP instructions, a user statement will be jointly developed with NEP that will provide answers to such questions as how far to go in collecting data, what size of samples are necessary, how much detail to include in flow diagrams, how sophisticated an evaluation design is necessary, etc. This user statement is viewed as an invaluable guide to the refinement of the Phase I evaluation framework.

TASK 4: DETAIL SPECIFIC INTERVENTIONS

For each street lighting project that is deemed within the scope of the topic area, a flow diagram of the actual chain of activities, hypotheses, interventions and outcomes will be developed, including an accompanying narrative that describes the diagram, specifies the possible intervening variables, and documents the associated input, process and output measures. The output of this task will constitute a deliverable product (i.e., product number 2) and should impact the refinement of the evaluation framework and the assessment of the present state of knowledge. The objective detailing of each project will rely on three sources of information: literature material, formal telephone interviews and structured site visits.

TASK 5: REFINE EVALUATION FRAMEWORK(S)

As stated earlier, the evaluation framework will undergo a series of refinements--the final version will be the one used both to evaluate each street lighting project (i.e., as required in Task 4) and to test the various assumptions or hypotheses (i.e., as a necessary input to Task 6, which assesses the present state of knowledge). In addition, as illustrated in Exhibit 1.4, the final refined evaluation framework itself (i.e., product number 3) and an adaptation of the framework to a single project (i.e., product number 6). Again it should be noted that more than one evaluation framework may be required to meet the evaluation requirements of the various street lighting projects.

TASK 6: ASSESS PRESENT STATE OF KNOWLEDGE

An assessment of the present state of knowledge will be based upon the refined evaluation framework(s) as applied to the various street lighting projects singly and collectively. A professional judgment will be rendered on the effectiveness of street lighting as an anti-crime strategy--confidence limits will be placed on this judgment.

As required by the NEP, the assessment will also determine the range of performance and effectiveness of the various street lighting projects; the accuracy and reliability of the data and results of the projects;

the factors that seem most likely to influence the success or failure of projects; the gaps existant in the present knowledge base, the reasons for it, and their impact on the assessment; and the costs of alternative versions of the projects.

As depicted in Exhibit 1.4, it is felt that the assessment should also contain a statement regarding the reliability and feasibility of undertaking a Phase II evaluation effort, should it be necessary. The output of this assessment task will be documented in a deliverable product (i.e., product number 4) and will impact any Phase II evaluation effort.

TASK 7: ADDRESS PHASE II EVALUATION

In accordance with the decision made in Task 6, a Phase II evaluation will either be developed or arguments presented against undertaking a Phase II effort--this will constitute a deliverable product (i.e., product number 5). Obviously, Phase II should not be undertaken if either Phase I findings are sufficient or it is infeasible to undertake a Phase II effort.

Should it be decided to proceed with a Phase II evaluation design, then a design based on the Phase I evaluation framework will be developed. The Phase II design should fill in gaps found in the present state of knowledge and should allow for a reliable judgment on the effectiveness of street lighting as an anti-crime strategy. The design will also estimate the importance, feasibility, methods, and costs of further testing the hypotheses identified in the Phase I evaluation framework. In addition, a determination will be made on whether the Phase II design can be applied to the set of existing projects (with additional data collection efforts) or if additional projects are required. Different levels of Phase II executions will be defined, costed and assessed.

1.3 SCOPE OF REPORT

The remaining sections of this report address issues that are relevant to an evaluation of street lighting and crime. Street lighting issues are addressed in Section 2, while related environmental and evaluation issues are discussed in Sections 3 and 4, respectively. The related issues are perhaps just as important as the basic issues, since the former set of issues places *constraints* on the latter. For example, as discussed in Section 4.4, the current state-of-the-art in evaluation technology may place a severe limitation on the feasibility of determining the impact of street lighting on crime.

Finally, there are two appendices. The first, Appendix A, contains a list of all the references to date, including articles, reports and individuals who have been contacted either by telephone or in person. Appendix B, as indicated earlier, contains a somewhat technical discussion of light measures.

2 STREET LIGHTING ISSUES

As briefly stated in Section 1, street lighting systems encompass a variety of elements and are designed to satisfy a wide range of objectives. As a result, the evaluation of the crime prevention effects of street lighting requires taking into account both the multiple dimensions of the street lighting system and the relative importance of objectives distinct from crime prevention or law enforcement. This section is intended to elaborate on issues to be considered in such an evaluation. It presents first a description of the input, process and output elements of typical street lighting systems, in order to set out the context within which the crime prevention objective can be considered. Next, an overview is given of reported experience with the crime prevention effects of street lighting. While a cursory inspection of the data presented appears to support the notion that street lights reduce crime, the brief summary contained in Section 2.2 is included primarily to illustrate the relative scarcity of controlled experiments, and to serve as background for the more formal discussion of hypotheses which follows. The section closes with the development of a framework for analyzing hypotheses which link street lighting with crime and/or the fear of crime.

2.1 STREET LIGHTING ELEMENTS

The development of an evaluation framework requires a systematic description of the system being evaluated, so that the evaluation is sensitive to the internal dynamics of the system and so that appropriate measures of system performance can be defined. For convenience, the elements of a street lighting system can be classified as input, process or output elements. Exhibit 2.1 shows the relationship of these elements to the overall evaluation process. The impact of the entire street lighting system on crime is assessed in the evaluation process, and these evaluation results are then used to refine street lighting objectives, thus closing the loop with the input elements of the system. The following three subsections address the input, process and output elements of street lighting, respectively.

INPUT ELEMENTS

As indicated in Exhibit 2.1, the discussion of input elements can be divided into sources of funds, allocation of funds, street lighting objectives, street lighting design standards, and street lighting components.

Sources of Funds

Street lighting projects can be paid for out of funds derived from federal, state and local government, and even from private sources. The major sources of funds for existing street lighting systems are listed in Exhibit 2.2. Frequently these sources act in tandem, as when federal programs require a local matching share, or when a merchant's association pays the operating expense of a system whose capital cost is born by the municipal government. Not explicitly included in Exhibit 2.2 is the situation in which the municipality leases street lights which are owned and operated by a utility company. In

EXHIBIT 2.1

Street Lighting Evaluation Process

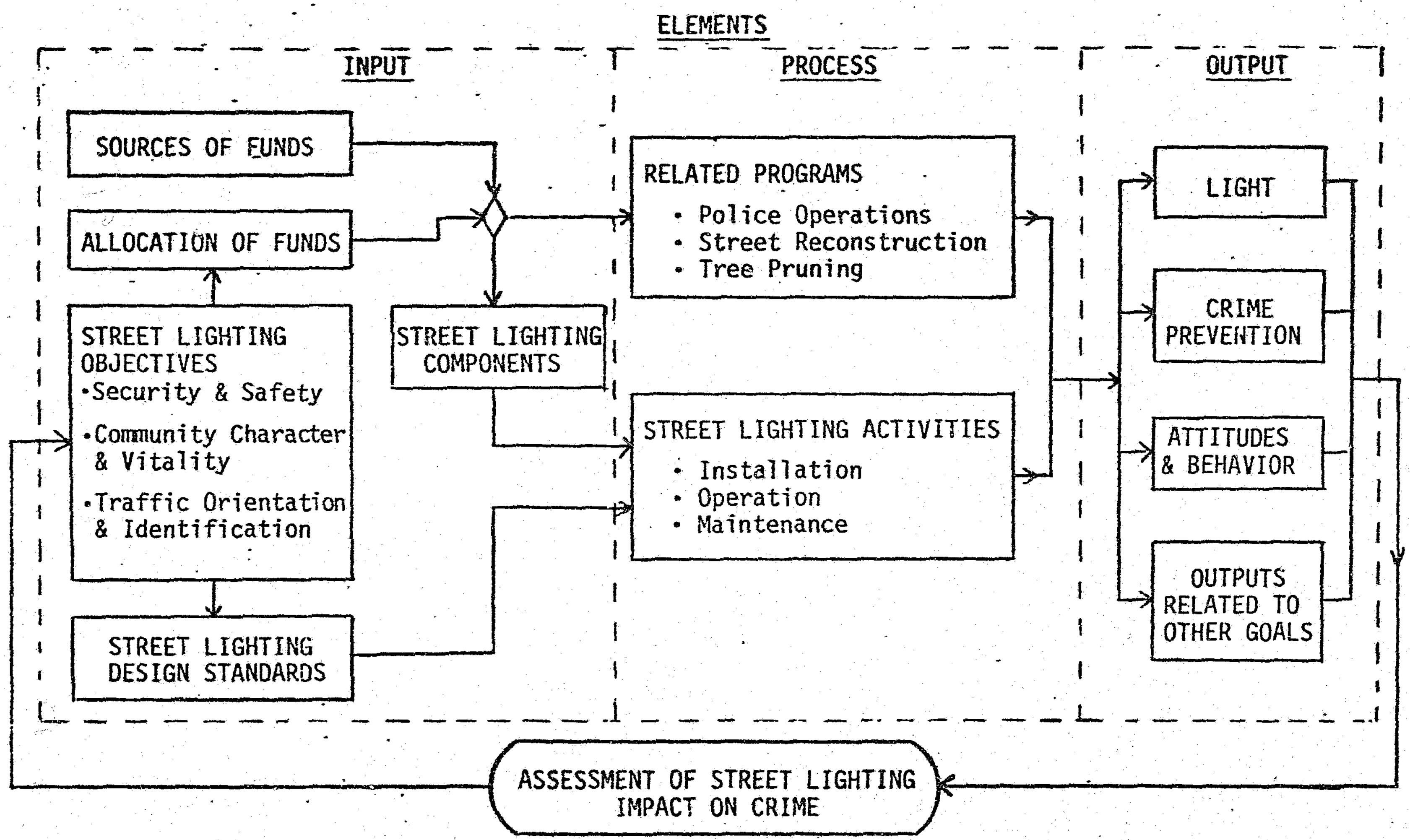


EXHIBIT 2.2

Sources of Funds for Street Lighting Projects

FEDERAL	
Department of Transportation	• Federal Aid Primary System • TOPICS
Department of Justice (Law Enforcement Assistance Administration)	• Block Action Grants • Discretionary Grants
Department of Housing and Urban Development	• Community Development Block Grants • Neighborhood Development • Historic Preservation • Model Cities • Urban Renewal • Concentrated Code Enforcement • Open Space
Treasury Department	• General Revenue Sharing

STATE/LOCAL
• General Funds • Bond Issues • Property Assessment • Redistribution of State Taxes • Special Tax on Income or Luxuries • Investment of Municipal Power Company Profit

PRIVATE
• Civic Organizations • Businesses and Merchants' Organizations • Private Citizens

Sources: [A.2-58, A.2-65 and A.2-107]

such a case, the capital and operating expense are combined in the utility company's rates charged to the municipality. Regardless of this variation in ownership pattern, the same sources of funds may be used to cover the leasing fees.

Many of the federal government funding sources have changed with the advent of revenue sharing. Thus, the Department of Transportation's TOPICS program and the Department of Housing and Urban Development's Model Cities and Urban Renewal programs are no longer active, while funds now flow via general revenue sharing and Community Development Block Grants.

The Law Enforcement Assistance Administration (LEAA) has funded lighting programs both directly through discretionary grants to municipalities, and indirectly through block action grants to the states. Unfortunately, there is no available information regarding the exact amount expended by LEAA for street lighting installation. However, a review of information contained in LEAA's Grants Management Information System (GMIS) suggests that several million dollars have been expended for such purpose.

Perhaps more important than the amount spent to date by LEAA on street lighting, is the possible future level of funding. Exhibit 2.3 contains a bill currently pending before Congress (HR 565), which would amend the Omnibus Crime Control and Safe Streets Act of 1968 to provide for 75% matching of costs incurred by cities for the purpose of improving street lighting. The total funding authorized by this bill is $300 million, over five years, a figure which underlines the importance of this evaluation effort.

EXHIBIT 2.3

A Pending Congressional Bill for Improved Street Lighting

94TH CONGRESS
1ST SESSION

JANUARY 14, 1975

H. R. 565

A BILL

To amend the Omnibus Crime Control and Safe Streets Act of 1968 to provide for grants to cities for improved street lighting.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That parts F, G, H, and I of title I of the Omnibus Crime Control and Safe Streets Act of 1968 are redesignated G, H, I, and J, respectively, and such title is further amended by inserting the following new part immediately after part E:

"PART F—LIGHT ON CRIME PROGRAM

"SEC. 461. It is the purpose of this part to encourage units of general local government to provide increased street lighting in urban areas within such limits, by making available direct Federal aid for such increased street lighting.

"SEC. 462. The Administration is authorized to make direct grants, without regard to any comprehensive State plan, to any unit of general local government for the improvement of street lighting systems in any urban place or places in such unit. Such improvement shall include the increased use of bright street lighting, such as high-pressure sodium lamps. Each grant made under this section shall be for an amount not to exceed 75 per centum of the cost of the project with respect to which such grant is made.

"SEC. 463. In addition to any other authorizations of appropriations for the purposes of this Act, there are authorized to be appropriated for the purposes of this part, to remain available until expended, $60,000,000 for the fiscal year ending June 30, 1976, and $60,000,000 for each of the next four fiscal years.".

It is interesting to note that no standards or guidelines are established in the proposed legislation to assure that crime prevention objectives are met, other than to require "increased use of bright street lighting, such as high pressure sodium lamps." There seems to be some evidence, however, that the impact of street lighting on crime is not only related to the brightness or the use of any particular light source but also to various other environmental factors. The definition and understanding of these relationships could certainly contribute to the establishment of guidelines necessary for the effective allocation of street lighting funds. In the meantime, the questions of whether and how street lights impact crime have not been definitively answered.

Allocation of Funds

Decisions on how funds are allocated to street lighting are, of course, closely related to the requirements of the funding sources themselves. Nevertheless, the official decision to seek funds is made by local government. During this decision-making process the costs and benefits of street lights receive considerable attention, since local funds are always required for part of the installation cost and, usually, all of the maintenance and operating cost.

A major influence on the decision-making process is that brought on by the industry. Considerable efforts have been made by representatives of manufacturing and utility companies to promote decisions in favor of increased and improved street lighting.* These efforts

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* See [A.1-1, A.1-9, A.1-10, A.1-33, A.1-36, A.1-44, A.1-46, A.1-53, A.1-66, A.2-41, A.2-52, A.2-57, A.2-65, A.2-84, A.2-89, and A.2-108].

include dissemination of statistics relating street lights to reduced crime and traffic accidents and preparation of promotional material including information on local government budget processes, advertising copy, sample speeches, and instructions on how to utilize public service access to media.

Although the activities of the most prominent of the industry groups, the Street and Highway Safety Lighting Bureau (SHSLB), ceased several years ago, they have provided a stimulus for such community crime prevention efforts as "Light the Night" and "To Stop a Thief, Light a Light." These activities have also done much to emphasize the importance of citizen support for local government in its effort to invest in capital-intensive projects, such as street lighting. Cooperation between citizens and government has also been emphasized by the National Advisory Commission on Criminal Justice Standards in its "Report on Community Crime Prevention" [A.2-89, pp. 198-200]. At the same time, perhaps because of the basic marketing interests underlying industry-sponsored promotional efforts, the statistics which have been collected and published by SHSLB are not useful for a careful analysis of the true relationship between street lighting and crime.

Street Lighting Objectives

As discussed in Section 1.1 and illustrated in Exhibit 1.1, street lighting has historically had three major objectives pertaining, specifically, to security and safety, community character and vitality, and traffic orientation and identification.

It is, of course, not obvious that street lighting systems can be designed to meet all of the objectives simultaneously. Apart from an incomplete knowledge of the specifications required for any one objective, there may be conflicts between objectives. For example, it could be supposed that even if very high intensity street lighting in shopping areas is best for the enhancement of business, a resultant visual disorientation and glare would contribute to traffic accidents. A comprehensive planning approach can do much to deal with the problem of designing for the integration of system objectives.

Unfortunately, as might be expected, comprehensive planning is the exception rather than the rule in street lighting. If the overall "streetscape" is chaotic and characterless, it is difficult to coordinate street light designs with the undefined streetscape. Large scale urban renewal programs constitute one of the few instances where both planning and implementing funds are available, and where other activities, such as street reconstruction, housing development and replacement of street signs, are coordinated with lighting installation or upgrading.

Even in less ambitious street lighting plans, lighting engineers have seldom seen their carefully planned designs executed according to specifications. Problems which have been cited include substitution of equipment because of price considerations or change of local ordinances, refusal of utility companies to work with innovative designs, and inability of harassed and overworked municipal officials to examine detailed proposals carefully [A.1-71, A.2-80].

Nevertheless, comprehensive plans for street lighting have been executed [A.1-21, A.1-52 and A.1-71].

Because the balancing of diverse objectives is at the heart of the development of a comprehensive design [A.2-123], the information generated by an evaluation of the crime prevention effects of street lighting can have a significant impact on future street lighting systems, even though it is questionable whether it would ever be the dominant influence.

Street Lighting Design Standards

Technical standards for the performance of street lighting systems in the United States are put forward by the American National Standards Institute (ANSI), under the sponsorship of the Illuminating Engineering Society (IES) of North America [A.2-59]. IES has developed and amended these standards, known as "American National Standard Practice for Roadway Lighting," since 1925, and has specifically designated its Roadway Lighting Committee as the group responsible for updating of the standards to reflect changes in knowledge and technology.

The other organization involved in setting standards for street lighting systems is the International Commission on Illumination (CIE, which are the initials of its French designation, Commission Internationale de l'Eclairage). CIE publishes international recommendations based on general principles, to serve as a basis for the drafting of uniform national codes among participating countries. As such, it is not a binding professional standard, but it does represent another view on the desired characteristics of street lighting systems.

Exhibit 2.4 compares the ILS and CIE standards: it is seen that there are similarities as well as significant differences between

EXHIBIT 2.4

Street Lighting Standards and Recommendations

FACTOR	TYPE OF SPECIFICATION	
	IES (Illuminating Engineering Society)	CIE (International Commission on Illumination)
Horizontal road or walkway surface illumination	Recommended minimum	Not addressed
Road surface luminance (brightness)	Addressed qualitatively in conjunction with other factors	Recommended minimum
Ratio of average to minimum illumination	Maxima given as guidelines (to be considered with other factors)	Not addressed
Ratio of average to minimum luminance (brightness)	Not addressed	Recommended maximum
Glare	Addressed qualitatively in conjunction with other factors	Recommended maximum level
Road classification	Indirectly addressed through classification of recommendations, including recommendations for pedestrian walkways	Indirectly addressed through classification of recommendations. Pedestrian walkways treated in separate document
Land use	Indirectly addressed through classification of recommendations	Not addressed

EXHIBIT 2.4

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FACTOR	TYPE OF SPECIFICATION	
	IES (Illuminating Engineering Society)	CIE (International Commission on Illumination)
Brightness of "Surround"*	Included under "Glare"	Indirectly addressed through classification of recommendations
Visual guidance	Not addressed	Guidelines given
Optical guidance	Not addressed	Guidelines given
Other factors (luminaire type, mounting height, spacing and arrangement, traffic conflict areas, border areas, transition lighting, and alleys)	Guidelines given (to be considered with other factors)	Not addressed

* The "surround" is defined by lighting engineers as a specific area immediately surrounding a visual task.

Sources: [A.2-59], and International Commission on Illumination , "Draft Recommendations for the Lighting of Roads for Motorized Traffic," Publication CIE No. 12/2 (TC-4.6), December, 1975.

their recommendations. For example, the IES standard for the amount of light is based on illumination of the horizontal road or walkway surface (i.e., amount of light falling onto the surface) while the comparable CIE recommendation is made for the road surface luminance (i.e., amount of light reflected from the surface). Similarly, the recommendations on uniformity of the light distribution deal with illumination and luminance, respectively. Although IES and CIE both recommend different light levels for different types of street (e.g., arterial versus local residential), they differ in the definition and classification of streets. The IES includes pedestrian walkways as well as diverse land use in its classification, while the CIE focuses on the brightness of the "surround" and treats pedestrian separately. The CIE also gives quantitative recommendations for the limitation of glare, while the IES gives overall guidelines to minimize glare in conjunction with a variety of other factors.

The somewhat different outlook of these two professional organizations suggests that differences of opinion may also arise as to the specification of systems for optimal crime prevention. In fact, as is discussed in various sections of the report, there are diverse opinions on the relationship between street lighting and crime prevention.

Street Lighting Components

The major components of a street lighting system are lamps, luminaires, poles and brackets, and electrical system. For the purpose of the present discussion, only the first two components are examined in this subsection.*

Lamps

Exhibit 2.5 summarizes the characteristics of different types of lamp. Lamps are generally classified according to the physical processes by which they produce light. Incandescent sources contain a thin wire filament which heats up and glows upon passage of an electric current. All other sources used in street lighting are called high intensity discharge (or gaseous discharge) lamps, and produce light by passing an electric current through a gas, usually containing one or more metal vapors as well as other elements. The effect is to "excite" the atoms of the gas to higher than normal energies. The atoms then discharge this excess energy in the form of light, and the colors of the light are very narrowly defined and specific to the combination of elements in the lamp. Some lamps use phosphorescent coatings on the bulb surface to broaden the range of colors produced. In fact, the discharge in a fluorescent lamp produces mostly invisible ultraviolet light, and these lamps rely on coatings to convert the light into visible colors.

In a discussion of crime prevention related issues, it is instructive to further discuss two of the characteristics that are identified in Exhibit 2.5--efficacy and color rendition. The term efficacy is used to denote how efficiently a lamp converts electrical energy

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* For a more complete description of street lighting principles, and design, see [A.2-24].

EXHIBIT 2.5

Selected Characteristics of Basic Lamp Types

Characteristics	LAMP TYPE				
	Incandescent (Including Tungsten Halogen)	High-Intensity Discharge (HID)			
		Fluorescent	Mercury-Vapor	Metal-Halide	High-Pressure Sodium
Wattages (lamp only)	15 to 1500	40 to 219	40 to 1000	400, 1000, 1500	75, 150, 250, 400, 1000
Life (hours)	750 to 12,000	9000 to 30,000	16,000 to 24,000	1500 to 15,000	10,000 to 20,000
Efficacy (lumens per watt, lamp only)	15 to 25	55 to 88	20 to 63	80 to 100	100 to 130
Color rendition	Very good to excellent	Good to excellent	Poor to very good	Good to very good	Fair
Light direction control	Very good to excellent	Fair	Very good	Very good	Very good
Source size	Compact	Extended	Compact	Compact	Compact
Comparative fixture cost	Low because of simple fixtures	Moderate	Higher than incandescent, generally higher than fluorescent	Generally higher than mercury-vapor	Highest
Comparative operating cost	High because of relatively short life and low efficacy	Lower than incandescent; replacement costs higher than HID because of greater number of lamps needed; energy costs generally lower than mercury-vapor	Lower than incandescent; replacement costs relatively low because of relatively few fixtures and long lamp life	Generally lower than mercury-vapor; fewer fixtures required, but lamp life is shorter and lumen maintenance not quite as good	Generally lowest; fewest fixtures required

Source: [A.2-4]

as measured in watts, into light, as measured in lumens (lumens are defined in Appendix B). In general, high-intensity discharge (HID) lamps have higher efficacy than fluorescent bulbs, and, among the HID sources, high-pressure sodium lamps are the highest. One source not used as commonly in the United Sates as it is in Europe, the low-pressure sodium lamp, has an even higher efficacy than high-pressure sodium. There are, however, some technical and safety problems with low-pressure sodium.

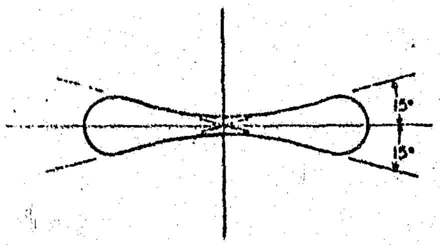
Color rendition is, of course, governed by the colors of the light produced by a source. Incandescent and fluorescent bulbs have the best color rendition, while uncoated mercury vapor has the worst, emitting a bluish light with no orange or red component. Somewhat between these extremes lies high-pressure sodium, which emits a yellow-white colored light. There is still some controversy over how to assess the color-rendering properties of HID sources. This issue is dealt with in Section 4.2.

Luminaires

The luminaire is the unit which contains a lamp in its correct position; protects it from the elements and other hazards; focuses and reflects the light in a given distribution; and connects the lamp to electrical power. Luminaires are designed to produce light distributions which conform to the standard types that are shown in Exhibit 2.6. In addition to the indicated light distribution in the horizontal roadway plane, one can also consider the distribution of light in a vertical plane.

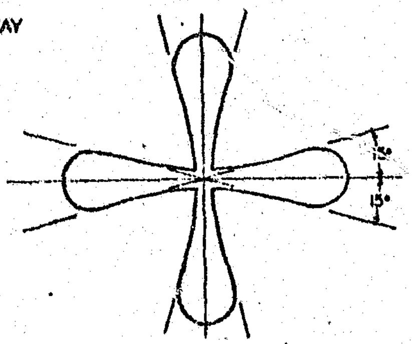
EXHIBIT 2.6

Representative Luminaire Light Distribution Types

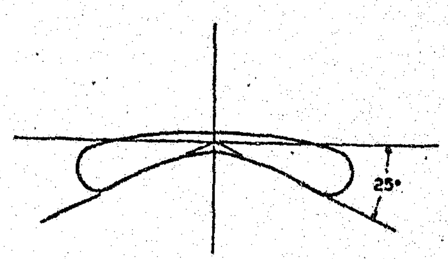


Type I lateral distribution has the two principal light concentrations in opposite directions along the roadway. The vertical plane through maximum candlepower is parallel to the curb. This type of distribution would generally be used when the roadway is narrow and the luminaire is mounted over the center of the street.

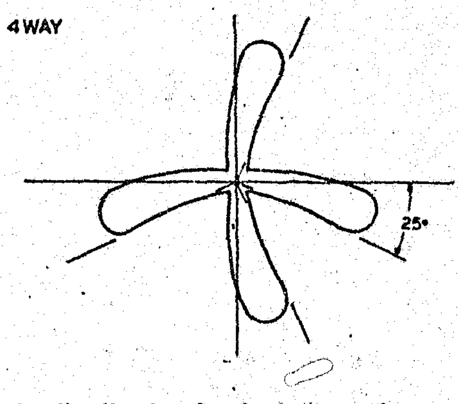
4 WAY



Type I four way is the same as above except that there are four concentrated beams. This unit should be mounted over the center of a four-way intersection.



4 WAY



Type II distribution luminaires are for mounting along the curbs of relatively narrow roadways. The main candlepower beams are along the road; however, they are broader and bent toward the roadway (not parallel to curbs).

Source: [A.2-24, pp 33 and 93]

Note: Diagrams in this exhibit show region on road surface of maximum candlepower distribution

EXHIBIT 2.6

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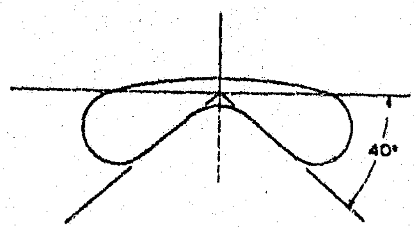
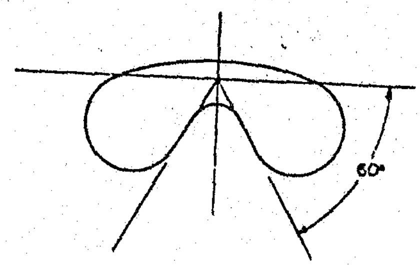
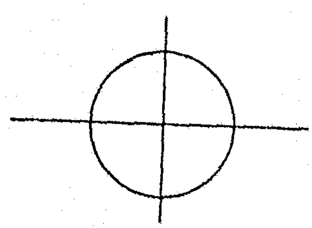


Type III is for use in wider roadways than Type II. This unit has a broader beam and covers a greater transverse distance than the Type II distribution.



Type IV is for use on still wider roadways because of its ability to cover greater transverse distances than Type II or III.



Type V luminaire provides a circular pattern of light. May be used at intersections or islands in parkways.

Luminaires are also classified as "full cutoff," "semicutoff" or "noncutoff," to indicate the degree to which the lamp's glare is shielded from an observer, full cutoff being the most shielded. The cutoff feature is important to traffic safety and overall visual order, since the glare from a luminaire can produce attention conflicts between the luminaire and other elements in the field of vision, due to the phototropic, or light-seeking, reflex of the human eye [A.1-72].

Given the properties of light sources and luminaires, and the chosen design standards, it is the lighting engineer's task to choose a configuration of system elements which meets the required standards. The three critical configuration parameters used in this process are luminaire mounting height, pole spacing and arrangement. The first two are self-explanatory, while luminaire arrangements along the street are usually categorized as "opposite," "one-sided" or "staggered."

PROCESS ELEMENTS

The discussion of process elements focuses on the installation, operation and maintenance of street lighting system, and related police operations and other related activites, such as street reconstruction and tree pruning.

Installation, Operation and Maintenance

The installation of street lights involves coordinating the efforts of several municipal departments, as well as of private industry. A typical street lighting project requires coordination among the following organizations: public works, police, city engineer's, redevelopment authority or planning agency, local utility company and lighting equipment manufacturers. The smooth execution of an installation or upgrading program clearly depends on effective management of the process. One of the major concerns of the Phase I evaluation of street lighting will be to document the number and variety of agencies involved in street lighting installation, as well as to determine the project management techniques that are utilized.

Additionally, this evaluation will address installation and operating costs, and maintenance practices. Maintenance practices may be important if they adversely affect lighting output. Some of the reasons for normal deterioration of street light output include dirt, insects and dust, aging of lamps, lamp outages, accidental damage, vandalism, variations in electric current or voltage, and tree foliage interference with luninaires. The steps recommended for a quality maintenance program include cleaning of luminaires, replacement of lamps (whether spot-or group-replacement), regulation of voltage and current, and contracting of maintenance to private industry [A.2-24]. These practices will also be examined through the analysis of project interventions.

Police Operations and Other Related Programs

Although police departments seldom if ever change their tactics specifically because of the installation of street lights, it is frequently remarked that street lights increase the effectiveness of police patrols by making potential criminals and victims more visible. However, it often happens that changes in police patrol methods are taking place simultaneously with, and usually independent of, street light upgrading. For example, while Kansas City was undertaking a major relighting program in 1971 and 1972, it was also increasing its police force from 1.89 per thousand population in 1970 to 2.52 per thousand in 1973, and, additionally, conducting an experimental preventive patrol program. In Washington, D.C. the police force increased by more than two-thirds during and after a major relighting program [A.2-47]. As a result, is is technically difficult if not impossible for an evaluation to separate the effects of the street lighting and police patrol programs. This problem is further discussed in Section 4.

Frequently street lights are funded in conjunction with large-scale programs of street reconstruction, urban renewal activities, neighborhood improvement programs, etc., and, as with changes in police operations, the effects of these concurrent programs on crime prevention cannot easily be estimated or ruled out.

OUTPUT ELEMENTS

The output elements of street lighting include light and those measures of light relevant to street lighting, crime prevention, subjective attitudes, and outputs related to other street lighting objectives, such as traffic safety and visual orientation. A detailed discussion of light measures is contained in Appendix B: an understanding of these measures is essential, inasmuch as any impact of street lighting on crime must be a function of the various light measures. This subsection then briefly discusses the latter three sets of output elements: the issues associated with measuring these outputs and using them in evaluations are discussed at length in Section 4.

Crime Prevention

Although there is no controversy over the fact that one output of street lights is light, as much cannot be said for crime prevention. On the one hand, millions of dollars of municipal, state and federal expenditures have been justified over many years, in part by the presumed crime prevention effects of street lights. Support for this notion comes from the former Director of the Federal Bureau of Investigation [A.2-53, A.2-54, A.2-55], the chiefs of police [A.2-110], numerous published reports and an intuitive sense derived from everyday experience. On the other hand, most careful, controlled investigations have either come to qualified conclusions [A.2-3, A.2-117] or have been frustrated by the elusiveness of results that are significant.

The balance of Section 2 deals with the available reports of street lighting and crime prevention and what has been learned from them. Section 4 continues the analysis with an examination of the methodological issues involved in evaluating the crime prevention effects of street lights.

Subjective Attitudes

The fear of crime is, perhaps, even more prevalent than crime itself. It is often held that if street lights reduce the fear of crime, crime will be subsequently reduced [A.1-40, A.1-56, A.2-3, A.2-96 and A.2-105].

Others feel that increasing the citizens' sense of security is in itself a desireable goal [A.2-3, A.3-24].

There are, of course, many other attitudes affected by street lighting. User studies have been able to determine other dimensions of importance to those citizens who live or work within areas affected by street lights. Again, a more complete discussion of the status of this research is given in Section 4.

Outputs Related to Other Objectives

The street lighting output which receives the most attention is traffic safety. Continuing studies of this aspect of street lighting have accumulated a great deal of evidence not only on how much, but how street lights prevent accidents [A.2-13, A.2-63 and A.2-99]. In fact, research into traffic safety and related aspects of street lighting bears considerable significance for the development of crime prevention evaluations. This point is discussed further in Section 2.3.

2.2 STREET LIGHTING EXPERIENCE

This section provides a brief summary of the crime-reduction experience reported by a number of communities following the installation or improvement of their street lights. Because the sources of information vary widely in their reporting objectives and techniques, the section only highlights the available information. However, it should not be assumed from this that journalistic reports and carefully controlled evalutions are both given the same weight. Controlled studies, and their methodological contributions and difficulties, are further discussed in Section 4 and will be analyzed in depth in the ensuing months. In sum, the objectives of this section are simply to list reported results, to note some of the issues raised by the manner in which many non-controlled studies have been reported, and to pave the way for the more formal discussions of street lighting and crime hypotheses and evaluation methodology which follow in Sections 2.3 and 4.

Exhibit 2.7 briefly presents some reported impacts of street lighting on crime in various cities. It should be noted that Exhibit 2.7 is not all inclusive: in general a study is included in the exhibit only if information on the date of the street lighting project and the assessed crime-related impacts are documented and readily available. The exhibit includes the city or town where the street lighting project took place, the year of the project, the type of street lighting changes, if available, and the reported impacts of the project. In reviewing Exhibit 2.7, it should be realized that any list of *reported* happenings is subject to suspicion and bias, since if the anticipated happening does not occur, the chances are that it would not be reported.

In most of the studies listed in Exhibit 2.7, the assessment of impacts is based on "before and after" police statistics; and whenever there has been a reduction in the incidence of target crimes, the reduction has been attributed to the street lighting project. Unfortunately, in the vast majority of cases, no controls were used to eliminate the effects of other variables capable of affecting crime (e.g., level of police activity, socio-economic conditions, etc.). In

EXHIBIT 2.7

Some Reported Impacts of Street Lighting on Crime

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Asheville, N.C. [A.1-2]	1973	315 street lights replaced; from 21,000 lumens (mercury) to 50,000 lumens (high-pressure sodium)	Compared to 1972-1973, in 1973-1974 the numbers of incidents of breaking and entering, larceny, vandalism, purse-snatching and hit-and-run were reduced.
Atlanta, GA. [A.1-3]	1973	275 mercury lamps replaced by 400 high-pressure sodium lamps	The preliminary analysis showed no significant differences between relit and unrelit areas with respect to the percentage of target crimes that occur at night.
Baltimore, MD.			
[A.1-7]	1969	Street lighting improved	Compared to June 1968, in April 1970 the number of night-time major crimes decreased.
[A.1-5]	1975	High-pressure sodium lamps installed in residential streets	A residents' survey showed that (i) 34% felt a decrease in criminal activity; (ii) 66% felt more safe; and (iii) public unaware of an increase in crime
Charleston, W.VA. [A.1-11]	1973	165 street lights added	Reductions in total offenses (by 9%), felonious assaults (by 70%) and auto theft (by 13%) were observed.

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Chicago, IL.			
[A.2-13]	1959	Several "districts"relit	Reductions of night robberies (by 30%), purse-snatches (by 30%), strong-arm robberies (by 87%) and auto thefts (by 10%) were observed in some districts.
[A.1-16, A.1-18, A.2-78]	1966	51,000 mercury lights added in alleyways	Crimes in alleys were reduced.
[A.1-15]	1974	High-pressure sodium lights added	Compared to 1974, in 1975 reductions in incidence of murder (by 12.6%), rape (by 22%), serious assault (by 0.9%), robbery (by 10.5%), theft (by 0.7%), auto theft (by 12.5%) were observed, while burglary increased (by 5.8%).
Cleveland, OH. [A.1-25, A.2-78]	1966-1973	58,000 mercury lights added	Total number of offenses was increased (by 80%), but incidents of purse-snatching were reduced (by 78%).
[A.1-22, A.1-23]	1975	948 mercury lights added	Street lights were installed primarily for crime prevention purposes; assessment unavailable as yet.

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Dade County, FL. [A.2-101]	1972	100 watt incandescent lamps replaced by 250 watt mercury lamps in a public housing project	Reductions in Part I crimes (245 to 189) and in Part II crimes (72 to 35) were observed in a nine-month period.
Detroit [A.1-78]	1968	675 mercury lights added	Night offenses were reduced (by 12%) in relit area and were increased (by 14%) in "control" area.
Flint, MI. [A.2-117]	1956	6,000 lumen incandescent lamps replaced by 20,000 lumen mercury lamps	Reductions in felonies and misdemeanors (by 60%) and in larcenies (by 80%) were observed.
Gary, IN. [A.2-88]	1953-1955	Mercury lamps installed in dimly lit areas	Reductions in number of assaults (by 75%) and robberies (by 65%) were observed.
Indianapolis, IN. [A.1-35]	1959-1962	1,000 new lights (900 mercury, 100 fluorescent) added per year	Night offenses were reduced (by 60%) and 255 fewer total incidents of crime were reported in relit areas the year after light improvement.
Kansas City, MO. [A.2-13]	1950-1953	40% of streets relit in 1950-1951, 65% of streets relit in 1952-1953	The ratio of night to day crime rates was reduced city-wide but a higher reduction was observed on better lit streets.

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Kansas City, MO. (continued) [A.1-40]	1971-1972	1800 mercury and sodium lights added in 500 blocks in downtown area and in a mixed residential/commercial neighborhood	This most controlled study concluded that (i) crimes against person (robbery and assault) were significantly deterred by street-lighting; (ii) crimes against property were unaffected; (iii) crime rates in commercial areas decreased faster than in residential areas; and (iv) some of the robberies were displaced from relit areas to non-relit areas.
Miami, FL. [A.1-49]	1971	Street lighting improved by mercury and high pressure sodium lights	Except for larceny, in 1972, compared to 1971, reductions in murder (by 32%) rape (by 49%) robbery (by 13%) assault (by 14%) burglary (by 2%) and auto theft (by 12%) were observed in the central business district.
[A.1-48]	1971	350, 47,000-lumen high pressure sodium lights added	In the garment district crimes were dramatically decreased in 1971 due to increased patrol activity combined with new lights.
Milwaukee, WI. [A.1-54, A.1-55]	1972	Incandescent lights replaced by sodium lights for 3.5 miles of streets	In this controlled study the following were observed: (i) decrease (by 6%) in night crime in test area as opposed to a smaller decrease (by 2%) in control area; (ii) decrease in person-related crimes in test area as opposed to an increase in control area;

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Milwaukee, WI. [A.1-54, A.1-55] (continued)			(iii) no difference in property related crimes, except auto thefts increased in test area as opposed to a decrease in control area; (iv) residents felt safer; and (v) police reported better effectiveness.
New York City [A.2-117]	1957-1959	Incandescent lights replaced by mercury lights in 111 blocks	Night offenses were reduced (by 49%).
[A.1-63]	1960-1961	Lighting improved in 392 playgrounds	Incidents of vandalism were reduced by 100% in Staten Island, by 86% in Brooklyn, by 81% in Manhattan, by 50% in Bronx and Queens)
Norfolk, VA. [A.1-69, A.1-70, A.1-71]	1973-1974	Street lighting improved	An attitude survey showed that (i) 96% felt that new lighting had a beneficial impact; (ii) public was enthusiastic about the new lighting system; (iii) night environment is a cause of concern for most of the public; (iv) security, insufficient lighting and fear of strangers were the major factors which limited the use of streets at night; and (v) lighting alone does not make an environment more secure.

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Owensboro, KY. [A.1-74]	1968-1970	5,000 mercury lights added	The following were observed: (i) reduction in total offenses (by 22% in 1968 and by 9% in 1969), compared to an 11% increase experienced by "comparable communities" in 1969; (ii) reduction in armed and strong-armed robberies (by 25% in 1968 and by 33% in 1969), and in reported break-ins (from 387 in 1967 to 306 in 1968 and 276 in 1969); and (iii) an increase in the rate of convictions.
Plainfield, NJ. [A.1-75]	1972	136 sodium lamps added in downtown area	Reduction in burglaries (by 50%) and robberies (by 65%) were observed.
Plainview, KY. [A.1-38]	1975	Mercury vapor lights installed in a new residential subdivision	In this controlled study the following were observed: (i) fewer burglaries and thefts in well-lit as compared to poorly-lit areas; (ii) residents believed that street lights deter crime; and (iii) residents had positive attitudes toward street lighting.

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Portland, OR. [A.1-76, A.1-79]	1973	330 lamps (rated at 7,000 lumens) added	This controlled study indicated that (i) only 25% of the residents were aware of additional lighting;and (ii) available data were inconclusive about the crime prevention property of street-lighting.
Richmond, VA. [A.1-81]	1974	213 mercury lamps added and 597 lamps replaced by mercury and sodium lamps	The study concluded that (i) non-residential burglaries were significantly reduced (from 142 to 103); (ii) residential burglaries were increased (from 204 to 218); and (iii) the decrease could also be partially attributed to a new police patrol plan, and the differences between residential and non-residential burglaries could have been due to foliage related obstruction of street lighting in residential area.
St.Louis [A.1-83, A.2-89]	1964	1,402 incandescent lamps replaced by 1,120 mercury lamps of 1,000 watts each in the downtown area	An increase in night-time business and reductions in crimes against persons (by 40%),auto theft (by 28.6%) and business burglaries (by 12.7%) were observed.
Savannah, GA. [A.1-84, A.1-85]	1970	Incandescent lamps phased-out and mercury and sodium lights installed	Incidents of crime and vandalism were reduced (by as much as 50%)

EXHIBIT 2.7

City [Reference]	Year of Change	Street Light Changes	Reported Impacts
Tuscon, AZ. [A.1-89]	1966	Street lighting improved	Total offenses were reduced (by 50%)
Washington, D.C. [A.1-91]	1970	High pressure sodium lamps added in 113 high-crime blocks	Acceleration of the 1969-1970 rates of decrease in robbery, housebreaking, auto theft and vandalism incidence in 1970-1971 and 1971-1972 was observed following relighting. Total annual incidence of all four crime types decreased by 29.5% from 1970 to 1971 and by 34% from 1971 to 1972.

such cases, given a reduction in crime, this reduction cannot obviously be attributed to street lighting. In an experimental sense, only the Kansas City (1971-72), Milwaukee (1972), and Portland (1973) studies have been identified as being "controlled;" that is, in each case some effort was made in the evaluation to account for crime trends, socio-economic variables, and level of police activity. These and some of the other partially controlled studies are discussed more fully in Section 4 in terms of the methodological issues they raise. It should also be noted that some of the studies listed ((Baltimore 1975, Milwaukee 1972, Norfolk 1973-1974, Plainview 1975, and Portland 1973) examined the <u>attitudes</u> of the people affected by improved street lighting, and obtained statistically significant information on variables other than crime incidence. The methodological issues raised by these studies are also discussed in Section 4.

On closer examination, much of the supporting information in studies of street lighting and crime turns out to be the untested opinions of criminal-justice administrators and urban planners. For example, a 1960 magazine article by Don Murray [A.2-88] is often cited in studies attempting to show the positive impact of street lighting on crime. Murray claims that street lighting projects in Cleveland, New York City, Chattanooga (Tennessee), Denver, Brookings (South Dakota), Marion (Indiana), Winston-Salem (North Carolina), Austin (Texas), Flint (Michigan), Highland Park (Michigan), McPherson (Kansas), Albuquerque, Philadelphia, Washington (D.C.), Kansas City (Missouri), Houston, Chicago and Gary (Indiana) have decreased the incidence in one or more crime categories, including murder, rape, assault, burglaries, auto-thefts and vandalism. Most of Murray's claims are, however, based on the opinions of the police chiefs in the respective towns and cities and no references are made to any studies or data sources except in the instances of New York City and Gary, Indiana.

In a later, 1972 magazine article, Callander [A.2-17] gives a similar presentation, citing several of the claims made earlier by Murray. Former F.B.I. Director J. Edgar Hoover claimed in a 1963 article [A.2-53] and again later in a 1970 article [A.2-54] that it was a fact that street lighting deters crime. He went on to say that "in a survey of some 1300 police officials, 85% reported a drop in local crime rates." Hoover did not, however, point out the fact that the response rate of the survey was less than 10%, resulting in a possibly large, but unknown bias [A.1-38]. While it is not claimed here that these journalistic articles serve no purpose, they do provide only questionable proof that street lighting deters crime. On the other hand, the perception that street lighting *can* impact crime is an important and potentially positive phenomenon--certainly, fear of crime would be decreased among those who believe lighting is a deterrent to crime.

The Street and Highway Safety Lighting Bureau has also conducted several studies and published numerous articles in its trade magazine, Street and Highway Lighting, which claim that improved street lighting has resulted in reduced crime rates [A.1-98]. However, many of the Bureau's claims are based on the questionable statistics quoted from

Murray, Callander, Hoover and other similar sources, and the bulk of the reported data shows no evidence of controls being used. Thus, the strength of these inferences is subject to the same limitations as discussed above.

Paul Box, in a special report to the Public Works Committee of the U.S. House of Representatives, 89th Congress, states that, although public officials and law-enforcement officers agree that lighting deters crime, "the fact is not sufficiently documented" [A.2-13]. He also cites a few experiences of crime reduction after improvement of street lighting in some cities, but points out that the data collection procedures and the sundry other factors affecting crime rates must also be carefully considered before specific conclusions can be drawn. It is of course the purpose of this evaluation effort to draw such conclusions, if indeed they can be drawn.

No review of street lighting and crime is complete without reference to the studies undertaken by the Legislative Reference Service of the Library of Congress. First in October 1965 [A.2-7], then in August 1970 [A.2-66], and most recently in May 1976 [A.2-6], a series of studies was conducted for the Education and Public Welfare Division of the Library of Congress, entitled "The Impact of Street Lighting on Crime and Traffic Accidents." In the first two studies (the second was an update of the first one), the often-quoted statistics of Gary, McPherson, Chattanooga, etc. are cited, and the opinions of various researchers and criminal-justice planners are quoted. The authors then state that "the specific conditions in each city mentioned...are different, but in all cases the conclusions reached are that fewer crimes are committed...following a significant increase in the level of illumination." Although the studies give a good review of the subject matter and appropriately list various opinions objectively, the authors only mention the positive statistics and opinions. Despite being subject to the same problems of reporting bias and controls as their sources, the Legislative Reference Service studies themselves have provided the basis for statements made by congressmen and senators in connection with debates over bills designed to fund installation of street lights for crime reduction [A.2-22]. The third Library of Congress study is somewhat different from the former two in that it gives a critical summary of the crime-related impacts of street lighting. The study mentions many of the studies referenced here, both controlled and uncontrolled, but adds:

> Since it was generally not feasible to control forother possible causes (e.g., weather, number of police in a given area, economic conditions), the conclusion that the reductions were due to improved street lighting must generally be viewed as conjectural or intuitive, rather than scientific."

This study is recommended both as a comprehensive, critical review of earlier studies and as an example of the cautiousness required when interpreting the results of these studies.

In conclusion, since many of the above-cited studies are based on questionable data and conjecture, decision-makers must use the results with great care when planning street lighting for crime prevention purposes.

The following section, Section 2.3, deals with a description of the hypotheses put forward in the literature on street lighting and crime.

2.3 STREET LIGHTING HYPOTHESES

If for the moment, one can accept the conclusion of the preceding section--that no evaluation reviewed to date of the crime prevention effects of street lighting has provided definitive evidence of the existence or strength of such effects--then one can regard all the "conclusions" of the studies reviewed in Section 2.2 as tentative *hypotheses* which await confirmation or rejection. Further, this position is supported by the striking absence of unanimity not only as to whether, but also as to how street lighting deters crime. Therefore an attempt is made in this section to define and classify the range of hypotheses which relate or link street lighting to crime. First a framework is developed, then the hypotheses are classified, and, finally, some related issues are discussed.

FRAMEWORK

A review of the literature concerning street lighting and crime, and brief conversations with individuals working in the areas of crime prevention, lighting engineering and environmental design, reveal that to date there is neither a general agreement on how to systematize the present knowledge of the subject matter, nor a research strategy to refine this knowledge base. A framework is therefore developed in this section for the classification of all hypotheses that have been identified to date.

As indicated in Exhibit 2.8, one can divide the independent and dependent variables into broad categories, including classification of dependent variables into attitudes, behavior and crime. Also checked off in Exhibit 2.8 are the *links* among the variables which have been established by existing hypotheses. For example, the first check in the Exhibit 2.8 matrix defines a link between light quantity and citizen attitude. In this regard, a hypothesis can be defined as *a set of one or more links*. The simplest hypothesis consists of a single link, as in the hypothesis which states that "light quantity affects citizen's attitude." An example of a more complex hypothesis containing two links is that "light quality affects citizen behavior (primary link), which in turn affects crime (secondary link)." It may be seen from this example that the designation "dependent variable" in Exhibit 2.8 must be regarded flexibly since "citizen behavior" changes from being a dependent variable in the first link to an independent variable in the second link. In a similar manner, an independent variable such as "street lighting quantity" could be viewed as a dependent variable; for example, an increase in crime rate in a given area could lead to a decision to include that area in a relighting program. Finally, the dependent or independent variable could be a combination of two variables acting simultaneously, as in "street lights and increased police patrols reduce crime."

A detailed classification and listing of hypotheses follows a discussion of the independent and dependent variables.

EXHIBIT 2.8

Matrix of Key Variables Basic to Street Lighting and Crime as Discussed in Available Literature

INDEPENDENT VARIABLES	DEPENDENT VARIABLES								
	Attitudes			Behavior			Crime		
	Citizen	Criminal	Police	Citizen	Criminal	Police	Opportunity	Level	Displacement
Light Quantity	X	X	X	X	X		X	X	X
Light Quality	X	X	X	X	X	X	X	X	X
Environmental Design		X		X	X	X		X	
Related Police Activities								X	
Intervening Variables								X	

Independent Variables

The individual variables falling within the independent variable classification are shown in Exhibit 2.9 under the headings light quantity, light quality, environmental design, related police activities and intervening variables.

The most common group of independent variables are those associated with Light Quantity; they may include either quantitative measures of illumination or some proxy for it, such as the average number of street lights visible from the sidewalk, whether an area or block is included in a relighting program, or lamp type (incandescent, mercury vapor, high pressure sodium, etc.). Measured illumination level may also be approximated by the rated illumination level for the total system, either allowing for lamp and luminaire depreciation or not.

Light Quality is used here, as in the preceding section, to designate other properties of a street lighting system's direct output: uniformity, gradient, existence of dark areas on walkways, lamp type, color, glare, visibility, and overall street lighting pattern--arterial versus areal.

Environmental Design variables reflect the awareness of many authors that crime patterns are to some extent, although not entirely, a function of the environment.* Similarly, Related Police Activities are recognized as affecting the potential crime deterrent properties of street lights, as are a number of other Intervening Variables.

Dependent Variables

Although the focus of this report is crime, it is impossible not to include other dependent variables in the discussion, since many

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* This subject matter is discussed in more detail in Section 3.4.

EXHIBIT 2.9

Some Independent Variables

Light Quantity	Light Quality	Environmental Design	Related Police Activities	Intervening Variables
Horizontal illumination Vertical illumination Number of street lights Area or block relit (yes/no) Lamp type	Uniformity Gradient Existence of dark areas on pedestrian walkways Lamp type Color Glare Visibility Arterial or areal pattern	Land use Street type (major, collector, local, alley) Distribution of targets Provision of cover for potential offenders Encouragement of citizens' territoriality Exterior building lighting Interior building lighting	Police patrol level of activity Police patrol tactics Other crime prevention programs	Temperature Season Street price of drugs

hypotheses consist of a series of links involving the perceptions and attitudes of ordinary citizens, criminals and police; the behavior of these actors; and the changes in crime patterns. Moreover, as noted in Section 2.1 some authors consider changed attitudes alone to be a goal of street lighting. Finally, since it is seen in Section 4 that there are many reasons to doubt whether simple correlations of street lighting and crime can ever be put on a sound methodological footing, some consideration must be given to the detailed links by which street lighting intervenes in crime patterns. Accordingly, dependent variables are grouped into the three broad categories of attitudes, behavior and crime as shown in Exhibit 2.8. Individual attitude, behavioral and crime variables are displayed in Exhibits 2.10, 2.11 and 2.12, respectively. For convenience and reasons of logic, the attitude and behavioral variables are listed under citizen, police and criminal headings, and crime variables fall under the headings of opportunity, level and displacement of crime.

CLASSIFICATION OF HYPOTHESES

Apart from the mere descriptive convenience afforded by classifying the large number of hypotheses appearing in the literature, another end is served as well. This is to enable a comparison between the links which have been proposed to account for the effects of street lights on crime and those which have been tested by existing evaluations. It is seen that many such proposed links remain unexamined, a situation which raises the issue of the scope of a desireable approach to the evaluation of street lighting. Thus, the classification of hypotheses

EXHIBIT 2.10

Some Dependent Attitude Variables

CITIZEN ATTITUDES	CRIMINAL ATTITUDES	POLICE ATTITUDES
Sense of fear	Perceived visibility	Sense of fear
Perception of reduced crime	Perceived risk or vulnerability	Perception of reduced crime
Perception of street-lighting improvements		
Perception of how well lit streets and sidewalks are		
Number of anti-crime measures taken to protect home		
Stigmatization of area by high intensity streetlights		
Environmental legibility		
Ambience: sense of appropriateness		

EXHIBIT 2.11

Some Dependent Behavioral Variables

CITIZEN BEHAVIOR	CRIMINAL BEHAVIOR	POLICE BEHAVIOR
Use of streets or parks	Visibility of criminal	Patrol tactics
Commercial area business activity	Ability to surveil potential victims	Patrol effectiveness
Ability to see and evade criminals	Ability to detect potential witnesses in darkened areas	Patrol surveillance of potential victims and offenders
Ability of victims or witnesses to identify attackers	"Light-hardening"	
Likelihood of a witness intervening	Criminal background	
Number of witnesses		

EXHIBIT 2.12

Some Dependent Crime Variables

OPPORTUNITY	LEVEL	DISPLACEMENT
Risk of apprehension Opportunity for "secrecy," i.e., cover for potential offenders	Crime rates for stranger-to-stranger crimes by street/ nonstreet, night/day, residential/commercial and relit/unrelit blocks Arrest rates Conviction rates	Spatial displacement Target displacement Temporal displacement Functional displacement Tactical displacement

given in this section provides an understanding of reasons for the various methodological approaches that are discussed in Section 4.

Exhibit 2.13, following the framework outlined above, shows the eight hypothesis categories within which most, if not all, of the known hypotheses can be included. Except for cagegories D and E, the hypothesis types each consist of a single link. Category D contains two and category E contains three links. Exhibit 2.13 shows which variable types are linked by each hypothesis category.

It should be recalled that each hypothesis category includes a variety of individual hypotheses (i.e., link(s) between individual variables). Thus, the hypothesis category A includes the hypothesis, "Street lights have a differential effect on commercial and residential burglaries." For convenience, Light Quantity and/or Quality is used throughout as one variable, even though the previous discussion of variables treated them separately. This choice was made because although conceptually light quantity and quality are different entities (and should be treated as such in future evalutions), few studies explicitly separate the two and refer simply to the generalized lighting outputs of street lights.

Using the above-described classification of hypothesis categories, Exhibit 2.14 lists all the hypotheses that have been gleaned from the available literature (see Exhibits A.1 and A.2), and from those individuals who have been contacted (see Exhibit A.3). It should be noted that the detail in this exhibit goes from the more general towards the more specific, as for example, in hypothesis A.6, which is followed by A.6.1, specifying locations and crimes in more detail.

EXHIBIT 2.13

Hypothesis Categories

Definition of Hypothesis Categories as Defined by Link(s)

A. Light Quantity and/or Quality affects Crime.

B. Light Quantity and/or Quality affects Attitudes.

C. Light Quality or Environmental Design affects Behavior.

D. Light Quantity and/or Quality, or Environmental Design affects Citizen Behavior (D_1), which in turn affects Crime (D_2).

E. Light Quantity and/or Quality, or Environmental Design affects Citizen Behavior (E_1), which affects Criminal Attitudes (E_2), which affects Crime (E_3).

F. Light Quantity and/or Quality, and Other Independent Variables together affect Crime.

G. Light Quantity and/or Quality and Criminal Behavior together affect Crime.

H. Light Quantity and/or Quality, and Environmental Design and Citizen Behavior together affect Crime.

EXHIBIT 2.13

Hypothesis Categories

(page 2 of 2)

(b) Hypothesis Category Links as Displayed in Variable Matrix

INDEPENDENT VARIABLES	DEPENDENT VARIABLES								
	Attitudes			Behavior			Crime		
	Citizen	Criminal	Police	Citizen	Criminal	Police	Opportunity	Level	Displacement
Light Quantity	B	B, E_2	B	D_1, E_1, H	G		A	A, D_2, E_3, F, G, H	A
Light Quality	B	B, E_2	B	C, D_1, E_1, H	C, G	C	A	A, D_2, E_3, F, G, H	A
Environmental Design		E_2		C, E_1, H	C	C		E_3, F, H	
Related Police Activity								F	
Intervening Variables								F	

EXHIBIT 2.14

Summary of Street Lighting and Crime Hypotheses

Hypothesis	Reference(s)
A. Light Quantity and/or Quality Affects Crime	
A.1 Street lights reduce crime.	A.1-5, A.1-76 A.1-91 and A.2-53
A.1.1 Street lights reduce crime more in relit blocks than in adjacent non-relit blocks, the overall city, or other comparable areas without improved lighting.	A.1-40, A.1-76
A.2 Street lights, above a specific minimum threshold level of light, deter crime.	A.1-40
A.3 Street lights reduce crime up to a specific maximum threshold level of light, which may vary by community.	A.2-48
A.4 Illumination level, uniformity, lamp type, illumination gradient and other quality parameters determine the amount of crime prevented.	A.1-90, A.2-19
A.5 Street lights reduce different crime types by different degrees.	A.1-40, A.1-54
A.5.1 Within relit blocks, street lights reduce night street crime more than night non-street or day street crime.	A.1-40
A.5.2 The decrease in night street crime after relighting, relative to night non-street or day street offenses, is greater for relit than for non-relit blocks.	A.1-40
A.5.3 Street lights have a differential effect on commercial and residential burglaries.	A.1-40
A.5.4 Within night street crime, robbery is reduced the most by street lights.	A.1-40
A.5.5 The crimes to be reduced by street lights are night robbery, ordinary, serious and aggravated assault, burglary, rape, theft, vandalism, petty larceny, breaking and entering and murder.	A.1-3, A.1-15, A.1-16, A.1-76 and A.2-114
A.6 A portion, but not all of the decrease in night crime resulting from street lights is displaced.	A.1-3, A.1-40, A.1-54, A.1-56, A.1-76, A.2-3, A.2-95 and A.2-105

Note: "Street lights" are defined in this exhibit as either an increase in street lighting over time or the presence of street lights in some areas as opposed to others, unless an individual hypothesis is more specific.

EXHIBIT 2.14

(Page 2 of 4)

Hypothesis	Reference(s)
A.6.1 Displacement effects of street lights vary by type of crime and setting (to which crimes are displaced).	A.1-40
A.6.2 Street lights displace night crime from relit to non-relit areas, from night to day, from street to non-street and to other crime types.	A.1-40
A.6.2.1 Street lights displace some night robbery and assault to adjacent non-relit areas.	A.1-76
A.7 Street lights increase the risk of detection and apprehension.	A.1-40, A.2-117
A.7.1 Street lights reduce the opportunity for "secrecy" (i.e., cover for potential offenders).	A.2-55
A.7.2 Street lights illuminate areas where potential attackers may hide.	A.1-40
B. Light Quantity and/or Quality Affects Attitudes	
B.1 Street lights increase citizens' and police officers' perceived security.	A.1-5, A.1-38, A.1-54, A.1-56, A.1-79, A.2-2, A.2-3, A.2-35 and A.2-92
B.1.1 The overall lighting pattern can increase perceived security, safety, ambience (i.e., sense of appropriateness) and legibility of environment.	A.1-71
B.1.1.1 High visibility within the "public distance threshold" increases perceived security.	A.2-71
B.2 Citizens are aware of improvements to street lights.	A.1-79
B.2.1 The number of street lights in an area increases the perception of how well lit the area is.	A.1-38, A.1-79
B.3 After installation of street lights, police perceive a reduction in crime.	A.1-54
C. Light Quality or Environmental Design Affects Behavior	
C.1 Glare prevents criminals, citizens and police from seeing beyond lighted areas.	A.2-26
C.2 Changes in environment increase pedestrian traffic.	A.1-40

EXHIBIT 2.14

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Hypothesis	Reference(s)
D. Light Quantity and/or Quality, or Environmental Design, Affects Citizen Behavior (D_1), Which in Turn Affects Crime (D_2)	
D.1 Street lights increase street use, which leads to crime reduction.	A.1-40, A.1-56, A.2-3, A.2-96, and A.2-104
D.1.2 Street lights increase the likelihood of citizen intervention, which reduces crime.	A.1-40, A.2-99
D.1.3 Mercury vapor light quality reduces the use of streets and the likelihood of citizen intervention, which may increase crime.	A.2-3
D.2 Street lights increase potential victims' ability to see and evade attackers, which in turn reduces crime.	A.2-13, A.2-99 and A.2-105
D.3 Street lights increase potential victims' ability to identify criminals, which increases the apprehension and conviction rates.	A.1-40, A.1-74, A.2-35, A.2-53, A.2-106, A.2-110 and A.2-114
D.4 Street lights increase police patrol effectiveness in detecting potential crime and crime in progress, which reduces crime opportunity and increases apprehension, respectively.	A.1-56, A.2-3, A.2-13, A.2-35, A.2-92, A.2-105, A.2-110 and A.2-114
D.4.1 Street lights prevent crime only if there is a probability of detection.	A.2-71
D.5 Light in building perimeters and interiors makes criminals more visible.	A.1-64
D.6 Effective environmental design increases the likelihood of citizen intervention and criminals' vulnerability, which reduces crime opportunity.	A.2-34
E. Light Quantity and/or Quality, or Environmental Design Affects Citizen Behavior (E_1), Which Affects Criminal Attitudes (E_2), Which in Turn Affects Crime (E_3)	
E.1 Light quantity and quality makes intruders more visible, which increases intruders' perception of their own visibility or vulnerability, which in turn prevents crime.	A.1-40, A.2-26
F. Light Quantity and/or Quality, and Other Independent Environmental Variables Together Affect Crime	

EXHIBIT 2.14

(Page 4 of 4)

Hypothesis	Reference(s)
F.1 Street lights and all other lighting together reduce crime.	A.2-35
F.1.1 Street lights and lighting the rear of buildings together reduce crime.	A.2-110
F.2 Street lights and land use (commercial versus residential) together determine the amount of crime reduction.	A.1-40
F.2.1 Street lights in arterial streets, local streets, alleys and off-street areas reduce crime.	A.2-12
F.3 Street lights and increased police patrols prevent crime.	A.2-117
F.4 Street lights and lower temperatures reduce crime.	A.3-10
G. Light Quantity and/or Quality and Criminal Behavior Together Affect Crime	
G.1 Street lights and nature of criminal background (i.e., professional versus amateur) determine the amount of crime prevented.	A.2-96
G.2 Street lights deter crime until criminals become "light-hardened".	A.1-40
H. Light Quantity and/or Quality, and Environmental Design, and Citizen Behavior Together Affect Crime	
H.1 Street lights and lighting of backyards and citizen surveillance together prevent crime and contribute to offenders' apprehension.	A.2-114

RELATED ISSUES

In a sense, every untested hypothesis is in itself an issue, stating a matter over which there is controversy. However, the significance of any individual hypothesis lies not so much in its own possible validity, as in its relationship to the whole body of knowledge in the field of crime prevention and street lighting. An examination of the overall structure into which the present set of hypotheses fits raises three issues of importance to this Phase I evaluation effort:

- the need for a better evaluation approach;
- the problem of hypotheses which cannot be tested; and
- the question of the completeness of the structure of hypotheses.

Need for a Better Evaluation Approach

The first issue arises out of the fact that hypotheses about the effect of street lights on crime are divided into those that simply predict an effect on some crime-related variable, and those that include, in whole or in part, predictions of the effect of street lighting on intermediary attitudinal or behavioral variables. Many of the hypotheses listed in Exhibit 2.14 do not predict a reduction in crime, since they refer to attitudinal or behavioral outputs other than crime. Still others predict crime reduction or displacement through a specified series of intermediary attitudinal or behavioral effects. These hypotheses consist of a series of predicted links between light and attitude, attitude and behavior, behavior and crime, etc., and are fundamentally different from hypotheses of type A (see Exhibit 2.14), which do not model or specify the reasons for the predicted effects of street lighting on crime. Although the first class of hypotheses addresses the "bottom line" of the street lighting and crime relationship, it is by no means clear that continual refinement of the statement of these hypotheses will result in tests which can answer the implicit question, "Do street lights deter crime?"

Even if the question could be answered unequivocally, or even conditionally, the important question of how street lights affect crime would also require an answer. Just as answering the question of whether street lights reduce crime is important in decisions regarding the allocation of law enforcement resources, a knowledge of how this effect takes place is necessary for the specification of project characteristics to optimize the desired results.

It is interesting to note that evaluations in the parallel field of street lighting and traffic safety have begun to address both the whether and how questions. While much has been and is being written about the "bottom line" traffic safety aspects of street lighting [A.2-6, A.2-13], a great deal of effort has also been made by the United States Department of Transportation (DOT) to direct research towards such areas as performance criteria for lighting system designs, measures of visibility and driver comfort under variable environmental conditions and definition of driver visibility requirements [A.2-72, A.2-79].* An analogous crime prevention research program might, for example, be concerned with visual task requirements for pedestrians and police officers, and with the development of corresponding performance requirements.

Testing of Hypotheses

The issue of testability of hypotheses arises out of the specificity, or lack of it, used in the definition of many hypotheses. In order to be tested, a hypothesis must be expressed in terms of *measurable* variables, and must reflect a specific prediction or outcome which is *discernable* from all other outcomes. Many of the hypotheses contained in the literature fail to meet one or both of these criteria.

Some hypotheses fail to articulate a specific link to an outcome, and instead merely assert that there exists some relationship among a given set of variables. This type of assertion could be contradicted by a finding, for example, that results are always independent of one or more of the candidate variables, but otherwise the generality of the hypotheses indicates a lack of understanding. Even controlled studies, which go to great lengths to define sampling procedures and statistical tests, frequently use such a gross measure of light quantity as "relit versus nonrelit block." While an argument could (and should) be made against the creation of a false appearance of precision through the

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*"Lighting Needs, November 1975 Final Report," prepared for the Federal Highway Administration, Offices of Research and Development, Washington, D.C., and "FCP Annual Progress Report, Year Ending June 30, 1976: Improved Traffic Operations During Adverse Environmental Conditions," copy obtained from Richard N. Schwab, Project Manager, Environmental Design and Control Division, Federal Highway Administration, Washington, D.C.

introduction of sophisticated light measuring instruments, there is clearly a wide range of choice available. The definition of which measures should be used can be made only in relation to what best serves the requirements of the evaluation design that is ultimately chosen. The concern of measurability of variables extends beyond light measures to concepts such as risk of apprehension, opportunity for secrecy, land use, likelihood of citizen intervention, and many others. This concern is also discussed in Section 4.2.

Completeness of Hypotheses

The question of the completeness of the set of hypotheses is raised both by gaps in the variable matrix (e.g., the gap in the environmental design and police behavior cell) and by the inherent dynamism of a long-range research program. In either case, one can always be certain that new questions will arise leading to new ways of looking at street lighting and crime. This could only be prevented if it were possible to stage one grand and final experiment whose results would simultaneously define all the design tradeoffs inherent in the complex problem of street lighting and crime. It is obvious, however, that such a static view of street lighting research is entirely unrealistic.

3 RELATED ENVIRONMENTAL ISSUES

There are interactions between street lighting systems and its contiguous, larger environment which are somewhat relevant to a study of street lighting and crime.

These interactions involve street lighting and its energy demand, its impact on trees and shrubs in the environment, certain legal issues, and overall environmental design considerations. With the possible exception of environmental design, none of these bears heavily on the inherent ability of street lighting to prevent crime. However, each of these interactions may be viewed as placing *constraints* on street lighting system design. These constraints, in turn, cannot be ignored when the results of a street lighting and crime evaluation are applied to design or resource allocation decisions.

In a sense, then, the issues discussed in this section are background issues, but it would be naive to ignore their implications when evaluating the impact of street lights on crime. The four issues listed above are discussed in turn.

3.1 ENERGY DEMAND

Since the energy shortage of 1973-1974, virtually every system which consumes energy has come under scrutiny for the identification of possible energy savings, and street lights are no exception. In fact, this scrutiny is probably as much related to the conspicuousness of street lights as to the total amount of energy consumed. The energy shortage has also intensified public awareness that all energy-consuming systems should be designed for optimum efficiency, and the rising cost of energy has reduced the payback times for many equipment changes which were previously uneconomical.

Exhibit 2.1 shows that of the total energy consumed in the United States, approximately 75% comes from sources other than electricity. Of the 25% consumed by electricity, 20% is for non-lighting applications--resulting in lighting consuming 5% of *all* energy. However, only 3.5% of all lighting energy goes to street lighting, resulting in an energy consumption equal to .18% of all U.S. energy.*

This section briefly considers two questions associated with the energy demand of street lighting: (1) the possible occurrence of "natural experiments" resulting from the reduction of street light output levels during the energy crisis, and (2) an overview of approaches to energy conservation, including implications for street lighting design.

OPPORTUNITY FOR "NATURAL EXPERIMENTATION"

The question arises whether a reduction in street lighting output (i.e., a "brown-out") by a community during or after the energy crisis provided the conditions for retrospectively determining a change in the level of crime attributable exclusively to a change in light level. This

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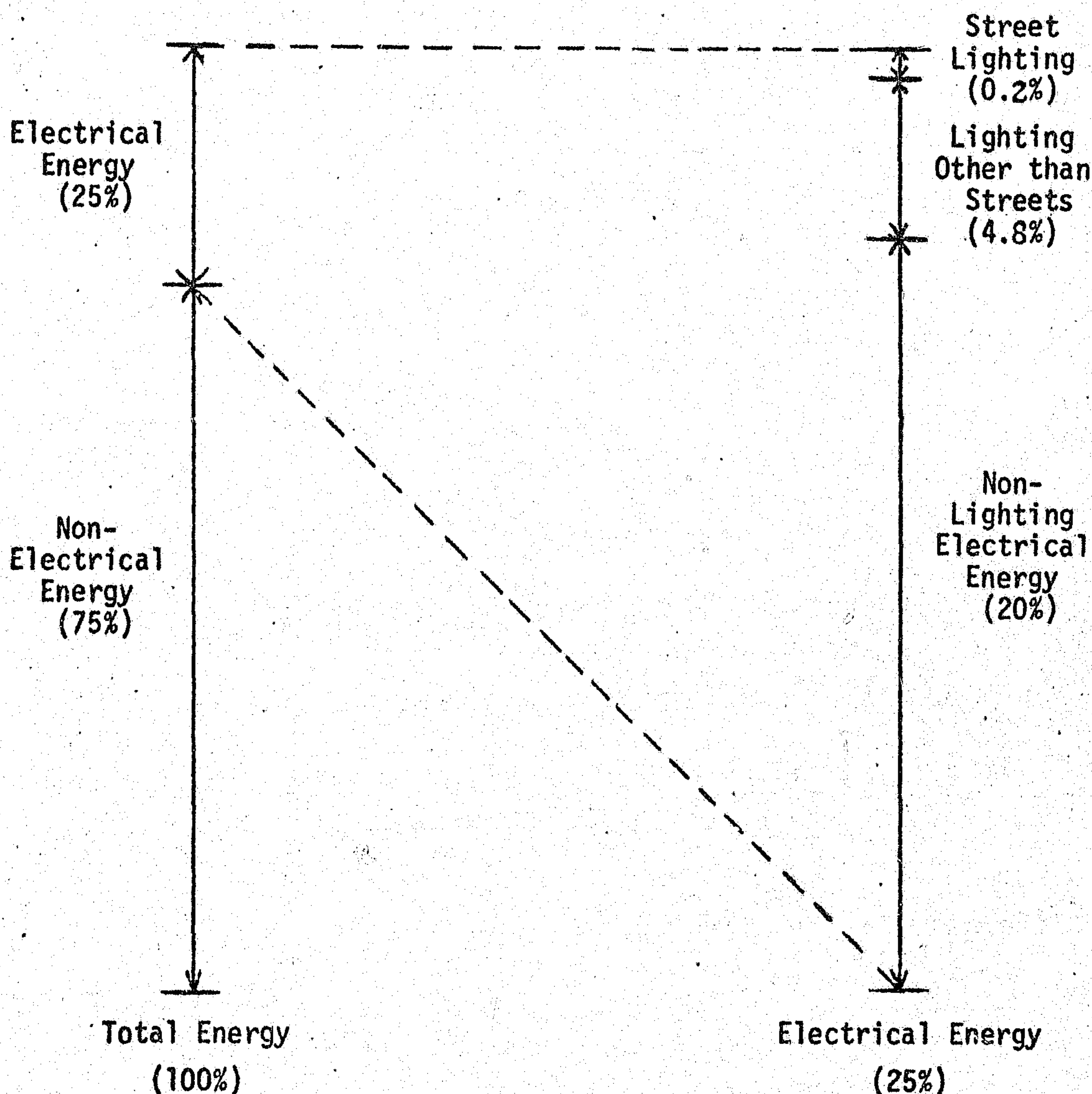
* An informative and somewhat more detailed description of street lighting and energy may be found in [A.1-40, pp. 110 to 119].

EXHIBIT 3.1

U.S. Energy Consumption:
Street Lighting vs. Total



Source: [A. 2-39, No. 100A]

might appear to be possible if a sudden decrease in street light output were accompanied by an increase in night crime. In order for such a "natural experiment" to be successful, however, three questions would have to be answered: How long was the duration of the experiment? Were there any concurrent, possibly energy-related, changes in police patrol activities? Were there any other energy-related changes in overall crime patterns?

Not unexpectedly, in communities where street light output was reduced, police and citizens were especially sensitive to the possible public safety and security consequences. As a result, local officials have tended to place street lights high on their list of priorities for restoration to earlier energy use patterns, and street light curtailments have usually been brief, limiting the amount of available data. For example, when a drought in the states of Washington and Oregon resulted in a shortage of hydroelectric power and cutbacks in electrical usage, officials acted after only two to four months to return lighting to its original level [A.2-39, No. 106 and 119]. The town of Rensselaer, Indiana, turned its street lights off completely, but, after four businesses were burglarized in one night, restored the lighting after only two weeks [A.2-39 No. 105, A.2-75]. In general, public safety officials are unwilling to risk citizens' lives or security for the sake of energy conservation, and they usually feel that it is their duty to argue against programs for curtailing street light. As a result, it may not be possible to identify a municipality which curtailed street light output long enough to accumulate statistically meaningful data.

The survey of individual project interventions to be undertaken in the balance of this Phase I evaluation effort will address this question.

The second question, that of concurrent, possibly energy-related, changes in police patrol activities, is relevant in two respects. On the one hand, cutbacks in police patrols due to a shortage of available fuel could have contributed to an increase in crime. On the other hand, some police departments may have increased patrols in darkened areas and eliminated or reduced energy savings as well as intervened in the natural experiment.

Although federal fuel allocation regulations during the energy crisis provided for law enforcement agencies to receive 100% of their accustomed consumption, actual allocations varied widely [A.2-74]. Some police departments either had to curtail operations because of unavailability of fuel, or had to institute energy conservation practices for budgetary reasons, as the price of available fuel increased. Another factor that could have affected police operations was in connection with plans for "rolling blackouts"--a technique to lower total electrical energy consumption, without placing an enduring burden on any one segment of a community. Under this technique, various areas of the city are disconnected from electrical service for two to three hours on a somewhat random basis and with about a 24-hour notice. Existing federal guidelines for law enforcement agencies recommend the preparation of strategies involving additional personnel for patrols and traffic direction [A.2-76]. Despite the existence of plans for rolling blackouts, the authors are unaware of any that has actually been implemented. Yet, these plans do reflect law enforcement officials' awareness of the need for extra activity during a period of reduced street lighting. As a result, any retrospective analysis of "natural experiments" would have to be able to take police patrol activity changes into account.

The third question, the impact of the energy crisis on crime patterns, arises out of the fact that some, previously law-abiding, individuals could be severely impacted, both economically and physically, and violent crimes are one possible expression of the resulting frustration [A.2-77]. Raw crime statistics may also be inflated by incidents unrelated to the lighting of the night environment, such as arrests during group protests or strikes provoked by the energy shortage. Marital disputes and drinking-related problems are also expected to increase reports of some crime types [A.2-75].

In summary, although it may be possible to identify localities where crime trends during a period of reduced street lighting can be observed retrospectively in a natural experimentation sense, such an evaluation would have to take into account the short duration of the experiment, the changes in police patrol activity, and the independent, energy-related changes in crime patterns.

APPROACHES TO ENERGY CONSERVATION

An examination of the responses of municipalities and the lighting industry to demands for street lighting energy conservation shows that the solutions chosen by many municipalities have a direct influence on street lighting design. It is seen that the earliest and simplest energy conservation recommendations have in time given way to a more comprehensive approach which affects the entire street lighting system. Therefore, the higher the priority given to energy conservation, the more constraints will be placed on street lighting system designs.

Reduction of Output

Four basic approaches to the reduction of street light output are:

(1) keep alternate bulbs dark;

(2) turn all (or some) lights off after a certain hour;

(3) reduce the wattage, as with dimmer transformers; and

(4) replace higher-wattage bulbs with lower-wattage bulbs [A.1-40, p. 113].

However, the reduction of output is not the only, nor is it the most recommended, energy conservation alternative. A fifth approach, increasing fixture efficiency, has been used with increasing frequency in recent years.

It is interesting to note that the IES published twelve recommendations for maximum utilization of lighting energy over a year before the dimensions of the 1973-1974 energy crisis became evident. Exhibit 3.2 shows that the total systems approach of the IES, while not immediately adopted, was eventually recognized by the federal agencies regulating energy use. Thus, for example, despite an initial emphasis by the Federal Energy Office on reduction of illumination levels, the recommendations of federal agencies soon shifted toward the use of more efficient light sources and careful planning with a total system perspective. The availability of the higher efficacy, high-pressure sodium vapor lamps greatly assisted the trend away from reduction of illumination levels.

EXHIBIT 3.2

Some Street Lighting-Related Energy Conservation Recommendations

Date	Source	Recommendations
12/72	Illuminating Engineering Society (IES) (Recommendations for maximum energy utiliziation)	• Design lighting pattern for expected activity • Use more effective and efficient luminaires • Use efficient light sources • Select luminaires with good cleaning capability and lamps with good lumen maintenance • Provide flexible switching and dimming controls
12/73	Federal Energy Office (Fact Sheet on National Energy Conversation)	• Reduce indoor illumination levels by approximately 50% in commercial and industrial buildings
3/74	Law Enforcement Assistance Administration (Energy Report No. 2)	• Reduce street lighting energy use only under following conditions: - as part of a comprehensive community conservation program - after review of sensitivity of crime to street lights, with police and citizen representatives - after exploring alternative more efficient light sources

EXHIBIT 3.2

Date	Source	Recommendations
4/74	Federal Energy Office (Decreased Illumination of Highways: Guideline)	• Reduce highway lighting energy requirements by 50% • Retrofit with more efficient light sources • Maintain IES-recommended illumination levels as maxima • Reduce illumination in proportion to daily traffic density variation, while maintaining IES-recommended uniformity ratio
5/74	Federal Highway Administration (Letter re: lighting on federal-aid highways)	• Maintain IES-recommended illumination levels and uniformity ratios
11/74	Federal Energy Administration (Lighting and Thermal Operations Guidelines: Energy Management Action Program)	• Encourage efficient lighting practices • Recognize that complexity of scientific, management, engineering and architectural components limit applicability of simple guidelines • Maintain previous indoor illumination standards as maxima • Convert to more efficient sources • Practice periodic cleaning and maintenance
12/74	Federal Highway Administration (FHA Guidelines)	• Maintain previously recommended illumination levels and uniformity ratios

Date	Source	Recommendations
6/75	International Committee on Illumination (CIE) (CIE Statement on Energy Conservation and Lighting)	• Design for required tasks and needs of user population • Maintain recommended light levels • Select most efficient lamps, taking into consideration color rendering needs • Select efficient luminaires • Provide flexible switching and dimming controls • Establish adequate cleaning and maintenance program

Sources: [A.2-4, A.2-39 (Nos. 120, 122, 123, 129 and 130), A.2-62, A.2-67 and A.2-75]

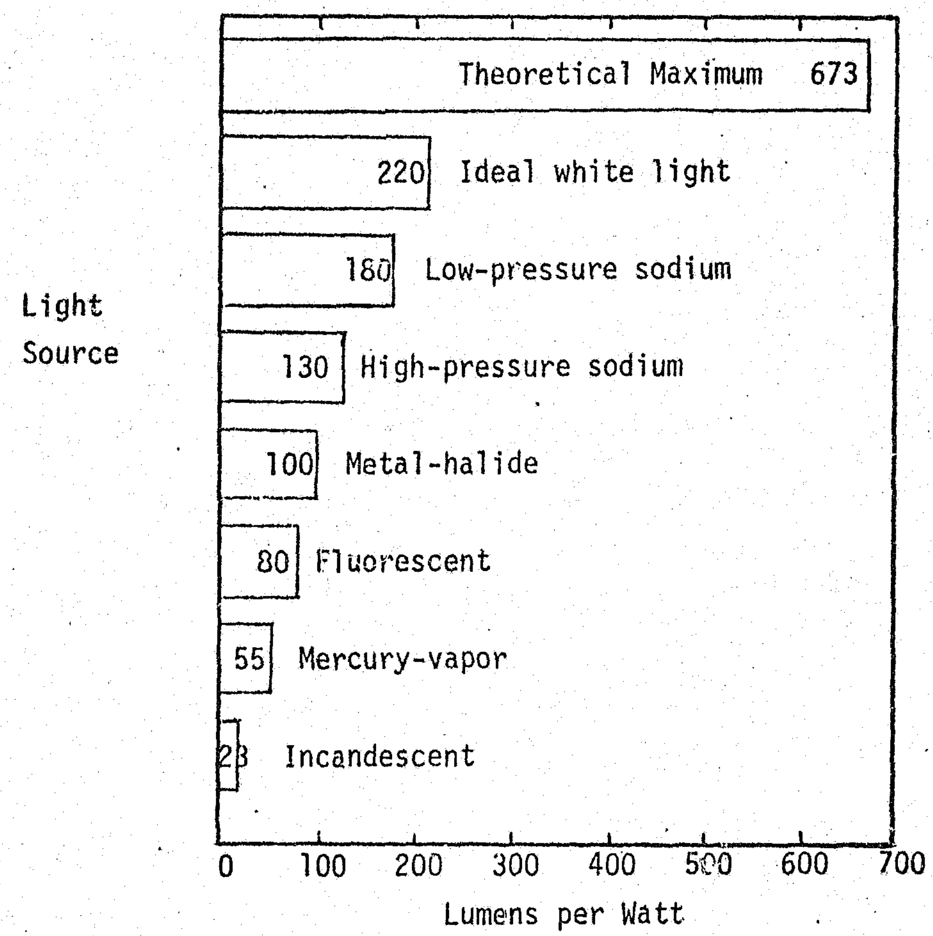
Increased Source Efficacy

While high-pressure sodium fixtures are more expensive than their less efficient mercury vapor counterparts, conversion to the high-pressure sodium light sources has become feasible as energy costs have increased. Exhibit 3.3 shows that high-pressure sodium lamps produce more than twice the lumens per watt yielded by mercury vapor, and five times the visible lumens per watt of incandescent lamps. Because of this fact, many cities have begun large-scale conversion from incandescent or mercury vapor lamps to sodium vapor, resulting in increased illumination levels and decreased energy costs [A.1-12, A.1-17]. That this is possible is illustrated in Exhibit 3.4. It is assumed that a hypothetical downtown street is lit with either a mercury vapor or high-pressure sodium system, each with identical luminaire mounting heights, pole spacings and arrangements. Despite the greater total lumen output of the mercury sources, the high-pressure sodium system consumes only 40% of the energy and yields 80% higher average illumination of the road surface. The first of these two advantages results from the higher efficacy of the high-pressure sodium source, while the second is a result of the fact that the smaller size of the luminous element in the sodium source permits better optical control and hence greater "utilization" of available light onto the road and sidewalk surfaces, instead of into other directions. Another advantage of the high-pressure sodium system is lower annual maintenance cost.

These powerful economic arguments for the use of high-pressure sodium sources have been well articulated by the lighting industry [A.1-12, A.1-17, A.2-39, A.2-44, and A.2-107]. There are, nevertheless,

EXHIBIT 3.3

Relative Efficacies of Light Sources



Source: [A.2-4]

EXHIBIT 3.4

Comparison of Mercury Vapor and High-Pressure Sodium Street-Lighting Systems

Background Elements
(Hypothetical Downtown Street)

• Street width (feet)	50
• Mounting height (feet)	35
• Number of luminaires	36
• Pole spacing (feet)	150
• Pole arrangement	Opposite

	High-Pressure Sodium	Mercury Vapor
Input Elements		
• Lumens/lamp	50,000	63,000
• Watts/lamp	400	1,000
Process Elements		
• Efficacy (lumens/watt)	125	63
• System energy consumption rate (kilowatts)	17.28	38.88
• Annual maintenance cost	$380.00	$853.00
• Relative total initial investment/footcandle	1.00	1.70
• Relative annual cost/ footcandle	1.00	2.62
• Average illumination (footcandles)	5.09	2.81

Source: [A.2-39, No. 102]

other considerations which must be weighed. Given limited municipal capital budgets, some cities have replaced bulbs but not luminaires. Because of the difference in the size of the luminous element in high-pressure sodium, as opposed to mercury vapor lamps, a luminaire designed for the latter may result in a very inefficient utilization of the light from a high-pressure sodium source. In particular, light at high angles to the road surface that was not objectionable with mercury vapor sources may, with sodium vapor, produce unacceptable glare and illumination of upper-story residential windows [A.3-25]. The use of luminaires designed for high-pressure sodium lamps can overcome this problem, but at higher cost. The City of Chicago is presently relighting with high-pressure sodium lamps and a luminaire especially designed to light sidewalks as well as streets [A.1-17]. In another approach, the City of Philadelphia requested a manufacturer to design a low-watt, high-pressure sodium bulb which produces essentially the same total number of lumens as the higher-watt mercury vapor bulb it replaced [A.3-25].

The issue concerning the negative reactions that people have to the color-rendering properties of high-pressure sodium lights has been intensified by the economic pressures in favor of conversion to more efficient sources. Both of these issues are important to the crime-prevention performance of street lights and are discussed in Section 4.4.

Systems Approach

Both the IES and the CIE recommendations in Exhibit 3.2 point to an energy conservation approach that is based on total system design, rather than on isolated changes in equipment or practice. This approach is, of course, being utilized in other environments as well. For example, in new residential or office buildings, the Total Energy Management (TEM) program, developed by the National Electrical Manufacturers Association and the National Electrical Contractors Association, uses a total energy budget based on all energy consuming systems of a building [A.2-4]. One of the key features of this approach, and of the IES and CIE recommendations, is the design of lighting systems for expected activities, and the reduction of light in areas not relevant to those activities.

This leads to the question of how this feature might be applied in street lighting. The first step is the specification of required activities, and it should be recalled from the discussion of hypotheses in Section 2.3 that there is as yet little agreement on which crime prevention related activities are primarily supported by street lighting. In effect, the execution of a total system design which maximizes energy efficiency would require the results of the research agenda suggested in Section 2.3, i.e., answer to the question of *how* street lights can prevent crime. Without this information, the specification of activities necessary for crime prevention will be highly speculative.

The systems approach to street lighting energy conservation, then, can be seen as part of a comprehensive street light plan. As an illustration of how this approach can lead to design solutions which defy "conventional wisdom," a street lighting project in Norfolk, Virginia [A.1-17] is briefly discussed here. In this project, a street lighting system in the Ghent inner-city residential neighborhood of Norfolk was relit with a design developed to differentiate street types, pedestrian paths and intersections in a clear visual hierarchy. One aspect of the design was the use in residential streets of low-intensity lamps mounted on closely spaced and relatively low poles, using colonial-style luminaires, compatible with neighborhood characteristics. The objective was to use the money saved in operating costs of the low-wattage system for such desireable elements as aesthetically pleasing incandescent sources, greater illumination uniformity, and better and more fixtures. The design as described above resulted in illumination levels lower when compared to what would have been obtained with mercury vapor or high-pressure sodium sources. The very high level of satisfaction demonstrated by a user study after the completion of the project indicates that "efficiency" may not be able to be measured simply in terms of its efficacy (i.e., lumens of output or footcandles of illumination per watt), but may also require a careful analysis of the total illumination level required. Then if other design objectives can be met better by using low-efficacy sources (e.g., incandescent), total energy consumption may be minimized without necessarily using the brightest or most efficient light sources.

Perhaps the most important conclusion to be drawn from this description of IES and CIE standards, and the Norfolk, Virginia, experience is that guidelines can only be based on general principles, and that detailed planning of street lighting can best be assisted by the results of a research agenda which continually refines the understanding of those principles.

3.2 ENVIRONMENTAL IMPACT

Another issue which could act as a constraint on street lighting system designs, regardless of the results of evaluations of street lighting and crime, is the impact of street lighting systems on trees and shrubs in their immediate surroundings. Following experiments performed at the United States Department of Agriculture's Agricultural Research Center in Beltsville, Maryland, a report was issued by Dr. H. Marc Cathey which suggested that street lights can increase the growth rate of a plant, increase the plant's susceptibility to air pollution and delay its dormancy in autumn (which in turn increases the danger of early frosts to the plant's health).*

CONTROLLED TESTS

The above-mentioned effects were studied under controlled conditions over a two-year period using five different light sources on seedlings of twenty-two species of trees and other plants [A.2-93]. Among the results were the fact that the three effects (i.e., on growth, pollution sensitivity and dormancy) are most acute for incandescent and high-pressure sodium lamps.

Publication of these results has resulted in public concern that high-pressure sodium lights could damage existing trees and plants [A.1-29, A.1-82, A.2-113]. If there is significant damage, a tradeoff would have to be made between safety and aesthetic objectives, and officials in

* For a more complete discussion of this issue, see [A.1-38].

Detroit, Michigan, and Richmond, Virginia, have said that definite evidence of tree damage would lead to a decision to replace high-pressure sodium lights with mercury vapor or incandescent. Recently, New York City has announced plans to coordinate street and park light installation with the selection of more resistant tree varieties, and with scheduling plantings during dormant periods.

FIELD ASSESSMENT

Inasmuch as the Cathey experiments were not field tests, the City of Chicago commissioned Dr. John W. Andresen, Professor of Urban Forestry at the University of Toronto, to study the field effects of existing lighting installations. The negative results of the study led the City of Chicago to proceed with its relighting program.

On the other hand, in Dade County, Florida, conversations with experts familiar with the situation indicates that several county commissioners, who are opposed to the high illumination levels and light quality of high-pressure sodium sources, have raised the issue of tree damage to support their position.

Evidently this issue is not yet settled, and may continue to affect street lighting design decisions.

3.3 LEGAL ISSUES

Two significant dimensions of the legal environment of street lighting are discussed in this section. First, the establishment of local building security ordinances, which extend the concept of building codes to include property owners' obligations to provide basic security measures (including lighting), and, secondly, the possible civil liability of individuals or municipalities for damages incurred as a result of criminal activity following reductions in outdoor lighting.

BUILDING SECURITY ORDINANCES

Based on the premise that physical planning can reduce criminal opportunity, some municipalities have introduced ordinances requiring design or performance standards to be met by property owners to facilitate crime prevention. The Law Enforcement Assistance Administration has awarded funds through both the block action and discretionary grant programs for the design of secure public areas, and many of these programs include the drafting of model building security ordinances.

To the extent that such ordinances require some sort of indoor or outdoor lighting, they result in effects on the overall design of the environment and on who should pay for the outdoor lighting facilities. As with all regulatory activities, the monitoring of building security code compliance also entails a certain amount of public expense and commitment.

The passage of building security ordinances including mandated privately-funded lighting may help to establish more firmly the notion that both private property owners and municipalities are exposed to civil liability for damages incurred by crime victims in unlit areas.

CIVIL LIABILITY

Municipal officials are sensitive to the possible crime-related liability of cities which curtail street lighting output. This sensitivity and sense of obligation have limited the application of energy-conserving illumination reductions in a number of cities.

At the present time, no cases are known in which municipalities have actually been found guilty of negligence for reducing street lighting, but a search of cases performed by James E. Rooks, Jr., Assistant Editor of the Association of Trial Lawyers of America (ATLA) reveals several in which a city or property owner may incur liability in other lighting-related situations. The City of Chicago Heights, Illinois, was held liable for injuries sustained by a motorist at an intersection with an improperly placed and glaring street light. The court did not, however, review the city's estimate of public needs, its discretion in selecting a plan, or its inherent legislative powers. Only the positive action which created a dangerous condition was considered [13 ATLA News L. 11-12 (1970)]. In another case, the City of Los Angeles was found liable for injuries sustained by a plaintiff who fell after the parking lot lights were suddenly extinguished [11 ATLA News L. 411 (1968)]. Private property owners have been held liable for injuries and criminal attacks sustained by employees, church members, tenants and customers as a result of missing or defective lighting.*

*[12 NACCA L.J. 167-69, 183-86 (Nov. 1953); 20 NAACA L.J. 132-33 (Nov. 1957); 11 ATLA News L. 276-77 (1968); 13 ATLA News L. 30-31, 93, 124-125 (1970); 15 ATLA News L. 379-380 (1972); and 17 ATLA News L. 298-99 (L974)].

In one of these cases, the widow of a police officer who was killed while patrolling the rear of a store at which the owner had turned off the outside lights successfully sued the store owner for negligence imperiling the safety of an invitee [Fancil vs. Q.S.E. Foods, Inc. 311 N.E. 2d 745 (Ill, App. 1974)]. Testimony in the trial of this case included an amici curiae (friends of the court) brief filed by the Americans for Effective Law Enforcement, Inc., the Illinois Association of Chiefs of Police and the Illinois Police Association. It is interesting to note that the brief cited two studies which concluded that street light improvements can reduce commercial burglaries and assaults that are committed on commercial properties [A.2-23]. This situation underlines the need for accuracy and methodological rigor when reporting on the crime prevention effects of street lights. One of the studies cited in the brief shows no evidence of having addressed the issues of randomization, control sites and tests of significance [A.2-66, p. 10], while the other does not specifically address the question of off-street lighting [A.1-40].

Another interesting legal issue concerns the possibility of citizen suits against municipalities for failure to deliver equal street lighting services in different neighborhoods within the same taxing jurisdiction. It is not unlikely that, with the dismantling of neighborhood advocacy programs, such as Model Cities, this issue will emerge from the bureaucratic process into the legal process, in much the same way that the movement for equal housing rights has evolved.

3.4 ENVIRONMENTAL DESIGN

It was mentioned in the discussion of comprehensive planning in Section 2.1 that street lighting master plans must integrate and balance a set of widely differing objectives. The field of Crime Prevention Through Environmental Design (CPTED) addresses the interaction between human behavior and the physically built environment. Many of the hypotheses listed in Section 2.3 are concerned with this interaction, which is based on the microstructure [A.2-26] and the macrostructure [A.1-52, A.2-2, A.2-34 and A.2-71] of the environment.

In brief, the CPTED approach is based on the hypothesis that the proper design and effective use of the built environment can lead to a reduction in crime and fear and concomitantly, to an improvement in the quality of urban life [A.2-119]. Although the purpose of proper design of the built environment is to indirectly elicit the desired human behavior pattern and the effective use of the built environment represents a direct influence on human behavior, it is the combination of proper design and effective use that symbolizes the strength of the CPTED approach, leading to a synergistic outcome, where the combination is more effective than the sum of its parts. In terms of street lighting, it might be stated that improved street lighting alone (representing a design strategy) is ineffective against crime without the conscious and active support of both citizens (in reporting what they see) and police (in responding and conducting surveillance). In sum, CPTED encompasses those strategies--whether they be physical, social, management or law enforcment in nature--that affect, either

CONTINUED

1 OF 2

directly or indirectly, human behavior with respect to the built environment.

Four design concepts have been noted within CPTED [A.2-119]:

(1) access control, which is primarily directed at decreasing crime opportunity and operates to keep unauthorized persons out of a particular locale;

(2) surveillance, which aims at increasing the risk to offenders and consists basically of keeping potential offenders under observation;

(3) activity support, which involves methods of reinforcing existing or new community activities as a means of making effective use of the built environment;

(4) motivation reinforcement, which, in contrast to the more mechanical concepts of access control and surveillance, is a correctional concept that seeks not only to affect offender behavior but also offender motivation--similarly, it seeks to elicit positive, motivation-based behavior on the part of the non-offender community.

Depending on the environmental mode(s) of concern to a CPTED program (e.g., residential, commercial, school, transportation, etc.), design concepts are integrated into a design strategy, leading ultimately to design directives and the creation or installation of relevant design elements.

Although CPTED has not been proven to be an effective crime prevention approach, the CPTED *process* is a powerful tool for conceptualizing and implementing environmental interventions to attain desired goals. As with any systematic approach, the usefulness of individual applications (e.g., street lighting), depends on the goal statement and on how carefully tradeoffs are made between conflicting goals.

It should be noted that street lighting is a key element in the CPTED approach. Thus, an evaluation of the impact of street lighting on crime will also significantly enhance the CPTED state of knowledge. In fact, any framework for the effective evaluation of street lighting would also be applicable to an effective evaluation of any CPTED program.

4 RELATED EVALUATION ISSUES

This section draws on the material presented in the preceding sections and discusses the issues directly related to the design and conduct of street lighting and crime evaluations. Specifically, evaluation objectives, measures, methodology and technology are examined in Sections 4.1 through 4.4, respectively.

The evaluation issues highlighted in this section include only those that are unique to street lighting. Thus, for example, such evaluation issues as lack of an evaluation design, lack of data, unreliability of data, etc. are not treated in this section, since, although they are pertinent to any crime prevention evaluation, they are not unique to a street lighting evaluation.

4.1 EVALUATION OBJECTIVES

Although there is no universal agreement on the definition of the term "evaluation," the one by Suchman [A.2-116] clearly states all the major dimensions required for the present task:

> The process of determining the value or amount of success in achieving a predetermined objective. It includes at least the following steps: formulation of the objective, identification of the proper criteria to be used in measuring success, determination and explanation of the degree of success, and recommendation for further program activity.

It is clear from this inclusive definition of evaluation that most of the studies summarized in Exhibit 2.7 fail to fall into the category of true evaluations. With the exception of a few, these studies usually do not identify the criteria or objectives against which to measure success and, hence, are not able to determine or explain the degree of success. As a result, their usefulness in supporting recommendations for further activity is restricted.

One must keep in mind that the primary reason for performing an evaluation of a program is to facilitate decisions relating to further program activity [A.2-35, p. 9]. For example, in evaluating law enforcement programs, the National Evaluation Program of the LEAA includes the following objectives:

- To provide a timely, objective and reliable assessment to Congress and the public of the effectiveness of LEAA's programs.
- To extend our present knowledge and technical capability in all aspects of criminal justice.
- To test criminal justice standards and goals and, through critical research, refine and evaluate them.
- To provide criminal justice administrators with relevant information which they can use to administer their programs more effectively.

Note that these objectives focus, as of course they should, on the decision-making needs of law enforcement and criminal justice administrators and planners.

In the case of street lighting, one must broaden the set of evaulation objectives to include the lighting objectives detailed in Exhibit 1.1--namely, security and safety, community character and vitality, and traffic orientation and identification. Unfortunately, in the actual conduct of a street lighting evaluation, two problems arise in connection with the objectives. First, the objectives, as stated, could be conflicting. For example, security requirements might require lighting levels that are in conflict with the community's physical character. Secondly, the relative importance of the diverse objectives can change, depending on the funding source. Thus street lighting can be billed as a beautification program if funded by a bond issue; a safety program if funded by the Department of Transportation; or a security program if funded by the LEAA. Consequently, any effective evaluation design must remain flexible enough to take into consideration, possibly, conflicting and shifting program objectives.

Once the program objectives are formulated, evaluation measures can be defined and subsequently assessed. The next section considers some issues dealing with the actual measurement of such measures, while Section 4.3 considers the manner in which the measures are used to assess street lighting projects.

4.2 EVALUATION MEASURES

This section addresses a number of issues relevant to the measurement of the variables linked by the hypotheses classified in Section 2.3. The discussion parallels that section's categorization of variables, and examines the measurement of the independent and dependent variables. The manner in which data pertaining to these variables is or might be used in evaluations is discussed in Section 4.3.

INDEPENDENT VARIABLES

The quantitative and qualitative measures of light are first examined, and then the remaining independent variables are addressed.

Light Measures

Sections 2.1 and Appendix B contain a discussion of the light quantity and quality variables which are used by lighting engineers in the description and design of street lighting systems. These variables may collectively be referred to as photometric variables. In general, it is time-consuming and somewhat expensive to measure the various photometric variables. For example, the measurement of horizontal illumination requires a complex procedure in which measurements are taken every ten feet along the center of each lane, and detailed information is recorded on the description and condition of lamps and luminaires, pole mounting height, spacing and arrangement, foliage interference and existence of extraneous light sources [A.2-60]. Given this data, average illumination, uniformity ratios and isolux diagrams can be generated and compared with stated specifications. Collection of the data over a period of time can enable the measurement of system deterioration. Interviews with municipal officials indicate that this type of measurement is made only rarely, and usually only in a test installation. It is therefore unrealistic to expect accurate illumination or other photometric data to be available for evaluation purposes unless the evaluation design and budget explicitly provide for it.

In another approach, a system was developed to be mounted on a vehicle and to record automatically both the illumination level on the street and, indirectly, the illumination of the sidewalk area adjoining the street, as the vehicle proceeded down the street [A.1-40, pp. 181-183].

This system was quite expensive and problems were encountered in obtaining stable performance over the range of illumination levels found in the field. There are now packaged systems available for direct measurement of illumination level, which are thought to be more reliable and which do not require expenditure of development costs [Ibid., p. 183].

It is not clear, however, from the present degree of refinement of hypotheses, which photometric measures should be recorded. Illumination level, taken at enough points on the road and sidewalk surfaces--not merely the center of the lane--allows a comparison of system performance with IES standards. Yet, many hypotheses, and a number of experts consulted, suggest that other photometric measures, such as road surface luminance, glare and color rendering index, may be more relevant to street lighting evaluations than illumination. In order to make this determination, hypotheses will have to be formulated which link objective photometric measures with attitudes or behaviors whose measured values can be unambiguously attributed to the lighting variables in question.

The justification for the use of gross measures of light such as "relit versus nonrelit block" lies in the assertion that since data showing both the exact location and time of each crime are not generally available, correspondingly detailed information on light parameters would therefore be superfluous. Instead, some geographical entity, such as a block or census tract is chosen; areas are categorized according to some overall light characteristic (e.g., lumen output) and variations within these areas are considered to be random.

A second issue concerning light measures can be characterized as photometry versus radiometry, and can be relevant once true photometric light variables have been chosen for use in an evaluation. It is common practice to measure illumination and luminance, and therefore all measures derived from them (e.g., uniformity, glare, visibility, etc.), using so-called "color-corrected" meters. These meters employ a filter whose light transmission properties, as a function of wavelength (i.e., color), vary in a way which approximates the response of the human eye to different wavelengths. The term *photometry* applies to such measures, in contrast to *radiometry* which characterizes measurements weighting all wavelengths equally. The human eye is approximately five times as sensitive to green light as to violet or yellow light, when adapted to nighttime light levels (i.e., scotopic vision), and, when adapted to daytime levels (i.e., photopic vision), is five times as sensitive to yellow light as to blue or red [A.2-24, p. 18].

The issue which has arisen is that, although the color-correcting filters are relatively accurate on the average over the whole spectrum, and therefore are suited to measurement of sources with continuous spectra, they may be inaccurate when used with line spectrum sources such as high-pressure sodium or mercury vapor. The problem stems from the fact that an error at one particular wavelength in the response of the "color correcting" filter, relative to the human eye's response, would not be compensated by errors in the opposite direction, since all the light is concentrated at a few wavelengths [A.2-9, p. 150]. Research is presently being conducted on this question, and the results will be significant for any evaluation which requires comparison of the light quantity or color-rendering properties of different light source types.

Other Independent Variables

An examination of the other independent variables basic to the street lighting and crime hypotheses leads to the conclusion that, while some are at least capable of quantification (e.g., land use, street type, police patrol tactics, temperature, etc.), others either are not quantifiable, at least not without further research (e.g., concept of territoriality), or are relevant only to a level of geographical detail not commensurate with presently available crime data.

Even one of the apparently well-defined environmental design measures, land use, should be more closely examined because actual land use in many areas is a function of the time of day, while traditional classification systems may not reflect the fact. For example, a street may be used for retail shopping during the day, but for entertainment and illegal activities at night.

Because most lighting and other independent variables are susceptible to such wide range of definition, a negative result obtained in the test of a hypothesis may only mean that the wrong measure was used for the concept that the hypothesis was formulated to address.

Finally, another set of independent variables that should be considered involves project management measures. Since street lights require the expenditure of large sums of money for the installation of equipment which will affect the environment for a long time, the management of street lighting projects is a relevant subject for evaluation. Toward this end, the definition of management objectives is essential to the evaluation design. The Newark, New Jersey, street lighting evaluation design is an example of a system in which management evaluation is included at the outset [A.1-56]. The experiences of Norfolk, Virginia [A.1-72] and Cleveland, Ohio [A.23] may be cited as examples where close monitoring of the project management process would have been helpful. In both cases, overruns occurred due in part to lax management.

DEPENDENT VARIABLES

Attitudinal, behavioral and crime-related measures are considered in this subsection.

Attitude

In terms of the service rendered, street lights may be justified as much for causing a reduction in the fear of crime as for reducing crime itself. Also, a number of hypotheses state that the attitudinal changes brought about by street lights cause changes in crime incidence. However, a general cautionary note should be borne in mind in connection with attitudinal measures, in particular, with measures of the fear of crime.

The National Crime Panel of the LEAA has attempted to include measures of the fear of crime in its victimization surveys, but the results have never been published, owing to the Panels' lack of confidence in the available techniques. The problem stems from the inability to ask the question directly: "fear" is a term that brings out different feelings in different persons. The alternative approach is to use various proxies for the fear of crime, such as how often the respondent goes out on the street alone at night. Then a new problem is created, which is that all proxy measures of fear are subject to being influenced by other variables, such as land use or economic status of respondent.

In any case all such proxies stand for a variable which has no independent, objective definition. It may well be that a careful analysis of this problem would lead to the replacement in the hypotheses of all intermediary, attitudinal variables with behavioral ones, such as pedestrian traffic, commercial activity, frequency of witness intervention, etc. Actually, attitudinal studies are being used with increasing frequency as a source of user feedback for the purpose of design evaluation. Many municipal officials interviewed reported spontaneous expressions, usually, but not always, of satisfaction, from citizens in relit areas. The Norfolk, Virginia, evaluation is an explicit attempt to obtain attitudinal information to assess how well a design met its objectives. User-oriented evaluation studies presently being funded by the U.S. Department of Housing and Urban Development and the Department of Health, Education and Welfare are likely to generate methodological contributions relevant to the evaluation of street lighting and crime.

Behavior

Many of the hypotheses expressed in the literature and summarized in Exhibit 2.14 assert a direct effect by various street lighting properties on human behavior. Moreover, subjective reactions to lighting environments are known to be quite varied. For example, one individual has claimed that high-pressure sodium street lights produce adverse psychological effects, ranging from destruction of a sense of territoriality and reduced pedestrian use of streets to headaches, disorientation, depression and suicidal tendencies [A.2-39, No. 127; A.2-95; A.3-23]. On the other hand, these same lights have drawn praise [A.2-39, Nos. 125, 128, 130]. The question arises, therefore, whether any systematic studies have been performed which can help to clarify this issue. Are there fundamental human reactions to the way the environment is lit? Bettleheim claims that:

> Darkness brings out the violence in a sick person and likewise, the basic fear of the dark contributes to the likelihood of an innocent person being victimized [A.2-108, p. 12].

A review of the literature in the field of environmental psychology, while not revealing a direct answer to this question, suggests several approaches to its answer. First, studies concerned with the impact of light on human behavior are quite limited, and are generally restricted to the observation of automobile driver performance [A.2-5, A.2-27, A.2-64]. Second, an indirect approach is suggested by the prevalence of studies relating to spatial characteristics and behavior. For example, behavioral traits such as territoriality, dominance, space and contact behavior, crowding, orientation and communal behavior may be affected by the delineation of spaces by lighting [A.2-27].

Recent experiments conducted in the fields of traffic safety, building security and indoor illumination design suggest experimental tools for measuring the light-behavior relationship. Traffic safety research emphasizes the definition of tasks whose performance a lighting system is expected to affect. Even though objective observations of crime in progress as a function of lighting cannot be readily performed, it may be possible to define tasks which are, at least logically, related to crime prevention [A.3-39]. The pedestrian lighting subgroup of the IES Roadway Lighting Committee has, for example, included in its draft 1977 version of the American Standard Practice for Roadway Lighting a guide to enable lighting systems in high-crime areas to achieve enough vertical illumination to facilitate facial recognition [A.3-8]. The development of this guide was based on a series of simple and direct experiments, carried out by the pedestrian lighting subgroup, and is admittedly only a beginning. Further examination of factors affecting both recognition and other parameters such as color rendition will undoubtedly be carried out in the future.

Building security studies deal explicitly with the manipulation of glare, contrast and creation of "no-man's land" zones and further examination of this research may reveal some conclusions relevant to street lighting and crime [A.2-26, A.2-79].

Specific techniques which have been used in laboratory studies of the effect of light on impression and behavior include the use of semantic differential rating scales for factor analysis, multidimensional scaling and behavioral mapping [A.2-30, A.2-68]. While these techniques have not had widespread application in outdoor nighttime environments (with the exception of [A.1-71]), they appear to have potential applicability to the study of the impact of street lighting on human behavior.

[illegible]

As indicated at the beginning of this section, a discussion of the issues related to the definition and collection of crime data is omitted here, inasmuch as the discussion would not have been unique to this street lighting evaluation effort. The use of crime data to evaluate street lighting projects is discussed in the next section, Section 4.3.

4.3 EVALUATION METHODOLOGY

This section contains a review of the methods that have been used in evaluating the impact of street lighting on crime. For convenience, the section is divided into three parts: input considerations, output considerations and statistical considerations. This division parallels the traditional evaluation approach which first considers the input variables, then monitors the output results, and, finally, tests the hypotheses using various statistical techniques.

INPUT CONSIDERATIONS

In an ideal experimental design situation, such as those conducted in a psychology laboratory with mice, the two most important procedures in setting up the experiment are (i) selection of experimental and control groups, and (ii) randomization among treated population. In real-life social experiments both these procedures are usually not fully carried out; this is mainly because ideal laboratory conditions do not exist in the real world and because of the high experimental costs involved. In the case of street lighting, the first of the above procedures translates to *selection of experimental and control sites*, while the second to *randomization to account for intervening and external variables.*

Selection of Experimental and Control Sites

Inasmuch as street lighting serves many purposes, the selection of street lighting sites is more often than not a compromise among differing interest groups--thus from an experimental viewpoint, the selected site may not be the best. Additionally when street lighting is ostensibly installed to prevent crime, the selected site is usually one with a high incidence of crime [A.1-52]. This selection process raises two key issues. First, if a high crime area is examined from one year to another, the crime rate (corrected for trend) in that high crime area has a significant probability of decreasing. This is true, regardless of whether a street lighting project is carried out or not. It is due to the fact that the current high level of crime may just be an extreme value for a distribution of crime levels [A.2-18, p. 11]. Secondly, in most situations, high crime areas are demographically different than the rest of the city and, hence, trends and street lighting effects cannot be compared with any other control site <u>unless</u> the control site is demographically similar and also has a comparably high crime rate. However, such a site would most likely be a part of the test site.

The phenomenon of displacement is another key issue in the selection of street lighting sites. Of special concern is spatial displacement. That is, if street lighting deters crime in an area, then there is a possibility that some of the deterred crime is displaced to adjacent localities. Hence, in developing a street lighting experimental design, one needs not only to specify experimental and control sites but also *displacement sites*. The displacement sites must be similar in crime patterns and socio-economic character to both the experimental and control sites. In the Portland (1973) study, some effort was made to select experimental, control and displacement sites. However, the socio-economic similarities between these sites was lacking. A final point should be made about displacement sites. In nearly all instances when displacement sites are selected, they are identified as being contiguous to the experimental site. However, it should be noted that the displacement sites could be in non-contiguous areas since, in addition to spatial displacement, there may be target, temporal, functional, and tactical displacements of crime.* For example,

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* For a more thorough discussion of crime displacement see [A.2-119].

target hardening of a commercial area could displace burglars to other, most likely non-contiguous, commercial areas.

Randomization to Account for Intervening and External Variables

Intervening and external variables have often confounded and, in some instances, invalidated program evaluations. In fact, the study findings listed in Exhibit 2.7 are all subject to doubt, especially when the confounding factors are identified and taken into account. For example, in the Kansas City Street lighting experiment [A.1-40], there was another on-going experiment: the Kansas City Preventive Patrol Experiment. The effect of one experiment on the other was not taken into consideration in the street lighting evaluation. Furthermore, there were two other changes in the police department at the time of data gathering for the Kansas City street lighting experiment: (i) the Kansas City police force increased from 1.89 per 1000 citizens in 1970 to 2.52 per 1000 in 1973, and (ii) the day and night beat boundaries were made constant in 1972, while they were different prior to that date.

One means of accounting for confounding factors is to use randomization in the evaluation design: situations may arise where this is possible [A.2-35, p. A3]. However, in most situations, conditions for randomized experiments are not met. One then may have to consider other evaluative techniques such as quasi-experimental approaches [A.2-18], regression-type modeling, and intervention analysis [A.2-11]. These techniques are discussed in Section 4.4.

OUTPUT CONSIDERATIONS

In Section 4.2, the measurement of different evaluation measures is discussed. In this section, the use of the measures to evaluate street lighting projects is examined. More specifically, the section focuses on the crime and attitudinal measures, as these are the principal measures used in the evaluation of street lighting to date: other measures (e.g., light measures, behavior measures, etc.) have only rarely been used in street lighting evaluations.

Crime Measures

The issues relating to the selection of crime types, the relative frequency of nighttime crimes, and the fluctuations in crime rates are considered below.

Selection of Crime Types

It is hypothesized that street lighting effects vary by type of crime. For example, the Kansas City (1971-1972) study [A.1-40] found that after improvement of street lights there were significant decreases in violent crimes and only moderate decreases in crimes against property. Similar findings were obtained in the Milwaukee (1972) study [A.1-54].

Hence, an issue arises regarding which types of crimes to measure. An argument can be made to measure all crimes in order to monitor the functional displacement of crime (i.e., displacement of crimes from one crime type to another). However, for certain crime types (e.g., forgery, fraud, gambling, etc.), it is obvious that there can be no possible effects from street lighting. In the Milwaukee (1972) study [A.1-54], nine categories of crimes were measured: (1) criminal damage to property, (2) disorderly conduct, (3) robbery, (4) aggravated assault, (5) other assault, (6) burglary, (7) theft, (8) auto-theft and (9) false fire alarm.

The Kansas City (1971-1972) study [A.1-40], the most complete study to date, included the five general categories of assault, robbery, larceny, auto-theft and burglary. It also broke the categories down by time of occurrence and location, as street lighting may have different impacts, if any, on nighttime crime versus daytime crime, on on-street versus off-street crime, and on crimes in residential neighborhoods versus crimes in commercial neighborhoods. In fact, the Kansas City study found that in commercial neighborhoods the declines for both robbery and assault were significant, whereas in residential neighborhoods the declines were significant only for robberies. The study also concluded that in the relit neighborhoods only violent nighttime street crimes were significantly reduced, compared to daytime crimes or nighttime off-street crimes.

A final issue that should be addressed is the manner in which crimes are classified. In essence, the FBI UCR classification of crime is based on legal definitions. From a research viewpoint, the current legal classification of crime is lacking and not sensitive to the causal factors that contribute to the incidence of crime. For example, a more causal-oriented, classification scheme might categorize all crimes by the different motives (e.g., money, jealousy, etc.), locale of occurrence (e.g., on-street, off-street), time of occurrence (e.g., night, day), and character of the neighborhood (e.g., slum, run-down, good, etc.). It is obvious that when crimes are classified on a causal-oriented scheme and collected in the same manner, the search for solutions to crime problems can be more readily carried out. There are two arguments against adopting a more causal-oriented, classification scheme. First, the causal factors of crime are not known--nevertheless, enough is known so that a *more* causal-oriented classification scheme can be established. Second, the amount of detail required would make the data collection effort unmanageable--undoubtedly, more data would have to be collected, but with data processing techniques the job will not be unmanageable. It is therefore suggested that intensive research be conducted to establish a problem-relevant, classification scheme of crime. The benefits appear to be worth the effort required.

Relative Frequency of Nighttime Crimes

If it is hypothesized that street lighting does not affect incidence of daytime crime, then the daytime crime rate may be used as a control. The influence of other factors that may affect the incidence of nighttime crime (e.g., demographic characteristics, land-use, etc.) can be controlled for to the extent that they may be assumed to have a proportionate influence on daytime and nighttime crimes. Hence, the relative frequency of nighttime crime, that is, the ratio of number of crimes occurring during nighttime hours to the total number occurring during all hours of a day, may be used as a measure to evaluate impacts of street lighting. The Kansas City [A.2-41], Atlanta [A.1-3] and Baltimore [A.1-5] studies considered this measure in their evaluations. The problems with this measure, however, are that (i) this ratio's sensitivity to street lighting may vary according to neighborhood characteristics, and (ii) the use of streets and, in general, land is different during the day than during the night. It may, therefore, be difficult to assess the unique effect of street lighting, if any, using this ratio. For example, in the Kansas City study [A.1-41] significant correlation was found between this ratio and the socio-economic characteristics--resulting in a discontinuance of this measure in the final analysis [A.1-40].

An initial analysis of the Kansas City experiment also considered the use of relative frequency of nighttime crimes in a regression-type analysis. For each crime incidence, the dependent variable was coded as one (1) if it occurred at night and zero (0) if it took place during the day. The independent variables included the various predictors characterizing the neighborhood and the street lighting level. Some very weak correlations were found between the relative frequency of nighttime crime and the predictor variables: the relative frequency of nighttime crime tended to drop with increasing entertainment activity, average rent and proportion of whites. Interestingly enough, the analysis showed a <u>rise</u> in relative frequency of nighttime crime with increased illumination. However, since the analysis used absolute values for street lighting illumination (and <u>not</u> the relative change in the illumination) and relative frequency for nighttime crime (and not the change in this ratio), the regression results indicate an association of relative frequency of nighttime crime with the absolute level of street lighting illumination and not the change in the level. Had the regression-type of analysis been applied to the *relative changes* of the predictor variables instead of their absolute values, a different finding may have resulted.

Fluctuations in Crime Rates

One problem in measuring the impact of street lighting on crime is that there are wide variations in the crime rates. Variations in crime rates could be caused by (i) the seasonal fluctuations, (ii) the crime trends, and (iii) the unpredictable nature of criminal incidences. Some of these variations can be accounted for by proper selection of control sites. However, the seasonal fluctuations and the crime trends must be carefully studied in any evaluation of street lighting.

The fluctuation problem has affected the findings of some studies. The Baltimore study [A.1-5] revealed that, due to the fluctuations in crime rates, the data they obtained were inconclusive with regard to the effect of street lighting on crime. In the Milwaukee (1972) study [A.1-54], the first six months after street lighting improvement saw a large decrease in nighttime crime in the test area and an increase in the control areas. However, in the next six months, the differences between the experimental and the control sites evened out. Therefore, the findings based on the estimates of the first six months were quite different from the findings based on the data obtained during the entire year.

Attitudinal Measures

Considering the many problems associated with crime data and their measurement, the examination of attitudes on street lighting is an important aspect in any street lighting evaluation. The issues with regard to attitudes relate to (i) awareness of street lighting improvements, (ii) sense of security, (iii) perception of crime rates, and (iv) identification of user population.

Awareness of Street Lighting Improvements

Before evaluating an individual's attitude towards street lighting, a preliminary consideration is whether the individual is aware of the street lighting improvement. The Portland (1973) study [A.1-79] considered this issue and found that only 25% of 350 residents interviewed were aware that street lights had been added. This awareness issue is related to the individual's perception on how well an area is lit. In the Portland study, the relationship between the number of lights near an interviewee's residence showed only a weak correlation with his/her perception on how well the streets were lit, and, thus, the poor awareness result is not surprising. In contrast, the Plainview, Kentucky study [A.1-38] showed that an individual's awareness of and satisfaction with the lighting level were related to the number of lights that were near his/her residence.

Sense of Security

Most of the attitudinal studies show that individuals feel more secure after street lighting improvement--the Milwaukee [A.1-55], Plainview, Kentucky [A.1-38], Norfolk [A.1-71] an Baltimore [A.105] studies support this thesis. However, in the Por and study, this was not the case; of the 79 persons who knew of the s eet lighting improvements, 58% did not change their feelings o curity.

The change in a community's sense of securit ay also be measured by the additional number of people who go out at ight. In Baltimore 14% felt that they went out more at night, while ilwaukee more than 50% felt that way. However, the fact that s et lighting is just one factor that may affect nighttime pedestrian t fic, this proxy measure must be used with care. The Norfolk stud raised this issue and concluded "lighting alone will not radically t ansform the image of areas thought extremely insecure" [A.1.71, p. 32].

Perception o. Crime Rates

In the Balti re study [A.1-5] over 50% felt at street lighting had no effect on c me, while in the Milwaukee [A. 55] and Plainview [A.1-38] studies, people indicated that street lig ing was a significant crime deterrent. However, there is reason to believe that people have a poor perception of crime rate unless the cr rate is extremely high. For exampl in the Baltimore study the att de survey showed that people were unaware of an increase in crime i idence. In the same study, another survey is cited that found peo e were unaware of a decrease in crime rate. Hence, in questioning the public on the relevance of stre lighting on crime, one must als consider the people's percept f crime rate.

Another measure of people's perception of crime rate is obtained by measuring their "crime consciousness." In the Plainview (1975) study, they measured the crime consciousness of a person as the number of defenses (e.g., burglar alarms, chains on doors, locks, etc.) he/she used. They then correlated crime consciousness with lighting and some of their conclusions are that

(i) individuals in poorly lit areas used more defenses;

(ii) individuals who thought there was a crime problem used more precautions; and

(iii) individuals considered exterior lights as a defense and used them more when they felt there was a crime problem.

This type of measure may be useful in measuring people's perception of crime rate, but care must be taken in interpreting the results.

There is also the issue of police perception. In many of the Street and Highway Safety Lighting studies it is indicated that police feel that street lighting reduces crime significantly. The Milwaukee study [A.1-55] also surveyed police opinion; of the 16 policemen interviewed,

(i) 69% indicated street lighting helped crime victims identify assailants,

(ii) 89% said that the effectiveness of their patrol was increased by street lighting, and

(iii) 69% felt that street lighting helped deter purse-snatching.

Identification of User Population

In all the attitudinal surveys, a sample of the residents in the experimental and control areas were interviewed. However, attempts were not made to survey the users of the streets, who may or may not have lived in the surveyed area. This is especially true in commercial areas where people travel from outside the area to conduct business. Likewise in residential areas, the user profile may be quite different than the resident profile--it is known that lower economic groups tend to use the streets more than their richer counterparts. The users of the streets may have different responses than the residents of the area. Hence, in any street lighting evaluation it is important to identify the user population.

With a focus on pedestrian flows during evening hours, a major link to crime rates could be established by estimating the crime-specific victimization probability per pedestrian mile. Although this may be a hard measure to estimate, it nevertheless provides a conceptual basis for considering a large number of interrelated, indirect performance measures. In considering this victimization probability, it would be necessary to estimate pedestrian flow rates as a function of street lighting. This may be done by examining changes in (i) store hours, (ii) entertainment activity, and (iii) pedestrian specific activities (e.g., pedestrian motor vehicle traffic accidents, telephone calls made from street telephone booths, etc.).

The crime rate relative to the pedestrian traffic may be an important measure to assess in studying the impact of street lighting improvements. Although street crimes could increase, the victimization probability per pedestrian mile could decrease. For example, before street lighting improvements one may have five pedestrian miles per day and two muggings, making the probability of a mugging equal to 0.4 per pedestrian mile. After street lighting improvements, one may have 50 pedestrian miles per day and four muggings, giving the resultant probability of 0.08 per pedestrian mile. Such large fluctuations in pedestrian traffic and crime rates due to street lighting are quite possible.

STATISTICAL CONSIDERATIONS

Given the outputs of an experiment, the final step in an evaluation is to determine the significance of the outputs, which is, of course, dependent on the hypothesis the evaluator wishes to prove or disprove. For example, the statistical tests involved in proving that street lights specifically *deter* crime are quite different from those used in proving that street lights merely *affect* crime in a general sense.

The research design, in order to evaluate the significance of the outputs, must first examine whether the assumptions for the statistical tests are met, such as randomization of the intervening and external variables. If the assumptions are met, the significance of the outputs must be evaluated in terms of the hypothesis being tested.

The hypotheses pertaining to change in crime levels may be tested using classical statistical techniques such as t-test and analysis of variance, comparing before and after crime data [e.g., A.1-76]. Some of the changes in crime levels which are termed "significant" in the studies discussed above did in fact use these techniques. Use of the

Chi-square distribution to compare differences between categories is another method employed to evaluate the significance of these differences [e.g., A.1-40]. Unfortunately, few of the studies explicitly report the statistical tests that were used. Of course, one must keep in mind that, in many evaluations, the type of data available restricts the choice of the applicable statistical tests to a few simple tests. Nevertheless, it is apparent that in most studies the design of the statistical tests was done *after* the data were obtained, instead of attempting to obtain more detailed measurements to use in previously designed statistical tests.

The hypotheses pertaining to citizen's attitudes are tested from the results of surveys or questionnaires. The proportion of responses agreeing with a given hypothesis indicates the strength of the hypothesis. All the attitudinal studies reviewed above reported the results of the evaluation in terms of these proportions. The "significance" of the proportions is left for the reader to ascertain.

Probably the hardest hypotheses to test are those related to displacement. In street lighting, one can consider spatial displacement (e.g., from relit area to non-relit area), location displacement (e.g., from street to off-street), temporal displacement (e.g., from nighttime crime to daytime crime), and functional displacement (e.g., from one type of crime to another). To evaluate spatial displacement the crime rates in the displacement sites must be compared with comparable rates in the corresponding control sites. The Kansas City and Milwaukee studies showed indications of displacement from relit areas to non-relit areas, but the significance of these results is questionable. Furthermore, in both these studies, the same control area was used to test for direct impact on the experimental sites as well as to test for displacement--a questionable procedure, considering the fact that a difference between the crime levels in the two sites could be due to a synergistic combination of direct impacts, displacement, and natural fluctuations--thus, separating one cause from another is difficult.

To evaluate displacement of crime from night to day and from street to off-street, crime rates in the experimental and control areas must be compared. In the Kansas City study it was observed that there was no significant displacement from night street to night off-street crimes, and that there was no shift from nighttime crimes to daytime crimes. The Atlanta (1973) study [A.1-3] also concluded that there was no shift between nighttime and daytime crimes. Finally, it can be simply stated that evaluating functional displacement presents a formidable, if not impossible, problem. No statistical tests of functional displacement have been made to date. For that matter, the other forms of displacement--target and tactical--have also not been analyzed. Actually, possibly the only way to ascertain crime displacement is to conduct an intensive and exhaustive offender interview program, including offenders who have been previously incarcerated as well as those who have never been incarcerated.

4.4 EVALUATION TECHNOLOGY

It has already been pointed out that in most of the street lighting projects that have been evaluated, true experimental conditions were not obtained. In such cases one must consider other possible evaluative techniques that may be applicable to street lighting. If these other techniques are also not appropriate, then the question arises: *Is the state-of-the-art in evaluation technology advanced enough to be able to determine the impact of street lighting on crime?* The answer to this question is presently unknown. However, there are some techniques that may be appropriate for street lighting evaluations: (i) quasi-experimental design [A.2-18], (ii) regression-type models, and (iii) intervention analysis [A.2-11]. These techniques are summarized below, followed by an outline of a "bounding" approach to the evaluation of street lighting.

QUASI-EXPERIMENTAL DESIGN

There are many situations in which the researcher can introduce a "quasi" experimental design, even though the researcher lacks full control over the experimental setting [A.2-18]. Such non-randomized experiments have been called "quasi-experiments." Some researchers feel that quasi-experimental design may be very appropriate for many law-enforcement program evaluations [A.2-35].

In quasi-experimental design, it is important that the evaluator be aware of which specific variables are not controllable. Thus, when the sample is not randomly drawn and the entire population is not represented, the quasi-experimenter identifies that segment of the population of which the sample is typical, and, of course, the evaluation results apply only to that segment.

In evaluating street lighting, the quasi-experimenter would select those situations in which there exist some experimental controls (e.g., normal socio-economic representation, perceivable differences in levels of light). From these situations the experimenter would select a site where measurement of appropriate output variables is possible. Care must be taken to avoid introducing "Hawthorne"* related bias of the selected site.

The evaluator must determine the possible links that may logically exist between any bias factor and the level of nighttime street crime (e.g., raised crime conciousness of the citizens might increase the number of reported crimes and, hence, increase the number of recorded crimes.) If a link is established, it should not be written off by means of a simplifying assumption; instead measurements should be taken to find out if there is some empirical relationship, or the lack thereof. In that respect quasi-experimentation has a drawback in the eyes of some researchers; namely, that the experimenter runs the risk that a rival hypothesis might prevail. But that of course should be part of any evaluation and "the policy-maker is ill-advised to conduct research which is directed solely at definitively testing some highly specific theory" [A.2-35].

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* The bias introduced, if any, in a social experiment due to the conduct of the experiment itself is called the "Hawthorne" effect.

REGRESSION-TYPE MODELS

The study conducted by Fairley et al [A.2-28] of the New York City Rand Institute is relevant here. The study examined different security measures (e.g., locks, lights, physical layouts, alarms, identification aids, security guards, etc.) in housing developments and their effect on "security", which was measured in terms of felony rate. The independent variables were the security measures, while the dependent variable was the felony rate in a statistical regression-type analysis. Such an approach may also be applied to street lighting evaluations. The level of street lighting and the change in the level of street lighting could be just two of the independent variables; other variables could include such measures as socio-economic characteristics, nature of land-use, levels of police operators, and, the changes in these measures. The independent variables could then be regressed on, first the *levels* of target crimes and, secondly, the *changes* in those levels. The first regression gives the association between target crimes and factors identified by the independent variables, while the second regression gives the relationship between changes in crime rates and the independent variables. The relative contribution of street lights, and changes in street lights, to the target crimes may be obtained from the resulting regression coefficients. *If assumptions of normal distributions are valid,* one could obtain the levels of significance in accepting the resulting coefficients.

Obtaining displacement effects in this type of analysis is difficult since it is hard to include dependence among felony rates between adjacent areas in the modelling process. However, the crime-correlated area model of Budnick [A.2-16] may be more suitable in this case. Budnick postulated that level of crime in one area of the city might be a function of crime level at another area. Using reported offenses in Washington, D. C., Budnick did show the existence of crime correlated areas. However, the degree of correlation was not sufficiently high for prediction or "inference" purposes. Budnick also studied displacement effects of a police patrol experiment in Washington, D.C. He analyzed the spatial displacement of target crimes for 23 adjacent areas and concluded that there was displacement of crime into only 3 of these areas. He also studied temporal displacement using the crime-correlated area model and found no displacement effects. In conclusion, Budnick pointed out that his model may be potentially useful in evaluating the impact of street lighting on crime. If sufficient data can be obtained to identify areas which are crime-correlated, if they exist, and some of these areas have had street lighting improvements, while others can act as control and displacement sites, then the Budnick approach may be directly applicable.

It should be noted here that defining independent variables is always a problem. Besides identifying all possible predictors such as lighting level, socio-economic and demographic characteristics and police patrol levels, defining geographical homogenous units of area presents a problem. For example, an interior of a homogeneous area has different crime-related influences than the border of the area. In fact, it has been postulated that neighborhood borders are 'good target' areas as compared to the interior of the neighborhood. Another study has shown that analyses of spatial patterning of crimes have been unsuccessful mainly because the topological structure of the spatial environment has been neglected [A.2-14]. The study then presents a topological method of constructing neighborhoods, where a neighborhood consists of a set of blocks, so that the predicted variation in crime rate within a given neighborhood is below a specified percentage -- this method was applied to burglary patterns in Tallahasse, Florida. The method may be useful in defining geographical areas in evaluations of the impact of street lighting on crime. In such a case, one would partition the region being evaluated into "neighborhoods" instead of using police districts or census tracts. However, in defining a neighborhood, one would probably consider block faces instead of blocks, since a street light illuminates both the street and the adjacent block faces.

INTERVENTION ANALYSIS

One problem in evaluating law enforcement programs is that the outputs occur in a time series. In other words, by examining the outputs of a dynamic system the evaluator has to make a determination about whether a given intervention (such as street lighting) affected the output, and the degree of the effect, if any. Thus, the assumptions of classical statistics do not hold since the before and after distributions of data are dependent. Also, since the underlying process is often not stationary (due to the many external factors that are working on the system) the distributions probably do not have the same mean and variance. Hence, confidence intervals and significance levels obtained using classical statistics have little credence, since all the necessary assumptions are invalid.

Recently, Box and Tiao [A.2-11] introduced a mathematical statistical technique called "Intervention Analysis" which may be applied to the above described situation. Basically, the technique calls for (i) mathematically modeling the various processes that work on the system, including the possible effects of the intervention, and (ii) fitting the actual data to the model. If the parameters associated with the effects of the intervention were inadequate, the analysis is repeated with another model of the intervention. The final values of the parameters give the level of intervention: a low value implies little or no effect and a high value a large effect.

Box and Tiao also presented in their paper two applications of this analysis, which showed the effect of opening a new freeway and the effect of a new smog control law on the pollution level in downtown Los Angeles, respectively. In like manner, intervention analysis may be applicable in evaluating the impact of street lighting on crime.

Finally, the main difference between intervention analysis and the other techniques is that in intervention analysis the dynamic nature of crime occurence is explicitly considered and time series of crimes are examined, while in the other techniques time dependence is only implicitly considered and static models are analyzed.

A "BOUNDING" APPROACH TO EVALUATION

The issues discussed in this report lead to the speculation that what appears to have been the goal of evaluations of street lighting and crime, namely the verification of a causal link between street lighting and crime, may not be realistic *at least at the present time*. Yet even if there is no available "Newton's Law" of street lights and crime, one still hopes to be able to answer the questions of whether street lighting impacts crime (and the fear of crime), and, if so, how does it impact crime. An evaluation approach is, therefore, proposed in this subsection that could be used to answer both questions, not in an exact manner but in a "bounded" manner. That is, each question will be answered in terms of a range of answers -- the bounds on this range will be specified.

The motivation behind this approach is based on the realization that exact answers to questions in social experimentation are neither warranted nor, in many instances, possible to arrive at. In fact, should an exact answer be derived, it would still be questionable since it would most likely be based on limited -- possibly invalid -- data and usually controversial assumptions. On the other hand, bounds on the answer could be derived from simpler models of reality and with manageable analysis. Moreover, close bounds make for a more exact answer. For example, just as traffic studies have shown that beyond a certain level, further increases in the illumination level do not affect a driver's ability to avoid road hazards, street lighting studies may be able to define an illumination level above which no increased crime prevention benefits are derived. Continuing in this line of thought, one might postulate that the minimum number of nighttime crimes is in some manner bounded by the number of crimes occuring during the daytime, since the best street lighting system is that provided by daylight. Care must be taken in this analysis, however, since the land use characteristics during daytime are usually different from those during nighttime.

Whatever is the outcome of this "bounding" concept, it is clear that the overall structure of an evaluation approach is in need of definition not only in the area of street lighting and crime, but also in the general field of social experimentation. Hopefully, this report has helped to provide a basis for developing such an approach.

APPENDIX A

REFERENCES: BIBLIOGRAPHY AND CONTACTS

To facilitate the identification of references dealing exclusively or primarily with individual cities, counties or states, the bibliography of written materials is presented here in two separate exhibits. Exhibit A.1 contains only those references dealing with specific governmental jurisdictions, and is organized alphabetically by jurisdiction. Exhibit A.2 contains all other written references, including several which report on more than one jurisdiction (where appropriate, the latter are cross-indexed in Exhibit A.1 under the corresponding cities). Finally, Exhibit A.3 lists individuals working in fields relevant to street lighting evaluation who have been contacted to date either by telephone or in person: it is expected that most of these individuals will be interviewed at greater length in the ensuing months.

Both Exhibits A.1 and A.2 classify the contribution to date of each document to the Phase I Street Lighting Evaluation. This is accomplished by indicating to which of five categories each document contributes: background, elements, interventions, environment and evaluation. Background includes the history of street lighting practices and goals, and materials relevant to the evolution of the evaluation process in the crime prevention area. Elements include all of the components and activities encompassed by a street lighting system: resource allocation, design, hardware, installation and maintenance practices, supporting activities or activities supported by street lighting (such as police patrol practices, street reconstruction, tree trimming, etc.), as well as descriptions in general terms of system outputs, including lighting, criminal activity, attitudes, and outputs related to other goals (such as traffic safety, enhancement of commercial activity, urban design, etc.). Interventions include reports on measured crime-related consequences of street lighting activity and hypotheses which attempt to explain how these consequences arise. Environmental contributions include documents dealing with important issues which, although only indirectly related to the crime-prevention effects of street lighting, are relevant to questions of resource allocation, design, environmental impact and legal constraints. Finally, Evaluation contributions are those that bear directly on the design of and conduct of alternative street lighting evaluation techniques, both existing and potential.

Documents for which no contribution is shown are those with potential relevance, but which have not yet been located. Documents reviewed and found to have no relevance to street lighting evaluation are not included in the bibliography. Throughout the text of this report, references are keyed to the exhibit and the sequence number within the exhibit. For example, reference A.1-16 refers to the "Chicago Takes the Menace Out of Dark Alleys," (Nation's Cities, March, 1967) article.

The bibliography must be viewed as constantly changing, as new materials are reviewed and new relevance is found in existing references. Nevertheless, its format is designed to facilitate the next tasks required by the NEP Phase I Street Lighting Evaluation: the development of an evaluation framework or frameworks and the systematic detailing of specific street lighting interventions. These will in turn lead to a model single project evaluation design, a general assessment of the state of knowledge as to the effects of street lighting on crime, and to recommendations for a possible Phase II evaluation design.

EXHIBIT A.1

Street Lighting References Reporting on Individual Governmental Jurisdictions

JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Alabama	1. Street and Highway Safety Lighting Bureau, "Governor Wallace Presents Awards to Two Alabama Women's Clubs...," Press Release, August 14, 1974.		X			
Asheville, N.C.*	2. "Crime in Downtown Asheville Within Study Area," (undated, anonymous), National Crime Prevention Institute.			X		
Atlanta, GA.	3. City of Atlanta, Georgia, "Streetlighting Pilot Project, Grant No. 72-09-07-17, Quarterly (April 30, 1974) and Semi-Annual (November 8, 1974) Evaluation Reports."			X		
Atlanta, GA.	4. "Street Lighting Project Funded," _The Atlanta Journal_, March 9, 1973.			X		
Baltimore, MD.	5. City of Baltimore, Md., Mayor's Coordinating Council on Criminal Justice," Sodium Vapor Street Lighting - Report on Resident Survey," August, 1975.			X		X
Baltimore, MD.	6. "Charles Center - Growing Momentum for Renewal," Inner Harbor Management, Inc.		X			

* See also Reference A.2-42.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	Background	Elements	Interventions	Environment	Evaluation
Baltimore, MD. (continued)	7. Mastromatteo, Dominic, Baltimore, Md. Police Department, May 25, 1970 letter to F. Pierce Linaweaver, Director of Public Works, Baltimore, Md.			X		
Boston, MA.	8. Editorial, Christian Science Monitor, June 27, 1959.			X		
Boston, MA.	9. Street and Highway Lighting, "Ring of Lights Around Boston," (date unknown), obtained from Massachusetts Council on Crime and Correction.		X			
Charleston, W.VA.	10. Higginbotham, Wilma, "Lighting Award Set at White House," Charleston Daily Mail, April 22, 1974, p. 13A.		X			
Charleston, W.VA.*	11. Slack, John M., Speech, Congressional Record, 93rd Congress, Second Session, Vol. 120, No. 167, December 3, 1974.		X	X		
Chattanooga, TN.**	12. General Electric Co., Nela Park, Cleveland, Ohio, "1,000 Watt Lucalox Relighting in Downtown Chattanooga Gives Four Times the Light Without Adding to Energy Needs," Press Release No. 134-75, October 29, 1975.		X		X	
Chicago, IL.	13. Chicago Association of Commerce and Industry, Minutes of the June 22, 1972 Crime Prevention Committee Meeting.		X	X		

* See also Reference A.2-42.

** See also Reference A.2-88.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Chicago, IL. (continued)	14. Chicago Park District, "Security Lighting in Public Parks," Grant Application No. 2-07-06-0299-01, 1971.		X	X		
Chicago, IL.	15. Chicago Police Department, James M. Rochford, Superintendent, February 13, 1976 letter to Francis M. Degman, Acting Commissioner, Bureau of Streets and Sanitation, crime summary enclosed.			X		
Chicago, IL.	16. "Chicago Takes the Menace Out of Dark Alleys," Nation's Cities, March, 1967.		X	X		
Chicago, IL.	17. General Electric Company, Nela Park, Cleveland, Ohio, "Lucalox Relighting of Chicago Streets Doubles Illumination, Cuts Energy Usage," April 11, 1975, Press Release No. 42-75.		X		X	
Chicago, IL.	18. Street and Highway Lighting, "51,000 Alley Lights Brake Chicago Crime," (date unknown).			X		
Chicago, IL.*	19. Box, Paul, "Public Lighting Needs," Illuminating Engineering, September, 1966.					
Chicago, IL.**	20. "Light: A Proven Deterrent to Crime," Street and Highway Lighting Bureau, May 24, 1973, p. 6.					

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* See also Reference A.2-13.

** See also Reference A.2-78.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Cincinnati, OH.	21. Malt, Harold Lewis, and Associates, "Operation STREET-SCAPE--A Demonstration Furnishing the City Street," prepared for the Department of Urban Development, Cincinnati, Ohio.		X		X	
Cleveland, OH.	22. City of Cleveland, Department of Public Utilities, "Impact Streetlighting Project Evaluation Report -- September, 1973 Through November, 1974."		X			
Cleveland, OH.	23. City of Cleveland, "Impact Streetlighting," LEAA Grant Application 73DF05S015, 6/1/73-6/30/74.		X			
Cleveland, OH.	24. O'Brien, Robert, "Light on Our Streets," <u>National Civic Review</u>, April, 1960.			X		
Cleveland, OH.*	25. Rosanen, George, "Crime Rises Despite Brighter Street Lighting," <u>Cleveland Plain Dealer</u>, January 7, 1973, p. 18-A.			X		
Dade County, FL.	26. Vardell, Larry, "Final Report, COPP Program," Governor's Council on Criminal Justice, Dade County, Florida, May, 1975.		X		X	
Danville, IL.	27. Pitt, Paul J., East Central Illinois Criminal Justice Commission, March 30, 1972 letter to Gerald Gersey, Illinois Law Enforcement Commission.			X		X

* See also Reference A.2-78.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Denver, CO.	28. City and County of Denver, Colorado, Streetlighting Project, Application for Grant 75-DF-0800002 CH.		X	X		X
Detroit, MI.	29. Head, John F., "New Street Lights May Harm Trees," <u>Detroit Free Press</u>, October 1, 1973, p. 3A.				X	
Detroit, MI.*	30. Luedtke, Gerald and Associates, "Crime and the Physical City: Neighborhood Design Techniques for Crime Reduction," A Pilot Study prepared for the National Institute of Law Enforcement and Criminal Justice, Michigan, June, 1970.			X		X
Durham, N.C.	See Reference A.2-42.					
Ft. Wayne, IN.	See Reference A.2-42.					
Garland, TX.	31. City of Garland, Texas, Crime Prevention Environmentalist, Grant Application #5-11-03018, August 22, 1975.			X		
Gary, IN.	See Reference A.2-88.					
Greendale, WI.	32. "The People's Choice in Roadway Lighting," <u>Illuminating Engineering</u>, March, 1970, p. 121.		X			
Gulfport, MI.	See Reference A.2-42.					
Indianapolis, IN.	33. "Clubwomen Turn Lights on Crime," <u>Atlanta Journal and Constitution</u>, October 22, 1972, p. 15-H.		X	X		
Indianapolis, IN.	34. Dunn, Jack, "Crime? Blight? We Fix It," <u>Outdoor Lighting Digest</u>, January, 1969, pp. 3-4.			X		

* See also Reference A.2-78.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Indianapolis, IN. (continued)	35. "Planned Light Prevents Crime and Reduces Accidents," The American City, March, 1963, pp. 125-126.			X		
Indianapolis, IN.	36. Street and Highway Lighting, "Blueprint for Good Lighting," (date unknown).		X			
Jacksonville, FL.	37. Malt, Harold Lewis et al., "Tactical Analysis of Street Crime," H.L. Malt Associates, Washington, D.C., January, 1973.			X	X	
Jeffersontown, KY.	38. Kellem, Carl, Harmansky, George, Landan, Elizabeth, and West, John Denis, "A Comprehensive Study of Streetlighting With an In-Depth Analysis of Plainview Subdivision, Jeffersontown, KY.," Institute of Community Development, University of Louisville, Louisville, KY., April 23, 1976.	X	X	X	X	X
Kansas City, MO.	39. Kerby, J.E. and Horrigan, J.J., "Lighting's Up-To-Date in Kansas City!", Outdoor Lighting Digest, Vol. 21, No. 2, May, 1967.		X			
Kansas City, MO.	40. Wright, R., Heilweil, M., Pelletier, P. and Dickinson, K., "Impact of Streetlighting on Crime," University of Michigan at Ann Arbor, May, 1974. (Prepared for the National Institute of Law Enforcement and Criminal Justice, Grant No. 73-NI-99-0046-G, Project Director - R. Wright.	X	X	X	X	X

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Kansas City, MO. (continued)	41. Wright, R., Thomas, D., Pelletier, P., and Dickinson, K., "Study to Determine the Impact of Streetlighting on Crime - Phase I Final Report." Prepared by University of Michigan, Ann Arbor, for the National Institute of Law Enforcement and Criminal Justice, 1972.			X		X
Kansas City, MO.	42. Wright, R., Thomas, D., Pelletier, P. and Dickinson, K., Kansas City Public Works Department, "Study to Determine the Impact of Streetlighting on Crime - Phase II Final Report." Prepared by University of Michigan, Ann Arbor, for the National Institute of Law Enforcement and Criminal Justice, July, 1973.		X	X		X
Kansas City, MO.*	43. Box, Paul, "Public Lighting Needs," Illuminating Engineering, September, 1966.					
Massachusetts	44. Massachusetts Council on Crime and Correction, "Light the Night," News Release, 1970.		X	X		
Massachusetts	45. Massachusetts Department of Public Works, "Highway Lighting and Electrical Energy Conservation - Vol. 1, General Warrants and Recommendations," February, 1974.				X	

* See also Reference A.2-13.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Massachusetts (continued)	46. Street and Highway Lighting, "Holding Crime at Bay in the Bay State," (date unknown), obtained from the Mass. Council on Crime and Correction.			X		
McPherson, KS.	47. "To Make Streets Safe After Dark," National Civic Review, April, 1960.			X		
Miami, FL.	48. Clements, Sid, "Sodium Vapor Lighting Cuts Crime," Electrical South, April, 1972, pp. 27-31.			X		
Miami, FL.	49. Francis, Edward, "Miami Relights: A Report on Street Lighting Programs and Procedures in the City of Miami," Department of Public Works, City Commission of Miami, Report #232, December, 1973.		X	X	X	
Miami, FL.	50. Miami Police Department, Annual Report, 1971.			X		
Miami, FL.	51. Johnson, P.J., "In Miami, It's Light in the Streets Vs. Crime in the Streets," Street and Highway Lighting (date unknown), obtained from P.J. Johnson.		X			
Miami Beach, FL.	52. Harold Lewis Malt Associates, "Illumination of High Crime Areas," conducted for the City of Miami Beach, Florida, co-sponsored by the State of Florida's Governor's Council for Criminal Justice, 1974.		X		X	

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Midlothian, IL.	53. Raday, Harry, "City Sells a Lighting Program," American City and County, April, 1976.		X			
Milwaukee, WI.	54. Department of Intergovernmental Fiscal Liason, Milwaukee, Wisconsin, "Preliminary Report--Milwaukee High Intensity Street Lighting Project," December 28, 1973.			X		X
Milwaukee, WI.	55. Department of Intergovernmental Fiscal Liason, "Final Report--Milwaukee High Intensity Street Lighting Project," July 15, 1974.			X		X
Newark, N.J.*	56. Kupersmith, G., "Sample Impact Project Evaluation Components -- National Impact Program Evaluation." Prepared by MITRE Corporation for NILECJ, 1974.					X
New Haven, CT.	57. South Central Criminal Justice Supervisory Board, New Haven, Conn., "Innovative Patrol Operations," 1976.					X
New Orleans, LA.	58. Sternhell, R. and Carroll, S., "New Orleans - Mayor's Criminal Justice Coordinating Council - Target Area Evaluation - A Six-Month Report on The Development of Target Area Projects and the Evaluation System," 1974.		X	X		X

* See also Reference A.2-42.

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
New York	59. Carmody, Dierdre, "Thirty-Nine Business Areas Getting Super Lights to Cut Crime," New York Times, April 24, 1972.		X	X		
New York	60. "Crime Flourishes in Darkness... New York Fights Back With $28.8 Million Program," Electrical World, October 3, 1960.		X	X		
New York	61. Goldberg, Hyman, "Crimes of Darkness," Cosmopolitan, April, 1959, pp. 60-65.					
New York	62. Lurkis, Alexander, "Combatting Juvenile Deliquency with Light," Illuminating Engineering, October, 1961, p. 606.		X	X		
New York	63. Lurkis, Alexander, "More Lighting and Fewer Juvenile Problems," The American City, January, 1962.		X	X		
New York	64. New York City Police Department, "Lighting as a Deterrent," obtained through Wilfred Horne, Deputy Commissioner for Press Relations, September 11, 1970.			X		
New York	65. "New York City Requires Outdoor Lighting Around Multiple-Family Dwellings," (date and publication unknown), obtained from General Electric Company, Nela Park, Engineering Applications Department.				X	

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	Background	Elements	Interventions	Environment	Evaluation
		CONTRIBUTION				
New York (continued)	66. Street and Highway Lighting, "To Stop a Thief, Light a Light," (date unknown).		X			
New York	67. "Vandal-Proof Lighting for New York's Central Park," The American City, October, 1966.		X			
New York	68. Wyatt, Hugh, "New Lighting Aims at Cut in Harlem Crime," New York Daily News, March 16, 1973, p. 30.		X			
Norfolk, VA.	69. Barr, Vilma, "Improving City Streets for Use at Night--The Norfolk Experiment," Lighting Design and Application, April, 1976, p. 25.		X		X	X
Norfolk, VA.	70. "First Award--Gary Hack and William Lam Associates," Progressive Architecture, 1:75.		X	X	X	
Norfolk, VA.	71. Norfolk Redevelopment and Housing Authority and William Lam Associates, "Improving City Streets for Use at Night (The Norfolk Experiment)," prepared by Gary Hack, Assistant Professor of Urban Design, MIT, June, 1974.		X	X	X	X
Norfolk, VA.	72. Powell, John Lamont, May 29, 1975 memorandum (unpublished).		X	X	X	

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	Background	Elements	Interventions	Environment	Evaluation
		CONTRIBUTION				
Oakland, CA.	73. Brown, Bill, "Let's Light Up the Land," Street and Highway Lighting, September, 1971, p. 5.					
Owensboro, KY.	74. "Owensboro, Kentucky Pulls the Switch on Crime," Street and Highway Lighting, Vol. 20, No. 4, December, 1970, pp. 13-17.			X		
Pigeon Forge, TN.	See Reference A.2-42.					
Plainfield, N.J.	75. "Plainfield Lights Up to Catch A Thief," New Jersey Municipalities, June, 1973.			X		
Plainfield, N.J.	See also Reference A.2-78.					
Portland, OR.	76. Inskeep, Norman R. and Goff, Clinton, "A Preliminary Evaluation of the Portland Lighting Project," Oregon Law Enforcement Council, Salem, Oregon, August, 1974.			X		X
Portland, OR.	77. Schneider, Anne L., "Crime and Victimization in Portland: Analysis of Trends, 1971-1974," Oregon Research Institute, Salem, Oregon, February 10, 1975.					X
Portland, OR.	78. Schneider, Anne L., "The 1974 Portland Victimization Survey: Report on Procedures," Oregon Research Institute, Salem, Oregon, January 8, 1975.					X

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Portland, OR. (continued)	79. Schneider, Anne L. and Reiter, Paul, "Portland Lighting Project--Final Report--Citizen Perceptions of Streetlighting," Oregon Research Institute, Salem, Oregon.					X
Rehoboth Beach, DE.	80. City of Rehoboth Beach, Delaware, Rehoboth Burglary Prevention, Detection, Deterrence and Apprehension Program, Grant Application No. 76-071.		X			
Richmond, VA.	81. PRC Public Management Services, Inc., "Richmond HIT Project--Final Evaluation Report for Phase I HIT Program," prepared for Virginia Division of Justice and Crime Prevention.			X		X
Richmond, VA.	82. Ryan, David D., "City Checks for Tree Damage," <u>Richmond Times Dispatch</u>, October 5, 1973.				X	
St. Louis, MO.	83. "It's 'Meet Me in St. Louis Where the Lights Are Bright," <u>Electrical World</u>, October 19, 1964.			X		
St. Louis, MO.	See also Reference A.2-13.					
Salem, OR.	See Reference A.2-42.					

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	Back- ground	Elements	Interventions	Environment	Evaluation
Savannah, GA.	84. "Lighting Decreases Crime Rate," Municipal South, (date unkn...			X		
Savannah, GA.	[illegible] Save Energy, Make Savannah a Safer Place to Live." Congressional Record, 94th Congress, [illegible] Session, Vol. 121, No. 2, January 15, 19[illegible]			X	X	
Smyrna, DE.	86 City of Smyrna, Delaware, Burglary Control Program, Grant Application No. 76-(					
Tampa, FL.	) "Tampa Relights 70 Square Blocks," Street and Highway Lighting, September, 1971, pp. 7-9.					
Tucson, AZ.	88. City of Tucson, Arizona, "Dusk to Dawn Alley Lights Application for LEAA Grant No. 70DF090417.					
Tucson, AZ.	89. Garmine, Bernard L., "Ligh Up for Safety," Congressio Record (Appendix), Extensi of Remarks of Hon. Charles P. Farnsley, November 21, 1966, p. A-5774.			X		
Tulsa, OK.	90 [illegible], Alice, "Critic Fa to [illegible] Hugo Street Lights, The Tulsa Tribune, July 31 [illegible]				X	
Vincennes, IN.	See Reference A.2.-42.					

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JURISDICTION	REFERENCE (Author, Title, Agency, Publisher and Date)	Background	Elements	Interventions	Environment	Evaluation
Washington, D.C.	91. Basaran, Saut, "Crime Deterrent Lighting in Washington, D.C.," Traffic Planning and Street Lighting Division, Washington, D.C., 1973.			X		X
Washington, D.C.	92. Colen, B.D., "D.C. Lights the Way in Fighting Crime," The Washington Post, February 7, 1971.			X		
Washington, D.C.	93. "Cutting the Crime Rate: How the Nation's Capital Does It," U.S. News and World Report, April 10, 1972, pp. 24-25.					
Washington, D.C.	94. Goodman, George and Schreider, F., "Light a Candle," Look Magazine, (date unknown).		X			
Washington, D.C.	95. Hartley, John, "Lighting Reinforces D.C. Crime Fight," The American City, August, 1974, p. 59.			X		
Washington, D.C.	96. Hartley, John, "Nighttime Revival in the Nation's Capital," Nation's Cities, December, 1970.		X	X		
Washington, D.C.	97. "Improved Street Lighting in the District of Columbia," Congressional Record--Senate, October 9, 1970, p. S-17621.		X	X		

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JURISDICTION		REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
Washington, D.C. (continued)	98.	Landman, Amos, "Street Lighting Has Cut Crime," Journal of Commerce, May 18, 1972.			X		
Washington, D.C.	99.	Marks, Dorothy, "Neighbors in D.C. Light Up a Block Rather Than Curse Crime Statistics," North American Newspaper Alliance, (date unknown).		X			
Washington, D.C.	100.	Holland, William, "New D.C. Lights Cut Crime," The Evening Star, Washington, D.C., June 18, 1971.			X		
Washington, D.C.	101.	"New 'Globe Power' in Washington, D.C.," Street and Highway Lighting, Vol. 20, No. 4, 1970.		X	X		
Washington, D.C.	102.	"Washington, D.C.--Capital of Light," (undated), published by the District of Columbia.		X	X		
State of Washington	103.	"Evans Orders Street Lights On," The Seattle Times, February 7, 1974.		X		X	
Wichita Falls, TX.	104.	Wichita Falls, Texas Police Department, "Crime Analysis Data for Increased Street Lighting Program," 1976.					X

EXHIBIT A.2

Other Street Lighting References

REFERENCE (Author, Title, Agency, Publisher and Date)	Background	Elements	Interventions	Environment	Evaluation
1. Anderson, John W., "Street Trees are Safe With Sodium Lighting," American City, December, 1975.				X	
2. Angel, Shlomo, "Discouraging Crime Through City Planning," W.P. Number 75, Institute of Urban and Regional Development, University of California, Berkeley, February, 1968.			X		
3. Ashley, Myer, Smith, "City Signs and Lights, a Policy Study," prepared for the Boston Redevelopment Authority and the U.S. Department of HUD, January, 1971.		X	X	X	
4. Beardsley, Charles W., "Let There Be Light, But Just Enough," IEEE Spectrum, December, 1975, p. 28.		X		X	
5. Bell, Gwen, Randall, E., Roeder, J.E.R., "Urban Environments and Human Behavior--An Annotated Bibliography," Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pennsylvania, 1973.				X	
6. Bennet, Beverly L., "The Impact of Street Lighting on Crime and Traffic Accidents," Education and Public Welfare Division, U.S. Library of Congress, Washington, D.C., May 7, 1976.			X	X	X

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REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
7. Berla, Nancy, "The Impact of Street Lighting on Crime and Traffic Accidents," Education and Public Welfare Division, Library of Congress Legislative Reference Service, October 5, 1965.			X		
8. Blackwell, H. Richard, "Development of Procedures and Instruments for Visual Task Evaluation," Illuminating Engineering, April, 1970, p. 267.				X	
9. deBoer, J.B., "Modern Light Sources for Highways," Journal of the IES, January, 1974, p. 142.		X		X	X
10. Boggs, Sarah L., "Urban Crime Patterns," American Sociological Review, Vol. 30, December, 1965.					
11. Box, G.E.P. and Tiao, G.C., "Intervention Analysis with Applications to Economic and Environmental Problems," Journal of the American Statistical Association, March, 1970, pp. 70-74.					X
12. Box, Paul C., "Accident and Crime Prevention Experience with Modern Roadway Lighting," Street and Highway Lighting, Second Quarter, 1964, p. 19.					X
13. Box, Paul, "Public Lighting Needs," Illuminating Engineering, September, 1966.			X		X

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REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
14. Brantingham, Patricia L. and Paul J., "Residential Burglary and Urban Form," Urban Studies, Vol. 12, 1975, p. 273-284.					X
15. "Brief History of Streetlighting," (date unknown: after June, 1971), copy obtained from National Crime Prevention Institute.	X				
16. Budnick, F.S., "Crime-Correlated Area Model--An Application in Evaluating Intensive Police Patrol Activities," prepared for NILECJ, Washington, D.C., 1972.					X
17. Callender, Don, "Light, a Weapon in War on Accidents and Crimes," American Motorist, March, 1962.			X		
18. Campbell, Donald T. and Stanley, Julian, C., "Experimental and Quasi-Experimental Designs for Research," Rand McNally & Co., Chicago, 1966. Reprinted from "Handbook of Research on Teaching," N.L. Gage Ed., Rand McNally, 1963.					X
19. Center for Government and Public Affairs Review, Auburn University at Montgomery, Alabama, "Robbery Prediction Project," Vol. 1, No. 1, 1976, p. 3.			X		X

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	REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
20.	Chamberlain, Gary M., "Improve Your City's Streetlighting," The American City, November, 1974.				X	
21.	Clark, Francis, "The Case for Step-by-Step Procedures for Calculations in Roadway Lighting Design," Illuminating Engineering, November, 1970, p. 637.		X			
22.	Correlation Between Street Lighting and Crime, prepared for Rep. Charles P. Farnsley by the Education and Public Welfare Division, U.S. Library of Congress, Congressional Record (House), October 12, 1965, p. 25855.					
23.	Davis, Ron, "Memorandum of Law," submitted to Doyle Shackelford, National Crime Prevention Institute, March 27, 1975.				X	
24.	Edison Electric Institute, Street and Highway Lighting Committee, "Street Lighting Manual," 2nd Ed., 1969.	X	X			
25.	Edman, W.H., "Highway Lighting Need," The American City, November, 1969.					
26.	The Electricity Council, "Security Lighting--the Great Deterrent," printed in England (date unknown), obtained from the National Crime Prevention Institute.			X		
27.	Esser, Aristide H., Ed., "Behavior and Environment--The Use of Space by Animals and Men," proceedings of an International Symposium held at the 1968 meeting of the American Association for the Advancement of Science in Dallas, Texas, Plenum Press, (New York-London), 1971.				X	

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REFERENCE (Author, Title, Agency, Publisher and Date)	CONTRIBUTION: Background	Elements	Interventions	Environment	Evaluation
20. Chamberlain, Gary M., "Improve Your City's Streetlighting," The American City, November, 1974.				X	
21. Clark, Francis, "The Case for Step-by-Step Procedures for Calculations in Roadway Lighting Design," Illuminating Engineering, November, 1970, p. 637.		X			
22. Correlation Between Street Lighting and Crime, prepared for Rep. Charles P. Farnsley by the Education and Public Welfare Division, U.S. Library of Congress, Congressional Record (House), October 12, 1965, p. 25855.					
23. Davis, Ron, "Memorandum of Law," submitted to Doyle Shackelford, National Crime Prevention Institute, March 27, 1975.				X	
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2. Bennett, Beverly — U.S. Library of Congress, Washington, D.C.

3. Bobish, Rick — Division of Light and Power, Department of Public Utilities, Cleveland, Ohio

4. Bowles, Hal — National Electrical Manufacturers Association, New York, New York

5. Box, Paul — Westmoreland Building, Skokie, Illinois

6. Broughman, James — Data Systems and Data Processing Division, U.S. Department of HUD, Washington, D.C.

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9. Crouch, C.L. — Illuminating Engineering Research Institute

10. Dantes, Dale — Research and Development Division, Chicago Police Department, Chicago, Illinois

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11.	Dogin, Henry S.	Office of Planning and Program Assistance State of New York/Division of Criminal Justice New York, New York
12.	Dumbrys, Robert	Division of Light and Power Department of Public Utilities Cleveland, Ohio
13.	Flynn, John E.	Architectural Engineering Department Penn State University State College, Pennsylvania
14.	Gersey, Gerald	Crime Prevention Specialist Illinois Law Enforcement Commission Chicago, Illinois
15.	Girard, Charles	International Training Research and Evaluation Council Falls Church, Virginia
16.	Heath, Bruce L.	Utah Council on Criminal Justice Salt Lake City, Utah
17.	Heilweil, Martin	Ann Arbor, Michigan
18.	HUD Regional Office	Office of Coummunity Planning and Development Boston, Massachusetts
19.	Jacobson, William	Office of Policy Development and Research U.S. Department of HUD Washington, D.C.
20.	Janoff, Michael S.	Franklin Institute Research Laboratory Philadelphia, Pennsylvania
21.	Johnson, P.J.	New York, New York
22.	Kellem, Carl	National Crime Prevention Institute University of Louisville Louisville, Kentucky

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23.	Kilduff, Thomas	Bureau of Electricity Department of Streets & Sanitation Chicago, Illinois
24.	Lam, William M.C.	William M.C. Lam Associates Cambridge, Massachusetts
25.	Malt, Harold Lewis	H.L. Malt Associates Washington, D.C.
26.	McGowan, Terry K.	Engineering Applications Division General Electric Company Nela Park Cleveland, Ohio
27.	Powell, John	William M.C. Lam Associates Cambridge, Massachusetts
28.	Rau, Richard	National Institute of Law Enforcement and Criminal Justice Law Enforcement Assistance Administration Washington, D.C.
29.	Rayl, Officer Dennis	Research and Development Division Chicago Police Department Chicago, Illinois
30.	Richardson, James	Office of Justice Programs City of Portland Portland, Oregon
31.	Ryan, Thomas	National Electrical Manufacturers Association Washington, D.C.
32.	Schwab, Richard N.	Federal Highway Administration U.S. Department of Transportation Washington, D.C.
33.	Stein, Harry	Department of Intergovernmental Fiscal Liason City of Milwaukee Milwaukee, Wisconsin
34.	Smith, Marilyn	General Electric Lighting Business Department Hendersonville, North Carolina

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35.	Trueworthy, Jan J.	Project Monitor Office of Research Programs Law Enforcement Assistance Administration U.S. Department of Justice Washington, D.C.
36.	Turrek, Robert	Managing Director Chicago Electric Lighting Institute Chicago, Illinois
37.	Waldner, Dudley	Edison Electric Institute New York, New York
38.	Wright, Roger	Department of Business Administration University of Michigan Ann Arbor, Michigan
39.	Yonemura, Dr.	National Bureau of Standards Gaithersburg, Maryland

APPENDIX B

LIGHT MEASURES

This appendix contains a somewhat technical but essential discussion of the parameters most widely used to specify and measure the light output of a street lighting system.

The most general and complete definition of light in physical terms is that light is an electromagnetic field whose wavelength distribution includes the visible range from 380 to 760 nanometers.* By "field" is meant a quantity whose magnitude is defined or specified for each point in space. The quantity in this case is a combination of electric and magnetic fields whose variation in time and space is governed by a particular set of physical laws known as Maxwell's equations. Given (i) a specification of all light sources in a system; (ii) a specification of the light transmitting and reflecting properties of the media through which the light is propagating (e.g., air, lenses, mirror, etc.); and (iii) a specification of the boundaries of a system (e.g., street, building and sidewalk surfaces, etc.), one can in principle, but rarely, if ever, in practice, compute the electromagnetic field at any point and at any time.

In fact, an electromagnetic field contains essentially an infinite amount of information, although only a small portion of this information is used while viewing a visible object. Some of the measurable concepts

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* A nanometer is 10^{-9}, or one-billionth of a meter.

corresponding to the parameters of light which are relevant for the establishment of visibility are illustrated in Exhibit B.1. The total light output from a system is given by the measure of luminous flux. Some of this light travels in directions relevant to the object to be viewed, while the rest goes elsewhere. Of the light travelling in directions relevant to the object, some parameters are not important. For instance, in everyday situations, the amount of ultraviolet light is immaterial to the visibility of an object (unless it happens to have fluorescent properties).

Angular distribution is one relevant parameter dealing with quantity of light, and is measured for any direction by the luminous intensity. Light travelling in these various directions arrives at surfaces and illuminates them. When this light passes through or reflects from these surfaces, they acquire brightness, or luminance.

Further refinement of these quantitative measures is provided by the qualitative notions of uniformity, glare and color. Discussion of the qualitative measures leads to the idea that the visibility of an object is a function of the lighting quantity and quality, as well as of other factors in the environment.

LIGHT QUANTITY

The quantitative measures of light are summarized in Exhibit B.2. The total amount of radiant energy leaving a source in all directions per unit time is known as luminous flux, and is measured in units of lumens. A standard candle source emits a total luminous flux of 4π (i.e., 12.57) lumens.

EXHIBIT B.1

Selection of Light Parameters
Relevant to Visibility of an Object

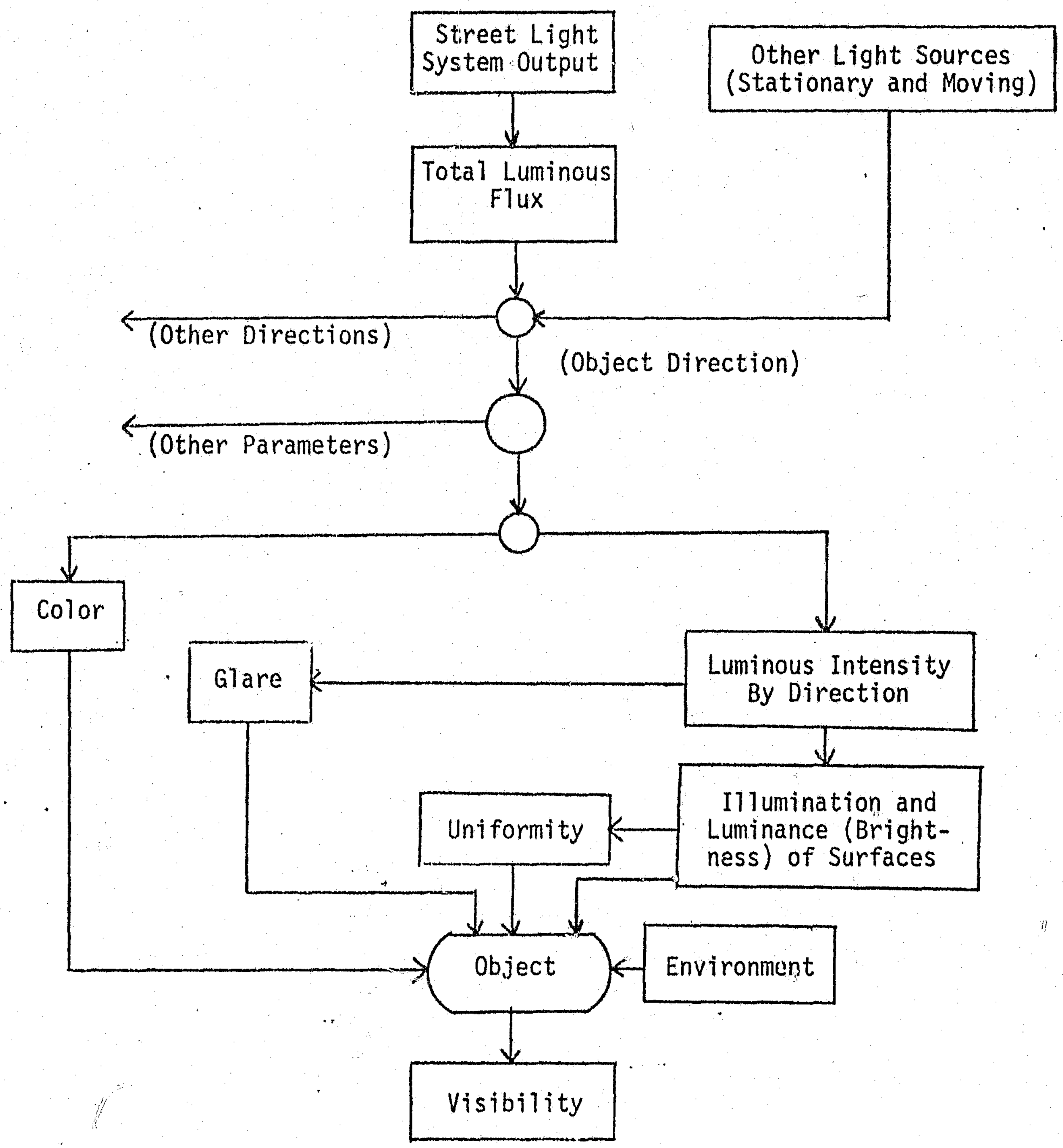


EXHIBIT B.2

Common Measures of Light Quantity

Measure	Definition	Common Unit	Unit Definition
Luminous Flux	Radiant energy per unit time	Lumen	Luminous flux of standard candle source ÷ 4π
Luminous Intensity	Luminous flux emitted per unit solid angle by a source	Candela	Luminous intensity of a spherically symmetric standard candle source
Illumination	Luminous flux incident per unit area on a given surface	Foot candle	One lumen per square foot
Brightness (Luminance)	Luminous flux emitted, transmitted or reflected per unit area by a source or surface	Foot lambert (or candela/in^2)	One lumen per square foot (or 452 foot lamberts)

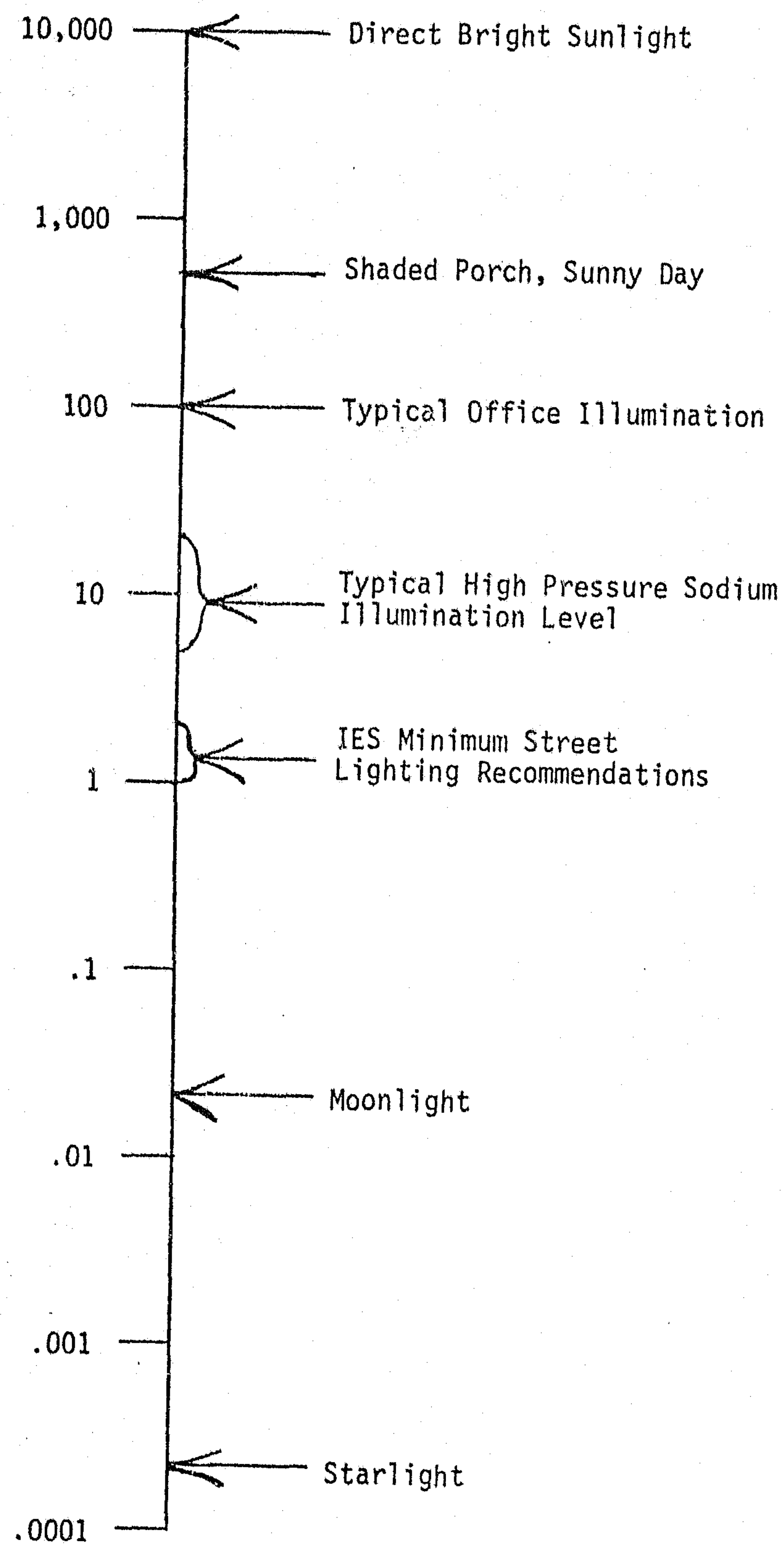
The luminous flux emitted by a source in a given direction is called luminous intensity, and is measured in units of candelas. A standard candle source emitting 4π lumens over a spherical region has an average luminous intensity in any given direction of one candela.

The effect of light arriving at a given surface is called illumination. Illumination measures the density of luminous flux arriving per unit area, and is measured in footcandles. An illumination of one footcandle is produced by an incident flux density of one lumen per square foot. Illumination is one of the most frequently used measures of street lighting: illumination of the horizontal roadway plane is the quantity specified in the minimum standards of the American National Standard Practice for Roadway Lighting [A.2-59]. Some common illumination levels are given in Exhibit B.3. It should be noted that the range of illumination levels varies by a factor of 10^8, and that night street lighting illumination levels occupy a relatively small portion of this range, from one to ten footcandles. By its definition, illumination varies from point to point on any given plane. It is therefore common practice to define average values of illumination on a horizontal or vertical plane [A.2-24, A.2-59, A.2-60]. Roughly speaking, illumination in the horizontal plane lights the road and sidewalk surfaces, while vertical illumination increases the visibility of people and objects.

The eye, however, does not directly perceive illumination in any plane except that of its own iris. What one sees is the light emitted, transmitted or reflected by the surfaces in the field of vision toward the eye. For surfaces which are not sources (i.e., for reflecting

EXHIBIT B.3

Typical Illumination Levels



or transmitting surfaces) the combination of illumination and the surface's properties together result in the brightness of that surface. Brightness is defined as the luminous flux emitted, reflected or transmitted per unit area of a surface, and is measured in footlamberts (or candelas per square inch). A surface has a brightness of one footlambert when it emits one lumen per square foot. One candela per square inch equals 452 footlamberts. The term luminance is also used for brightness. Pavement brightness is of concern in street lighting systems, and in fact is used in the specification of minimum standards used by the International Commission on Illumination (CIE)*.

LIGHT QUALITY

The qualitative measures of light are summarized in Exhibit B.4. The first set of qualitative measures is due to the fact that a street lighting system does not produce a uniform pattern of illumination or brightness, thus creating a need for measures of uniformity of varying detail. These measures include isocandela and isolux diagrams, uniformity ratios, gradient and glare. Other qualitative measures include color and visibility.

The distribution of luminous intensity or illumination can be plotted on appropriate coordinate systems to produce contour maps showing the directions in space of equal luminous intensity or the loci of equal

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* International Commission on Illumination, "Recommendations for the Lighting of Roads for Motorized Traffic," DRAFT for approval by National Committees, December, 1975 publication CIE No. 12/2 (TC-4.6), 1975.

EXHIBIT B.4

Common Measures of Light Quality

Measure	Definition
Isocandela Diagram	Curves traced on an imaginary sphere with the source at the center and joining all points corresponding to those directions in which the luminous intensity is the same.
Isolux Diagram	The locus of all points on the road surface where the illumination has the same value.
Uniformity Ratios	
- Luminance Uniformity	
• Overall Luminance Uniformity	Ratio of average to minimum road surface luminance.
• Longitudinal Luminance Uniformity	Ratio of maximum to minimum local luminance along center line of lane, as seen from an observation point on the same line.
- Illumination Uniformity	Ratio of average to minimum illumination on a given surface.
Gradient	Maximum luminance difference between two specified points, expressed as a percentage of the average luminance.
Glare	
- Disability Glare	Impairment of the ability to see due to harsh contrast between a luminaire and its background.

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Measure	Definition
- Disability Glare (continued)	
• Disability Veiling Brightness (DVB)	A function of illumination in the vertical plane at the eye, and of the angle between the line of sight and the glare source.
• Equivalent Veiling Luminance	A function similar to that used to calculate DVB.
- Discomfort Glare	Discomfort due to harsh contrast between a luminaire and its background.
• Glare Control Mark	A function predicting a nine-point subjective discomfort index from lighting system characteristics.
Color	
- Spectral Energy Distribution	The relative energy emitted by a source as a function of wave-length
- Color Temperature	The temperature at which an ideal black body spectrum most closely approximates a given source's spectrum.
- Correlated Color Temperature	The temperature at which the chromaticity of an ideal black body most nearly resembles that of a given source.
- Color Rendering Index	An index describing how well the colors of standard objects are rendered, relative to the performance of an ideal black body lamp of identical correlated color temperature.
Visibility	
- Visibility Distance	The distance at which an object can just be perceived by the eye.

illumination on the horizontal roadway surface. Although an understanding of these detailed engineering tools, called isocandela and isolux diagrams, respectively, is not necessary for the present discussion, some simpler expressions of the distribution of light can be helpful. With regard to roadway illumination and luminance, uniformity ratio is used to express the ratio of the average level to the minimum level, and both the IES and the CIE express limits on allowable uniformity ratios in their recommendations. According to the IES recommendations, illumination uniformity ratio should not exceed a ratio of 3 to 1, except for local residential streets, which should not have a ratio exceeding 6 to 1. The CIE recommendations apply to overall luminance uniformity and to longitudinal luminance uniformity. The latter is defined as the ratio of the maximum to the minimum local luminance along the center line of the lane, as seen from an observation point on the same line.* Overall luminance uniformity should not exceed a ratio of 2.5 to 1, while acceptable longitudinal luminance uniformity is limited to a range of 1.4 or 2 to 1.

Gradient is an expression of the rate of change of a quantity in space, and roadway luminance gradient is defined as the maximum luminance difference between two specified locations, expressed as a percentage of the average luminance. No standards for gradient have been expressed by the illuminating engineering societies, but the measure has been held to be significant for clear perception and ease of recognition [A.2-102].

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* Op. Cit., International Commission on Illuminating. For convenience, the international definitions of uniformity, which are the reciprocal of the American indices, have been inverted to make comparison of the standards easier.

Glare refers to a condition of excessive brightness contrast, such as between a luminaire and its background. Two types of glare, disability and discomfort glare, have been discussed in the literature. Disability, blinding or veiling glare refers to a condition in which the ability to see is impaired by the harsh contrast between a luminaire and its background. The effect of disability glare has been quantified by developing formulas which require measurement of (i) the illumination at the eye in the vertical plane (or in the plane perpendicular to the line of sight), and (ii) the angle between the line of sight and the glare source. The resulting quantities are called "disability veiling brightness" and "equivalent veiling luminance." Their precise formulation is not required here, but the fact that they allow disability glare to be quantified should be noted. Exhibit B.5 illustrates the relationships of the quantities involved in measuring disability veiling brightness.

Discomfort glare is inherently subjective, and as such its measure requires an attitude survey which can, however, be correlated with the photometric and geometric characteristics of a lighting system. These correlations have been made experimentally, and one such index is the glare control mark. It has been found that a sensation of glare (i.e., glare control mark) on a 9-point scale from "unbearable" (with a score of 1) to "unnoticeable" (with a score of 9) can be predicted from a knowledge of certain system characteristics.* CIE recommendations require that the glare control mark be in the range of 4 to 6, depending on road

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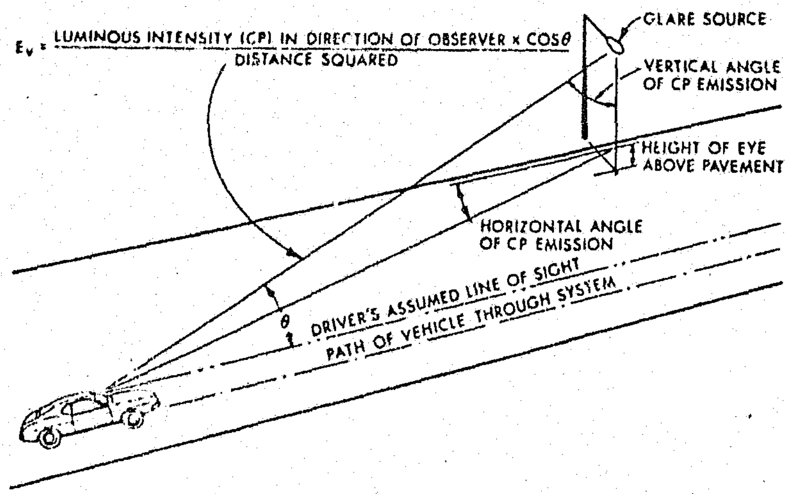
* Op. cit., International Commission on Illumination.

EXHIBIT B.5

Measurement of Disability Veiling Brightness (DVB)



(a) Angular relationships for calculating DVB from one source and for one observer position.

(b) $DVB = \frac{10\pi E_V}{\theta^2}$

Source: American National Standard Practice for Roadway Lighting (A.2-59, p. 30).

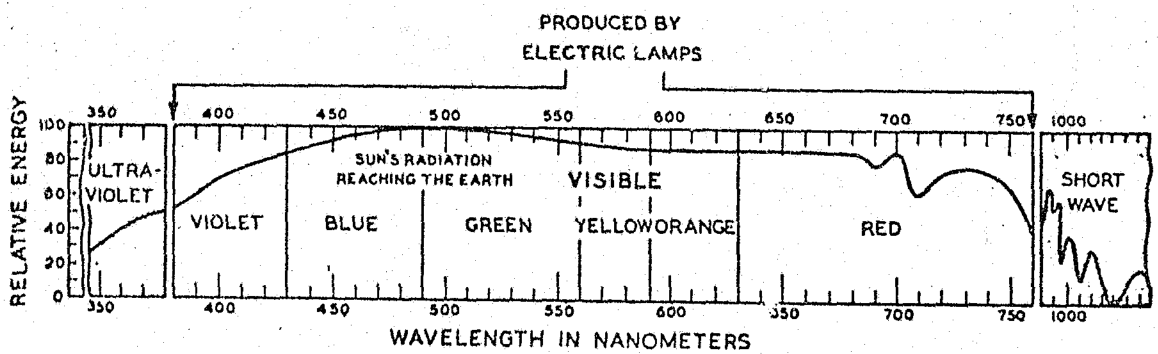
type and brightness of the surrounding area.

Color rendering properties are important for several reasons, including recognition of faces and identification of clothing color. The subjective sensation of color can be correlated with the objective wavelength distribution, or spectral characteristic, of the light source. When the spectral energy distribution (or spectrum) of a light source is measured, a graph results, showing energy as a function of wavelength. Exhibit B.6 shows the sun's spectrum, which contains all visible wavelengths in approximately equal proportions--thus causing sunlight to appear as white, or colorless. The fact that light is the same entity as radio waves, ultraviolet waves, and other forms of electromagnetic radiation is illustrated by Exhibit B.6, which shows the visible spectrum in relation to phenomena associated with other wavelengths. Exhibit B.7 shows that the spectral distribution from an incandescent lamp is likewise continuous, and has the visible portion of its energy peak at the longer visible wavelengths, corresponding to red. In fact, extension of the graph in Exhibit B.7 to longer, invisible wavelengths would show that most of the energy of an incandescent bulb is radiated outside the visible range. This energy ultimately gets dissipated as heat. As the temperature of an incandescent bulb's filament increases, the spectrum changes shape to include relatively more energy in the shorter wavelengths (i.e., towards blue and green).

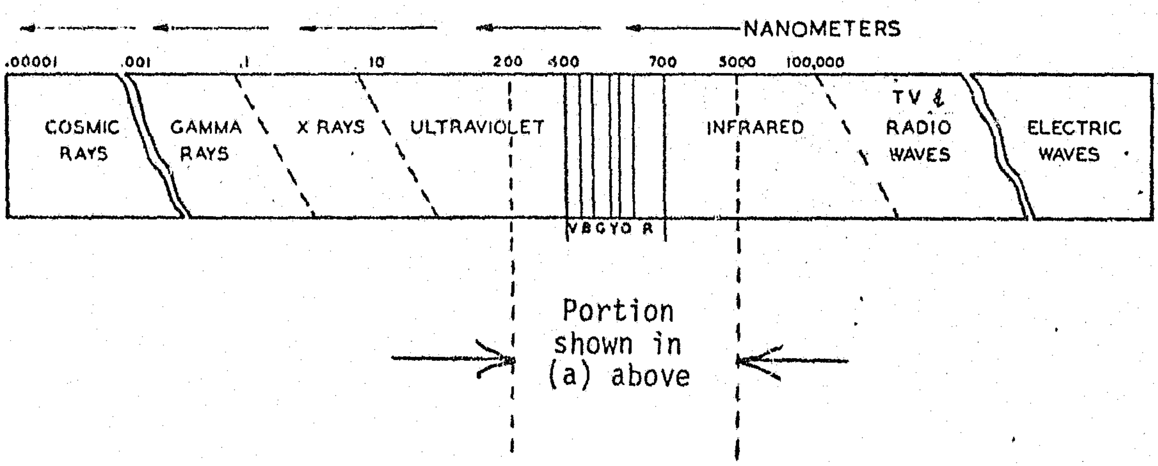
It is possible to approximate the spectrum of an incandescent bulb by an idealized spectrum known as a black body emission spectrum. This idealized spectrum is completely defined by one parameter: the hypothetical

EXHIBIT B.6

The Electromagnetic Spectrum



(a) Visible Wavelengths

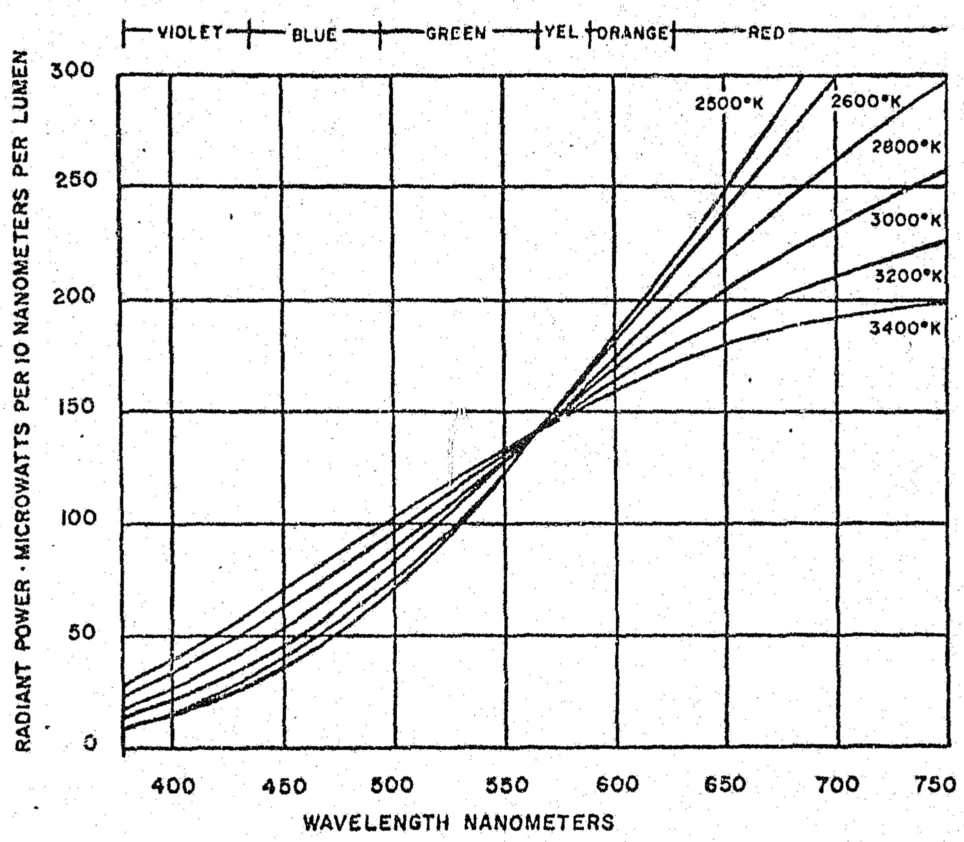


(b) Full Spectrum, Including Visible Portion

Source: Edison Electric Institute, Street Lighting Manual (A.2-24, p. 15).

EXHIBIT B.7

Spectral Energy Distribution of an Incandescent Lamp at Various Filament Temperatures



Source: Edison Electric Institute, Street Lighting Manual (A.2-24, p. 113).

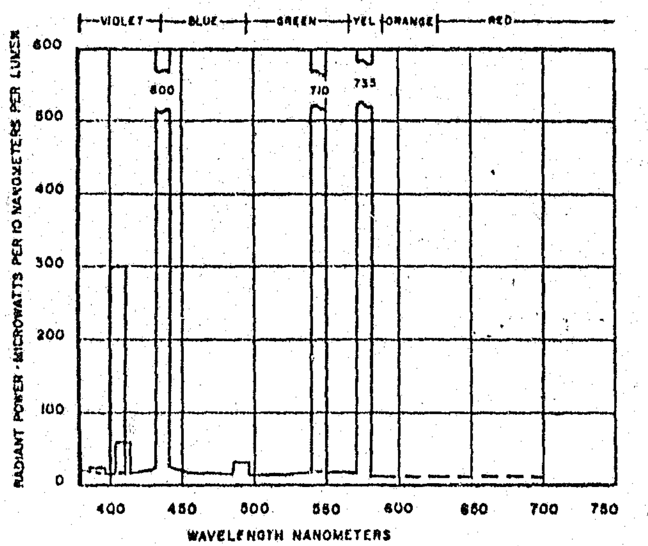
temperature of the ideal black body.* Thus, the best fit of an incandescent spectrum to the black-body curve results in the measurement of color temperature, the temperature at which an ideal black body would most closely approximate the spectrum of the given light source. Note that a bulb's color temperature does not equal its filament temperature, since the bulb is not a true black body.

High-intensity discharge lamps such as mercury vapor, metal-halide and high-pressure sodium do not have a continuous spectrum. Their energy, as can be seen in Exhibit B.8, is concentrated in narrow ranges, or lines, and the distribution cannot be modelled by the black body curve. Hence, the use of color temperature as a measure of such a "line spectrum" is unwarranted. Nevertheless, there are still subjective responses to the spectra of gaseous discharge lamps for which some measure less cumbersome than an entire spectral distribution is required. One such measure, which is based on the spectrum itself, is correlated color temperature, which is the absolute temperature of that black body whose chromaticity most nearly resembles that of the light source [A.2-71]. However, sources with different line spectra and different color rendering properties can have the same correlated color temperature and for this reason the color rendering index is used. The index reflects how well the colors of standardized illuminated objects

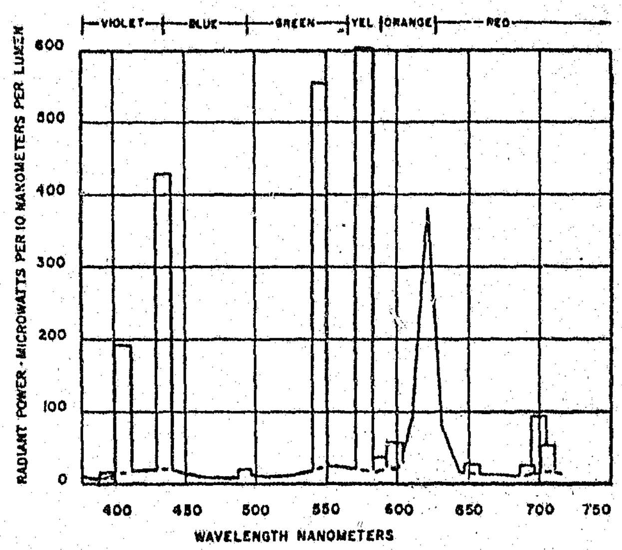
* An ideal black body is an object which absorbs all energy falling on its surface. Its characteristic black body emission spectrum, which is a function of temperature, is often used as a standard for comparison.

EXHIBIT B.8

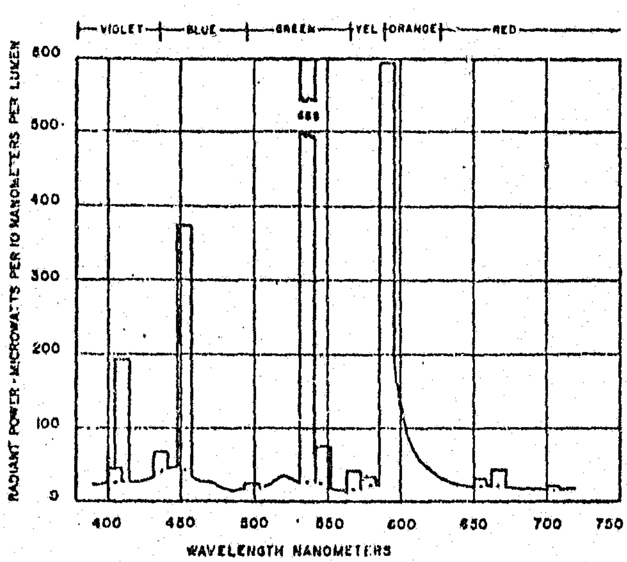
Spectral Energy Distributions of Principal Gaseous Discharge Lamps



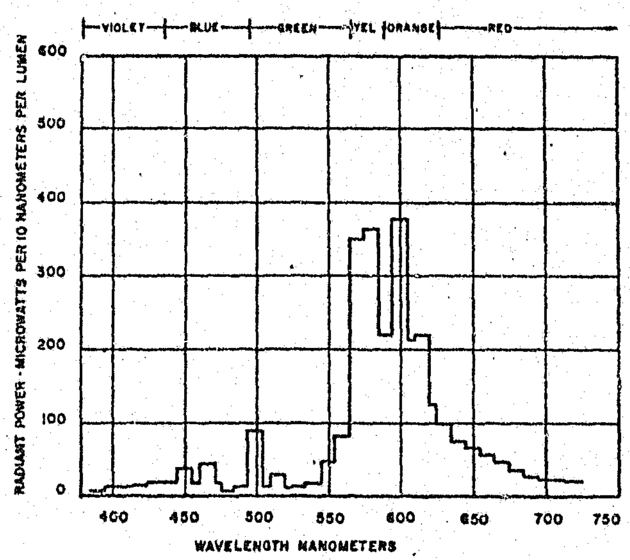
(a) Clear Mercury



(b) Deluxe White Mercury



(c) Metal Halide



(d) High-Pressure Sodium

Source: Edison Electric Institute, Street Lighting Manual (A.2-24, pp. 117-119).

are rendered, relative to the performance of an ideal black body lamp of the same correlated color temperature [A.2-71].

Visibility is a concept which depends on a number of environmental factors, one of which is clearly the performance of the street lighting system. Visibility is also a function of the particular object being viewed. The critical factors entering into the determination of visibility have been summarized as [A.2-24]:

1. *Size* of the object or its critical detail.
2. *Contrast* of the object and its background or in its complement parts.
3. *Brightness* of the object.
4. *Time* available for seeing or speed of vision.

Much of the research into the concept of visibility has taken a two-step approach: first it is to determine with experimental subjects the visibility of specified objects under various lighting conditions, and then it is to find some physical measure that can predict visibility*. The objects which have been used in such tests range from mannequins and vehicles to discs, rings and cubes. Visibility distance, the simplest measure of visibility, is the distance at which the object can just be perceived. The photometric measures which have been used as

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* See, for example:

Gallagher, V, Koth, B. and Freedman, M., "The Specification of Street Lighting Needs," Report No. FHWA-RD-76-17, The Franklin Institute Research Laboratories, prepared for the Federal Highway Administration, Offices of Research and Development, Washington, D.C., November, 1975, and

Blackwell, O. Mortenson and Blackwell, H. Richard, "Technical Progress Summary: Simulation Studies of Visibility and Highway Lighting," Interim Report EES-263, Engineering Experiment Station, Ohio State University, Columbus, Ohio, March 31, 1967.

predictors of visibility include average, maximum and minimum object luminance, horizontal pavement illumination and pavement luminance.

Finally, it should be noted that the qualitative measures of light are highly interrelated. The American National Standard Practice for Roadway Lighting [A.2-59, p. 14] states:

> It should be recognized that in many instances changes intended to optimize one factor relating to quality will adversely affect another and the resultant total quality of the installation may be degraded.

The problem of the illuminating engineer is to achieve a compromise among all relevant quality factors, based on the needs of the particular street lighting application.