RURAL AT-GRADE INTERSECTION ILLUMINATION

Metz Reference Room
Civil Engineering Department
3106 C. E. Building
University of Illinois
Urbana, Illinois 61801

by

R. H. WORTMAN and M. E. LIPINSKI

A Report of the Rural Intersection Illumination Criteria
Project IHR-001
Illinois Cooperative Highway Research Program

Conducted by

DEPARTMENT OF CIVIL ENGINEERING
AND HIGHWAY TRAFFIC SAFETY CENTER
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

in cooperation with

ILLINOIS DEPARTMENT OF TRANSPORTATION

and

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
URBANA, ILLINOIS

MAY 1974
## RURAL AT-GRADE INTERSECTION ILLUMINATION

### Abstract

This document is the final report of the Rural At-Grade Intersection Illumination Project which had as objectives the development of warrants for fixed roadway illumination and the determination of recommended levels for lighting design. The project examined existing rural intersections in Illinois as the basis for determining the effectiveness of fixed roadway illumination. In the case of rural intersections, safety was the primary design concern; therefore accident reduction was utilized as the criterion for the evaluation of effectiveness. Accidents at the existing intersections were evaluated, and a predictor of accident reductions due to illumination was determined.

Warrants for rural intersection illumination were developed which are based on the ratio of night accidents to total accidents. The ratio serves to indicate the intersections at which accidents can be associated with the need for fixed illumination. For a comprehensive intersection lighting program, priorities for lighting may be established by ranking the intersections based on the greatest probable or overall accident reduction.

Due to limitations in the data base, it was not possible to define an evaluation between lighting design and accident experience. The researchers used a review of literature and current research to make recommendations on lighting levels.
ACKNOWLEDGMENTS

This final report on the at-grade intersection illumination criteria was prepared as part of the Illinois Cooperative Highway Research Program Project IHR-001, "Rural Intersection Illumination Criteria." The research was conducted by the Department of Civil Engineering, University of Illinois at Urbana-Champaign in conjunction with the State of Illinois and the U. S. Department of Transportation, Federal Highway Administration.

The assistance of the Bureaus of Design, Planning, and Traffic Illinois Department of Transportation, in the data collection phase of this work is acknowledged.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Illinois or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.
EXECUTIVE SUMMARY

FINAL REPORT

RURAL AT-GRADE INTERSECTION ILLUMINATION

by

R. H. WORTMAN AND M. E. LIPINSKI

A Report of the Rural Intersection Illumination Criteria
Project THR-001
Illinois Cooperative Highway Research Program

Conducted by

Department of Civil Engineering
and Highway Traffic Safety Center
University of Illinois at Urbana-Champaign

in cooperation with

Illinois Department of Transportation

and

U. S. Department of Transportation
Federal Highway Administration

University of Illinois at Urbana-Champaign
Urbana, Illinois

May 1974
ACKNOWLEDGEMENTS

This report was prepared as part of the Illinois Cooperative Highway Research Program Project IHR-001, "Rural Intersection Illumination Criteria." The research was conducted by the Department of Civil Engineering, University of Illinois at Urbana-Champaign in conjunction with the State of Illinois and the U. S. Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Illinois or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.
INTRODUCTION

One element of the highway system that has been shown to be particularly hazardous for the driver is the rural at-grade intersection. Accident rates at intersections are generally higher than elsewhere on the roadway because of the increased opportunity of conflict between the motor vehicles and the increase in driver decisions and complexity of the driving task. Several studies have been conducted which have shown the night accident rate to exceed the day accident rate and the fatality rate at night to be two to three times that of the daytime rate.

While a number of factors, including the differences between the day and night driving populations in relation to age, sex, amount of fatigue and percentage of drinking drivers, may contribute to the higher nighttime accident rate, it is generally concluded that the absence of good seeing conditions at night is the primary reason for the highway system's failure to operate at the same level during both day and nighttime periods.

Increased nighttime visibility can be achieved by providing increased roadway illumination, by increasing the efficiency of the illumination systems of the individual vehicles, or a combination of the above.

Realizing the seriousness of this problem, the Illinois Department of Transportation responded by initiating a research project on Rural Intersection Illumination Criteria. This project was begun in July 1967 with the following objective:

The general objective of this study is to develop techniques and procedures for the selection of rural at-grade intersections to be illuminated, and subsequently, the level and types of illumination to be used. Specific objectives are as follows:
a. A study of the practices employed in selected states to determine the basic reasons for illumination and the methods presently being employed for rural at-grade intersections, and an evaluation of this information to be used to guide the collection of data and subsequent procedures for the research project.

b. Development of quantitative and qualitative criteria for use in determining which rural at-grade intersections merit illumination.

c. A determination of the types and levels of illumination required at those rural at-grade intersections which warrant illumination according to the criteria developed.

CONCLUSIONS AND RECOMMENDATIONS

It is believed that the efforts which resulted from the research represents an advancement with respect to the state of knowledge concerning rural intersection illumination because a rational basis is provided for establishing illumination programs and needs.

Based on the research which was conducted, the following specific conclusions can be drawn concerning intersection illumination:

1. While the rural intersection presents a relatively hazardous highway location, very little emphasis has been placed on the utilization of illumination as a means of improving highway operations.

2. Accident reduction was found to be the most feasible criteria
for evaluating the benefits of illumination as satisfactory measures of driver comfort are not available at the present time.

3. From the analysis of examples of Illinois' rural intersections, containing 445 intersection data years, it was found that illumination does have a significant and beneficial effect on night accidents. The average reduction in night accidents was deduced to be 30 percent.

4. An estimate of the average number of accidents saved per year, by installing lighting at previously unlit intersections, can be obtained by subtracting one-third of the average number of day accidents per year from the average number of night accidents per year which occurred prior to the installation of illumination.

5. The illumination program should be based on a priority list ranked in order by means of the benefit/cost ratio; expressed as estimated accident reduction per year divided by the annual cost of each installation in dollars.

6. The recommendations for illumination levels as indicated in the American Standard Practice are reasonable for rural intersection application. Lighting levels at rural intersections should be maintained at low intensities. At low intensities, there is little evidence that changes in lighting levels are significant or critical.

While this project seemed to make significant advancements with
respect to rural intersection illumination, there are a number of areas which merit and require future investigation. Basically, the additional study is associated with:

1. Expanding the scope of the warrants to include a more comprehensive design base which would consider geometric features and traffic control devices;
2. The refinement of accident predictors; and
3. The understanding of driver behavior and information needs as they relate to intersection design and illumination.

SUMMARY OF WORK

Basically, the project was divided into three specific work tasks. The first was the development of the current status of knowledge which was pertinent to rural intersection illumination. This was accomplished by a review of literature and a survey of current practices of state and other governmental agencies. This information was presented in an interim project report entitled, "Summary of Current Status of Knowledge on Rural Intersection Illumination." This report was subsequently published by the Highway Research Board in Highway Research Record 336.

The second phase of the project dealt with the development of warrants for intersection illumination. Safety was judged to be the most appropriate goal to be achieved; thus, the research utilized a study of accidents as a basis for developing lighting warrants. A review of previous studies revealed considerable variation in the effectiveness of roadway illumination in reducing night accidents; therefore, the project undertook a study of rural intersections
in the State of Illinois to determine a valid data base for predicting effectiveness.

Rural intersections throughout the State were selected and illumination, intersection geometries, traffic characteristics, and accident data were collected for each. This information was analyzed by selecting a random sample and utilizing an analysis of variance methods. The final sample contained 445 intersection data years with 263 lighted data years and 182 unlighted data years. An interim project report entitled, "Development of Warrants for Rural At-Grade Intersection Illumination" was prepared by the staff.

The third and final phase of the project focused on the determination of lighting levels. An analysis of data from intersections in Illinois was insufficient to reveal any relation between lighting intensities and accident experience. The project staff utilized an extensive review of the state of knowledge to make recommendations concerning lighting levels.

IMPLEMENTATION

It is proposed that the following be utilized as the recommended warrant for rural at-grade intersection illumination:

"Rural intersections should be considered for lighting if the average number of nighttime accidents (N) per year exceeds the average number of day accidents (D) per year divided by three. All the accident data available since the data of the last modification to the intersection should be used when calculating these averages. If N is greater than D/3 the likely average benefit should be taken as N - D/3 accidents/year.

The likely benefits of lighting new or modified intersections should be estimated from previous experience. It is recommended that illumination should be provided whenever an intersection is channelized."
The estimated cost of lighting the intersections, which show a benefit using the above criteria, should be computed. The lighting program should then be based on the resulting list of intersections ranked in priority order by means of the benefit/cost ratio (expressed as annual reduction in accidents/annual cost).

This lighting program should be reviewed at intervals as additional accident data becomes available."

Application of Warrant

The recommended warrant has been designed to give the decision makers the most information possible based on current knowledge. It has been implicitly assumed that the highway improvement budget will be limited and thus interest will be focused on maximizing the benefits of a limited budget. For this reason, reductions in number of accidents rather than accident rates have been used. One important implication of this approach is that the distribution of funds for lighting improvement will tend to be directed into the areas of high traffic volumes. Thus, if intersections are ranked on a statewide listing, the distribution of the budget will not be the same as one distributed by listing intersections on a district basis. The latter would spread improvements more uniformly throughout the state, but at a lower overall benefit/cost ratio.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Statement of Problem</td>
<td>1</td>
</tr>
<tr>
<td>Purpose</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>WARRANT DEVELOPMENT CONCEPTS</td>
<td>7</td>
</tr>
<tr>
<td>Roadway Lighting as a Systems Problem</td>
<td>7</td>
</tr>
<tr>
<td>The Driver-Vehicle-Roadway Relationships</td>
<td>11</td>
</tr>
<tr>
<td>Intersection Illumination Warrants</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>WARRANT DEVELOPMENT</td>
<td>17</td>
</tr>
<tr>
<td>Methodology</td>
<td>18</td>
</tr>
<tr>
<td>Data Collection</td>
<td>20</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>24</td>
</tr>
<tr>
<td>Correlation with Other Studies</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>ILLUMINATION LEVELS</td>
<td>37</td>
</tr>
<tr>
<td>Research Approach</td>
<td>37</td>
</tr>
<tr>
<td>The Lighting Design Problem</td>
<td>38</td>
</tr>
<tr>
<td>Influence of Illumination Levels</td>
<td>51</td>
</tr>
<tr>
<td>Current Recommended Practice</td>
<td>52</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>RESULTS</td>
<td>56</td>
</tr>
<tr>
<td>Summary of Findings</td>
<td>56</td>
</tr>
<tr>
<td>New or Modified Intersections</td>
<td>56</td>
</tr>
<tr>
<td>Priorities Based on Benefits and Costs</td>
<td>59</td>
</tr>
<tr>
<td>Illumination Levels</td>
<td>61</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>63</td>
</tr>
<tr>
<td>Recommended Warrant for Implementation</td>
<td>64</td>
</tr>
<tr>
<td>Application of Warrant</td>
<td>65</td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>RECOMMENDATIONS FOR FURTHER STUDY</td>
<td>67</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>70</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Significance of Relationships Between Lighting and Accident Measurement Variables</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Mean Night Accident to Total Accident Ratios</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Confidence Intervals for Difference of Proportions</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>Actual and Predicted Accidents per Year</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>Recommendations for Average Horizontal Footcandles</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>Highway Lighting Engineering Recommended Illumination Levels of Luminance Values for Rural Continuously Lighted Roadways</td>
<td>54</td>
</tr>
<tr>
<td>7</td>
<td>Summary of Uniformity Recommendations for Rural Roads</td>
<td>55</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HIERARCHY OF DESIGN SYSTEMS</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>THE DRIVER-VEHICLE-ROADWAY SYSTEM</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>FUNCTION OF ROADWAY LIGHTING.</td>
<td>14</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

Statement of Problem

In order for the transportation system to fulfill its goal of providing for "... the safe, comfortable, and convenient movement of persons and goods" it must furnish the user with an acceptable level of service over a wide range of environmental conditions.

An analysis of highway accident statistics reveals the failure of the highway component of the system to satisfy this level of service under nighttime conditions. Several studies have been conducted which showed the night accident rate to exceed the day accident rate and the fatality rate at night to be two to three times that of the daytime rate.4,26

While a number of factors, including the differences between the day and night driving populations in relation to age, sex, amount of fatigue and percentage of drinking drivers, may contribute to the higher nighttime accident rate, it is generally concluded that the absence of good seeing conditions at night is the primary reason for the highway system's failure to operate at the same level during both day and nighttime periods.

Increased nighttime visibility can be achieved by providing increased roadway illumination, by increasing the efficiency of the illumination systems of the individual vehicles, or a combination of the above.

Under present technological and economic conditions, roadway illumination offers the most comprehensive means of correcting situations of inadequate visibility. Proper use of roadway lighting can provide quick, accurate, and comfortable seeing conditions for the night driver and can result in an overall improvement in night driving performance.
One element of the highway system that has been shown to be particularly hazardous for the driver is the rural at-grade intersection. Accident rates at intersections are generally higher than elsewhere on the roadway because of the increased opportunity of conflict between the motor vehicles and the increase in driver decisions and complexity of the driving task. It is reported that about 15 percent of the fatal rural accidents and 25 percent of all rural motor vehicle accidents occur at intersections.\(^1\) The intersections, however, account for a very small portion of the total rural highway mileage.

Realizing the seriousness of this problem, the Illinois Department of Transportation responded by initiating a research project on Rural Intersection Illumination Criteria. This project was begun in July 1967 with the following objective:

The general objective of this study is to develop techniques and procedures for the selection of rural at-grade intersections to be illuminated, and subsequently, the level and types of illumination to be used. Specific objectives are as follows:

\(a\). A study of the practices employed in selected states to determine the basic reasons for illumination and the methods presently being employed for rural at-grade intersections, and an evaluation of this information to be used to guide the collection of data and subsequent procedures for the research project.

\(b\). Development of quantitative and qualitative criteria for use in determining which rural at-grade intersections merit illumination.
c. A determination of the types and levels of illumination required at those rural at-grade intersections which warrant illumination according to the criteria developed.

The initial efforts of the project were directed toward the development of a report summarizing current rural intersection illumination practices, including a comprehensive review of literature relating to the rural lighting problem. The findings of this review indicated that very few research studies have been conducted pertaining to illumination problems at rural intersections.

The report also included the results of a survey conducted to determine the extent of established illumination programs for rural at-grade intersections which disclosed the existence of such programs to be minimal. This survey indicated that out of 49 highway agencies returning a mail questionnaire, only 29 states and one Canadian province had a program of installing illumination at rural locations. Even more surprising, of these 30 highway departments reporting, less than 10 had a formally defined procedure listing the criteria that must be met to install illumination.

Most states described their procedures in very general terms such as "where there is a high percentage of night accidents" or "at very important rural intersections with raised channelization." Some states indicated that they follow the American Standards Association's "Warrants," which are not truly warrants, but recommended illumination intensities once a location has been judged to merit lighting. Of the specific methods used by these states and provinces reporting formalized warrant procedures, no two were identical. However, in each approach, one or more of the following variables was considered in the formulation: total number of accidents/year, accident
rate, day/night accident ratio, intersection geometry or type of control, or night accident rate.

The procedure used in Illinois for unsignalized intersections considers total number of accidents/year and accident rate. For signalized intersections the day/night ratio is also examined.

The extreme variation among the techniques currently employed to determine which rural at-grade intersections merit illumination indicates the problems that exist in developing rural intersection lighting programs and evaluating the beneficial effects of illumination at these locations.

The major benefit derived from this investigation is the development of an empirical basis for the installation of illumination at rural intersections. Such installations when warranted, will represent an efficient allocation of resources to the problem of accident reduction and will result in improved capacity and flow at the rural at-grade intersection. If these results are accepted and applied on a national basis, there will be an additional benefit of uniformity of application. This would prove to be especially valuable in communicating information to people who are driving in unfamiliar surroundings. The development of warrants for rural intersection illumination should also encourage the more efficient use of limited highway funds.

**Purpose**

The purpose of this research was three-fold; to evaluate the beneficial effects of illumination at rural at-grade intersections, to develop quantitative and qualitative criteria for use in determining which at-grade intersections merit illumination, and determine recommended levels of illumination.
Fixed roadway lighting has been effectively utilized for a number of years in urban areas where illumination has generally reduced accident rates, improved traffic flow, and improved overall operating efficiency of the roadway. The use of street lighting or fixed roadway illumination in rural areas, however, has been limited.

This study was thus a response to the need to determine more precisely the effect illumination of rural intersections has on nighttime accident rates, capacity and flow improvement, and the cost effectiveness of fixed lighting at these locations.

The results of the previously mentioned survey of current rural at-grade intersection illumination practices reveals the lack of uniform procedures and techniques employed in choosing locations for fixed roadway lighting. Additional research was needed to determine the locations where illumination would provide the greatest benefits in order to establish a set of criteria to be used in formulating warrants for illumination. Furthermore, current standards for fixed roadway illumination have not directly dealt with the rural intersection design question. There was a need to investigate the design of rural intersections illumination with a focus on the determination of recommended lighting levels.

This document represents the final report of the project and is the last of three reports that were prepared as part of the project effort. The two previous reports were:

"Development of Warrants for Rural At-Grade Intersection Illumination" by R. H. Wortman, M. E. Lipinski, L. B. Friche, W. P. Grimwade, and A. F. Kyle.

The first report was subsequently published by the Highway Research Board in *Highway Research Record 336* and represented a synthesis of information pertaining to rural intersection illumination. The second of the two reports was a documentation of the research work which determined the effects of illumination at rural at-grade intersections and formulated the recommended warrants for rural intersection illumination. That report was published as an interim report of the project in November, 1972 and is available through the National Technical Information Service as Report Number PB 218 057.

The purpose of this report is to present a documentation of the project work, conclusions, and recommendations. It was not the intent to duplicate all of the material that appeared in the earlier project reports in this document. This report does present in the sections that follow, a discussion of the warrant concepts that were utilized, a summary of the warrant development research, a discussion of the illumination levels investigation, the conclusions of the project staff, and the recommendations for further research in the area of rural at-grade intersection illumination.
2. WARRANT DEVELOPMENT CONCEPTS

Roadway lighting is only one of the elements or components that are involved in the design of a highway facility, and concerning roadway lighting must recognize this situation. The viewpoint that is taken by the designer or administrator is critical when considering roadway lighting because of the potential impact on the solutions which result and on the design warrants which are applicable. The variation in viewpoint may be associated with the scope of consideration and the number of components or variables which are included. Because of the influence on lighting warrants, it is deemed necessary to establish the concepts on which warrants are based. The purpose of this section, therefore, is to set forth the concepts which served to guide the investigation and the development of the resulting warrants.

Roadway Lighting as a Systems Problem

While roadway lighting has traditionally been treated in a somewhat isolated context, it must be recognized that it is a component of a highly interactive system in which the change of one component has particular impacts on other parts of the system. In developing warrants or dealing with a design problem, this system must be first defined and understood if a rational view of the problem is to be achieved. In view of this situation, it becomes relevant to review the position or place of lighting with respect to the transportation system. A comprehension of the overall nature of the problem and the interactions of the factors or elements in the problem leads to a better understanding of the problem which is faced. Thus, questions related to
illumination must be viewed in the larger context if they are to be rationally addressed.

The transportation system provides for the movement of persons and goods in response to a need which is generated by society. This need is associated with some society goal or objective which requires movement in order to be fulfilled. Thus, ultimately a question concerning illumination could be traced to the impact on the total transportation system or even on society in general.

Contained within the transportation system are several smaller systems of movement which are modal oriented. In this case, this smaller system of movement is the highway system. The highway system can be further subdivided into smaller units, the roadway, the vehicle, and the terminal. The discussion of the highway system in terms of an operating system has been an accepted practice among traffic engineers. While highway engineers focus primarily on the roadway component, it must be recognized that the resolution of highway system problems should consider all of the system components and the alternate solutions that they present. Certainly, it is not possible for the highway engineer to exercise control over the design of the vehicle or the licensing of the driver which operates the vehicle; however his view of a highway design problem should include an understanding of these aspects. The broader understanding gives the engineer greater insight to the alternatives and their feasibility.

Fixed roadway lighting is a component of the roadway system. Other elements in this particular system would include geometric design features, roadway support, and traffic controls. In essence, the roadway system would include all of the physical features associated with the roadway.
Figure 1 depicts this hierarchy of systems in which fixed roadway lighting exists. This hierarchy can be further expanded at both the higher and lower levels. For example, the transport system is a component of an overall society system; and roadway lighting can be divided into design components such as layout luminaire type, etc.

The recognition of the hierarchy is particularly important to design and the development of design warrants because the issues or questions which are involved will vary with changes in hierarchy levels. If the engineer is dealing specifically with the roadway lighting component, the design questions focus entirely on designing the most efficient lighting system from an illumination viewpoint. At the roadway system level, however, the engineer considers lighting as one of the design components and strives to achieve the best overall roadway design that is possible. Furthermore, the design goal at the highway system level is to provide a safe, economic, and convenient highway mode of transportation. In each case, the design goal changes because of the scope, nature and purpose of the physical or organizational system that is involved; and the basis for judging effectiveness of design alternatives should reflect the design goals. In determining design warrants, therefore, it is imperative that the basis for the warrants is clearly defined in terms of the systems context so that the designer understands their meaning and limitations.

In the case of this research, the project was limited to examining the need for roadway lighting per se. The project, therefore, was limited in that trade-offs between other components in the design of intersections were not considered. For example, delineation systems represent a possible
FIGURE 1
HIERARCHY OF DESIGN SYSTEMS
design attainment to roadway lighting. The fact that this limited viewpoint was taken is pertinent to the warrants which resulted.

The Driver-Vehicle-Roadway Relationship

In addition to hierarchy of systems which has been indicated, there is also a need for an understanding of the specific components which are directly related to the general highway design problem because of the nature of the operating interaction. For roadway illumination problems, the engineer is interested in the relation and interactions of the roadway, the vehicle and the driver. The roadway and the vehicle are components of the highway system. The driver in addition to being a user of the highway is also a component of the vehicle in that he provides the necessary operational control. Thus, a specific design system emerges as is shown in Figure 2 and serves to indicate the relationships between the three components and the operating environment which is pertinent to intersection illumination. The connecting links between the components depict the basic interactions or flows of information and activity. For example, the driver receives information from the roadway. This could be transmitted in a variety of ways but most often is in the form of visual stimuli. He then processes this information and uses it for the decision making which results in the guidance and control outputs necessary for satisfactory operation of the vehicle.

Fixed roadway lighting is a part of the roadway system and is a function of the needs of the driver with respect to visual conditions. Certainly, it must be recognized that vehicle lighting provides an alternate means of providing the necessary driver environment. In both cases, the need for lighting is brought about by the inadequacies of the driver's night
FIGURE 2

THE DRIVER-VEHICLE-ROADWAY SYSTEM
vision for vehicle operation; however, this project is focused exclusively on the need for fixed roadway lighting and does not attempt to develop a trade off between fixed and vehicle lighting.

The measure of effectiveness of roadway illumination, therefore, is the degree that the driver's needs for visual information are satisfied. Ultimately, this can be translated into the level of service that is given to the highway user. Figure 3 graphically depicts this role of lighting in terms of the pertinent components of the highway system.

Intersection Illumination Warrants

The measure of the effectiveness of roadway illumination, or any other improvement to the highway system, is the degree to which it assists the motor vehicle operator in the performance of the driving task. The beneficial effects of illumination in providing improved sight conditions as compiled by previous studies has prompted many researchers to advocate that continuous lighting be installed on all major highways and at all intersections. As convincing as this evidence may be, financial resources for illumination programs are limited. Therefore, the major problem faced in developing warrants is balancing the effectiveness of illumination in improving driving conditions against the costs of illumination.

Decision-makers at the higher echelons of the roadway system are confronted with the problem of allocating resources to achieve the "best" highway system. This best system is defined by the objectives set forth for the overall highway program. The manner in which decisions are made with respect to project funding becomes pertinent to warrants which apply. Thus, the
budgeting of roadway system improvements is a key factor, and it reflects the scope and nature of design decisions that may be considered.

In considering warrants, there are two basic questions which must be addressed. The first pertains to the feasibility of fixed illumination as a solution to rural intersection problems; and the second is related to the feasibility of fixed illumination as a solution as compared to other design alternatives. These two questions reflect quite diverse views on design and decision-making. In the first case, roadway lighting decisions are made on the merits of lighting alone and lighting programs are somewhat independent of other design improvements at intersections.

The latter question requires the designer to deal with the broader problem in which illumination is one of the design elements which may be considered. Because it is possible that one or more of the design elements can satisfy the same objective, an analysis of the trade-offs between the components is necessary to achieve a final design solution.

These two questions are clearly related to budgeting decisions. The first reflects the fact that lighting projects are funded on their own merits and funds are available specifically for that purpose. The second indicates that a general allocation is made for roadway improvements, and the designer will attempt to best achieve the objective with the available resources.

For the purpose of this project, the development of warrants was based on the first question or approach to the problem. Basically, rural intersection illumination projects are decided on the basis of the need for lighting. Furthermore, the scope of the project did not permit an analysis of the trade-offs with other design components which would be necessary
to address the broader design issue or question. Thus, the basic concept which was pursued in the conduct of this research was to identify intersections and intersection conditions where the application of fixed roadway illumination would result in operational benefits. In a situation where many intersections were to be considered, the intent of the warrants would be to identify the intersections which yield the greatest benefits for the available resources. This would result in a priority rating system for lighting improvements.
3. WARRANT DEVELOPMENT

The primary consideration in the development of an approach to warrant determination was to formulate a methodology that would identify and measure the effects of illumination in quantifiable terms.

Three criteria, or measures of effectiveness, were examined for their use in this analysis: improvements in capacity, decreases in driver tension, and accident reduction. As traffic volumes are relatively low in rural areas, capacity constraint is not considered to be a problem at the types of locations under investigation. Also, because of the impracticability of driver tension tests, the only major criteria that remains for evaluating lighting effectiveness is accident reduction. As previous research has indicated that this is the major benefit of illumination at rural locations, the use of this criteria appears to be valid.

To establish the beneficial effects of highway lighting at rural intersections it was decided to utilize data collected at rural intersections throughout the State of Illinois. An alternative method of study involving the construction of several test sites was considered but later rejected because of the anticipated difficulties in collecting information that would reflect the wide variability in physical features and traffic conditions among rural intersections in Illinois.

The use of data collected at numerous intersections in Illinois permitted the evaluation of illumination under a wide range of physical and environmental conditions. By relating these variations to the accident rates at rural intersections, it was felt that intersections may be selected for lighting, not only where several nighttime accidents have already occurred,
but also where there is a probability of accidents due to a combination of certain characteristics.

This analysis will result in the development of a method that can be used to rank the intersections which show the greatest potential for accident reduction when illumination is installed.

**Methodology**

It can be seen from the previous discussion that the missing link in the chain of warrant development is the relationship between illumination and accidents. Thus, the research problem was one of isolating the effect of illumination from the effects of the many other variables likely to influence accidents. A review of previous studies indicated that, in addition to illumination, variables such as traffic volumes, intersection geometry, traffic control devices, and channelization all have a significant effect on accidents. Thus, any research method directed towards isolating the relationship between illumination and accidents has to be designed to control for the effects of the many important variables other than illumination.

Three methods were considered and the data collection evolved accordingly. The first method of control considered was to compare data collected for a given intersection before and after illumination had been installed. This method rests on the assumption that no other important variables change during the entire study period. This approach proved to be unworkable as there were not sufficient before and after data available to make valid statistical comparisons. One reason for this insufficiency of data was that information from many illuminated intersections could not be used because other
improvements were made at the time lighting was installed. Thus, it wasn't possible to isolate the effects of illumination alone.

The second method considered was to match pairs of intersections so that they are essentially similar in all respects except that one has illumination and the other is unlit. As discussed in the next section this proved to be an impossible task.

The third method was control by randomization and involves taking a random sample of intersections and carrying out an analysis of variance. The underlying theoretical problem with this method is that the decision of which intersection to illuminate is not randomized. In fact it is presumably the opposite: a systematic decision based on intelligent analysis of the situation. An example will serve to illustrate the practical implications of this. Suppose that the analysis showed that less accidents occurred at illuminated intersections. It could be misleading to infer that illumination caused a reduction in accidents because it might well be that lighting was systematically installed at intersections with good geometrics and that this was the reason for the reduction in accidents.

A refinement of the third method, and the one finally used for warrant development, was to compare only the night to total accident ratio. This greatly reduces the possibility of errors occurring because the decision to install lighting was not randomized. The reasoning is easier to follow in terms of the night to day accident ratio (N/D). The variable N/D can be assumed to be far less sensitive to the variables (such as good geometrics) which might be systematically related to illumination, than to illumination per se. This is because the major difference between night and day conditions
is the change in visibility. Although not removing the problem of nonrandomization of the decision to light, this approach does greatly reduce the problem by decreasing the sensitivity of the accident criteria to variables other than illumination. In other words the experimental results will not be greatly influenced by causes other than illumination. (The criteria actually used for analysis was night accident to total accident ratio to which a similar argument applies.)

Data Collection

Categories of Data Collected

The data base used to measure the relationship between illumination and accident experience consisted of data collected at rural at-grade intersections in Illinois. The intersections to be included in the sample were selected from a list of rural U.S. and State highway intersections in Illinois furnished by the Bureau of Traffic, Illinois Department of Transportation. All illuminated rural intersections were included in this sample as well as a representative number of unlighted intersections. For each location the following categories of information were collected:

1. Illumination conditions,
2. Physical characteristics,
3. Traffic volume data, and
4. Accident data.

The data on the illumination conditions and physical characteristics were obtained from a number of sources. First was the list mentioned above supplied by the Bureau of Traffic. It contained most of the necessary information for all locations. However, as several intersections on the list had
incomplete or missing data, personnel in the Bureau of Design and the various
district offices were contacted to supply additional information. Secondly,
the Bureau of Design provided plans of all intersections in the study sample.
And thirdly, the project staff visited each intersection to verify the physi-
cal and environmental characteristics of the location and to photograph each
approach leg.

The following information was then recorded for each intersection:
1. Illumination conditions (number of luminaires if lighted),
2. Number of approach legs,
3. Number and width of lanes on each approach,
4. Type of pavement on each approach,
5. Speed limits on each approach,
6. Type of channelization on each approach,
7. Type of traffic control on each approach,
8. Degree of development on abuting land, and
9. Dates for illumination, traffic control, or geometric design
changes.

Traffic volume information was obtained from the Traffic Studies
Section, Bureau of Planning, Illinois Department of Transportation. The
first thought of the project staff was to obtain hourly traffic volumes for
all locations in order to estimate the traffic volume at the time of each
accident. However as this information was not available at all study loca-
tions, average daily traffic volumes (ADT's) were estimated for all inter-
sections. These were obtained from the annual state wide traffic volume maps
and the numerous county traffic volume maps. In many cases the traffic volume
for a particular location in a given year was not available. This necessitated
the application of correction factors developed by the research staff based
on the change in traffic volumes at locations where complete information was
available and that were judged to experience similar volume variations as the
intersection under study.

Therefore at each location in the study, an estimate of the traffic
volume was obtained for each approach of every intersection of the study.
The ADT (traffic through the intersection) was then computed by summing the
approach lane volumes. A separate series of volume estimates were made for
each year of the study.

Accident data for all locations were collected by the Accident
Studies Section, Bureau of Traffic, Illinois Department of Transportation.
They supplied collision diagrams for all locations for the year 1965 thru
1969. At the time the data collection was initiated (1970) only five years
of past accident records were stored. Thus, this limitation set the first
year of the analysis at 1965.

For each accident the following information was tabulated:
1. Time, day, month, and year of occurrence;
2. Weather conditions;
3. Severity (property damage, personal injury, fatality); and
4. Type of collision (right-angle, head-on, side-swipe, vehicle-
   pedestrian, single car, or rear-end).

In addition to the data collected from the State of Illinois for
use in this study, data were furnished by the State of Iowa. This additional
data contained accident figures collected before and after the installation
of rural intersection lighting and was used to test the adequacy of the accident predictor obtained from the Illinois data. The use of the data and the development of the predictor is discussed in later sections of this report.

Computer Program to Summarize Data

A computer program was developed to summarize the data and to calculate accident rates. A very brief discussion of this program follows; however full details of the program are presented in the interim project report on warrant development. The program identified the accident experience for each year of the study and the second table summarized the accident experience for the combinations of illumination and channelization listed below.

1. Unilluminated, and channelized,
2. Illuminated, and unchannelized,
3. Unilluminated and channelized, and
4. Illuminated and channelized.

Several locations underwent lighting or channelization improvements during the study period. In these cases the year of the improvement was excluded from analysis to avoid any possible bias due to the transition that would occur in the driving habits of the road user.

Tables of sunrise and sunset data were utilized to determine if an accident occurred in the day or night. It was assumed that an accident occurring before sunrise or after sunset on a given day was a night accident, except in times of inclement weather. On those days that the accident report form has listed as "rainy" or "snowing" the boundaries between nighttime
and daytime conditions were taken as sunrise plus one-half hour and sunset minus one-half hour.

Data Analysis

Determination of Sample Intersections for Analysis

It was first believed that the effects of illumination could possibly be determined by performing a statistical analysis on the before and after lighting accident experience at those locations in the study where data were available for the periods before and after the installation of illumination. However, with only five years of accident data available at each intersection, it was soon apparent that this type of analysis was not feasible. When the sample was examined it was found that many intersections were lighted in the early 1960's or earlier. Thus, collecting accident data for the period "before illumination" at the locations under study was impossible.

The approach utilizing the process of matching intersections that did not have lighting to those intersections that did have lighting was then initiated. The entire population of unlighted intersections in the State of Illinois was searched to find an "identical twin" of each lighted intersection. The major parameters that were considered in the matching process were:

1. Intersection ADT,
2. Intersection geometrics,
3. Type of traffic control, and
4. Vertical and horizontal alignment.

However, exact matching proved to be impossible, as no two intersections were identical in all respects.
The sample of intersections that was used in the third and final analysis procedure, analysis of variance, contained the total population of rural lighted intersections for the State of Illinois and a sample of unlighted intersections. Guidelines were developed in order to decide which of the many rural intersections in the State should qualify as "unilluminated intersections" for the purpose of the study. An initial screening prior to sampling was essential. For example, the inclusion of a rural intersection of a minor township road with a State highway would obviously be irrational. It was thus decided to only sample from the major unilluminated intersections in order to make the study meaningful. These were identified by referring to intersection ADT, intersection geometrics, type of traffic control and vertical and horizontal alignment. The basic reference for evaluating these parameters were the corresponding parameters in the illuminated intersection population. The unilluminated sample was then drawn from this restricted class of rural intersections. For the analysis of variance, each intersection year was used as the basic element for analysis. The final sample contained 445 intersection data years with 263 lighted intersection data years and 182 unlighted intersection data years.

Analysis Procedures

Prior to commencing the third analyses procedure, the intersections in the sample were categorized by the computer program according to the following parameters:

1. Presence or absence of illumination,
2. Presence or absence of channelization, and
3. Number of approach legs at the intersection (tee or cross).
Each intersection was then placed in one of eight groups, depending on how its characterization matched with the three dichotomous factors mentioned above. More parameters could have been included. However, the inclusion of additional parameters would have the tendency to make the problem more complex and possibly unsolvable due to the increased sophistication. For this reason only these three categories were utilized.

Seven measurements of accident experience were calculated for all the intersections in the sample. These were:

1. Night accidents per year,
2. Day accidents per year,
3. Total accidents per year,
4. Ratio of night accidents to total accidents per year,
5. Night accident rate,*
6. Day accident rate,*
7. Total accident rate.*

These seven accident measures were utilized because these were considered to be the conventional accident measurements and thus readily available, and because they should yield meaningful values to facilitate judgement of the effectiveness of rural intersection lighting.

In the initial stages of the study, it was assumed that accident severity at rural intersections would be one of the criteria that would be utilized in the determination of warrants for intersection illumination. No significant relationship between accident severity and illumination could

* The accident rates were calculated on the basis of the number of accidents per million vehicles thru the intersection. As night traffic volume information was unavailable for all locations, the assumption was made that the night traffic volume was 1/3 or the 24 hour traffic volume. Further discussion of this assumption is presented later in this chapter.
be inferred from the data. This criterion based on severity was not considered further.

The third method of analysis involved the use of analysis of variance. Analysis of variance is a useful tool to evaluate the statistical significance of relationships between variables. It is not the intent of this study to discuss the actual mechanics involved in the analysis of variance. Several references are available which give an adequate discussion of this statistical technique.\textsuperscript{5,8} Due to the size of the sample and the considerable number of calculations that are required for the analysis of variance, the analysis of variance program of the University of Illinois' SOUPAC programming package was utilized to calculate the results of this statistical test.\textsuperscript{32} This technique examined the relationships between each of the three independent variables--lighting, channelization and number of approach legs--and the seven dependent accident measures listed earlier. It also measured the effects of the interactions between the independent variables. A print out was generated by SOUPAC which contained computed means and levels of significance and thus revealed all the significant relationships between each of the seven dependent variables (accident measures) and the following combinations of independent variables:

1. The effects of lighting versus no lighting,
2. The effects of channelization versus no channelization,
3. The effects of varying the number of approach legs,
4. The interaction between the effects of lighting and channelization,
5. The interaction between the effects of lighting and a number of approach legs,
6. The interaction between the effects of channelization and the number of approach legs,

7. The interactions between the effects of lighting, channelization, and number of approach legs.

The 0.1 or 10 percent level was used as the criterion to determine if any of the relationships were statistically significant. Several of the relationships proved to be significant at this level. There was a significant difference in accident experience between lighted and unlighted intersections for several dependent variables. Table 1 lists the seven dependent variables and their corresponding levels of significance.

<table>
<thead>
<tr>
<th>Dependent Measurement Variable</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night/Total Accident Ratio</td>
<td>.082</td>
</tr>
<tr>
<td>Night Accident Rate</td>
<td>.003</td>
</tr>
<tr>
<td>Day Accident Rate</td>
<td>.068</td>
</tr>
<tr>
<td>Total Accident Rate</td>
<td>.003</td>
</tr>
<tr>
<td>Night Accidents</td>
<td>.426</td>
</tr>
<tr>
<td>Day Accidents</td>
<td>.746</td>
</tr>
<tr>
<td>Total Accidents</td>
<td>.991</td>
</tr>
</tbody>
</table>

For the first four variables, the effect of the independent variable, lighting, is statistically significant at the 0.1 level for the intersection data years sample with illumination as compared to the intersection data years sample without illumination. Of these four, only the day accident rate gives results
that were not expected; i.e., lighting reduces the day accident rate. An analysis of the data does not reveal an explanation for this result; however, it may be hypothesized that the lighting poles provide daytime delineation of the intersection. The other three variables give the results that lighting reduces the night to total accident ratio, the night accident rate, and the total accident rate. From the results that lighting reduces the day accident rate, a conclusion was made that the problem of systematic distribution of lighting discussed under methodology was important. The measurement variables which do not control for traffic volume, night accidents, day accidents, and total accidents, are insignificant at the 0.1 level.

Development of a Predictor for Warrant Determination

The determination of warrants for rural at-grade intersection lighting priorities for lighting installation are two of the objectives of this study. In order to determine which intersections warrant lighting and priorities for lighting installations, the effect of lighting on accidents should be ascertained. This section will present a refinement of the analysis of variance method used and apply the results to an accident predictor which is a function developed to forecast night accidents at rural at-grade intersections after lighting has been installed.

Under two earlier sections, Methodology and Determination of Sample Intersections for Analysis, a discussion was presented concerning the problems that are present in obtaining random samples for the analysis of variance. The conclusion was that the most reliable accident measurement variable was the night to total accident ratio. In addition to the methodological reason,
this measure has the practical advantage that knowledge of the night traffic volume is not required. An estimate of the night traffic volume is required in order to compute the night accident rate, which is a disadvantage because night traffic volume information is not readily available at many intersections. Based on information obtained from the Illinois Department of Transportation, the night volume for rural locations can be estimated by using 1/3 of the 24 hour volume. This value was used in the development of lighting warrants; however, it must be recognized that some variation in this value may be found at specific locations. For a specific intersection, the utilization of the actual night to total volume relationship would provide more precise results. Because night volume information is frequently not available at many intersections, the development of warrants was based on the estimate of night volume.

Table 2 shows the results for the analysis of variance for the night to total accident ratio.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Mean Night Accident to Total Accident Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illumination</td>
<td>Mean Night Accident</td>
</tr>
<tr>
<td>Yes</td>
<td>.25</td>
</tr>
<tr>
<td>No</td>
<td>.33</td>
</tr>
</tbody>
</table>

Thus, the final predictor involves the use of the night to total
ratio, which shows that illumination reduces night accidents in proportion to total accident. The predictor has been developed from the variables listed and explained below

\[ N_p \quad = \quad \text{present night accidents before lighting} \]
\[ N_f \quad = \quad \text{final night accidents after lighting} \]
\[ (N/T)_{illum} \quad = \quad \text{mean night to total accident ratio (.25) for illuminated rural intersections} \]
\[ D \quad = \quad \text{day accidents (before and after lighting)} \]
\[ T_f \quad = \quad \text{total accidents after lighting} \]

In addition it has been assumed that

\[ N_f = (N/T)_{illum} \cdot T_f \]

and

\[ T_f = D + N_f \]

This second equation assumes that day accidents will not be altered by the installation of lighting. While for reasons already discussed the analysis of the data in this investigation could not be used to support this assumption, it is felt that it is justifiable for use in developing a predictor. Other studies\(^2,_{15}\) where data are available for before and after the installation of lighting at a particular intersection support this assumption.

Substituting:

\[ N_f = (N/T)_{illum} (d + N_f) \]

solving for \( N_f \)
\[ N_f = \frac{(N/T)_{\text{illum}} \cdot D}{1 - (N/T)_{\text{illum}}} \]

Substituting:

\[ (N/T)_{\text{illum}} = .25 \]

which is the mean night to total accident ratio for lighted rural at-grade intersections (see Table 2).

\[ N_f = (.25/3) \cdot D \]

\[ N_f = D/3 \]

Therefore, the accident reduction is given by

\[ \text{Predicted Accident Reduction} = N_p - N_f = N_p - D/3 \]

The use of the reduction in night accidents as the criteria thus yields a predictor by which priority values can be generated for each intersection. The intersections with the highest priorities are those with the highest values of accident reduction.

The following example illustrates the computation of predicted accident reductions and the use of these computations in establishing lighting priorities for two hypothetical intersections. Intersection A currently has 6 day accidents and 5 night accidents per year. For this intersection, the estimated night accidents after lighting would be 6/3 or 2; and the predicted reduction in accidents due to illumination would be 5 - 2 or 3. Assume that Intersection B has 18 day accidents and 8 night accidents prior to lighting.
The estimated night accidents after illumination would be 6, and the predicted reduction in accidents would be 2. Intersection A, therefore, would receive a higher priority for lighting because of the greater reduction in accidents. Other intersections could be ranked in a similar manner.

Considering the equation

\[ N_f = D/3 \]

it can be seen that an intersection would not warrant lighting unless it had at least a value for night accidents equal to 1/3 the day accidents. At first glance, the equation above gives the impression of simplicity. However, looking further at the equation several factors are actually considered, such as the complexity of the intersection, geometrics, type of control and traffic volume, which are taken into account by utilizing the day accident information. Therefore, the above equation indirectly includes all the other important factors that affect both the day and the night accidents.

Correlation with Other Studies

The predictor which has been developed in this project is based on the ratio of night accidents to total accidents after illumination. In an effort to determine how reliable the predictor is, the data used to develop the predictor was compared to data from other studies. If the night accident to total accident ratio for the study data and the ratio obtained from other studies are not statistically different, then the predictor can be used to compute the theoretical number of after illumination night accidents per year for these studies. This can than be compared to the actual number
of night accidents per year. If the predictor is valid it should accurately predict the average number of night accidents per year.

Several studies were available which dealt with rural intersection illumination. The studies which were used in testing the predictor were furnished by the Iowa State Highway Commission\textsuperscript{33} and the Illinois Division of Highways.\textsuperscript{3}

The report prepared by the Iowa State Highway Commission was prepared in 1963. It is composed of a before and after study of 25 rural intersections to determine if illumination of those intersections was effective in reducing night accidents.

The previously conducted Illinois report, "An Evaluation of the Effect of Pavement Lighting on the Accident Pattern at Rural Channelized Intersections," was compiled in 1965. In this earlier study a before and after analysis was made of 26 rural intersections that had been channelized. These intersections are also included in the present project; however, the accident data for the present project is more recent.

In order to determine if there was any statistically significant difference between the study data and the data from these other reports, the confidence interval for a difference of proportions was determined. In such an analysis, samples are taken from two populations which have a characteristic which is to be compared. The proportion of this characteristic in each sample is determined, and from this the confidence interval for the difference between the population proportions is estimated. The proportion that was used in this analysis is the proportional number of total accidents that occur at night. If the 95 percent confidence limits for the difference
between the proportions includes zero, there would be no reason to reject the hypothesis that the samples were drawn from populations with the same proportion of night to total accidents at the 95 percent level of significance.\(^6\) If the hypothesis cannot be rejected, then there is no statistically significant difference between the samples. Thus, it is reasonably certain that the predictor developed in this project should also be able to adequately predict after illumination night accidents in both samples. If it does not adequately predict after night accidents then it is probably a poor predictor.

Using an after illumination night accident to total accident ratio for Illinois of 0.302, which was obtained by dividing the total number of night accidents by the total number of accidents, the confidence interval for a difference of proportions was determined.

**TABLE 3**

Confidence Intervals for Difference of Proportions

<table>
<thead>
<tr>
<th>Study</th>
<th>N/T Ratio</th>
<th>Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois (previous)</td>
<td>0.261</td>
<td>-0.0383 to 0.1200</td>
</tr>
<tr>
<td>Iowa</td>
<td>0.271</td>
<td>-0.0492 to 0.1111</td>
</tr>
</tbody>
</table>

The results (Table 3) show that the hypothesis that the samples were drawn from populations with the same N/T ratio at the 95 percent level
cannot be rejected as both the confidence intervals contains zero. Thus it is reasonable to use these samples to test the reliability of the predictor.

Table 4 shows that the predictor is useful in predicting after night accidents. These data also show there is little change in the number of day accidents after an intersection has been illuminated.

TABLE 4
Actual and Predicted Accidents per Year

<table>
<thead>
<tr>
<th>Study</th>
<th>Day</th>
<th>Night</th>
<th>Predicted Night Accidents = 1/3 D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Previous Illinois study</td>
<td>3.21</td>
<td>3.17</td>
<td>1.59</td>
</tr>
<tr>
<td>Iowa</td>
<td>1.86</td>
<td>1.85</td>
<td>1.54</td>
</tr>
</tbody>
</table>

The predicted number of night accidents for the Illinois study is within 4.5 percent of the actual number of after illumination night accidents and within 10 percent of the actual number of after illumination night accidents for Iowa.

As a result of these comparisons, it has been shown that the predictor is a useful and reliable way of estimating the average number of after night accidents. It should be noted that this is an average predictor and cannot be accurately used to estimate the number of accidents at an intersection during any one year. However, it can be used to predict the average number of night accidents to be expected after illumination.
4. ILLUMINATION LEVELS

The final phase of the project was to investigate the types and levels of illumination that are required at rural at-grade intersections which warrant illumination. This section outlines the work that was undertaken and accomplished in connection with the research efforts to develop recommendations concerning types and levels of illumination to be utilized.

Research Approach

During the course of the project there was a considerable change in thought among the staff concerning the approach and resolution of illumination levels. In the initial proposal for research, it was indicated that test installations would be considered as a means of addressing the warrants as well as the types and levels of illumination questions. It became readily apparent as the work progressed that the test intersection approach was not feasible for this project because of the number of variables that must be considered. As an alternative, the staff then examined intersections which had been lighted throughout the State of Illinois. While these intersections served as the basis for determining the effectiveness of lighting in general, they were also used in an attempt to find a correlation between safety and lighting levels.

It must be recognized that the intersections that were included in the study were somewhat restricted due to the fact that accident records were maintained for only five years. Thus, all of the intersections that were examined had roadway lighting installed in about the same period. For each intersection, the same basic design procedure and standard was utilized; therefore, there was little variation in the lighting levels and types.
Again, it must be emphasized that the staff recognized the broader scope and nature of the illumination level and type questions. It became apparent that such questions could not be realistically made in a fragmented context because of the operating system that is involved.

As discussed in a previous section of this report, intersection illumination is directly related to the roadway environment needs or requirements of the driver. The design of roadway lighting requires the designer to understand these needs and apply lighting design components which best solve the problem. This requires the designer to carefully examine the full scope of the problem in the design process.

There has been considerable work that has been conducted or is underway that address various aspects of lighting design. In view of the efforts that were being made on the part of many researchers, it was believed that a better approach to the question of lighting levels would be to synthesize the existing knowledge in terms of its application to rural intersections. Certainly, this represented a deviation from the originally proposed research approach; however, it represented a realistic approach to the comprehensive design question. Furthermore, the comprehensive approach provided a better basis for giving direction to needed research in areas where knowledge was lacking. Finally, this approach could be utilized and accomplished within the scope and resources of the current project; and the results obtained from this approach would represent a significant contribution in an area which has been relatively unexplored.

The Lighting Design Problem

As has been previously indicated, the purpose of fixed roadway
lighting is a function of the needs of a driver in which the lighting pro-
vides the motorist with the necessary environment for performing the driving
task. The lighting design must address the environmental needs of the driver
for obtaining information on which to base vehicle operating decisions.

Basically, the designer must accept the driver as an independent
design variable which has fixed attributes. In essence, the designer does
not have the freedom to vary the characteristics of the driver; and he must
accept the driver as an inflexible design input.

There is an extensive body of literature that relates to lighting
and seeing. Much is now known about the eye, the relationship between lighting
and the ability to see, and the relationship between seeing and the ability
to carry out visual tasks. What follows is a review of current knowledge as
it applies to the specific problem of rural intersection illumination. The
eye, the lighting system and the visual task form a complex interrelated sys-
tem of seeing. Understanding this system is the key to rational lighting
design.

Human Vision and the Eye

The logical starting point for any discussion of lighting is the
eye. An intelligent lighting design must be based on an understanding of
what the eye can and cannot do.

The following summary is intended to be a brief overview of the
functional aspects of the eye.

A. Central Vision

With the eye in a fixed position the area of most acute vision
is subtended by a cone whose angle is 3°. However vision is quite
sensitive within a visual cone of 5° or 6° and is still fairly satisfactory up to a range of 20°.²¹

B. Peripheral Vision

The total angle of peripheral vision usually ranges from 120 to 160° but because of visual concentration the angle of effective peripheral vision shrinks with increased speed. (About 100° at 20 mph and 40° at 60 mph)²¹

C. Eye Movement

Because of the limited field of vision it is necessary for the driver to shift his eyes in order to scan significant areas. The eye does not however move continuously as in order to see an object the eye must fixate. Thus eye movements consist of fixationed phases with jumps between one fixation point and the next. The fixation and jump both require time and thus the amount of visual information the driver can collect in a given time is limited. As vehicle speed and complexity of the driving situation increase, information collection become critical and information for less urgent tasks such as trip planning and direction finding can no longer be collected. There is in other words a hierarchy of tasks when his information processing capacity becomes overloaded.¹⁹

Any unusual movement or brightness in the peripheral field of vision attracts attention and tends to cause the eyes to automatically move in order to bring the object into closer vision. However experienced drivers do not rely on this reflex attraction and tend to systematically scan the field ahead.
The space that is actively scanned by the eyes of the motorist without special effort or movement of the head is referred to as the visual field. This visual field depends on many factors such as driver's experience, speed, lighting conditions and degree of vigilance.

D. Visual Acuity

Acuity, or the capacity of the eye to resolve and discriminate objects, decreases as illumination decreases.

E. Dark Adaptation

This process, which becomes less efficient with age, allows a viewer to take maximum advantage of decreasing amounts of light. It is affected by two types of eye cells, namely, the cones and the rods. Cone cells function best under high levels of illumination whereas rod cells are more efficient under low levels (cone cells are also proficient in color and form perception). If the eye is deprived of light, cone cells adapt to the loss in 5 to 10 minutes after which time the rod cells take over the light sensing function and adapt to low levels of illumination in 30 to 50 minutes.23

Because most persons function at frequently changing levels that exist somewhat between very high and very low illumination, the level of adaptation must also change to accommodate visual efficiency to the changing levels of illumination. At high illumination values a rapid rate of adaptation results from a moderate change in illumination, but when illumination is successively reduced, the rate of change slows down. It can be said, then, that
the most proficient viewer is one who can most efficiently adapt in the shortest possible time.

At night heavy demands are placed on the driver's adaptability to light changes. Going from darkness into light, the eye adapts itself much faster than when going from light into darkness. The temporary loss of vision due to the sudden change in level of luminance is thus more of a problem on the exit side of a rural intersection.

F. Glare

Stray light from opposing headlights and luminaires produces glare which is uncomfortable and reduces the effective visual conditions. This is a very significant factor and one that the designer cannot afford to overlook.

G. Perception of Space

The angular sizes and shapes of perceived details and their relative positions give the road user the ability to judge space. Monitoring the scene over time also allows the driver to judge the velocity of his own car and other moving objects. Space perception becomes much worse at low levels of illumination.

H. Night Vision

As has already been noted, low levels of illumination reduce the performance of the eye in accuracy, speed of adaptation and make it increasingly susceptible to glare. Space perception is also impaired.

The cumulative effect of all these factors is that the nature of seeing becomes significantly different at night as compared with the
day. At night objects are seen as forms which contrast with their background, whereas during the day objects are recognized by surface detail. Thus at night detection of contrast is more critical than visual accuracy.

The relatively small visual field and difficulty in identifying objects also means that at night the driver relies to a large extent on visual and mental memory. This reliance on memory to fill in the gap in the information received works well unless an unexpected situation arises. The amount of visibility required to maintain lateral control of a vehicle and maintain a reasonably constant speed is surprisingly small. One study found that drivers at night with headlights on could maintain speed and position while wearing special glasses that transmitted only 0.5 percent of the light falling on them. 29

This research has shown that for simple guidance tasks without hazards or other vehicles very low levels of illumination are sufficient. What is not yet clear is how much illumination is required for more routine tasks associated with intersections, other vehicles and the multitude of hazards that occur in real life.

Lighting Design Variables

In designing an illumination system there are four basic variables which must be considered. A change in any one of these variables will also produce a change in the quality of illumination. These variables are mounting height, placement of the luminaire—lateral and transverse spacing, type of luminaire and type of lamp.
During recent years mounting heights of luminaires have greatly increased. The basic reason for this increase being the development of more efficient lamps. The importance placed on the aesthetic appearance of the intersection and the removal of obstacles from the roadside has also led to the use of higher mounting heights. Higher mounting heights also decreases the discomfort glare.

The placement of the luminaires is another critical factor in the design of lighting systems. The longitudinal spacing of luminaires is often influenced by the location of utility poles, block lengths and property lines. It is important, however, to maintain the proper mounting height to spacing ratio which is within the range for which the luminaire is designed. In most cases, it is more economical to use larger lamps at reasonable spacings and mounting heights than to use smaller lamps at more frequent spacings and lower mounting heights.

Transverse location of luminaires depends largely on the type of distribution pattern of the luminaire. Optimum location is best determined from the photometric charts which show illumination distribution data. Access to luminaires for servicing, glare aspects, visibility of traffic signs and signals and the probability of vehicle-pole collisions also influences the transverse location of luminaires.

The luminaire consists of internal reflecting surfaces and in most cases enclosing glassware. The basic purpose of the optical assembly of a luminaire is to gather the light radiating from the lamp, direct it downward in the desired manner, and then shape a pattern on the roadway.

Different distribution patterns are needed to conform with the many
different roadway configurations which must be illuminated. Luminaire distribution patterns are grouped into five standard classes and designated Type I through Type V. These patterns are classified with respect to vertical light distribution, lateral light distribution, and control of light distribution above maximum candlepower.

Proper light distribution is essential to achieve the best and most economic design. The light should be directed downward so as to illuminate the pavement and adjacent area. The distribution should be one that would provide a maximum uniformity and pavement brightness with a given mounting height and spacing. It should also produce a minimum amount of glare.

The light should illuminate the pavement from curb to curb as well as extending 10 to 15 feet beyond the curbs. This is necessary to properly illuminate traffic signs, parked cars and pedestrians.

The choice of lamp size, type, and color is effected by luminaire distribution, as well as by degree of light controlled and glare. Increasing or decreasing the lamp size will also increase or decrease candlepower, illumination, and pavement and obstacle brightness. In most cases it is more economical to use the largest lamp size at maximum spacing which will provide an acceptable uniformity and pavement brightness.

Lamps are available in two general types: (a) filament and (b) gas discharge. Most lamps in use today are of the gas discharge type with most of them being mercury vapor. However, some research has indicated that the high intensity radium lamp is the best investment now.²⁰

These four basic variables must be considered together in the design of an illumination system. For instance, the use of a certain type of illumination
will influence the mounting height, position of luminaire and type of lamp to be used.

These variables should be designed to meet certain criteria. They should be coordinated so as to provide for a uniform pattern of illumination which will provide adequate pavement brightness and yet produce a minimum of disability and discomfort glare. For a successful design, the designer must apply these variables or design components so as to provide the necessary visual environment for the driver. These thoughts are substantiated by the work that has been accomplished by other researchers.

An article in the July, 1961, Traffic Quarterly entitled "Intersections at Night," written as the results of a study at the Texas Transportation Institute, indicated that intersection illumination, signing and design must be closely coordinated at the planning stage. The authors, D. E. Cleveland and C. J. Keese, concluded that no standard illumination design is adequate for the variety of geometric and environmental conditions encountered at all of the intersections.²

The Ontario Department of Highways "Interim Report on Highway Lighting" May 12, 1960, acknowledged the problems of developing a universal set of warrants by giving their interpretations of the many complex variables that should be considered. These variables were listed as: roadway geometry, traffic volume, turning movements, weather conditions, roadway surface materials and conditions, vehicle speed, headway, and driver psychology. It was suggested that these parameters be thoroughly investigated and coordinated for each intersection layout.³

Ketvirtis⁴ has possibly presented the most comprehensive discussion
of the intersection lighting to date. His intention was to establish a uniform description of minimum conditions under which lighting should be provided. The Conditions are systematically classified as follows:

Intersections at-grade

- Intersections of two illuminated roads
  - Class III
- Intersections with high accident rate
  - Class II or I (3 per year of more)
- Signalized intersections
  - Class II or I
- Channelized intersections
  - Class II or I
- Intersections adjacent to areas of high level illumination
  - Class II or I

Classification descriptions

Class I - Partial
Partial illumination is a limited lighting system consisting of luminaires at key positions only. The key positions are related to such geometrical features as the beginning of accelerating and decelerating lanes, left turns, bullnoses and other important road design features which require the motorist's special attention.

Class II - Intermediate
Intermediate illumination is a limited lighting system consisting of luminaires in key positions, plus additional lighting units required for ramps connecting to illuminated highways, or at grade intersections with illuminated highways.
Class III - Full

Full illumination is a complete road or interchange lighting system consisting of luminaires at key positions, and all additional lighting units required to provide the specified level of illumination and pavement uniformity.

This further serves to emphasize that the designer must examine each intersection individually to a certain extent. This examination must include the determination of the unique character of the particular lighting problem and the need for lighting at that intersection.

The increased emphasis on improving visibility and providing visual comfort for the driver has resulted in many improvements in lighting system design. One of the most significant of these advances is the introduction of higher luminaire mounting heights, which improve the field of vision, reduce glare and increase uniformity, instead of just increasing the illumination level.

A number of sources have cited the following benefits for higher mounting heights:

1. Increasing safety, because the wider transverse spacing and longer longitudinal spacing means a reduction in the number of poles in the immediate vicinity of the roadway;
2. Better uniformity of illumination due to an increased area of the bright spot under the luminaire and a wider distribution of light than is possible with low mountings;
3. A reduction in glare because the light source is located at a greater height above the driver's line of vision;
4. An increase in the driver's visual field which, by permitting him to drive under more comfortable conditions, could increase roadway capacity;

5. Decreased maintenance due to a reduction in the amount of dirt accumulating on the luminaires; and

6. A reduction in system costs through the elimination of a number of poles and luminaires. Also, because of the improved uniformity and lower glare, lower illumination levels are necessary to provide adequate seeing conditions. A detailed economic study by R. E. Faucett demonstrated that a system with higher mounting heights is more economical and has improved uniformity with regard to a conventional arrangement, if a reduction in level of illumination can be accepted.10,14,17,30,31

In spite of the benefits mentioned above, there are many reasons why higher luminaire mounting heights should not be used arbitrarily. Lindsay and Clark caution that changes in atmospheric conditions, such as fog, snow, and rain, cause attenuation of light flux which greatly reduces the illumination level and adversely affects illumination uniformity.20 At higher mounting heights these reductions are magnified and poor system performance results. Ketvirtis mentions that on narrow roads higher mountings may be wasteful because too large a percentage of the light falls on the surrounding area.17 Maintenance could also be a problem with higher mounting heights, unless trucks with sufficient reach to service the luminaires are available.

Another recent innovation in lighting practice is the use of floodlights mounted at 100 to 200 ft to illuminate intersections and interchanges.
This technique, first tried experimentally in Europe, has some definite advantages over conventional lighting system. First of all, such floodlights illuminate the entire area of the intersection, a benefit especially important at complex interchanges where drivers need a view of the entire area to plan maneuvers and to execute them in a systematic and safe manner. Secondly, fewer poles are required, so that no "forest of poles" detracts from appearance and visibility. Thirdly, with fewer light sources and higher mounting heights, glare is reduced.

Economic comparisons between floodlighting and conventional lighting systems are difficult to obtain. With a conventional system the goal is to provide a specified horizontal footcandle level on the roadway without regard to the illumination level on the surrounding area. However, floodlighting is intended to illuminate the entire area and improve overall visibility. To accomplish this, it must display relief features, as well as the roadway surface; and illumination of these features is measured not in horizontal footcandles, but in verticle footcandles, which enhance the visibility of objects presenting a vertical surface.

In spite of this difficulty in comparison, a study conducted by R. E. Faucett indicated that, for equal average illumination on the roadway, floodlighting cost less than conventional streetlighting. At test installations in both Fort Worth and Huntsville, Texas, professionals rated the high-level system superior to conventional lighting; the rating was a subjective one, based on the system's ability to produce a satisfactory night
driving environment. Other installations are now planned or under construction in Texas, Washington, and South Dakota.\textsuperscript{11,38} The Texas Transportation Institute is conducting further research in an effort to establish performance criteria for interchange area lighting.\textsuperscript{38}

**Influence of Illumination Levels**

Visibility is not necessarily directly dependent on horizontal levels of illumination; it depends, as well, on pavement brightness, relative contrasts between the task and background, uniformity ratio, disability glare, and dimensions of the visual field. However, even under the most favorable conditions, a minimum of light must be provided before the surroundings become visible. In highway lighting applications, the portion of light that effectively contributes to seeing is that part reflected and diffused from the pavement in the direction of the viewer's eye. It is desirable, therefore, to relate levels of illumination to the reflected light or luminous intensity of the pavement. Calculations based on roadway luminance are much more significant than those based on horizontal levels of illumination alone. Because road pavement reflectance can vary between 10 and 25 percent, the results of horizontal footcandle calculations can be in error by over 100 percent in terms of actual effective reflected light.

There are studies which indicate a relation between levels of illumination and accident experience. Turner,\textsuperscript{35} for example, reported that the ratio of night-to-day accidents decreased from approximately 0.8 to 1500 lumens per 100 feet to approximately 0.57 at 12,000 lumens per 100 feet. Other studies indicate that good lighting results in better accident records.
Most of these studies, however, have been associated with continuous lighted segments of roadways, and few if any have actually addressed the rural intersection problem.

Rural intersections present a different type of problem as compared to continuous lighted roadways because of dark adaptation characteristics of the driver. There is a need to keep illumination levels low in order to prevent the driver from having night vision difficulties as he departs the lighted intersection. It is significant to note, therefore, that a study of the Connecticut Turnpike concluded that there was no evidence that the night accident rate was different for illumination levels of 0.2 and 0.6 footcandles. Furthermore, this same study made the observation that a change in illumination intensity from 0.2 footcandles to 0.6 footcandles was not readily discernable to the human eye. Thus, there is some question if variations in the lower levels of illumination cause differences in accident rates.

These thoughts are further substantiated by the conclusions which resulted from studies of night visual requirements of drivers. It was concluded that

"the level of illumination on the road is not the most important factor to consider when attempting to provide sufficient information to the night driver."  

**Current Recommended Practice**

The recommended practices for roadway lighting generally do not deal directly with rural intersections. At the present time there is a lack of information concerning the procedures to be utilized in lighting isolated rural at-grade intersections. A review of the current literature reveals
that existing recommendations are limited to the intersections of two continuously lighted roadways or isolated freeway interchange areas. Table 5 contains American Standards Practices for Roadway Lighting recommendations for average horizontal footcandle levels and on outlying or rural roadways.

Table 5

Recommendations for Average Horizontal Footcandles

<table>
<thead>
<tr>
<th>Roadway Classifications</th>
<th>Average Horizontal Footcandles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expressways and Freeways</td>
<td>1.0</td>
</tr>
<tr>
<td>Major</td>
<td>0.9</td>
</tr>
<tr>
<td>Collection</td>
<td>0.6</td>
</tr>
<tr>
<td>Local or Minor</td>
<td>0.2</td>
</tr>
</tbody>
</table>

For intersections, it is recommended that the following factor be considered:

"Intersecting converging and diverging roadway areas at-grade require higher illumination than that recommended in the Table 1. The illumination in these areas should be at least equal to the sum of the illumination values provided on the roadways which form the intersection."?

At freeway interchanges an average illumination level of 1.4 footcandles is recommended for rural locations.

The American Standard Practice also considers the importance of uniformity of lighting. It is recommended that the ratio of the lowest footcandle value on the pavement to the average value should not be less than 1:3.

Another approach to determining the amount of illumination required is taken by Ketvirtis. He recommends that illumination be expressed in terms
of luminance rather than horizontal levels of illumination. Luminance is a
measure of the quantity of light that is reflected from the pavement in the
direction of the viewing eye. It is dependent upon the pavement surface re-
reflectance, the luminance light distribution characteristics and the level of
illumination provided.

Ketvirtis\textsuperscript{18} also suggests minimum levels of illumination in terms
of horizontal intensities in order to satisfy present illuminating engineering
standards. Table 6 presents the recommendations for levels of illumination
of luminance values on continuously lighted rural sections.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|}
\hline
Roadway Classifications & Average Horizontal Footcandles & Average Pavement Luminaire (foot lamberts) \\
\hline
Freeways & 0.8 & 0.14 \\
Expressways & 0.8 & 0.14 \\
Arterials & 0.8 & 0.14 \\
Collections & 0.6 & 0.11 \\
Locals & 0.2 & 0.04 \\
\hline
\end{tabular}
\caption{Highway Lighting Engineering Recommended Illumination Levels of Luminance Values for Rural Continuously Lighted Roadways}
\end{table}

Ketvirtis extends coverage of uniformity by considering maximum to
minimum ratios of horizontal intersections on the pavement as well as average
to minimums. He also mentions that the uniformity within the entries visual
field, which includes approximately 85 feet on each side of the line of vision,
should be considered. Table 7 summarizes these uniformity recommendations
for rural roads.
Table 7
Summary of Uniformity Recommendations for Rural Roads

<table>
<thead>
<tr>
<th>Roadway Classification</th>
<th>Average Minimum Ratio</th>
<th>Maximum-Minimum Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway</td>
<td>2.5:1</td>
<td>6:1</td>
</tr>
<tr>
<td>Expressway</td>
<td>2.5:1</td>
<td>6:1</td>
</tr>
<tr>
<td>Arterial</td>
<td>3:1</td>
<td>8:1</td>
</tr>
<tr>
<td>Collector</td>
<td>3:1</td>
<td>8:1</td>
</tr>
<tr>
<td>Local</td>
<td>4:1</td>
<td>10:1</td>
</tr>
<tr>
<td>Within Visual Field of Major Roads</td>
<td>5:1</td>
<td>10:1</td>
</tr>
</tbody>
</table>

It should also be noted that recent investigations of roadway lighting design by Walton and Rowan have resulted in the development of a design process for illumination levels which take into account the warrants for lighting, roadway, and traffic conditions. It is important to recognize, however, that the models utilize the recommended levels as indicated in the American Standard Practice as basic input information.
5. RESULTS

Summary of Findings

The study has several findings that are essential for an approach to a systematic analysis of rural intersection illumination needs. First, it was shown that lighting can contribute significantly to the reduction of night accidents. Second, lighting should not be seriously considered at intersections that do not have night accidents greater than the night accidents that can be forecasted by the use of the predictor discussed in the previous section. Third, the benefits of illumination, in terms of accident reduction, can be predicted. This forms the basis for a systematic approach to the problem of establishing priorities among the intersections which would benefit from illumination. Finally, the illumination levels as recommended in the American Standard Practice are satisfactory for use in the design of illumination for rural at-grade intersections.

In order to obtain the maximum benefits from a limited illumination budget the cost of lighting each particular intersection should be determined and included in the criteria for establishing priorities. The simplest method of doing this is to use a benefit-cost ratio as the criteria for ranking. However, before these ratios are compiled provision has to be made for including the illumination of new or modified intersections in the illumination budget.

New or Modified Intersections

In a previous section the reduction of accidents has been estimated
to be $N_p = D/3$, and this gives a logical means of ranking existing intersections in terms of the probable benefits of illumination. This method however, cannot be used for new, improved or modified intersections because accident figures to substitute into the predictors are not available.

Considerable research has been carried out to determine the relationship between intersection design and accidents, but it is not possible at the present time to reliably predict the number of accidents for a new intersection because of the vast numbers of variables involved. The data collection and analysis basis of this study were designed to yield information on the effects of illumination and cannot be used to predict accident rates for new intersections. This study was not designed to isolate all the other relevant variables. For example, although the channelized intersections have a significantly higher accident rate in the sample than un-channelized, this is not evidence to suggest that channelization increases accidents. The cause of the relationship may in fact be the otherway round and be related to the fact that only the high accident intersections warrant channelization.

Although accidents cannot be accurately predicted in advance for new intersections, a review of the literature indicates certain common trends:

1. Cross type intersections have higher accident rates than T-type.
2. Channelization and left turn bays can reduce accidents.
3. The accident rate is dependent on traffic volume, particularly the percentage of cross traffic on the minor road.
4. The type of traffic control has a considerable effect on the number and type of accidents.
5. Many other variables probably affect the number of accidents but these have not yet been isolated. Examples are intersection geometry, sight distances, deliniation, grades, skid resistance of the surfacing and traffic composition.

This study indicates that the average night/total ratio is 0.25 for illuminated intersections and 0.33 for unilluminated intersections. This is equivalent to a 30 percent reduction in night accidents. If it is assumed day accidents are not altered by illumination, then these figures also imply a 10 percent reduction in total accidents.

The predictor developed earlier should be used wherever previous accident figures are available, as it will show which intersections have a worse than average night accident record. However, with the limited data available for new intersections, the average figure of 10 percent reduction in total accidents may be used as a guide. The total accidents can be estimated from the literature.\textsuperscript{22,24,25,27,34} The building of an entirely new major intersection, other than on an interstate route, is a rare event and the more usual case is that of intersection improvement such as channelization. It is recommended that illumination should be considered whenever an intersection is channelized for two reasons: first, if channelization is warranted then the total number of accidents is likely to be high (the average number of accidents/year for channelized intersections in the sample used in this study was 8 for crosses and 4 for T-type); second, the glare from oncoming headlights frequently makes unilluminated channelization nearly invisible to the approaching driver; third, without any form of overhead illumination, it is difficult for the turning driver to pick out the gaps in the channelization.
Priorities Based on Benefits and Costs

Ultimately, the design engineer should be interested in obtaining the greatest benefits for the expenditures which are made for improvements. In the case of intersection illumination, this can be determined by comparing the expected accident reduction to the estimated cost of lighting improvements. This analysis would yield information for each intersection which would permit improvement priorities to be based on benefit/cost ratios.

As discussed in the section on warrant development, accident reduction is the most useful criteria for measuring the benefits of illumination. Using the methods described in the previous two sections, it is possible to estimate the likely reduction in yearly accidents at any particular intersection following the installation of illumination. The accident reduction is in terms of all accidents, as it was not found possible to make separate predictions based on dividing accidents into groups based on severity.

The other essential information required is the cost of illuminating a particular intersection. The current design procedures used by the Illinois Department of Transportation are those recommended in the American Standard Practice for roadway lighting, and cost estimates are therefore easily made. The estimates for the price per pole and the maintenance and operating costs that follow have been obtained by increasing the Illinois Department of Transportation Design Manual7 figures by approximately 25 percent.36 The current estimate for conventional lighting with underground wiring is that the price per pole varies from $25 to $40 per foot of mounting height. Thus, a 46 ft pole might, for example, cost $1500. The capital cost can be expressed as an
equivalent uniform series of annual payments by multiplying by the capital
recovery factor which is

\[ \frac{i(1 + i)^n}{(1 + i)^n - 1} \]

Where \( i \) is the interest rate and \( n \) the estimated life of the installation.
Fifteen hundred dollars with an interest rate of 5 percent is equivalent to
payments of $120/year for 20 years.\(^{15}\)

Maintenance and operating costs average from 12 cents to 23 cents
per lamp watt per year. A 700 watt luminaire would thus cost between $84
and $161/year for maintenance and operation. Thus, typical annual costs for
an 8 pole installation, 700 watt luminaire and 20 year design life might be
$1,750/year.

Illumination cost estimates would be required for each intersec-
tion under consideration. Using the predicted accident reductions and the
cost estimates for each intersection, a priority ranking of intersections
can be developed based on a benefit/cost criteria.

For example, assume that three intersections are under consider-
ation for lighting improvements. For intersection A, the predicted acci-
dent reduction per year is 9; and the annual cost of illumination is estimated
to be $1750. For B, the estimates are 10 accidents and $2000; and for C, they
are 15 accidents and $2500. The benefit/cost ratios for A, B, and C would be
.0051, .0050, and .0060, respectively. This would indicate that intersection
C would be given a priority for lighting improvement followed by A, then B.

Because of the value judgements required in trying to assign dollar
values to accidents no attempt has been made to convert the benefit/cost ratio to an all dollar ratio. The decision makers at the higher echelons of the roadway system have the problem of allocating a fixed budget to achieve the "best" highway system. The criteria developed above should be more useful in this respect than one in which fundamental information on accident reduction has been hidden by the arbitrary assignment of dollar values to human injury and death. Once the lighting budget has been established the same ranking system can be employed to develop a detailed lighting program.

It should be noted that because of extraneous factors and the probabilistic nature of the problem this approach does not accurately predict the benefits for a particular intersection for a particular year. Instead, it is based on means and is designed to yield the optimum results if applied consistently over the long run.

One further point should be noted. The benefit/cost ratio is only a measure of two of the important aspects of lighting: that is accident reduction and monetary costs. Other aspects to be considered by the decision maker, even though quantitative measures are not available, are increased driver comfort, aesthetic attributes of lighting installations, and other community desires.

Illumination Levels

The determination of illumination levels is a complex lighting design question which entails a number of variables. While it is possible to identify intersections which will benefit from the application of fixed roadway illumination, it is extremely difficult to specify universal design standards
which are applicable because of the character and nature of the individual intersection environment. Obviously, there is no substitute for professional design excellence when dealing with rural intersection problems.

Because of the fact that the driver must transition from a dark environment to a lighted area and then back to the dark when an illuminated intersection is encountered, there is a need for low levels of illumination. While some studies reveal a relation between adequate lighting and lighting levels and accidents, there is no indication that the level of illumination is a critical factor at the low intensities. Certainly, factors such as uniformity play an equally important role.

There has been a tendency to utilize higher luminaire mounting heights for fixed roadway lighting. Basically, the higher mounting heights yield a more uniform distribution of lighting which produces a better driving environment. This is particularly true in the case where the high level tower lighting has been utilized.

It is of utmost importance that the engineer determine the specific purpose of the lighting or the problem to be solved at a particular intersection. This is a key to lighting design questions. Different lighting purposes may require different lighting design treatments.

At this time, there is no basis for recommending changes in the recommended levels of illumination as indicated in the *American Standard Practice for Roadway Lighting*. These values are reasonable for rural intersection lighting design, and there is no evidence which would justify a different standard based on current knowledge.
6. CONCLUSIONS

Rural at-grade intersections, although only a small proportion of the total rural road mileage, are the scene of approximately one quarter of all rural motor vehicle accidents. Many of these accidents occur at night, which indicates that illumination could play an important role in reducing rural accidents. There is a need for methods which will aid in the rational determination of intersections that warrant lighting. Certainly, lighting is not the only improvement or design modification that can be made at an intersection; however, if applied properly, fixed roadway illumination can result in substantial benefits in terms of the road user.

This study was undertaken for the purpose of developing criteria for intersection illumination warrants and addressing the question of types and levels of illumination. It is believed that the efforts which resulted from the research has answered these questions and represents an advancement with respect to the state of knowledge concerning rural intersection illumination.

Based on the research which was conducted, the following specific conclusions can be drawn:

1. While the rural intersection presents a relatively hazardous highway location, very little emphasis has been placed on the utilization of illumination as a means of improving highway operations.

2. Accident reduction was found to be the most feasible criteria for evaluating the benefits of illumination as satisfactory measures of driver comfort are not available at the present time.
3. From the analysis of examples of Illinois' rural intersections, containing 445 intersection data years, it was found that illumination does have a significant and beneficial effect on night accidents. The average reduction in night accidents was deduced to be 30 percent.

4. An estimate of the average number of accidents saved per year, by installing lighting at previously unlit intersections, can be obtained by subtracting one third of the average number of day accidents per year from the average number of night accidents per year which occurred prior to the installation of illumination.

5. The illumination program should be based on a priority list ranked in order by means of the benefit/cost ratio; expressed as estimated accident reduction per year divided by the annual cost of each installation in dollars.

6. The recommendations for illumination levels as indicated in the American Standard Practice are reasonable for rural intersection application. Lighting levels at rural intersection should be maintained at low intensities. At low intensities, there is little evidence that changes in lighting levels are significant or critical.

Recommended Warrant for Implementation

Based on the results of this research the following is proposed as the recommended warrant for rural at-grade intersection illumination:

"Rural intersections should be considered for lighting if
the average number of nighttime accidents (N) per year exceeds
the average number of day accidents (D) per year divided by
three. All the accident data available since the data of the
last modification to the intersection should be used when cal-
culating these averages. If N is greater than D/3 the likely
average benefit should be taken as N - D/3 accidents/year.

The likely benefits of lighting new or modified intersec-
tions should be estimated from previous experience. It is
recommended that illumination should be provided whenever
an intersection is channelized.

The estimated cost of lighting the intersections, which
show a benefit using the above criteria, should be computed.
The lighting program should then be based on the resulting
list of intersections ranked in priority order by means of
the benefit/cost ratio (expressed as annual reduction in
accidents/annual cost).

The lighting program should be reviewed at intervals
as additional accident data becomes available.

Application of Warrant

The recommended warrant has been designed to give the decision
makers the most information possible based on current knowledge. It has
been implicitly assumed that the highway improvement budget will be limited
and thus interest will be focused on maximizing the benefits of a limited
budget. For this reason, reductions in number of accidents rather than
accident rates have been used. One important implication of this approach is that the distribution of funds for lighting improvement will tend to be directed into the areas of high traffic volumes. Thus, if intersections are ranked on a statewide listing, the distribution of the budget will not be the same as one distributed by listing intersections on a district basis. The latter would spread improvements more uniformly throughout the state, but at a lower overall benefit/cost ratio.

As more data becomes available it is likely that the predictor used in the warrant can be refined.

It is anticipated that the overall warrant philosophy will continue to be useful in the decision making process, particularly as the benefits of lighting become more accurately measurable and hence the predictor is improved.
7. RECOMMENDATIONS FOR FURTHER STUDY

While the project served to make significant advancements with respect to rural intersection illumination, there are a number of areas that merit and need further study. Basically, the additional study is associated with expanding the scope of the warrants, refining the accident predictors, and understanding driver needs and behavior as they relate to intersection design and illumination. These recommendations for further study are explained in the following discussion.

1. The project essentially developed warrants which view lighting as a separate entity with respect to roadway design. It was indicated in an earlier section of this report that in reality illumination is only one of the design elements in an operating system. For any particular design problem, there are other elements or components which may be equally effective in fulfilling the objective. This requires that the designer have information concerning the effectiveness of these other alternatives and the trade-offs between the design components that may be utilized. In the case of lighting, this means that research should be undertaken to define the effectiveness of illumination versus other design elements, such as traffic control and channelization, in alleviating operational difficulties. Each of these have a cost which are associated with their application. The designer is most interested in achieving an overall program which yields the greatest benefits to the user.
It is recommended that research be undertaken to develop a comparative analysis of the application of different design treatments.

2. The accident predictors which were developed in the course of this study are based on a relatively limited amount of data. Furthermore, they are based on existing accident records which are currently maintained. Valid results require that the reporting and record keeping systems are reasonably accurate and complete. While there have been significant improvements in this area, the improvement in accident data information would be extremely useful.

   Certainly, as additional information is available, it will be possible to undertake further analysis to refine the prediction of accidents at a particular intersection. A continuing project should be established to collect and analyze this information.

3. One of the major constraints associated with illumination research is the fact that there are limitations on the state of knowledge and understanding about the human and his characteristics as a driver. It is important to know, for example, the types of information that are required by the driver for guidance and control of the vehicle. Furthermore, in the case of illumination, it is important to ascertain the visual keys that the driver must have for night operation.
During the course of the project, the staff recognized the importance of this information; however the equipment technology was not advanced to the point that such research was possible. Since that time, these equipment limitations have been overcome, and it is possible to undertake studies to determine the visual keys used by the driver at night.

It is believed that this information concerning the driver is of utmost importance in dealing with intersection illumination design questions. It is recommended that projects for this specific purpose because of the importance on the design of lighting systems and levels of illumination.
REFERENCES


7. *Design Manual*, Bureau of Design, Division of Highways, Department of Transportation, State of Illinois, Section 3-901.03.


34. Traffic Control and Roadway Elements - Their Relationship to Highway Safety, Chapter 4, "Intersections," Highway Users Federation for Safety and Mobility, 1970.


