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# Public Roads

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Interstate Route 81 in the Pocono resort area, Susquehanna County, Pennsylvania.

# IN THIS ISSUE



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# Public Road

**A JOURNAL OF HIGHWAY RESEARC**

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Use of funds for printing this publication has been approved by t Director of the Bureau of the Budget, March 16, 1966.

# Application of Statistical Concepts to Accident Data

BY THE
BUREAU OF PUBLIC ROADS

Reported by [1,2] DONALD A. MORIN,
Urban Transportation Planning Engineer,
Region 8, Portland, Oregon

***In this article Morin has pointed out the necessity for applying statistical concepts to traffic accident data. Although procedures for determining the significance of accident data have already been developed little has been accomplished toward their application. Procedures are suggested by which the limited available accident data can be analyzed and erroneous conclusions avoided.***

***The importance of statistical analysis of data is illustrated by one State's failure to identify unstable accident rates. In this State's program, high priorities were assigned to some highway sections that had few accidents and low priorities were assigned to other sections that had numerous accidents. This and other examples of inaccurate interpretation of accident data illustrate the need for applying statistical concepts to accident data to determine the significance of accident rates. The author also discusses the normal chance variation in accident rates, the minimum accident rates that definitely exceed an established tolerable rate, and the percentage of accident reduction needed to establish the reliability of a road section improvement.***

## *Introduction*

THE CONCERN being expressed nationwide about the highway accident toll has generated a flood of magazine articles, promoted legislation, and encouraged discussion within technical circles as to what can and should be done. No pat answer or agreement on the solution has been reached. Some believe the solutions hinge on stricter enforcement of traffic regulations, others on more and better driver education, others on improved highways, and others on safer vehicles. Agreement seems to exist on one point, however, and that is the lack of adequate accident records to enable agencies to establish accurate conclusions on highway accidents. A method for obtaining adequate records is not proposed in this article, but methods are suggested by which better analyses of the limited available accident data can be made so that erroneous conclusions will not be made.

## *Conclusions*

From the investigation of existing statistical procedures for interpreting available accident data several conclusions have been drawn.

- Although statistical procedures based on quality control concepts were developed and successfully applied to accident data a number of years ago, traffic and highway engineers have made only limited use of them to date.
- A procedure must be found to accelerate the use of existing statistical procedures over the pace of the past to permit concentration of manpower and resources in those areas that offer the best prospects for improvement.
- When applied, statistical controls have enabled engineers to make valid conclusions as to the effectiveness of safety improvement projects.
- Application of statistical procedures has also enabled engineers to determine the amount of variation inherent in accident rate data and thereby has minimized the possibility of erroneous conclusions.

## *Statistical Concepts Needed*

Accidents are scarce events—a few accidents per million vehicle-miles of travel; the universe in which accidents occur is extremely large—many hundreds of millions of vehicle-miles. As a statistician might say, "We are dealing with a small sample of a large population." In this situation, erroneous conclusions can easily be made unless the engineer uses well established statistical concepts to determine the significance of the accident data. Although most highway and traffic engineers are not specifically trained in statistics, they should be able to recognize when the services of statisticians are needed. Examples cited in the following paragraphs illustrate situations that required the application of statistical concepts to the analysis of accident data.

In one State, priorities on hazardous rural and urban highway sections were established by ranking the sections according to their annual accident rate, that is, the first priority was given to the section that had the highest annual accident rate. The fallacy of this procedure is evident from the assignment of priority 4 to a 1-mile section of a rural road on which only 3 accidents had occurred, none of which had caused personal injury or fatality, and the assignment of priority 47 to another 1-mile section of rural road on which 186 accidents had caused 89 personal injuries. In this same State, a 0.2-mile section of urban road on which 66 accidents had caused 12 injuries was ranked 13th, and another 0.2-mile section of road on which 123 accidents had caused 70 injuries and 3 fatalities was ranked 190th. Of course, sections with few accidents had high accident rates and vice versa because of the wide variation in the number of vehicle-miles of travel on the sections. Road sections of equal length were not differentiated in terms of their respective vehicle-miles of travel.

In another State, the annual State highway accident report listed, by route, the accident rate for each control section. When submitted, each control section that had a rate of 10 or more accidents per million vehicle-miles of travel was underlined in red. Examination of the accident data for these sections showed that many of the sections having a rate of 10 or more were not significant nor worthy of closer scrutiny because only one or two accidents had occurred; the few accidents coupled with the low figures for vehicle-miles of travel produced high accident rates. Other seemingly significant sections on which the vehicle-miles of travel were large had not been singled out by the red underlining because the accident rates were slightly less than 10.

In another instance, highway and traffic engineers determined that the large number of accidents at a complicated intersection could be curtailed by the installation of overhead sign bridges, improved signals, and some limited approach widening. During the 3-month period after completion of the improvement project, the number of accidents had decreased by eight. A press release, *Intersection Made Safer*, stated that the city's ". . . most dangerous intersection . . . apparently has been tamed." At the end of the following 8-month period, however, there had been only 5 fewer accidents, a 12-percent decrease that was far short of the 38-percent decrease needed to assure reliability. No press release or publicity was given to this.

The proper application of statistical concepts could make it possible to avoid pitfalls, like the ones cited, by determining the amount of normal chance variation that should be expected in accident rates, the minimum accident rate that definitely exceeds an established tolerable rate, and the percent of accident reduction needed to establish the reliability of a road improvement project.

An attempt is made in the rest of this article to summarize statistical concepts that have been developed and applied to this problem area. Although many of these applications were developed more than 10

[1] Presented at the 46th annual meeting of the Highway Research Board, Washington, D.C., January 1967.

[2] Mr. Morin is now Chief, Public Transportation Branch, Urban Planning Division, Office of Planning, Washington, D.C.

years ago, only limited use has been made of them.

### *Control Limits*

The Office of Technical Services of the U.S. Department of Commerce in 1958 distributed a manual (*1*) [3] that described a procedure for determining the amount of variation in the accident rate that could be expected from chance probability for any highway control section. The input required is the overall accident rate for the highway and the number of vehicle-miles of travel on the control sections. However, in 1966 S. K. Dietz discovered an error in the equations as originally presented in the Technical Service manual and HRB Bulletins 117 (*2*) and 341 (*3*). The validity was improved by omitting the correction term, 0.829/m. The authors of the original equations have concurred in Mr. Dietz's correction. By applying the corrected equations, both upper and lower control limits on the overall accident rate can be established for each control section.

$$\text{Upper control limit} = \lambda + 2.576\sqrt{\lambda/m} + \frac{1}{2m} \quad (1)$$

$$\text{Lower control limit} = \lambda - 2.576\sqrt{\lambda/m} - \frac{1}{2m} \quad (2)$$

Where,

$\lambda$ = Overall accident rate for the highway.
$m$ = Vehicle-miles of travel on a control section.

Equations (1) and (2) provide expressions for the upper control limit that has a probability $1-P$ of being equalled or exceeded by chance. To define the upper control limit as one that has a probability $1-P$ of being exceeded, the equation would be,

$$\text{Upper control limit} = \lambda + 2.576\sqrt{\lambda/m} - \frac{1}{2m} \quad (3)$$

This is identical to equation (1) except that the sign of the $\frac{1}{2m}$ term is reversed.

To define the lower control limit as one that has a probability $1-P$ of being exceeded by a more negative number the equation would be,

$$\text{Lower control limit} = \lambda - 2.576\sqrt{\lambda/m} + \frac{1}{2m} \quad (4)$$

This is identical to equation (2) except that the sign of the $\frac{1}{2m}$ term is reversed.

### *Chance Variation*

It is possible with the equations cited to compare the actual accident rate for each highway section with the control limits on the overall accident rate to determine whether the variation from the overall rate is more than could be attributed to chance. The coefficient of the second term in the equation, 2.576, assumes a 0.995 or ½ of 1 percent probability level that either the upper or lower control limit could be exceeded by chance variation in the observed accident rate, or a 0.990 or 1-percent probability level

[3] Italic numbers in parentheses indicate the references listed on p. 137.

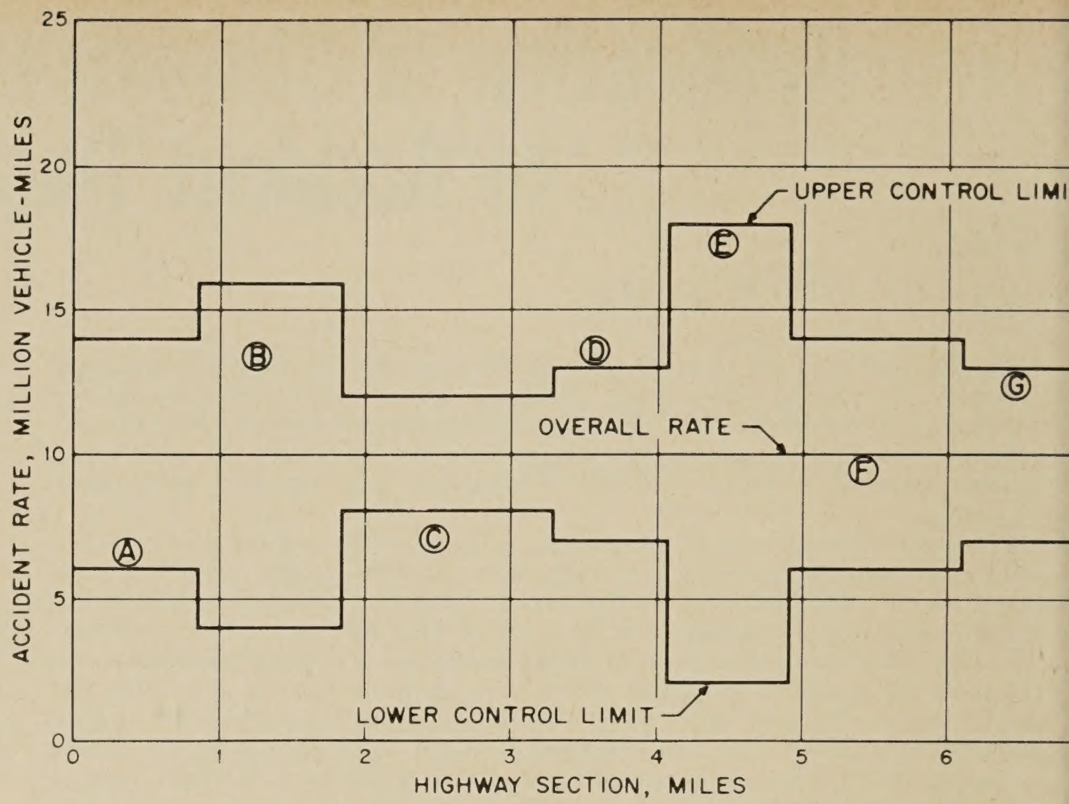



*Figure 1.—Relation of actual accident rates to control limits on overall accident rat*

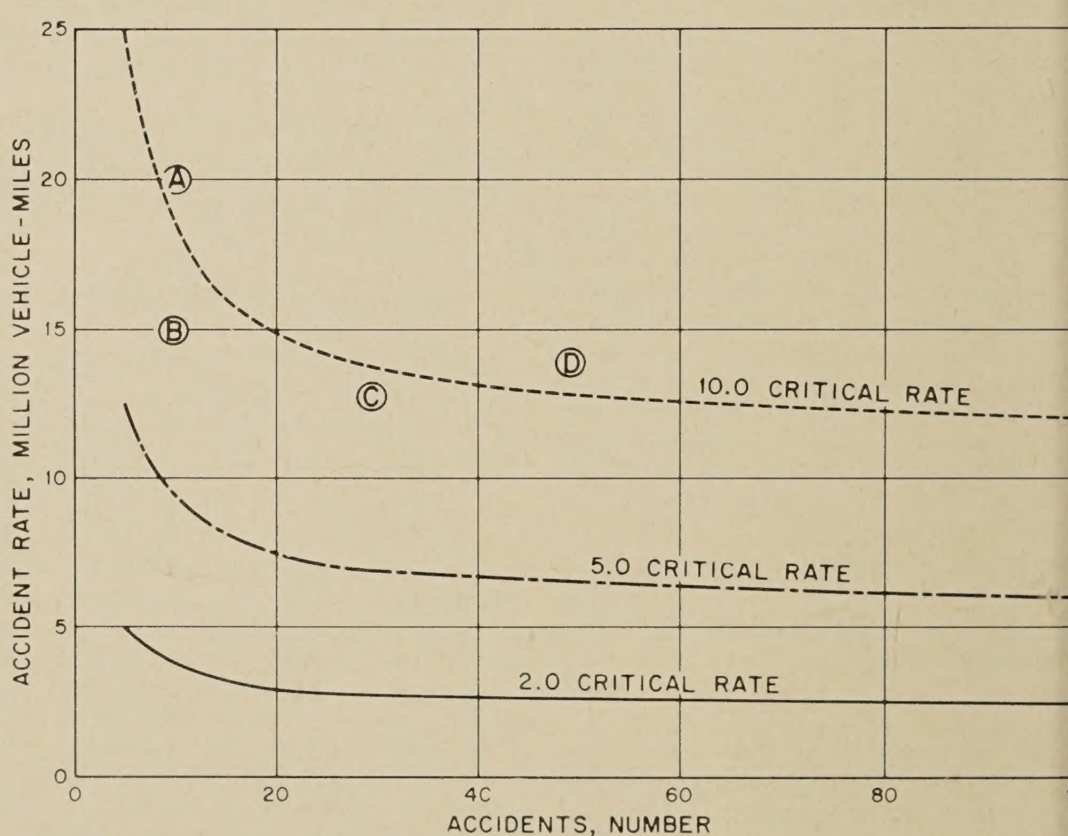



*Figure 2.—Minimum accident rates statistically significantly higher than critical r*

that both the upper and lower control limits could be exceeded by chance variation. For example, a value of 2.576 would mean that for 1 percent of the road sections the accident rate could be expected to fall beyond the control limits by chance even though there is nothing out of the ordinary about them, and that ½ of 1 percent of the accident rates for the road sections could be expected to fall above the upper or below the lower control limit by chance even though there is nothing out of the ordinary about them.

Other coefficients that would change the probability of labeling a rate as out of the ordinary when it is in fact normal could be used: 1.960 for 5 percent false detection of both or 2½ percent of either; 1.645 for 10 percent false detection of both or 5 percent of either; 1.440 for 15 percent false detection of both or 7½ percent of either; 1.282 for 20 percent false detection of both or 10 percent of either.

A comparison of the actual accident rates to control limits on the overall accident rate n be made from figure 1. In the figure the ›served accident rate at point E seems high. ecause of the few vehicle-miles of travel on is section, the control limits differed widely om the overall rate. It should be concluded at the apparently high rate at point E was ›t worthy of investigation as it was within e range of variation that could be expected r chance. By comparison, the observed cident rate at point D does not appear to be ry much higher than the overall rate and much lower than the rate at point E. it, because point D is outside the control nit for that section, its variation from the erall rate is more than could be attributed chance. Accidents on this section of the ad, therefore, warrant analysis. The ac-lent rate indicated by point C should also investigated, as something other than ance variation caused the accident rate to so much lower than the overall rate. vestigation of the causes of this low rate ight provide a means for attaining similar w rates on other road sections.

Rudy (*3*), in 1962 described the application Connecticut of the procedure for deter-ining the amount of variation in the accident te that could be expected from chance obability. The Montana State Highway ommission recently programed this pro-dure for their IBM 1620 computer and ccessfully ran their 1965 accident data. he program printed out the upper and lower ontrol limits and the observed accident te for each highway control section. The sults were indicated in the 1965 Annual ccident Report by an asterisk alongside e computed accident rate for sections here these rates were outside the control nits. Because these variations from the erall rate did not occur by chance, the next gical step is to find the reasons for the onormally high and low accident rates.

Under consideration is a procedure to semble in one report all possible data ncerning time and exact location of ac-dents, accident type, weather conditions, adway alinement and cross section details, ght distance, and so on for those road ctions where accident rates seem to be it of control. A team consisting of a traffic igineer, design engineer, maintenance en-neer, and law enforcement officer would udy the assembled data and physically ok at the highway sections to determine e reason for the abnormal accident rates.

## *Critical Rate Analysis*

A somewhat simpler application of statis-cal analyses to accident rate data, using e same basic concepts, is being used in laho. The procedure requires that the ghway authority establish the critical cident rate, that is, the highest accident te the authority agrees to tolerate. Then, r any established critical rate, a minimum cident rate can be determined for any imber of accidents that is statistically sig-ficantly higher than the critical rate of cidents on a particular road section. Mini-um accident rates that exceed the established

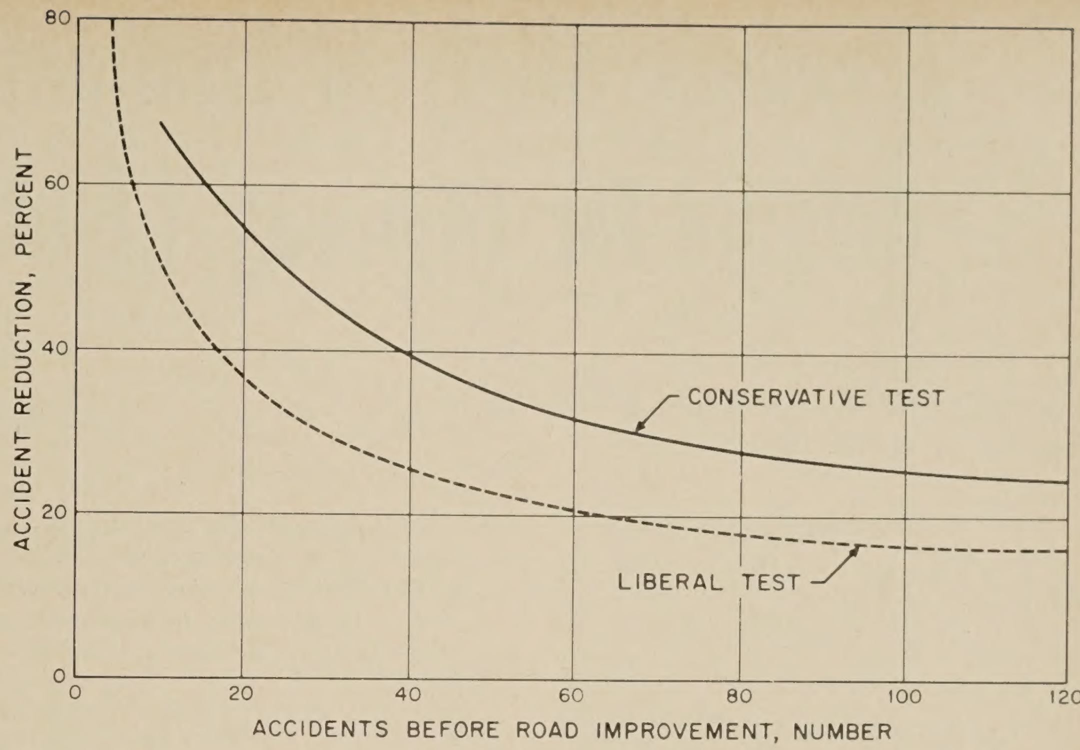



***Figure 3.—Curves for use in determining statistical significance of reduction in number of accidents.***

critical rates are illustrated in table 1 and figure 2.

In figure 2, the accident rates at points A through D and the established critical rate of 10 accidents per million vehicle-miles of travel indicate that the rate of 15 based on 10 accidents—point B—and 13 based on 30 accidents—point C—are not significantly higher than the critical rate of 10. The accident rates shown by points A and D, however, should be attributed to something other than chance variation; the rates of 20 based on 10 accidents—point A—and 14 based on 50 accidents—point D—are statis-tically significantly higher than the critical rate of 10 accidents per million vehicle-miles. Although the Idaho procedure provides a quick method for identifying road sections that have rates significantly higher than a predetermined critical or tolerable rate, it does not pinpoint road sections that have significantly low accident rates.

**Table 1.—Minimum accident rate statis-tically significantly larger than critical accident rate (probability level=0.95)**

| Critical accident rate per million vehicle-miles is— | Minimum accident rate per million vehicle-miles when— Actual number of accidents per road section is— | | | | | |
|---|---|---|---|---|---|---|
| | 5 | 10 | 20 | 30 | 50 | 100 |
| | *Mini-mum rate* | *Mini-mum rate* | *Mini-mum rate* | *Mini-mum rate* | *Mini-mum rate* | *Mini-mum rate* |
| 2.0 | 5.0 | 3.7 | 3.0 | 2.8 | 2.6 | 2.4 |
| 3.0 | 7.5 | 5.6 | 4.5 | 4.2 | 3.9 | 3.6 |
| 5.0 | 12.5 | 9.3 | 7.5 | 7.0 | 6.4 | 5.9 |
| 7.0 | 17.5 | 13.0 | 10.5 | 9.8 | 9.0 | 8.3 |
| 10.0 | 25.0 | 18.5 | 15.0 | 14.0 | 12.8 | 11.9 |

## *Effectiveness of Improvement Projects*

In 1959 Dr. R. M. Michaels published a procedure for determining the statistical sig-nificance of the percentage of reduction in the number of accidents on a road section after improvement as compared to the number before improvement (*4*). The Poisson distri-bution was considered an appropriate approx-imation of the accident probability for the liberal test. The chi-square test was used to determine whether there was a significant difference between the before and after samples for the conservative test. One of the main advantages of this procedure is that the engineer can test for significance knowing only the number of accidents before the road improvement and the percentage of accident reduction after improvement of the road section. The test involves spotting the per-centage of reduction on a graph, as shown in figure 3, to determine the significance of the reduction. If the point falls below the con-servative line, for example, the reduction is not significant by the conservative test.

The failure of engineers to apply the statistical procedures can lead to false con-clusions about highway improvement. An engineer in a recent article (*5*) reported that no definite conclusions could be drawn from a safety experiment because data were too limited and not statistically significant. How-ever, application of Dr. Michael's procedure showed that the percentage of reduction in accidents for the safety experiment was sta-tistically significant by the conservative test. Another article (*6*) reported the success of a safety project; but statistical analysis of the percentage of reduction of accidents showed that the accidents had not been reduced significantly.

## REFERENCES


(*1*) *Manual for the Application of Statistical Techniques for Use in Accident Control*, by Jack W. Dunlap, Jesse Orlansky, and Herbert H. Jacobs, U.S. Department of Commerce,



(*continued on p. 150*)

# Economic Study of Luminaire Mounting Heights for Highway Lighting Systems

*BY THE OFFICE OF ENGINEERING AND OPERATIONS BUREAU OF PUBLIC ROADS*

**Reported by[1] JAMES A. THOMPSON, Chief, Lighting and Traffic Control Branch, and BENDER I. FANSLER, Electrical Engineer, Highway Standards and Design Division**

***An economic study is a valuable prerequisite for an engineering project. The authors of the study reported in this article believe that an economic evaluation of the different highway lighting systems would prove helpful to highway engineers in designing new systems. Details of an economic and engineering study of lighting designs for different mounting heights of luminaries for use on controlled-access highways and how the mounting heights affect lighting costs are presented here. Also, formulas are given for making evaluations for the different mounting heights of luminaries.***

***From the research it was concluded that an economic study, such as that reported in this article, would provide more economical and effective lighting system designs and ultimately contribute to improved highway safety and esthetics. Based on the study reported here, the previously accepted standard, 30-foot mounting heights for luminaries, may be considered undesirable; the authors believe that highway lighting systems designed to use luminaires mounted at heights of 40 to 50 feet would be preferable in terms of economy, effectiveness, safety, esthetics, and flexibility for future modification.***

## *Introduction*

A WISER expenditure of public funds for highway lighting in relation to design should be possible from the information presented in this article. Details of an economic and engineering study of lighting designs for different mounting heights of luminaires for use on controlled-access highways and how the mounting heights affect lighting costs are presented. The method developed for evaluating different lighting designs should be useful in the design of more economical highway lighting systems. Although not a prime factor of the research study reported here, lighting system design can affect the esthetic properties of a highway and adequate lighting may increase safety on highways at night. Neither the degree of safety provided by night lighting nor the possible hazard of lighting poles along a highway has been formally studied, but the fewest possible poles per mile is a logical design consideration in relation to highway safety.

One of the factors sparking the study reported here is the increase in attention being given lighting of controlled-access highways in urban areas. As traffic volumes and operating speeds of vehicles have increased, a general public awareness of the need for and a demand for highway lighting has developed. Although several highway agencies have extensive lighting programs, many have limited programs or none at all. Despite the fact that each year highway engineers are considering the installation of more lighting systems, resistance to their cost plagues decision makers.

Although an economic study generally is a basic requisite for an engineering project, highway agencies heretofore have made little use of economic studies when designing highway lighting systems. The information and techniques discussed in this article should be helpful for evaluating proposed lighting projects. It is believed the evaluation methods discussed here emphasize the benefits to be derived from use of economic studies in relation to design. Methods for evaluating some of the cost differences of alternative designs are given, and other information is given on factors that may contribute to the design choice—factors that are impracticable to evaluate monetarily, such as esthetics and safety. An economic study should support planning and decision making so that more efficient and economical highway lighting installations can be provided—systems that will contribute to the safety and comfort of the road-user.

The authors caution that the cost information presented in this article represents relative values used only for examples in the economic evaluation procedures. The costs cited should not be used for project justification nor for budget preparations.

## *Conclusions and Findings*

Application of the information and techniques for evaluating highway lighting system designs given in this article should be helpful to highway engineers responsible for designing new systems, according to the conclusions made by the authors. The evaluation of present design techniques by the cost-effectiveness procedure discussed in this article is a basis that can be used for evaluating different designs. Use of this economic evaluation during planning of a lighting system could assure a wiser expenditure of public funds for more effective and esthetic lighting systems. These improved lighting systems could also improve safety conditions on the highways. Specific findings and related conclusions based on the research are given in the following statements.

On the basis of the research reported here, the previously accepted standard of 30-foot mounting heights for luminaires may be considered undesirable for divided highways. Highway lighting systems designed to use luminaires mounted at heights of 40 to 50 feet would be more economical and effective than the designs for luminaries mounted at 30 feet. Use of the higher mounting heights in lighting system designs generally would provide safer and more esthetic lighting. The designs using the higher mounting heights are more flexible and can be readily modified to use new lamp and luminaire improvements. Recent trends in lamp development are toward increased lamp efficiency and larger lumen output.

The uniformity of illumination should be studied and analyzed because the maximum to minimum ratio of illumination uniformity seems to be a more logical basis for comparison of the lighting system's effectiveness than the average to minimum ratio currently in use.

The authors also have concluded that continuous fluorescent bridge rail lighting, mounted at a low height, is not a wise investment of public funds because installation cost is high for such a system, questions abound as to the effectiveness of bridge rail lighting, and maintenance difficulties are many.

Definite conclusions regarding towerlighting for interchange areas generally cannot be based on the evaluation of a single interchange. Design engineers should make a cost-effectivness study for each individual interchange for which a lighting system is being planned because many geometric designs are available for the different requirements at each interchange.

[1] Presented at the 46th annual meeting of the Highway Research Board Washington, D.C., Jan. 1967.

The annual cost of towerlighting or flood-hting may be approximately the same the annual cost of a design for 30-foot ounting heights. The initial cost for each the three tower designs evaluated in the search reported here was less than the initial st for a 30-foot mounting height design.

### *Study Methods*

In the research reported here, only one ection of a highway was used to develop an aluation method for determining the most itable and economical highway lighting stem. Geometric and lighting design cri-ria were based on current design standards d principles, and they were selected so that e principal variable would be the mounted ight of the luminaire. The cost and designs the most commonly used mounting height 30 feet were compared to the same factors mounting heights of luminaires at 40, 45, d 50 feet; on bridge rail lighting at a height 3½ feet; and floodlights (a type of lumi-ire) mounted at a height of 100 feet in wers or on poles. Costs were computed for e following listed designs: (1) 250-watt lamps 2-lane roadways; (2) 400-watt lamps on 3-, and 4-lane roadways; (3) 700-watt mps on 3- and 4-lane roadways; (4) 1,000-tt lamps on 4-lane roadways; (5) bridge il lighting; and (6) interchange area flood-hting.

Only designs for divided, controlled-access ghways were considered. Comparable de-gns for lighting systems were compared for ly one direction of a roadway for 2-, 3-, d 4-lane pavements. All lanes were 12 feet de and the right shoulders were 10 feet wide. e luminaires were located over the right ge of the traveled way. Bridge rail lighting stems were evaluated with the roadway hting systems but lighting for interchange eas was evaluated separately.

A design level of average initial horizontal umination of 1.0 footcandle and an average minimum uniformity ratio that did not ceed 3 to 1 was used for all overhead lighting stem evaluations. A few design adjust-ents were made to obtain an acceptable hting uniformity ratio, which caused some viation from the average 1.0 footcandle of itial horizontal illumination. The minimum ceptable level of average initial illumination as established as 0.8 footcandle.

All overhead lighting designs considered ere based on one manufacturer's design arts for use of clear mercury lamps. At the gher mounting heights, increased lamp attages were required to maintain the 1.0 otcandle initial illumination at a fairly con-ant level. Therefore, 700-watt (34,600-men) and 1,000-watt (53,000-lumen) mercury mps were used when design requirements ceeded the capacity of the 400-watt (19,500-men) lamp. The 250-watt (10,500-lumen) ercury lamps were used only for designs for -foot mounting heights. For bridge rail hting design, 42-inch, 33-watt (2,190 lumens 300 milliamperes) fluorescent lamps in foot luminaires were studied.

For bridge rail lighting, in which light poles would be eliminated, fluorescent lights are mounted in a continuous line adjacent to or in lieu of a bridge railing. Although the concept and design for low-mounted lighting is different from overhead lighting, comparisons were made for installations that were judged to be comparable. Horizontal footcandle illumination, glare, and uniformity of illumination, which are the most common performance criteria used in designing a lighting system, did not seem to be a logical basis for comparing the low- and overhead-mounted lights. Other researchers have noted that a different method should be used to compute the average value of roadway illumination than is used to evaluate overhead lighting. Although the designs are different, for the purposes of this study the low-mounted lighting designs were considered to be similar to the overhead lighting system designs.

Other design criteria assumed to be constant for the lighting systems so that the principal variable would be the mounting height were: (1) Galvanized steel poles, anchor base, and concrete foundations; (2) 12-foot brackets, luminaire located over the edge of traveled way; (3) underground wiring system using cable-conduit; (4) multiple system circuitry; (5) power delivered at secondary voltage, no load center considered; (6) median wide enough so that lighting from opposite lanes would not be a factor; (7) comparable charac-teristics of pavement reflection so adjust-ments would not be required in computing average initial horizontal illumination; (8) time controls equivalent for all systems; (9) medium, semicutoff luminaires of IES types II and III; and (10) ballast in luminaires.

Interchange floodlighting systems may be designed so that mounting heights of the luminaires range from 80 to 150 feet. Each interchange should be evaluated separately to determine the mounting heights that will best fit the geometric features. A floodlight-ing system differs somewhat in concept from the 30- to 50-foot mounting height designs for roadway lighting systems. Footcandles computed for controlled lens lighting may be similar to footcandles computed for flood-lighting but roadway brightness measured by footlamberts may be different. The flood-lighting design generally used was considered to be comparable to the overhead system de-signs used in the study reported in this article. A sketch of the interchange area used in the study discussed herein is shown in figure 1.

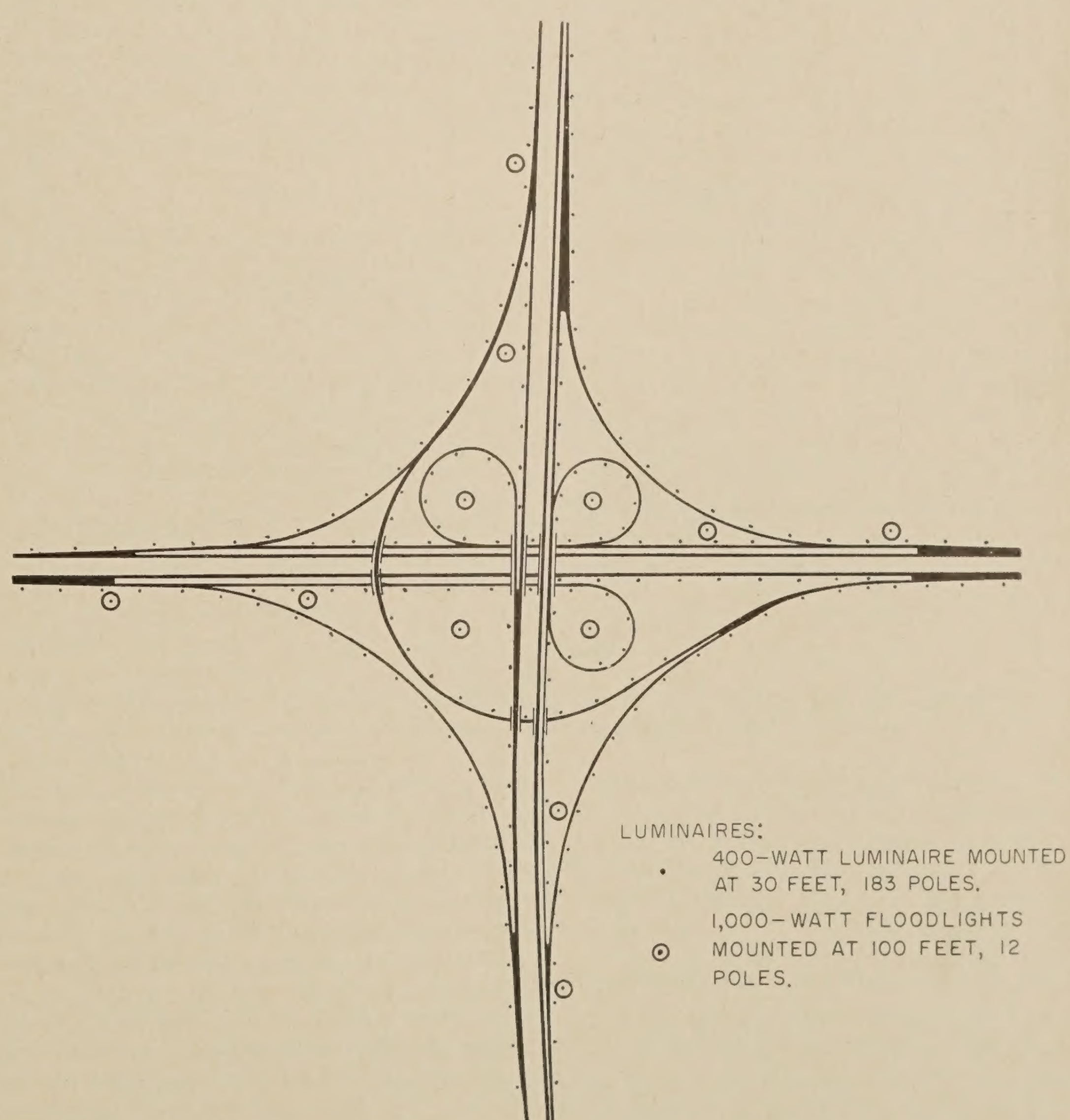



*Figure 1.—Interchange layout of lighting poles for 30-foot and 100-foot mounting heights of luminaires.*

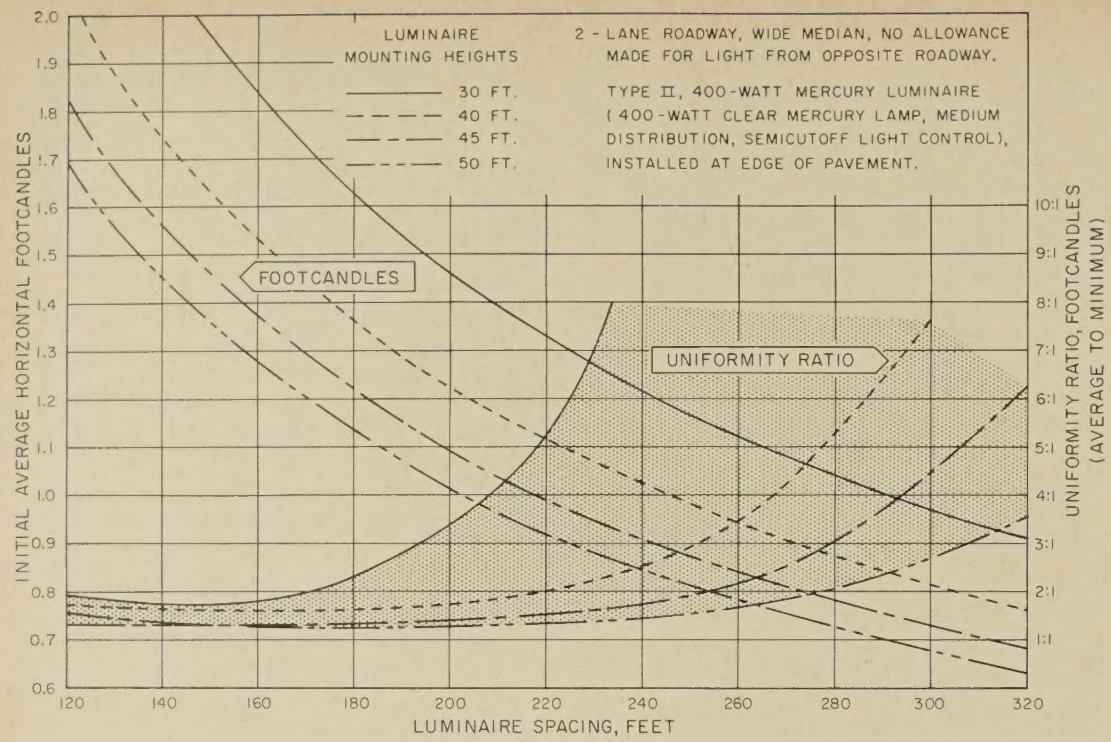



*Figure 2.—Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for 2-lane roadway.*

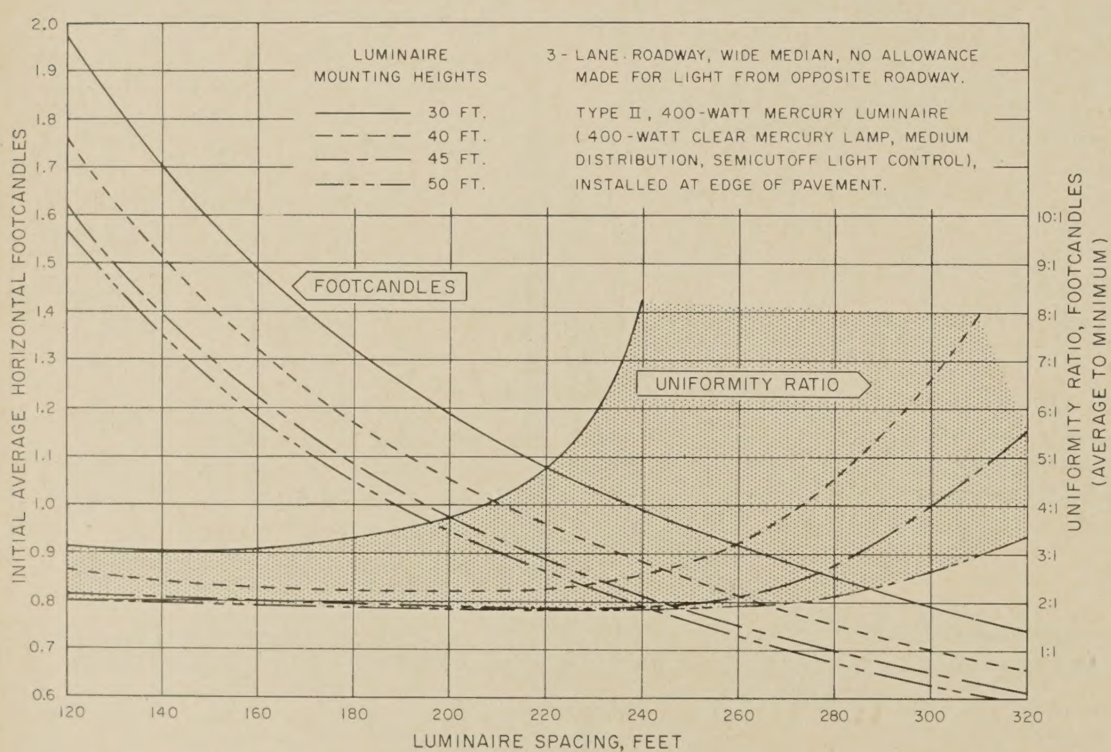



*Figure 3.—Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for 3-lane roadway.*

The area was 6.75 miles of separate roadways. Floodlighting designs using 400-watt and 1,000-watt lamps were evaluated. Also an industrial type, symmetrical distribution luminaire design, in which 1,000-watt lamps are used, also was evaluated.

## *Cost Data Conditions and Estimates*

The cost data in this article are based on information considered typical of national averages. These data are given as a basis for determining relative initial, operating, and maintenance costs for lighting systems in which the luminaires are installed at different mounting heights. These cost data should not be used as a guide for estimating the cost of specific highway lighting projects because material, delivery charges, electric energy, labor rates, and other costs may vary at different geographical locations. Initial costs for individual items were combined to obtain a total initial cost per mile, which was statistically converted and is restated as an equivalent annual cost. Luminaire maintenance and lamp replacement costs also were computed and are stated as equivalent annual costs. The estimated costs of luminaire cleaning and lamp replacement were based on maintenance being performed by owners and users. Repairs necessary because of

**Table 1.—Luminaire cleaning and lamp replacement costs**

| Luminaires | | | Lamps | | |
|---|---|---|---|---|---|
| Mounting height | Cleaning schedule | Estimated cost of cleaning one | Wattage | Group replacement schedule | Estimated cost |
| *Feet* | | | *Watts* | *Years* | |
| 3½ | Semiannually | [1] $2.00 | 33 | 2 | $2.( |
| 30 | Semiannually | 1.50 | 250<br>400 | 4 | 8.(<br>8.( |
| 40 | Annually | 1.50 | 400<br>700<br>1,000 | 4 | 8.(<br>14.(<br>16.( |
| 45 | Annually | 1.75 | 400<br>700<br>1,000 | 4 | 8.(<br>14.(<br>16.( |
| 50 | Annually | 2.00 | 400<br>700<br>1,000 | 4 | 8.(<br>14.(<br>16.( |
| 100 | Biannually | 3.00 | 400<br>1,000 | 4 | 8.(<br>16.( |

[1] Cleaning costs were based on current maintenance practice but more frequent cleaning obviously would be required to keep maintained illumination from this type of luminaire comparable to overhead lighting.

vandalism, pole knockdowns, and other miscellaneous factors were not considered in the evaluation.

The basic formula used to determine the equivalent annual capital cost, $EAC$, of a lighting system for a life expectancy of n years from an initial cost, $C$, at an interest rate of $i$ percent is,

$$EAC = C\,\frac{i(1+i)^n}{(1+i)^n - 1} \quad (1)$$

Where,

$n$ = 20 years life expectancy for lighting systems evaluated in study reported here.

$i$ = 6 percent interest.

$\frac{i(1+i)^n}{(1+i)^n}$ = Uniform series capital recovery factor, $crf$, at an interest rate of 6 percent and life expectancy of 20 years.

Therefore, for the computations discussed in this article,

$$EAC = C \cdot crf \quad (1a)$$

The basic formula used to determine the present worth, $PW$, of a single investment, $I$, $n$ years in the future at an interest rate of $i$ percent is,

$$PW \text{ of } I = I\,\frac{1}{(1+i)^n} \quad (2)$$

Where,

$\frac{1}{(1+i)^n}$ = Single payment present worth factor, $pwf'$.

The formula for determining present worth therefore becomes,

$$PW \text{ of } I = I \cdot pwf' \quad (2a)$$

Normally, the lighting system constructed and operated by a government agency is financed from road-user taxes in a method similar to that used to finance roadway construction. The road-user taxpayer, if allowed to keep it, could invest this tax money and earn a return. This post-

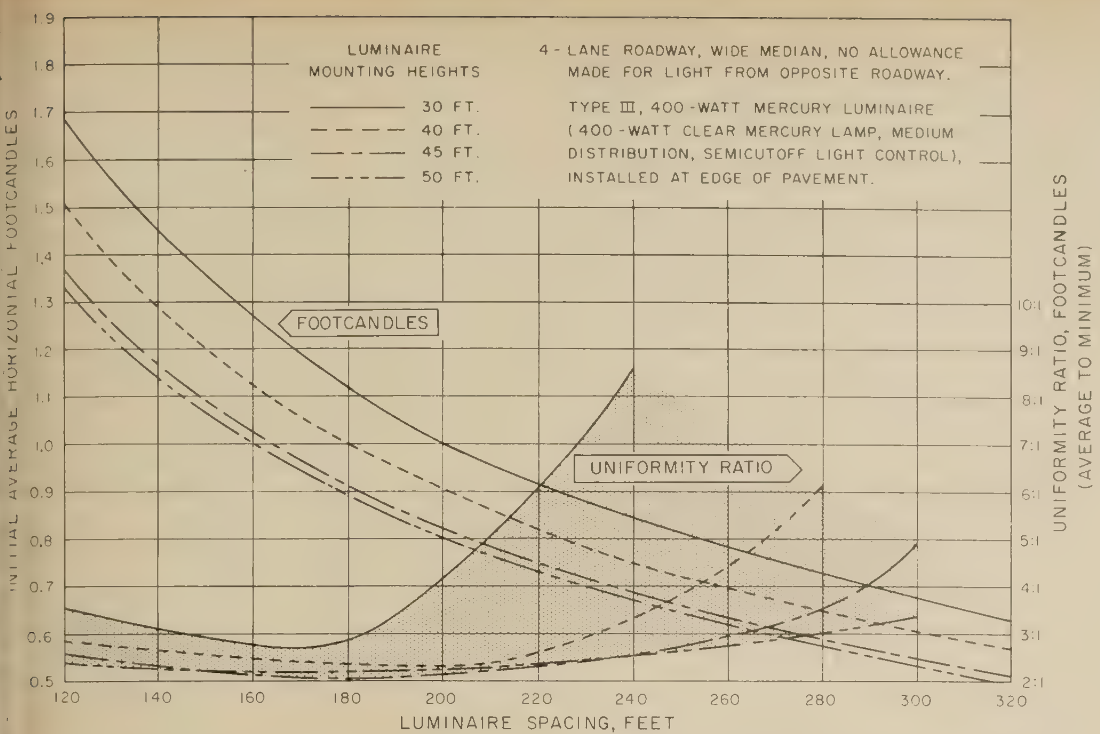



*Figure 4.—Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for 4-lane roadway.*

**Table 2.—Material and installation cost estimates for different luminaire mounting heights**

| Item | Luminaire mounting heights, feet— | | | | | |
|---|---|---|---|---|---|---|
| | 3½ | 30 | 40 | 45 | 50 | 100 |
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| Luminaire and ballast: | | | | | | |
| 6-foot fluorescent | 126 | ---- | ---- | ---- | ---- | ---- |
| 250-w. mercury | ---- | 92 | ---- | ---- | ---- | ---- |
| 400-w. mercury | ---- | 92 | 92 | 92 | 92 | ---- |
| 700-w. mercury | ---- | ---- | 144 | 144 | 144 | ---- |
| 1,000-w. mercury | ---- | ---- | 158 | 158 | 158 | ---- |
| 400-w. mercury floodlight | ---- | ---- | ---- | ---- | ---- | 125 |
| 1,000-w. floodlight | ---- | ---- | ---- | ---- | ---- | 200 |
| Lamps | | | | | | |
| 42-inch, T6 fluorescent | 2 | ---- | ---- | ---- | ---- | ---- |
| 250 w. mercury | ---- | 8 | ---- | ---- | ---- | ---- |
| 400-w. mercury | ---- | 8 | 8 | 8 | 8 | 8 |
| 700-w. mercury | ---- | ---- | 14 | 14 | 14 | ---- |
| 1,000-w. mercury | ---- | ---- | 16 | 16 | 16 | 16 |
| Poles | ---- | 200 | 250 | 275 | 325 | 2,000 |
| Installation per luminaire [1] | 40 | 350 | 400 | 425 | 450 | [2] 750 |

[1] Includes cost for foundation, bolts, wiring, conduit, trenching, and all miscellaneous labor and materials.
[2] Per pole.

vestment-opportunity cost should be the inimum interest figure used for determinaons of the equivalent annual cost for an itial investment in a highway lighting stem. A minimum interest rate should e established that is based on rates of vestment opportunities foregone by the taxyers, but it should be tempered by the ement of risk for the 20-year predicted life the lighting system.

The minimum attractive interest rate should clude a safety factor as recognition that en the best engineering estimates are subct to error. Therefore, an interest rate of 6 rcent has been used for present worth and pital recovery computations. A 20-year uipment life and no salvage value was used cause it was estimated that 20 years is the onomic life of most of the system comnents. It was assumed that the lighting stem would be owned by a government ency, which would eliminate tax and inrance costs from the evaluation.

Procedures for maintaining a highway hting system should always be considered the design of the system. However, beuse of the infinite variations in mounting ights and the uncertainty in determining a aintenance factor for bridge rail lighting, d to a lesser degree for the 100-foot mountg heights, maintenance factors such as lumen aintenance and dirt were not included in e evaluation of the highway designs in the udy reported here. The omission of mainnance factors permitted logical comparisons the designs.

Luminaire cleaning schedules vary; they pend on the mounting height, highway geoetrics, traffic volumes, and location. The minaire and lamp maintenance cost data ed in the study reported in this article are own in table 1. Material and installation st estimates are shown in table 2. Cost summary data are given in tables 3 through 6. The total kilowatt electric load per luminaire was based on lamp wattage, plus ballast loss wattage, plus a line loss of 5 percent. The lighting operation was estimated at 4,000 hours per year and the assumed current cost at $0.015 per kilowatt-hour.

## *Safety*

Few subjects have received so much attention and so little opposition as highway safety. The three major variables of highway safety are the driver, the vehicle, and the highway. Each variable considered separately is complex and indefinite, but combined, the variables present a mass of intangibles so nebulous and replete with insupportable opinions that it is impracticable to establish costs for accidents.

Information in some recent study reports indicates that lighting contributed to safer highway operations during darkness. But, formal research has not been reported that evaluates the degree of safety provided at night by highway lighting. Neither has the degree of hazard created by lighting poles along the highways been established for either day or night. Regardless of the lack of conclusive evidence, it seems logical, when considering highway safety, to favor a lighting system designed for the fewest possible number of poles per mile. It also seems logical to assume that operation in an interchange area would be safer if the number of lighting poles were reduced and located farther from the edge of the travelway. Towerlighting in lieu of roadside poles would provide such a situation. In addition, lighting the entire interchange area rather than just the roadways might improve safety.

The ability to see an object is reduced by glare in the field of view. The glare may be reduced by increasing the luminaire mounting height when the candlepower values remain constant. If glare is reduced, it follows that the result will be better visibility and improved safety. The authors, supported by observations, believe that an improvement in the uniformity of illumination, even when a slight reduction in level of illumination is necessary, would provide better highway lighting. This is one of the advantages to be gained from higher mounting heights and should be evaluated as a safety improvement.

Bridge rail lighting cannot be evaluated in the same manner as general highway lighting; poles on bridges are not considered hazards because thay are located on top or behind the bridge parapet. Because the mounting height of the bridge rail lighting is approximately on a level with the driver's eyes, any resultant glare would be a negative value in highway safety consideration. Also, because of the lack of light directed to the top and rear of the vehicles, a negative safety value may be introduced in the evaluation of bridge rail lighting. But driving conditions during fog or other bad weather may be improved by bridge rail lighting because roadway delineation is improved.

## *Esthetics*

All other design features considered equal, the height of the lighting pole can either enhance or detract from the esthetic quality of the highway. On narrow roadways, lighting from 30-foot mounting heights of luminaires is satisfactory. On wide roadways designed with a wide median or more than one median, a 30-foot mounting height may require four or more rows of poles. The result could be an unsightly forest of poles. A higher mounting height, combined when necessary either with 700-watt or 1,000-watt luminaires, sometimes may permit a reduction in both the number of rows and number of poles and may improve the appearance of the highway at all times.

The taller poles are esthetically acceptable when the ratios of roadway widths to pole heights are considered. When the design norm is considered to be 24-foot, 2-lane, 2-way roadways (two, 12-foot lanes and two 10-foot shoulders) equipped with 30-foot poles, the ratio of roadway width to height of pole is 44 to 30, or approximately 1.5 to 1. Therefore, a 50-foot pole should be acceptable for roadway widths of 75 feet or more, and 100-foot poles or towers should be acceptable for roadway widths of 150 feet or more. Also, in areas where the type of property development adjacent to the highway is higher than the lighting poles—such as industrial plants, high rise apartment buildings, and so on, or where deep roadway cuts exist—the taller poles or lighting towers blend more readily with the local environment than the shorter poles. But, if the adjacent area has one-story dwellings and the roadway cuts are shallow, use of a shorter pole may be more desirable.

Towerlighting in wide interchange areas seems to be esthetically desirable where acceptable width to height ratios exist. Lighting at night of landscaped areas between ramps enhances the appearance of the entire interchange area. The spill of light off the highway, which may occur when the mounting heights are higher than the surrounding areas, could be either a positive or a negative factor in the design evaluation of highway lighting. The quality of the factor would depend upon the adjacent property and the property owner. In a highly developed area where crime is a problem, spilled light could be an asset to owners of business and residential property. In relation to police protection, lighting is an asset in any area. Spilled light could be a negative factor and a source of complaint in private residential areas where crime is not a problem. In apartment dwelling and business areas, lighting is normally furnished in walking and parking areas, so spilled light from the highway may be desirable.

**Table 3.—Cost summary for 2-lane roadway**

| | Luminaire mounting heights, feet— | | | | | |
|---|---|---|---|---|---|---|
| | 30 | 30 | 40 | 45 | 45 | 50 |
| DESIGN DATA, 2-LANE ROADWAY | | | | | | |
| Luminaire: | | | | | | |
| Type | II | II | II | II | II | II |
| Spacing ... feet | 190 | 195 | 250 | 280 | 220 | 210 |
| Per mile ... number | 28 | 27 | 21 | 19 | 24 | 25 |
| Lamp ... watts | 250 | 400 | 400 | 400 | 400 | 400 |
| Illumination: | | | | | | |
| Avg. to minimum ... ratio | 3 to 1 | 3 to 1 | 3 to 1 | 3 to 1 | 1.6 to 1 | 1.4 to 1 |
| Avg. initial horizontal ... footcandles | 0.83 | 1.50 | 1.00 | 0.79 | 1.00 | 1.00 |
| Minimum ... do | 0.29 | 0.50 | 0.33 | 0.27 | 0.64 | 0.72 |
| COST DATA, 2-LANE ROADWAY | | | | | | |
| Initial cost ... per mile | $18,200 | $17,550 | $15,750 | $15,200 | $19,200 | $21,875 |
| Annual cost: | | | | | | |
| Equivalent capital ... do | 1,587 | 1,530 | 1,373 | 1,325 | 1,674 | 1,907 |
| Equivalent maintenance ... do | 129 | 124 | 65 | 64 | 81 | 90 |
| Power | 512 | 770 | 599 | 542 | 684 | 713 |
| TOTAL | 2,228 | 2,424 | 2,037 | 1,931 | 2,439 | 2,710 |

**Table 4.—Cost summary for 3-lane roadway**

| | Luminaire mounting heights, feet— | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 40 | 40 | 45 | 45 | 50 | 50 |
| DESIGN DATA, 3-LANE ROADWAY | | | | | | | | |
| Luminaire: | | | | | | | | |
| Type | II | II | II | II | II | II | II | II |
| Spacing ... feet | 150 | 255 | 220 | 225 | 220 | 265 | 190 | 290 |
| Per mile ... number | 35 | 21 | 24 | 24 | 24 | 20 | 28 | 18 |
| Lamp ... watts | 400 | 400 | 400 | 700 | 400 | 700 | 400 | 700 |
| Illumination: | | | | | | | | |
| Avg. to minimum ratio | 3 to 1 | 3 to 1 | 2.3 to 1 | 3 to 1 | 1.8 to 1 | 3 to 1 | 1.8 to 1 | 3 to 1 |
| Avg. initial horizontal footcandles | 1.60 | 0.83 | 0.96 | 1.29 | 0.90 | 1.02 | 1.00 | 0.85 |
| Minimum ... do | 0.53 | 0.27 | 0.42 | 0.44 | 0.50 | 0.33 | 0.55 | 0.28 |
| COST DATA, 3-LANE ROADWAY | | | | | | | | |
| Initial cost ... per mile | $22,750 | $15,750 | $18,000 | $19,392 | $19,200 | $17,160 | $24,500 | $16,794 |
| Annual cost: | | | | | | | | |
| Equivalent capital do | 1,983 | 1,373 | 1,569 | 1,691 | 1,674 | 1,496 | 2,136 | 1,464 |
| Equivalent maintenance ... do | 161 | 65 | 75 | 104 | 81 | 91 | 101 | 87 |
| Power | 998 | 599 | 684 | 1,174 | 684 | 978 | 798 | 880 |
| TOTAL | 3,142 | 2,037 | 2,328 | 2,969 | 2,439 | 2,565 | 3,035 | 2,431 |

**Table 5.—Cost summary for 4-lane roadway**

| | Luminaire mounting heights, feet— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 40 | 40 | 45 | 45 | 50 | 50 | 50 |
| DESIGN DATA, 4-LANE ROADWAY | | | | | | | | | |
| Luminaire: | | | | | | | | | |
| Type | III | III | II | III | II | III | III | II | III |
| Spacing ... feet | 185 | 180 | 220 | 210 | 255 | 250 | 160 | 280 | 265 |
| Per mile ... number | 29 | 29 | 24 | 25 | 21 | 21 | 33 | 19 | 20 |
| Lamp ... watts | 400 | 400 | 700 | 1,000 | 700 | 1,000 | 400 | 700 | 1,000 |
| Illumination: | | | | | | | | | |
| Average to minimum ... ratio | 3 to 1 | 2.4 to 1 | 3 to 1 | 3 to 1 | 3 to 1 | 3 to 1 | 2.2 to 1 | 3 to 1 | 3 to 1 |
| Average initial horizontal ... footcandles | 1.09 | 1.00 | 1.13 | 1.80 | 0.91 | 1.42 | 1.00 | 0.80 | 1.28 |
| Minimum ... do | 0.36 | 0.43 | 0.36 | 0.60 | 0.30 | 0.47 | 0.47 | 0.27 | 0.43 |
| COST DATA, 4-LANE ROADWAY | | | | | | | | | |
| Initial cost ... per mile | $18,850 | $21,750 | $19,392 | $20,600 | $18,018 | $18,354 | $28,875 | $17,727 | $18,980 |
| Annual cost: | | | | | | | | | |
| Equivalent capital ... do | 1,643 | 1,896 | 1,691 | 1,796 | 1,571 | 1,600 | 2,517 | 1,545 | 1,655 |
| Equivalent maintenance ... do | 134 | 90 | 104 | 118 | 96 | 104 | 119 | 92 | 104 |
| Power | 827 | 827 | 1,174 | 1,725 | 1,027 | 1,449 | 941 | 929 | 1,380 |
| TOTAL | 2,604 | 2,813 | 2,969 | 3,639 | 2,694 | 3,153 | 3,577 | 2,566 | 3,139 |

Bridge rail lighting has been promoted as an esthetic improvement even though it may break the continuity of overhead lighting for the highway. The use of rail lighting rather than lighting poles on bridges seems to present a more pleasing appearance during the day. This factor would weigh more heavily in design of bridge lighting on a parkway or scenic highway. As in the evaluation of safety, a dollar value cannot be given to the esthetic qualities of highway lighting, but for specific conditions, some weight should be given to choosing a lighting design that would fit or blend with the highway and adjacent property.

### *Results of Study*

The safest and most esthetic overhead lighting system may be considered the one that provides adequate and effective illumination with the fewest number of poles. The number of poles per mile can be reduced by use of higher mounting heights combined, when necessary, with more wattage for luminaires and lamps. As poles are the most costly item of the lighting system, a system design that reduces the number of poles generally will offset the cost of taller poles, larger foundations, and larger luminaires. Lamps are a small part of the cost.

Three factors are of prime consideration in the effectiveness of any highway lighting system: the level of illumination, the uniformity of illumination, and the control of glare. The uniformity of illumination may be more important than the footcandle level of illumination. And, as the mounting height of lamps is increased, the apparent improvement in light distribution may be better than a comparison of average to minimum illumination uniformity ratios would indicate. It seems that the ratio of maximum to minimum illumination factors should receive more consideration when alternatives are evaluated. Additional study to determine a more positive evaluation of light distribution related to uniformity in level of illumination is recommended by the authors. Results of such a study might show that the road-users ability to perform driving tasks may be improved more by better uniformity in level of illumination than by an increase in the footcandles of illumination.

Luminaires having cutoff vertical light distribution will help to reduce glare and may provide better visibility for the motorists than the semicutoff luminaires. The least glare control is possible when noncutoff luminaires are used, and their use probably should not be considered for expressway lighting. When medians are narrow, a high mounting height improves distribution of light on the opposite roadway. Because the position of the luminaire in relation to the traveled way is not as critical, many times it may be possible to save on the initial cost of a system by use of shorter bracket arms. When the 30-foot mounting heights are used, a pronounced bright spot is present under or near each luminaire. The size and brightness contrast of these pools of light can be reduced considerably by use of higher mountings—less

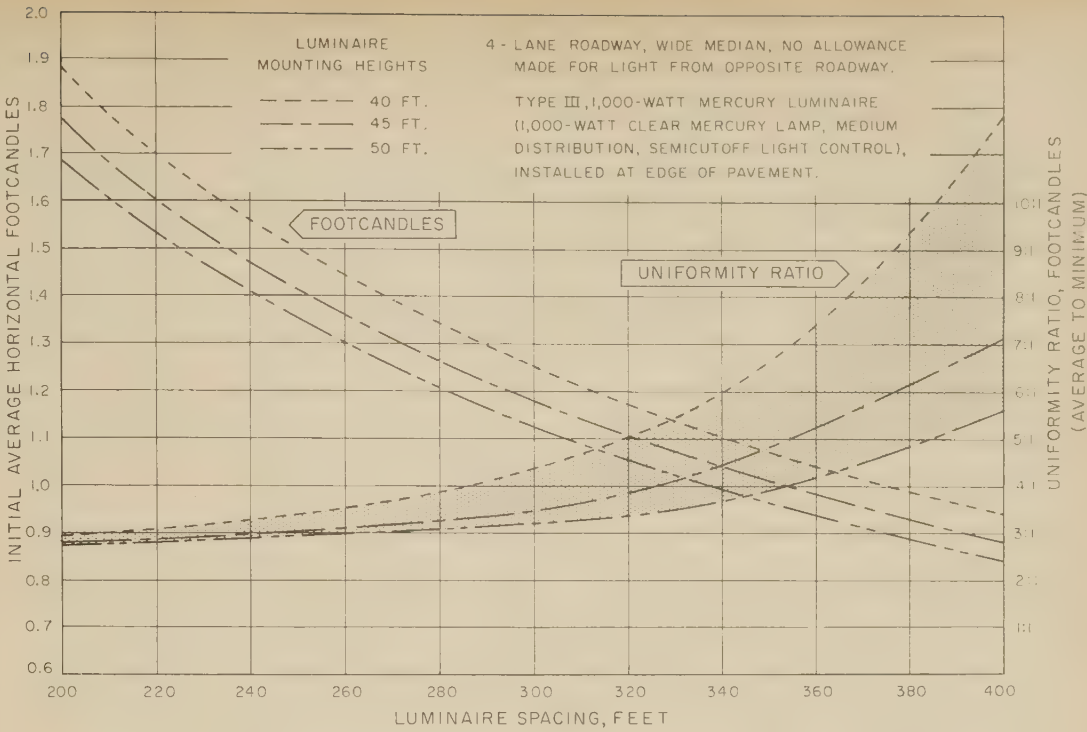



*Figure 5.—Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for 4-lane roadway.*

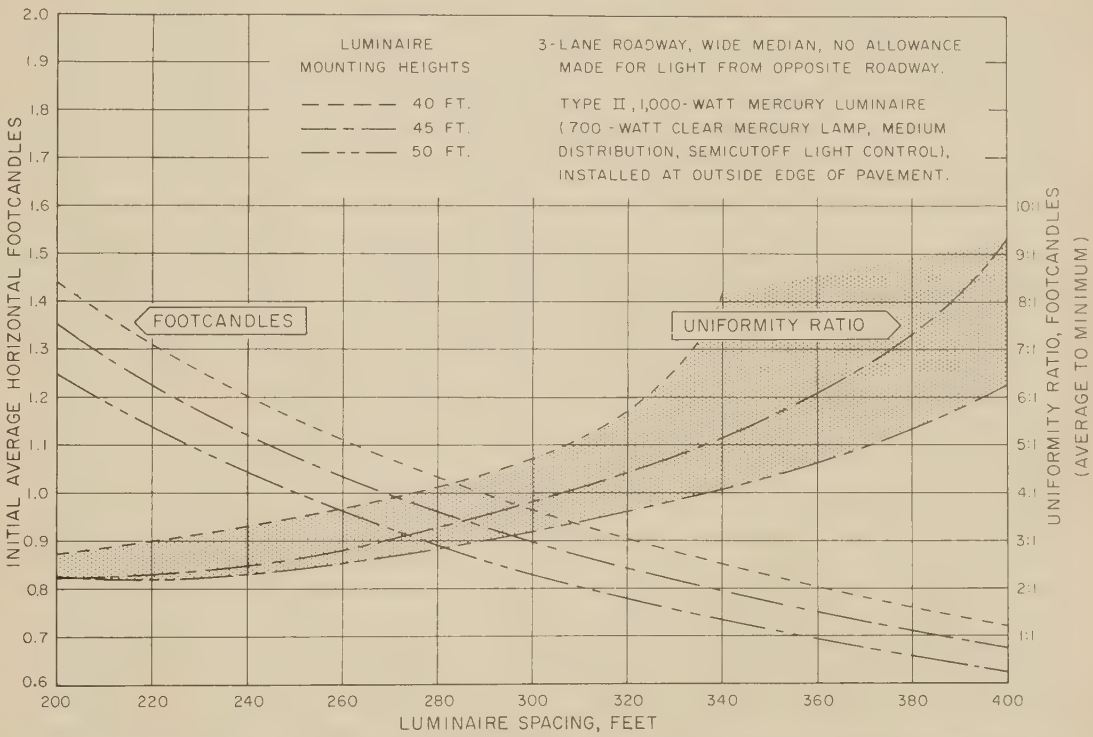



*Figure 6.—Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for 3-lane roadway.*

variation is present in pavement brightness and the frequency of eye adaptation is lessened because the driver is not traveling through a succession of intermittent bright spots.

According to results of a cost-effective analysis, a 30-foot mounting height for luminaires seldom should be used for lighting a divided, controlled-access highway. The curves in figures 2 through 7, which show the relation of luminaire spacing to lighting uniformity, illustrate that less change occurs in lighting uniformity in relation to an increase in luminaire spacing if the mounting height is increased. This relation also indicates that differences that may exist between calculated and actual measured uniformity would be less as the mounting height is increased.

Data that can be obtained from curves shown in figures 2 through 7 can be an aid in the preliminary design of a lighting system. For example, figure 2 shows that for a 30-foot mounting height of luminaires on a 2-lane roadway, 1.5 initial average horizontal footcandles of illumination are required to obtain a 3 to 1 lighting uniformity ratio and 1.4 footcandles for a 4 to 1 uniformity ratio. But at the 40-foot mounting height of luminaires, 0.8 to 1.2 footcandles of initial average horizontal level of illumination can be obtained when uniformity ratios are about 8 to 1 or 1.7

Table 6.—Cost summary for interchange floodlighting [1]

| | Luminaire mounting heights, feet— | | | |
|---|---|---|---|---|
| | 30 | 100 | 100 | 100 |
| DESIGN DATA, INTERCHANGE FLOODLIGHTING | | | | |
| Light distribution ... type | II | Flood | Flood | V |
| Poles ... number | 183 | 12 | 12 | 27 |
| Luminaires ... number | 183 | 492 | 204 | 108 |
| Per pole ... number | 1 | 41 | 17 | 4 |
| Lamp ... watts | 400 | 400 | 1,000 | 1,000 |
| Illumination: | | | | |
| Average to minimum ... ratio | 3 to 1 | Approx. 3 to 1 | Approx. 3 to 1 | Approx. 2 to 1 |
| Average initial horizontal ... footcandles | 1.5 | Approx. 1.0 | Approx. 1.0 | Approx. 1.0 |
| COST DATA, INTERCHANGE FLOODLIGHTING | | | | |
| Initial cost | $118,950 | $98,436 | $77,064 | $101,628 |
| Annual cost: | | | | |
| Equivalent capital | 10,370 | 8,582 | 6,718 | 8,860 |
| Equivalent maintenance | 844 | 2,268 | 1,269 | 672 |
| Power | 5,216 | 14,022 | 14,076 | 7,452 |
| TOTAL | 16,430 | 24,872 | 22,063 | 16,984 |

[1] Through roadways are two, 12-foot lanes and all ramps have 1 lane except the directional ramp, which has 2 lanes.

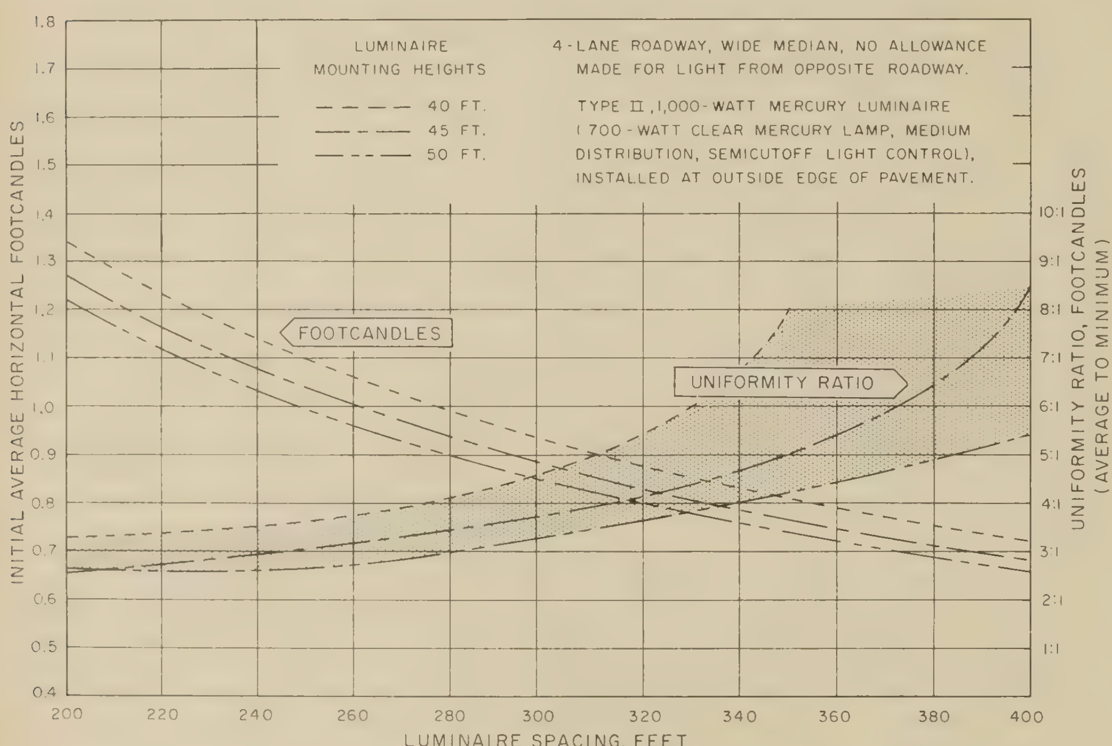



*Figure 7.—Initial average footcandles and lighting uniformity ratio for different mounting heights and luminaire spacing for 4-lane roadway.*

to 1. To obtain the same level of illumination, the uniformity ratio varies from 2.7 to 1 to 1.4 to 1 for a 45-foot mounting height, and from 1.6 to 1 to 1.2 to 1 for a 50-foot mounting height.

An analysis of the design and cost data tables shows that a 45-foot mounting height would be the most economical lighting design for a 2-lane roadway. The 45-foot mounting height also would be better than a 30-foot mounting height in relation to safety and esthetics. But a 50-foot mounting height would provide the most effective lighting, the best uniformity in illumination, and the least glare. The 30-foot mounting height would provide the most initial average horizontal footcandles.

Analysis of data for a 3-lane roadway, given in table 4, shows that a mounting height of 40 feet would be the most economical design. A 45-foot mounting height would provide the most effective lighting. At a mounting height of 50 feet, glare would be least; also, the 50-foot mounting height design would provide the best highway lighting system in relation to safety and esthetics. On the basis of the cost-effectiveness evaluation, the use of either a 45- or 50-foot design mounting height would be favored. On a 4-lane roadway, as shown in table 5, the 50-foot mounting height design would be a better lighting system on the basis of economy, uniformity, effectiveness, glare, safety, and esthetics. The 40-foot mounting height design would produce the most initial footcandles of illumination.

Bridge rail lighting, continuous rows of low mounted fluorescent luminaires placed adjacent to or in lieu of a bridge railing, eliminates

Table 7.—Interest factors used in computations of designs for ligh systems

| 6-percent compound interest factors [1] | | |
|---|---|---|
| Years | Single payment present worth | Uniform seri capital recove |
| 1 | 0.9434 | 1.06000 |
| 2 | 0.8900 | 0.54544 |
| 3 | 0.8396 | 0.37411 |
| 4 | 0.7921 | 0.28859 |
| 5 | 0.7473 | 0.23740 |
| 6 | 0.7050 | 0.20336 |
| 7 | 0.6651 | 0.17914 |
| 8 | 0.6274 | 0.16104 |
| 9 | 0.5919 | 0.14702 |
| 10 | 0.5584 | 0.13587 |
| 11 | 0.5268 | 0.12679 |
| 12 | 0.4970 | 0.11928 |
| 13 | 0.4688 | 0.11296 |
| 14 | 0.4423 | 0.10758 |
| 15 | 0.4173 | 0.10296 |
| 16 | 0.3936 | 0.09895 |
| 17 | 0.3714 | 0.09544 |
| 18 | 0.3503 | 0.09236 |
| 19 | 0.3305 | 0.08962 |
| 20 | 0.3118 | 0.08718 |

[1] The 6-percent compound interest factors for single ment present worth and uniform series capital rec calculations were based on investments made at the e each year (maintenance, replacement, and operation were assumed to be charges paid at the end of each Zero time ($n=0$) was assumed to be the day the install was completed and operational.

the need for lighting poles and overhead lu naires. This type of lighting should be stricted to locations where overhead ligh cannot be used. The total annual cost such an installation is approximately 10 ti that of conventional overhead systems. P ment brightness requirements may be me 2-lane roadways at the 3½-foot moun height, but whether these requirements met on 3- and 4-lane roadways is question Although a rail lighting system contribut the esthetic appearance of a bridge and h delineate the roadway at night, the prob inherent in maintaining a low mounted fl orescent system, coupled with the increas annual cost, generally should rule out sideration of such a design. Exposur luminaires to dirt from frequent splashin moisture on the highway makes it impr cable to maintain the same degree of cle ness for luminaires mounted at 3½ feet a overhead lighting. Use of bridge rail ligh designs should be reserved for sp situations.

The estimated initial cost for a ligh system using 6-foot fluorescent luminair $220,200 per mile of highway when 1 luminaires, mounted at 3½ feet, are inst in two rows. The equivalent annual ca cost per mile would be $19,197; equiva annual maintenance would be $7,995; annual power cost would be $4,290.

Flexibility in choice of equipment design of highway lighting systems seem increase in relation to the mounting h of the systems. Recent lamp developm could encourage the use of towerlightin floodlighting in the future. Interchange fl lighting has been used in Europe, bu installations have been made in this coun

(continued on p. 150)

# Severance Case Studies—
# Bridging the Gap Between Findings and Their Application

*BY THE OFFICE OF RESEARCH AND DEVELOPMENT BUREAU OF PUBLIC ROADS*

**Reported by[1] FLOYD I. THIEL, Economist, Economics and Requirements Division[2]**

***Amounts being received by owners of land taken for highway right-of-way construction for the National System of Interstate and Defense Highways and other Federal-aid highways, as payments for land taken, damages, and sales, often total more than had been anticipated, according to findings from studies of severance effects. Receipts often have totaled more than the estimated values, and losses have been relatively few and small.***

***The disparities in the estimated values and the actual values shown by analyses of findings—from the case studies in the Public Roads severance effects bank and 2,262 narrative reports on remainder sales—emphasize the savings that can be made. The findings also indicate that underpayments to landowners sometimes are being made.***

***The importance of applying the available findings from previous case studies to new acquisitions is stressed in this article. Attention is called to the possible source(s) of information, especially for current acquisitions that involve takings for unusual types of properties such as churches, golf courses, and/or schools. By applying these findings, highway takings can be evaluated more closely so that right-of-way can be acquired economically and owners can be paid equably.***

***Findings from the Public Roads severance bank of cases have been evaluated according to the benefits or losses to landowners, and findings from 2,262 remainder sales have been analyzed on an aggregate basis for different situations. Some of the facets of the analyses pertained to the relation of estimated values of remainder sales to usage before and after severance, and whether the remainder was landlocked or located near an interchange.***

### *Introduction*

THE GAP between the availability and application of findings from severance studies—land economic studies—for acquisition of land for highway right-of-way is of concern to all highway officials. Information on the type of findings available from severance studies and suggestions as to how these findings may be of use to appraisers and others concerned with highway construction are discussed in this article. Two sources of information are analyzed: the Bureau of Public Roads bank of severance studies, which is a central file of information; and reports on 2,262 remainder sales listed in *Narrative Reports of Highway Severance Effects: Index and Summary Analysis* (hereafter referred to as the Index), distributed to Public Roads and State highway department personnel.

The gap between findings and their application has occurred primarily because appraisers and others involved in right-of-way takings sometimes do not have access to the pertinent information when they need it. Although information has been collected on approximately 5,000 sales of highway severed property, difficulties seem to arise in getting the right information to the right place at the right time.

Beginning in 1961, the Bureau of Public Roads began collecting information on the effect of taking part of a property for highway right-of-way in a severance effects bank, which now includes 3,000 cases covering 4,000 sales of remainders from these cases. In addition, narrative reports have been collected on more than 2,262 remainder sales. Approximately 40 percent of the severance cases covered by the narrative reports are now recorded in the Public Roads severance bank maintained on electronic data processing equipment. The findings from these studies were intended to be the information that would be used to determine the present and future monetary effects of partial takings of property for right-of-way. These narrative reports have been useful for other purposes such as public relations and land use planning.

Although gaps exist between findings and application of the findings, some success has been achieved in using information from these studies. For example, landlocked areas had commonly been estimated to be damaged 90 percent by severance. But severance studies have shown that such damages usually amount to only about 10 percent of the original value of the land; this finding is now being applied to right-of-way settlements. Thus, some savings in acquisition costs of right-of-way have been accomplished by more accurate estimates of the value of landlocked parcels, as shown in figure 1.

The case study approach is basic for an understanding of the effects of right-of-way acquisition and for providing information in a form that can be applied to future land acquisition appraisals. As the States have completed more studies, the size of the task of recording and filing the data so that the information can be obtained readily has become larger. To ease this task, some States and Public Roads are relying on electronic data processing equipment. When a computer is used to record data, case information can be sorted and analyzed more readily and findings on comparable case situations can be provided more quickly and easily.

Public Roads has had limited success in using the computer to locate information on comparable studies. Some requests, however, have been filled for comparable cases that could be used in current land acquisition situations. Sometimes searches of the bank have been unsuccessful because time required for programs having higher work priorities prevented an adequate search. Also, the Public Roads severance bank contains only a few of the unusual types of cases.

Obtaining findings for the severance bank on takings from properties used for special purposes is very desirable; such information would increase the effectiveness of the data bank. Some of these special purpose property uses are for roller coasters, golf courses, riding stables, schools, and churches. To make it easier to enter data in the severance bank on cases pertaining to special use properties, a shortened case study form has been developed by Public Roads; this form is compatible to the longer form now being used and to the computer programs that have been developed.

### *Conclusions*

Bridging the gap between findings from land economic studies and the application of the findings depend primarily on organization of the findings and making them available in usable form. Case studies for comparable situations can ordinarily be obtained from

[1] Presented to the Land Economic Study Conference at the 12th annual National Seminar of American Right-of-Way Association, Denver, Colo., June 7, 1966.

[2] Ruth B. Ross, Gwen Van Domelen, John Yasnowsky, Jr., and M. Donald Nolden, also contributed work on which this article was based.

State highway departments; the Bureau of Public Roads can often help locate information for unusual types of cases by use of its severance effects bank maintained on EDP or by use of the Index. Sometimes the findings from land economic studies need to be aggregated and analyzed collectively. The conclusions listed in the following statements have been based on an aggregated analysis of cases in the Public Roads severance effects bank and narrative reports.

- Land values have increased from the estimated value for about four cases out of five.
- Special characteristics have been associated with the remainders for which sales prices were more than the average estimated value. Some of these characteristics of the remainder parcel are: (1) nearness of the remainder to an interchange area; (2) remainders caused by Interstate highway takings; and (3) use of the remainder for commercial purposes.
- Owners of landlocked remainders are not damaged to the extent anticipated at the time of settlement.
- Owners of vacant property are more likely to gain more from the sale of remainders than owners of residential or agricultural properties.

## *Narrative Reports*

In addition to the nearly 4,000 sales (more than 3,000 cases) recorded in the Public Roads severance bank, approximately 2,900 narrative case studies for 2,262 remainder sales have been processed. These narrative reports have been listed and compared in *Narrative Reports of Highway Severance Effects: Index and Summary.* This Index should make it easier for an appraiser to obtain information about a comparable situation from printed studies. The appraiser can check the Index to determine whether a narrative report is available for a situation similar to his current assignment. If so, he may obtain a copy of the report from his State highway department library, the State highway department originating the study, or from the Bureau of Public Roads.

The appraiser can refer to the Index to determine whether a severance study has been made on a landlocked parcel near an interchange for which the value has been within a specified range. Or, an appraiser having an assignment concerning leaseholds would learn from the Index that severance studies involving leaseholds have been reported by Florida, Colorado, Georgia, and Illinois. Narrative reports involving severance studies for church and school properties have been made by Michigan, Texas, Nebraska, California, Florida, Kentucky, Illinois, Ohio, and others. Some other special severance studies listed in the Index include land used for a boys home, a hunting camp, a drive-in theater, a trailer park, a golf course, a zoo, a gun target range, and a dam project, a remainder selling for corporate stock, a sale of more than a million dollars, and a remainder that had a loss of a lake view.

This Index will not end the need for the Public Roads severance bank of cases as approximately half the cases in the bank have not been reported in narrative form. But the Index should make information more readily available on the 2,900 severance cases covered in narrative reports. Such information should help bridge the gap between severance effects studies and the application of the study findings.

## *Overall Analysis Needed*

Shortening the gap between study findin[gs] and application to similar situations mig[ht] also be accomplished by analyzing sever[al] studies and making the results general[ly] available. The need for such an analys[is] was stated by Rudolf Hess, of the Californ[ia] Division of Highways, before the Americ[an] Institute of Real Estate Appraisers, meeti[ng]

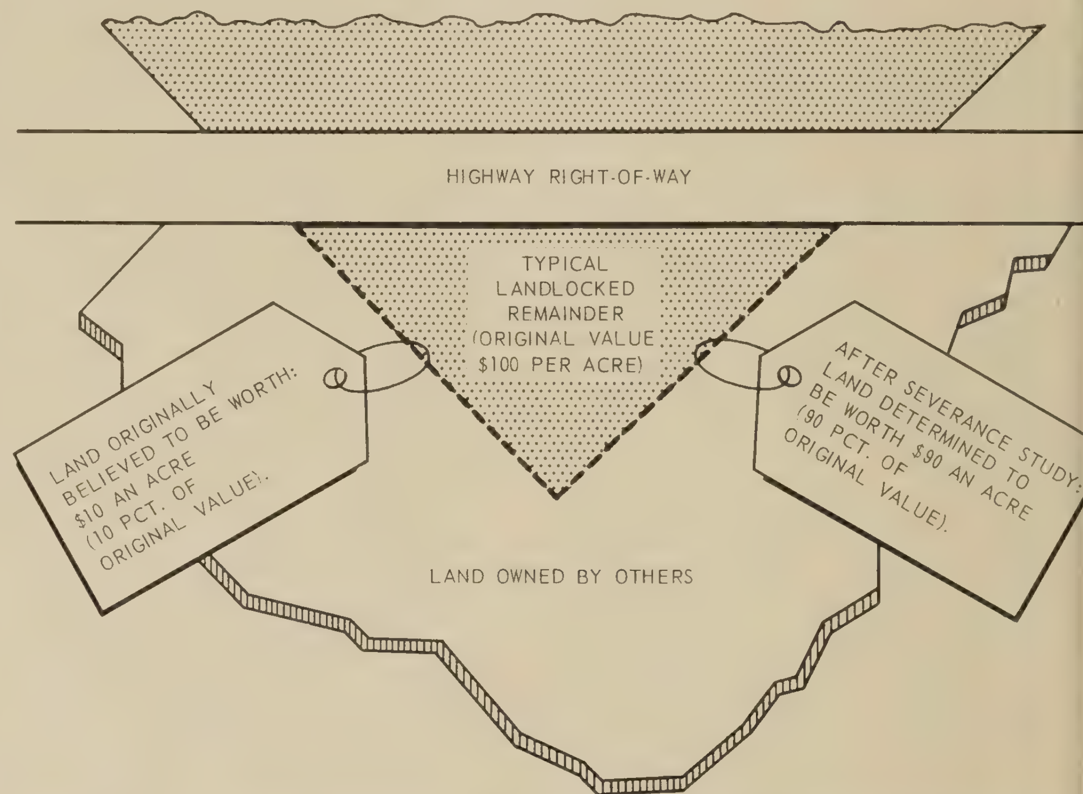



*Figure 1.—Savings possible from use of findings from studies on severance effects*

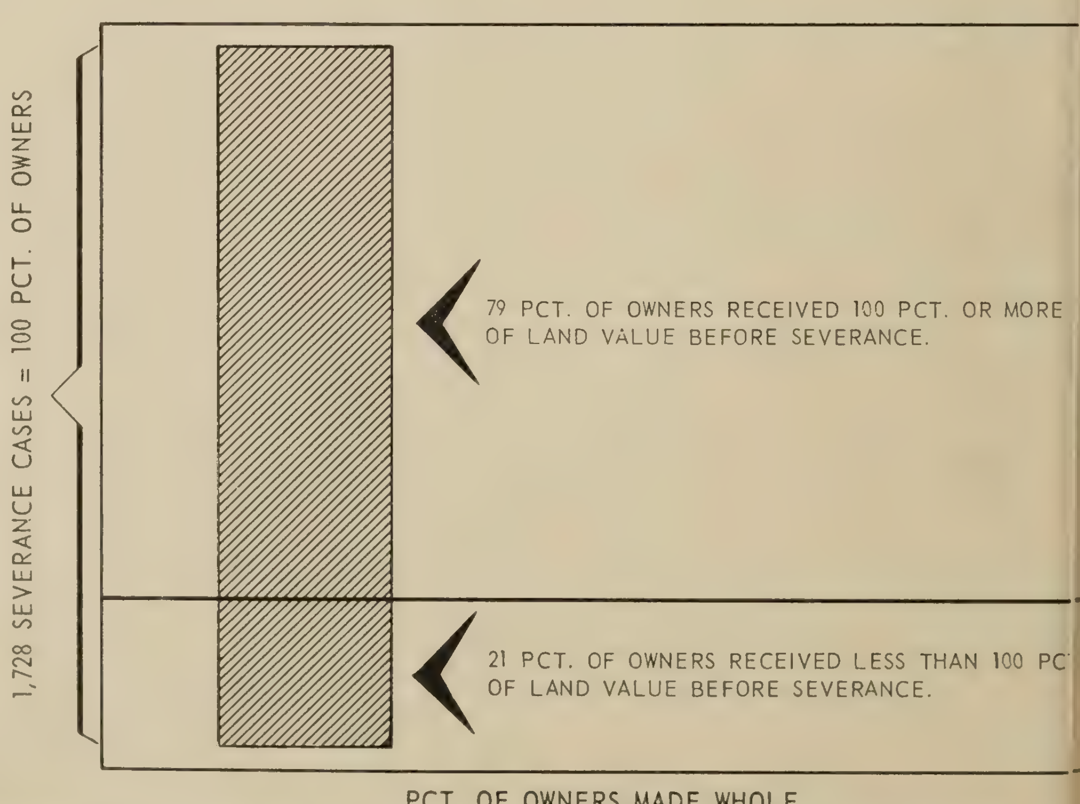


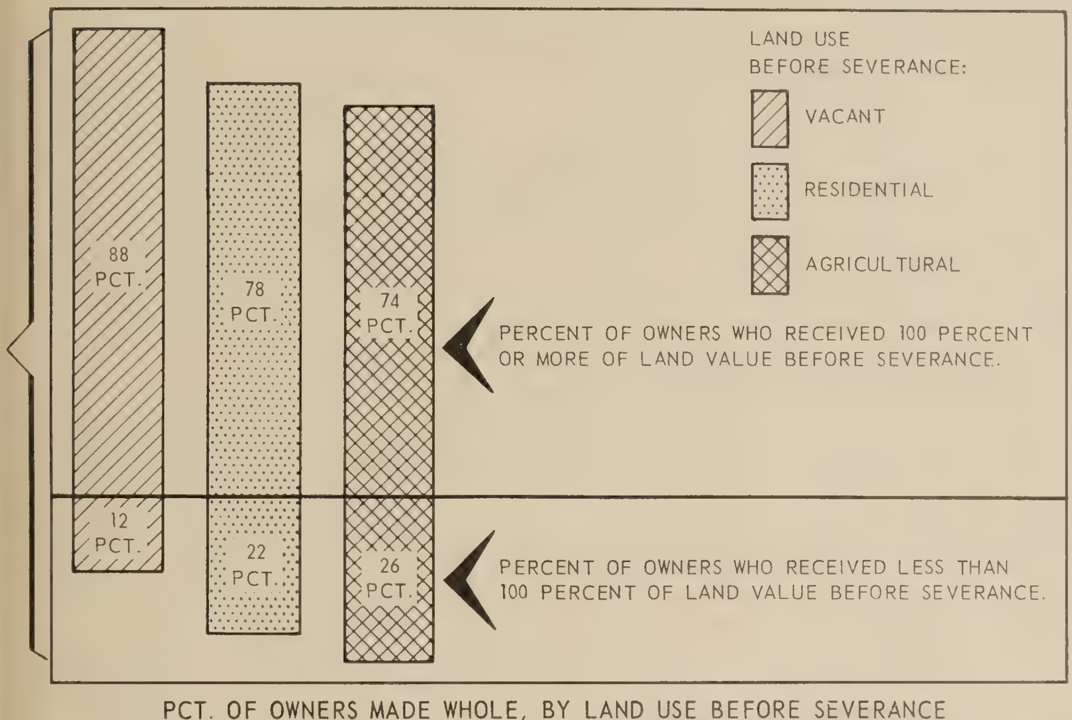

*Figure 2.—Percentage of owners made whole and percentage who lost based on 1,72[8] severance effects cases.*

Los Angeles in November 1964, as "The mainder parcel sales data collection is one the first direct research links between the ppraisal profession and land economics. he analysis of remainder parcel sales data ay provide the vehicle for a firmer marriage these two specialized areas; it may provide e means for appraisers to more conveniently nd confidently consider land economic data nd theory. Collective analysis is the key. Collective analysis is a tool of land economics. . . ."

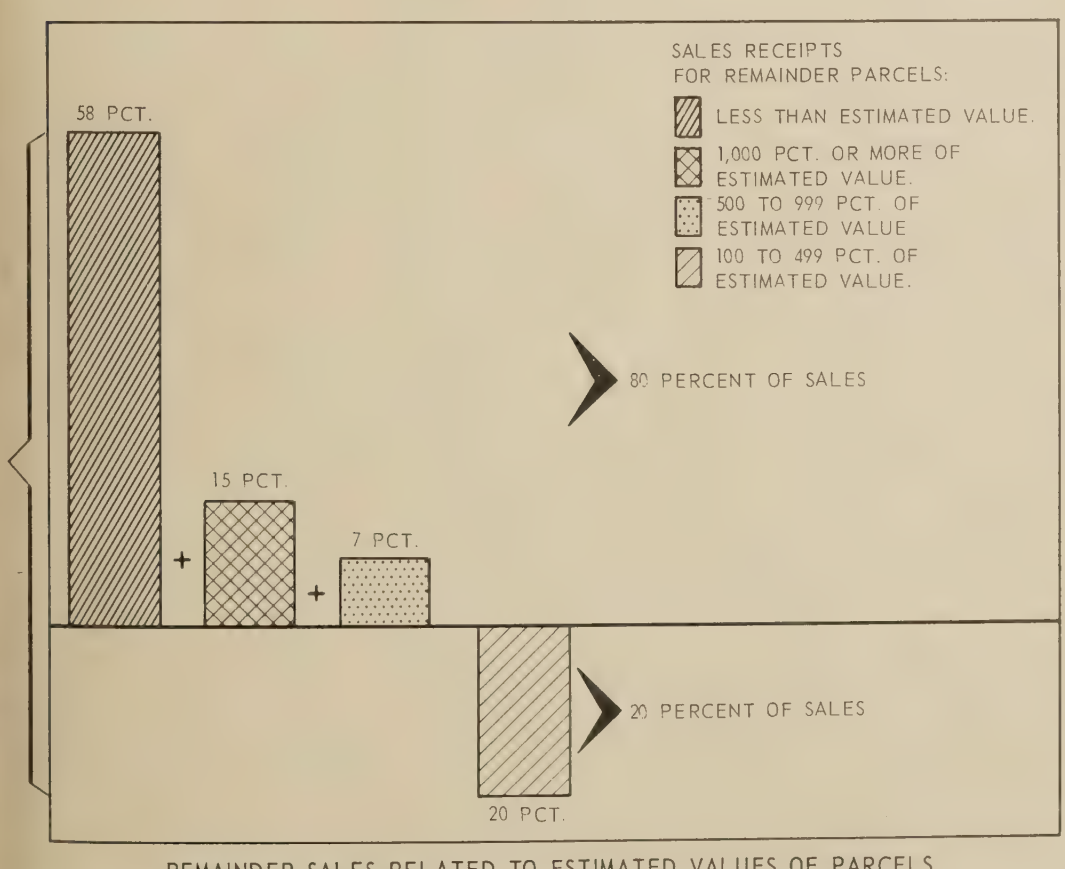
Several States have used overall analyses of severance studies. For example, A. B. Grace of the Texas Highway Department in an article, *Severance Damage Studies*, Right-of-Way, vol. 13, No. 1, February 1966, pp. 55–60, presented general findings on the Texas experience with severance studies. Mr. Grace believes that severance effects studies should not be used to ". . . advocate the development of appraisal formulas . . ." but ". . . as a source in locating comparable sales and as general information in predicting the change in use of a particular remainder."

Some analytical work has been done by Public Roads on both the 4,000 sales recorded in its severance bank of cases and the 2,262 sales for which the States have issued narrative reports. A few of the more important findings from these analyses are described here.

Findings from the Public Roads bank of severance studies and the narrative reports are very similar, as might be expected when the same case is reported in the bank and the narrative report. Approximately 60 percent of the narrative reports are for severance cases in the bank and nearly 40 percent of the cases in the bank are also reported in narrative form. The agreement of the findings from the two sources is shown by approximately the same percentage of owners (about 80 percent) receiving more than 100 percent of the original value of their land. Better than average agreement is also present in the findings concerning remainders near interchanges, remainders used for commercial purposes, and takings for Interstate highway routes.




*igure 3.—Land use before severance, by percentage of owners made whole, based on 1,728 severance effects cases.*




*igure 4.—Remainder sales and estimated values, based on 2,262 narrative reports on severance studies.*

### *Severance Bank Findings*

Many remainder parcel sales involve only a part of the remainder after a taking for highway right-of-way. When any part of the remainder has been sold, a preliminary comparison of the per acre value of the parcel sold can be made with the per acre value of the entire property at the time of severance. Such a comparison obviously cannot be conclusive; but its use makes possible a per acre comparison of the value of the part of the remainder that has been sold to the value of the entire property. The parcels that have been sold may have been more or less desirable than the entire property or the entire remainder. Such a comparison shows what happened to land values rather than to owners and does not show whether owners were benefited or damaged. However, such a comparison permits some tentative findings about highway severance effects in many situations where only part of the entire remainder has been sold. Thus a recovery rate can be determined by dividing the value per acre or per square foot of part or all of the remainder that has been sold by the per acre value at the time of the highway taking. Thus a recovery rate of more than 100 percent means that the remainder has had an increase in unit value. Conversely, when the rate is less than 100 percent, the remainder has declined in value. A recovery rate of more than 100 percent for remainder sales has been shown in most severance studies. Less than one-fourth of the remainder sales in the Public Roads bank had a recovery rate of less than 100 percent. About one-fifth had recovery rates of 500 percent or more and one-tenth had recovery rates of 1,000 percent or more.

Because of the extremely large increases in per acre values for some remainder parcels, simple arithmetic averages may not be a satisfactory summary measure of the typical recovery rate for severed land parcels. Median values provide another way of summarizing the overall recovery rate. As a median is a middle value with half of the cases above and half of them below, those remainder parcels having extremely large recovery rates do not have such a noticeable effect on median values as they do on average values. Thus, for the nearly 4,000 sales in the Public Roads severance bank of cases, the median recovery rate is 160 percent and the average value is 495 percent.

When sales of remainders are made after a lapse of time (1 year or more) after the taking, allowance should be made for general land value changes in the area. For this adjustment, an average increase in value of 7 percent per year was used for data reported here. Where this adjustment was applied, the overall median recovery rate was approximately 140 percent. For sales that are made 2, 3, or more years after the taking, recovery rates are larger than the overall recovery rate, even after the adjustment has been made for general land value increases. For example, the adjusted recovery rate for remainder parcels sold more than 3 years after the taking was nearly 170 percent. Apparently the value of remainders tends to go up more than land values generally, at least for 3 or more years following the right-of-way taking.

Comparison of the recovery rates for different types of remainders—for example, landlocked remainders—shows some significant variations. Damages to landlocked remainders previously have been estimated at 90 percent or sometimes at 100 percent. An estimate that the value of a remainder parcel will be damaged 90 percent means that the estimated recovery rate is only 10 percent. On the basis of cases in the Public Roads severance bank, such an estimate is seldom realistic. Data on the 94 landlocked cases in the bank suggest that landlocked parcels are damaged about 8 percent and that the median recovery rate for landlocked parcels is 92 percent. Landlocked remainders, however, are damaged more than other types of remainders. All types of remainders in the severance effects bank had a median recovery rate of 160 percent and an average recovery rate of 495 percent. Also more landlocked remainders are damaged—have a smaller recovery rate—than other remainders. About half of the landlocked remainders had recovery rates of less than 100 percent but only about one-fourth of the other remainders had recovery rates of less than 100 percent.

Special analysis has been made of changes in value of remainder parcels near interchanges, especially interchanges on the Interstate system. About 30 percent of the remainder cases in the Public Roads bank are located within a half mile of an interchange, a distance often used to distinguish between areas called interchange areas and noninterchange areas. As might be expected, recovery rates for remainders located within

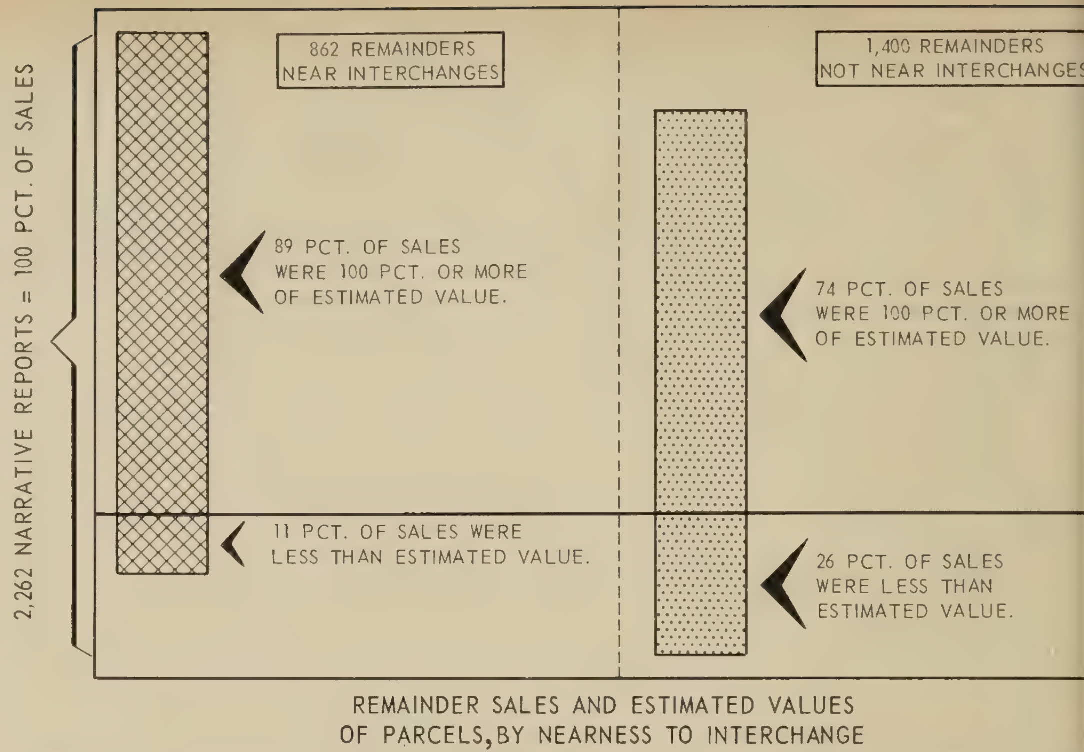



***Figure 5.—Remainder sales and estimated values by nearness of remainder to an interchange area, based on 2,262 narrative reports on severance studies.***

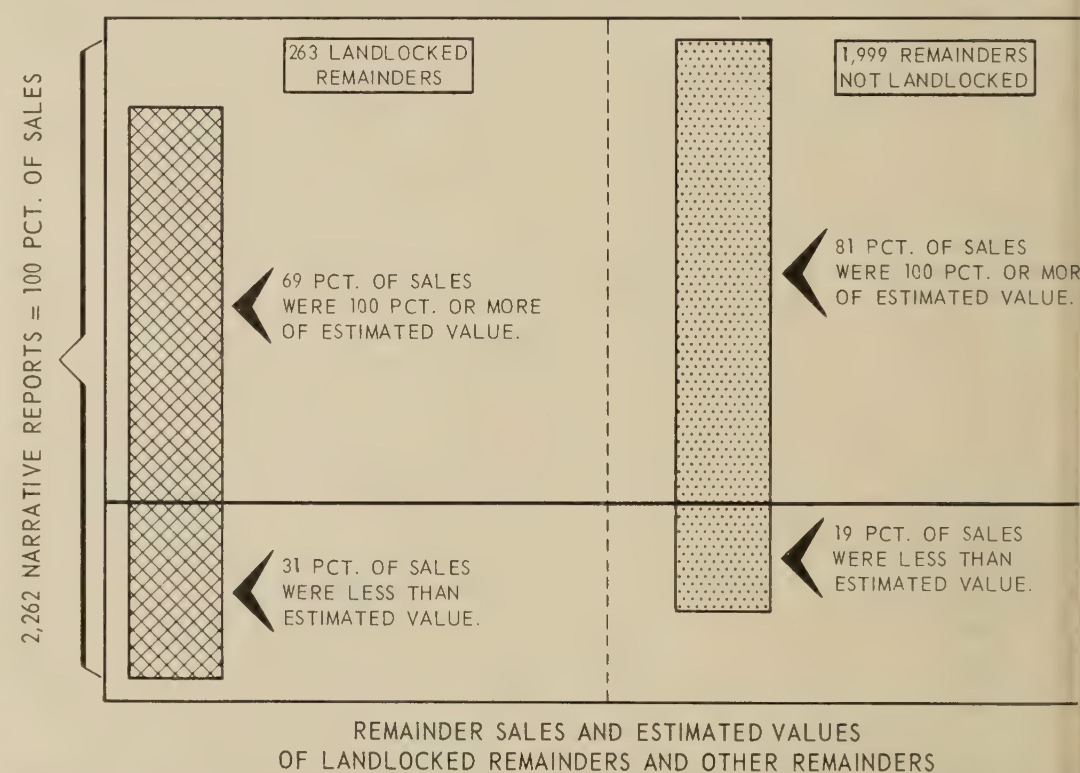



***Figure 6.—Effect of remainder being landlocked by remainder sales and estimated val[ues] based on 2,262 narrative reports on severance studies.***

a half mile of the interchange area are better than the recovery rates for comparable remainders located farther away.

## *Owners Made Whole*

The entire remainder parcel has been sold for more than 50 percent of the cases in the Public Roads severance bank. From these cases, enough facts are available for a determination as to whether the owner is in as good a position as he was before the taking for right-of-way acquisition. To make this determination information is needed on (1) value of the property before right-of-way acquisition, (2) payment to the owner [for] the part taken for the highway and estim[ated] damages to the remainder, and (3) rec[eipts] for the entire remainder. When the t[otal] receipts, for the right-of-way taken plus [the] amount received for sale of the remain[der] amount to as much as the estimated prop[erty] value before the taking, the owner ca[n be] said to have been made whole. For [the] 1,728 cases in the Public Roads bank [in] which the entire remainder has been [sold] approximately 4 out of 5 property ow[ners] were made whole. The other prop[erty] owners had less money after sale of the en[tire]

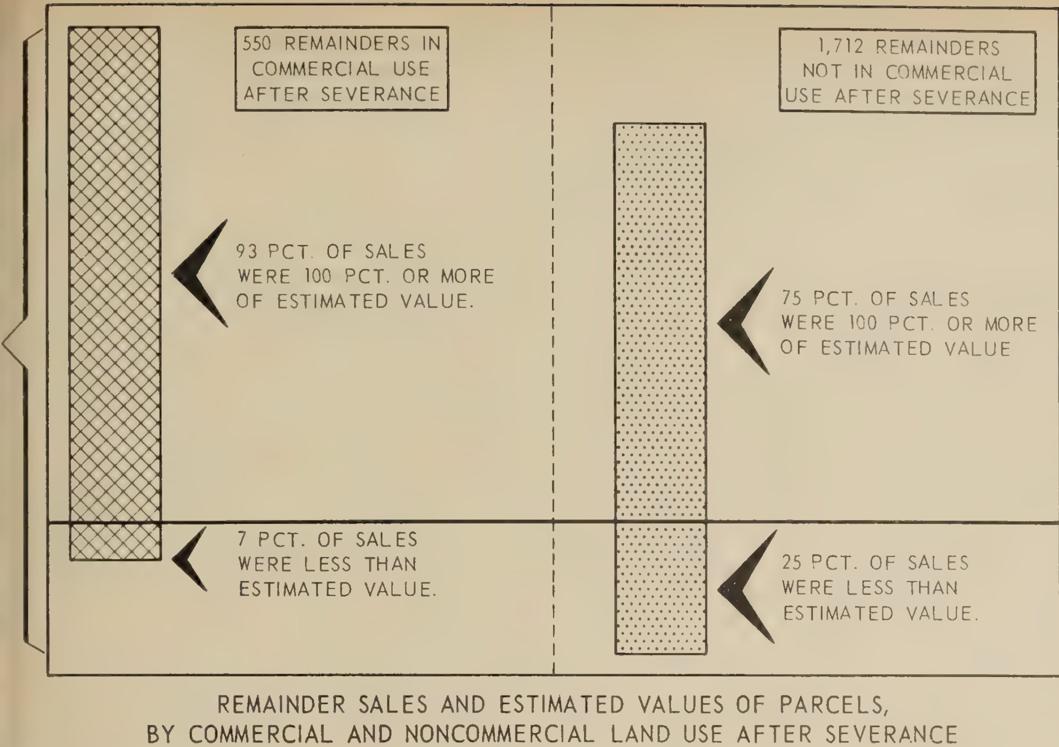



**Figure 7.—*Effect of commercial use by remainder sales and estimated values, based on 2,262 narrative reports on severance studies.***

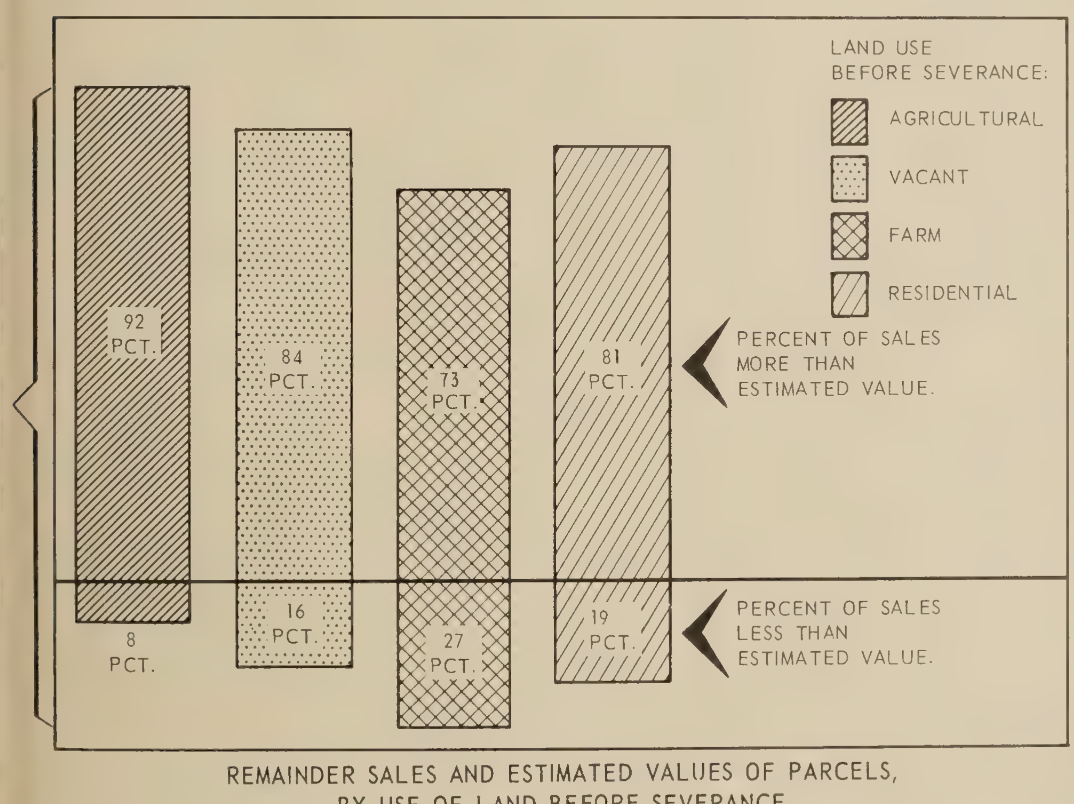



**Figure 8.—*Effect of land use before severance on remainder sales and estimated values, based on 2,262 narrative reports on severance studies.***

remainders than the value of their property at the time of severance, as shown in figure 2. Some owners received total receipts amounting to several times the worth of their property before the taking for the highway.

An analysis of the bank case data on owners not made whole—those who had receipts less than the original value of their property—shows that most of the losses were moderate. For nearly half of the owners who lost money, the loss was not more than 10 percent of the original value of the property. In 5 percent of the cases where the landowners had losses (1 percent of all sales recorded in the bank) the amount received was less than 50 percent of the original value. Efforts to close the gap between findings from severance studies and application of the findings should help prevent inadequate payments for right-of-way; this is a problem of as much concern to conscientious highway builders as excessive payments.

**Effect of land use**

Use of the property before severance, whether vacant, residential, or agricultural, affected the receipts of the owners for cases in the Public Roads bank. Owners of vacant land had receipts amounting to 135 percent of the before value of their property. Owners of residential and agricultural properties had receipts equaling 110 percent and 116 percent of the before value of their property. Owners of vacant property generally fared better than owners of residential or agricultural property. A partial explanation of the value increases of vacant land is that it is more frequently put to a more profitable after use than is residential and agricultural property.

As more experience has been gained in relation to right-of-way acquisition, the potential value of vacant property has been recognized. Data now available from the bank show that a smaller percentage of owners of vacant property—49 percent—are being paid damages than owners of agricultural and residential property—67 percent each. Latest available information on percentages of owners paid damages and the percentage having apparent losses, by land use before the highway taking are, respectively: (1) vacant, 49 percent and 12 percent; (2) agricultural, 67 percent and 26 percent; and (3) residential, 67 percent and 22 percent. Data combined for these three uses of land before the highway taking show that 61 percent of the owners were paid damages and 20 percent apparently had losses. The relation of receipts to estimated damages for these land uses before the taking is shown in figure 3.

## *Narrative Reports*

When a group of narrative reports has been assembled, analyses of the findings can be made and general comparisons noted as to which types of remainder parcels have been sold for a gain or a loss. Only a general indication of gains or losses can be obtained from aggregating narrative reports. State laws or practices differ as to the bases used for determining damage payments, the different uses of control areas, and the different methods for adjusting estimates in relation to general changes in land use. The information taken from the narrative reports permits a comparison of estimated values of remainder parcels and sales prices. Thus an indication can be obtained of the experience that owners have in relation to the sales of remainders. Generally, owners of remainder parcels that were sold for more than the estimated value can be said to have benefited. By the same reasoning, when the remainder was sold for less than its estimated value, the loss can be equated generally with a loss by the landowner.

Four-fifths of the sales reported in the 2,262 narrative cases exceeded the estimated values of the parcels sold. Also, for more than half of the narrative cases reported, sales prices exceeded the estimated values of the remainders by 50 percent or more. Large gains of 500 percent or more of the estimated value were noted for 15 percent of all narrative sales. Conversely, 20 percent of the remainder sales reported in the narrative cases were for less than the estimated value of the remainder. The relation between estimated values and remainder sales is shown in figure 4.

Nearly 900 cases for which there are narrative reports were for remainder sales for land near interchange areas. Nearly 90 percent of the remainder sales for parcels located near an interchange exceeded the estimated value of the remainder. But only about 75 percent of the remainder sales for parcels located away from an interchange area exceeded the estimated value. Also, larger gains in sales of 500 or 1,000 percent of the estimated value were more pronounced for interchange areas. This is shown in figure 5. These differences in relation to nearness to an interchange are significant at the 95 percent level of confidence.

Because of problems related to appraising the value of landlocked remainders when right-of-way for a controlled-access highway is acquired, special attention has been given to reports for this type of remainder. More than a tenth of the sales—262 of the 2,262 cases reported in narrative form—are landlocked remainder parcels. Sales for nearly a third of these remainders were less than the estimated values. At the same time, sales prices greatly exceeding estimated values are received more often for landlocked remainders than for other remainders. These findings—gains and losses for landlocked remainders in excess of those for other remainders—emphasize the problems associated with appraising landlocked remainders. The relation of sales and estimated values for remainders landlocked and those not landlocked is shown in figure 6.

Experience and logic indicate that land use and land value are positively related. Thus, if the ultimate use of a remainder can be determined at the time of the highway taking, this information can be useful in estimating the value of the remainder. For exam remainder parcels that are used for commer purposes after the severance seem to incr in value more than remainders used for o purposes. This is substantiated by the that of 550 remainders in commercial after the taking, 12 percent sold for 1 percent or more of the estimated value. A only 7 percent of the remainders used commercial purposes sold for less than estimated value, but 25 percent of the pro ties not used for commercial purposes sol less than the estimated value. These relat are shown in figure 7. The use of the prop at the time of the highway right of- acquisition also is an indicator of the pos value of the remainder. Vacant land or in commercial use is more likely to incr in value than land in residential or farm More data on such situations are show figure 8.

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## Application of Statistical Concepts to Accident Data

(*continued from p. 137*)

Office of Technical Services PB 151055, June 1958.

(*2*) *Application of Statistical Quality-Control Techniques to Analysis of Highway-Accident Data*, by Monroe L. Norden, Jesse Orlansky, and Herbert H. Jacobs, HRB Bulletin 117, Statistical Analysis of Highway Accidents, 1956, pp. 17–31.

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(*5*) *Daylight "Lights-On" Plan by Po New York Authority*, by Edmund Car Traffic Engineering, vol. 36, No. 3, Dece 1965, p. 17.

(*6*) *Technical Notes, the Effectivenes Painted Channelization*, by Ronald Failmezger, Traffic Engineering, vol. No. 5, February 1966, pp. 47–49.

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## Economic Study of Luminaire Mounting Heights

(*continued from p. 144*)

Actual installation of floodlighting systems would be necessary before the system could be fully evaluated as to effectiveness and economy. But, interchange floodlighting costs, shown in table 7, seem to be about equal to the costs of a conventional, 30-foot mounting height design. Also safety and esthetic considerations favor floodlighting because fewer poles are needed in this design. However, studies to determine the pavement brightness, glare, and effectiveness in fog or on wet pavement are needed to evaluate floodlighting or tower-lighting. Governing conditions, such as the type of property development adjacent to the highway, the highway geometrics, and the personal choice of the decision-maker, influence the cost-effectiveness evaluation of a specific lighting installation. Additional information regarding the differences in design criteria and field measurements would affect the final decision.

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### *Highways and Human Values, BPR 1966 Annual Report*

*Highways and Human Values,* the Bureau of Public Roads, U.S. Department of Commerce, annual report for fiscal year 1966, contains a review of the accomplishments of Public Roads with particular attention given to the social responsibilities inherent in the State and Federal-aid highway programs. *Highways and Human Values* is available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402, for 75 cents a copy, prepaid.

The illustrated publication points out the concern of the Bureau of Public Roads and the State highway departments for the total impact of highways on all the elements of life. A broad picture is presented of the many social values, such as highway safety and beautification, involved in the National System of Interstate and Defense Highways and other Federal-aid highway programs.

The 1966 annual report also reviews the progress of the Bureau of Public Roads in conservation and recreation and describes the highway construction in national forests, parks, and on other Federal lands that is done under the direct supervision of Public Roads. Foreign activities including construction, financing, and technical assistance are also outlined.

The revitalized interest in the human values associated with highway progress is illustrated by the change in size and presentation of the 1966 annual report; *Highways and Human Values* has been designed in both copy and format to be of more interest to the general public. Many photographs illustrate the extensive work being done by the Bureau of Public Roads to satisfy the needs of transportation as well as society. Statistical tables that cover the progress and status of the Federal-aid and allied highway programs for fiscal year 1966 are published in a supplement. The *Supplement to Highways and Human Values,* also can be purchased from the Superintendent of Documents; it is priced at 25 cents, prepaid.

### *Presplitting, A Controlled Blasti Technique for Rock Cuts*

*Presplitting, A Controlled Blasting Techni for Rock Cuts* is a 36-page research and velopment report presenting a state-of-the- summary of a relatively new control blasting technique that will be of interest State highway engineers, contractors, ma facturers, consultants, university engineer personnel, and others engaged in rock exca tion activities. The report is available fr the Superintendent of Documents, Gove ment Printing Office, Washington, D.C. 204 for 30 cents a copy, prepaid.

The findings of a staff study by the Bur of Public Roads on rock presplitting presented, particularly as they apply to hi way construction. The different field pr tices used to improve rock blasting operati are reviewed, and the use of presplitting emphasized as a method of producing smo wall surfaces that require less maintena and provide more safety during highw construction.