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A STUDY OF REFLECTORIZED LICENSE PLATES AND NIGHT ACCIDENT REDUCTION AND COST/BENEFIT ANALYSIS

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RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

A STUDY OF REFLECTORIZED LICENSE PLATES AND NIGHT ACCIDENT REDUCTION AND COST/BENEFIT ANALYSIS

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INTRODUCTION AND DISCUSSION

Over the past 25 years, there has been a half-dozen or so investigations into the effectiveness of fully reflectorized license plates. Usually, these investigations have taken place under state auspices and have interpreted "effectiveness" to mean a reduction in night, rear-end accidents. In a discussion of the literature, the term "investigation" is preferred to the term "research" because most work on potential accident reduction through plate reflectorization is more journalistic than scientific. This is not to say that these studies could not provide a basis for decision making. It is to say that the absence of tight, experimental control disallows the interpretation that observed accident reductions are uniquely the consequence of plate reflectorization. This is admitted by some authors. The point is also made in the literature critiques sponsored by interested parties such as reflective sheeting manufacturers. Reviews by academic consultants to these manufacturers usually take the position that while not conclusive on an individual basis, collectively the investigations point to a small but real accident reduction potential through reflectorization. Thus, it is generally conceded among consultants and reviewers that while no one study is definitive, the aggregated evidence establishes a favorable case for reflectorization.

> Taken as a group, the present authors feel that these seven studies provide evidence of a significant but not overwhelming safety benefit associated with reflectorized plates. To conclude to the contrary that no benefit exists requires the assumption that the accident reduction shown by all six of the studies (the Virginia study figures show a reduction in accidents, albeit not a statistically significant one in the viewpoint of the author) was in every instance artifactual, and that the behavior change measured in the Sacks study was not safety-related. An assumption of this nature, in the opinion of the present authors, cannot reasonably be defended at the present time, Hulbert and Berg (1).

At the time these reviews were written, the accident reduction investigations of Virginia, North Carolina, Minnesota, Washington, Iowa, and Maine were on record. Since then, data from Australia and Tasmania has become available and should be included in the corpus of "aggregated evidence." Some, but not all, of these investigations appear to show a small safety advantage for reflectorization. However, none of these findings were statistically significant, which is to say that the element of chance accident fluctuation could not be excluded. Technically, it is not feasible to combine these individual studies and address the question of collective statistical significance. Therefore, reviewers use a more subjective and intuitive argument, rather than a quantitative statistical one, when suggesting that the aggregated evidence supports the proposition.

Subjective evaluation of collective evidence is the usual basis of decision making since more precise and objective rationales are seldom available for complex decisions involving human behavior. In the case of plate reflectorization, reviewers who support the "bulk of evidence" point of view allude to the subjective improbability that other, uncontrolled variables explain the small favorable finding for reflectorization in the majority of investigations. While acknowledging the possibility of alternate explainations in individual cases, they suggest that it would be unlikely for a string of investigations to generally favor reflectorization unless reflectorization was really effective. On the face of it this argument is plausable. However, it should be pointed out that: a) not all investigations favor reflectorization; and, b) of those that do, many share the same research defect. Consequently, their results are open to the same alternate explainations, and the common theme argument applies here as well. This observation greatly reduces the cogency of the aggregated evidence argument since reflectorization is not the only common factor of the several studies.

Once having decided on whatever basis that reflectorization is effective, some authors and reviewers introduce a cost-benefit rationale to justify the policy of full plate reflectorization. It is pointed out that the accident reduction savings generated by reflectorized plates are greater than the additional cost of reflectorized sheeting itself. This alone, it is alleged, would justify the investment. We could not disagree more. Even if a program is cost-beneficial, one would not ordinarily impliment it if other programs offering superior benefits at the same cost were feasible. Until superior alternatives were exhausted, one would defer on a priority basis implimentation of the program in question. This is a problem in the allocation of resources toward the maximazation of some goal such as accident reduction. Thus, to improve decision making, the scope should be broadened to include all realistic alternative courses of action. This strategy is generally considered superior to cost-benefit analysis and is termed the "cost-effectiveness" approach. Our analysis of available accident accident reduction data will be based on this perspective.

Review of Literature on Accident Reduction with Reflectorized License Plates

A. "Before-After" Investigations

Both Minnesota (2) and Maine (3) compared night, rear-end accident statistics before and after introduction of reflectorized plates. Both investigations show fewer accidents of this type after introduction of the plates. Hulbert and Burg (1) in their critique concisely summarized these works and are quoted here:

The first attempt to determine whether the use of reflectorized plates led to accident reduction was carried out by Minnesota, which adopted reflectorized plates in 1956. In 1958, as reported by Baerwald, et al. (2), an analysis was made of accidents occuring in 1955 ("before") and 1957 ("after"). Accidents of all types were analyzed, and the percent change in number of accidents of each type between 1955 and 1957 was ascertained. The results showed a significant increase in total daytime accidents from 1955 to 1957 while nighttime accidents remained unchanged (total vehicle registrations increased during that period). This means that nighttime accidents represented a smaller percentage of total accidents in 1957 than they did in 1955, in contrast to nationwide figures from the National Safety Council that showed unchanged percentages from 1955 to 1957.

In addition, the Minnesota data showed a significant reduction in night rural non-intersection accidents, and a slight reduction in night rural intersection accidents. As Baerwald, et al., point out, these changes may have been a consequence of the introduction of reflectorized plates, but the evidence is only suggestive, not conclusive. In the absence of accurate information as to what other safety-related changes may have been insituted in Minnesota between 1955 and 1957, and because the percentage of night accidents in Minnesota went down steadily from 1954 to 1958, without further analysis the results of the Minnesota study thus far reported cannot be considered as convincing evidence of a safety benefit for reflectorized plates.

Another "before-after" study was conducted in Maine (3) in 1964, in which the rural accident data for the before period (1945-1949) were compared with the after period (1950-1963), and the percentage of change in each accident category calculated. The results showed that while total rural accidents increased 154. 6 percent, and rural night accidents increased 113. 8 percent, rural accidents involving a parked car decreased 14. 8 percent and rural night accidents involving a parked car decreased 57. 5 percent. Despite these impressive figures, we are faced with similar problems of interpretation as with the Minnesota data, as there was a downward trend in all rural night accidents, and we are not presented with enough data to see how other types of night accidents (e. g., head-on) fared during this period. Also, the same questions arise as to whether any other safety-related changes occurred in Maine during the period in question.

In conclusion, Hulbert and Burg state that:

> While the Maine and Minnesota studies both seem to show substantial accident reduction following introduction of reflectorized plates, before-after studies typically suffer from lack of control over other factors that may or may not have an influence on accident reduction. This shortcoming prevents such study results from being interpreted as being anything more than suggestive.

Generally, "other factors" are hopefully eliminated by careful sample selection through randomization and other statistical procedures. Even the courts, which are extremely particular about evidential quality, allow partial data or samples as legal evidence. The admission withstands objections of hearsay provided that samples are drawn in accordance with statistically sound procedure. It is not enough to present sample data or the conclusions drawn therefrom; one must demonstrate that proper statistical methodology was followed in the data acquisition process itself.

> When a sample is used to project an estimate, the burden of proof rests on the offerer to show that ... the sample was selected in accordance with accepted principles of sampling so that it appropriately represents the universe. (4)

The possibility of sample contamination with "other factors" plagues before-after accident studies, especially since long-term trends in accident statistics are commonplace. For example, Michigan data show a decline during the last decade in certain accident statistics which are relevant to the reflectorization issue. Considering night, rear-end accidents only, we find an eight-year decline in the percentage which occur at night both in general and nonintersection roadway sections (Figure 1). Had reflectorized plates been introduced in say 1970, the four-year "after" period would have shown a decline of about 27 percent. Because of the large number of accidents

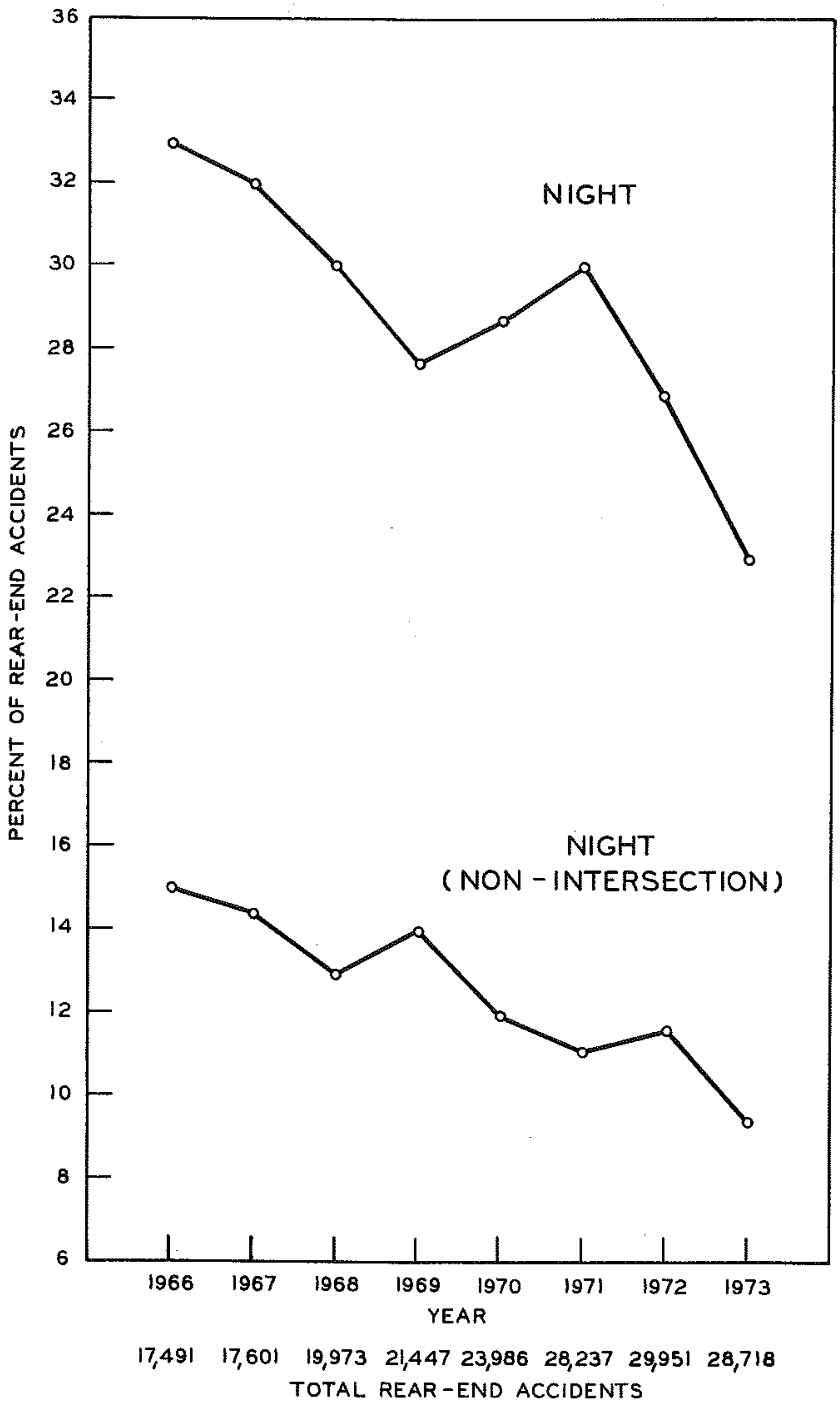

Figure 1. Michigan state trunkline accident experience excluding City of Detroit.

involved, the 3 percent decline would have been considered statistically significant and probably would have been credited to the introduction of reflectorized plates. However, since reflectorized plates were not introduced, other factors must have been responsible for the trend. Sometimes these factors are overt, as in the case of gradually improved vehicle rear-end lighting. They can also be quite subtle, as in the case of increasing daytime accident exposure following the growth of two and three car families.

The Minnesota statistics pertained to deaths from night, rear-end accidents only. Deaths from this type of accident are relatively infrequent (In 1974 they constituted about 5 percent of all highway falatities in Michigan), and consequently present an unreliable statistic. In the Minnesota study, the reduction in fatalities would have to be substantial in order to produce statistical significance. The Minnesota data are not available for this determination. Moreover, during the study of both the Minnesota and Maine Departments, all nightime accidents decreased; not just rear-end. This fact alone suggests that other, more general causes are at work which tend to reduce head-on, fixed object, etc., as well as rear-end accidents. Therefore, it is difficult to maintain that the use of reflectorized license plates in Minnesota and Maine are uniquely responsible for the observed reduction in accident statistics.

B. Non-Randomized Simultaneous Investigations.

Simultaneous studies are inherently superior to "before and after" studies because they eliminate the interference of extraneous time trends in the data. If there are time trends, presumeably they affect experimental (reflectorized plates) and control (non-reflectorized plates) groups equally and one can still measure any differential effects on accident statistics due to the introduction of the experimental variable. In addition, good design procedures require that simultaneous studies randomize the allocation of experimental and control treatments to the individuals in the study sample. For example, one cannot merely pass out reflectorized plates on a first come, first served basis. If this is done, one runs the substantial risk of introducing into the experiment human behavioral proclivities and thereby biasing the results. In fact, under these conditions, no statistical significance testing is legitimate since these tests generally assume that samples are selected randomly. This point is absolutely fundamental and is succinctly elaborated by Hulbert and Burg in their review of the Iowa study (5).

> Reflectorized license plates were issued to some 60,000 vehicle registrants, until the supply was exhausted; the remaining registrants, representing some 39.9 percent of the total of 99,831 vehicle registrations, received conventional plates. Subsequent accident data showed that while 61.1 percent of the registered vehicles had reflectorized plates, only 23.3 percent of the parked cars involved in rear-end nighttime accidents had reflectorized plates. The Iowa study used simultaneous study of the accident experience of reflectorized and non-reflectorized groups, a much more powerful design than the "before-after" approach used in Minnesota, and thus the results are more compelling. However, caution must be used in interpreting the Iowa results because of the way in which the reflectorized plates were distributed — on a first-come basis. It is possible that that there were important accident-related differences between people who purchased their plates early and those who bought them later (after the supply of reflectorized plates was exhausted). This question could and should have been resolved by conducting an analysis of the personal and driving record characteristics of the drivers (registered owners) in the two groups. Even had this been done, we still would not have been positive that the 61.1/39.9 split of reflectorized/conventional plates in the population also represented the split for nighttime parked cars. In addition, as with most studies involving driving records, there is a question of how "pure" the criterion data are, due to inadequacies of the accident reporting/encoding/storage process. For example, it is not known how many parked cars were hit by drunk drivers, drivers falling asleep at the wheel, drivers swerving to avoid an obstacle, and so on. Despite these drawbacks, however, the Iowa study remains a strong one.

The same problem occurs in the North Carolina study (6) where the public was allowed to obtain reflectorized plates on a demand basis during a change over period of six weeks. Again Hulbert and Burg remark:

> (The North Carolina) effort was an attempt at a simultaneous study of reflectorized and non-reflectorized groups, but suffered from the fact that the study could not be set up properly in advance. Campbell and Rouse fully acknowledge the shortcomings of their study, and are very cautious in interpreting their data. The accident data analyzed were from a six-week period early in 1967, during which there was a changeover in North Carolina from conventional to reflectorized plates and either one could be used legally. Accident-involved cars with and without reflectorized plates were compared during this period; however, the study design suffered from two problems. First of all, there was no plan for distribution of reflectorized plates during the six-week period, so it could not be determined whether there were any significant differences in composition between the reflectorized and non-reflectorized groups. Secondly, it could not be ascertained whether the two groups were equal in their exposure to night accidents during the six-week period. The latter is a problem common to all studies conducted to date, however.
>
> Campbell and Rouse made an attempt to compensate for these shortcomings by comparing daytime as well as nighttime accidents, and rear-end vs. non-rear-end accidents. Their data included 1,362 rear-end collisions and 2,096 other collisions, and the breakdowns indicate that whether or not the striking car had reflectorized plates, reflectorized vehicles constituted a smaller percentage of the struck vehicles than did vehicles with conventional plates. Using a one-tailed test of significance (which is entirely appropriate in studying reflectorized plates since there is no reason to anticipate an increase in accidents attributable to the use of such plates), Campbell and Rouse find the differences in favor of reflectorized plates to be of borderline significance. That is, the probability that the differences occurred by chance does not quite meet the .05 level commonly used; however, as is pointed out later in this paper, it has not been uncommon to use a less stringent criterion, such as the .10 level, to assess the significance of results in behavioral research.
>
> Campbell and Rouse conclude that "In summary, the data support the primary hypothesis, that reflectorized plates are effective in reducing nighttime rear-end collisions. Reasonable alternatives were examined, but the alternatives were not supported by the data." (p. 14) They go on to estimate that this reduction would amount to some 13 percent, or about twice the amount necessary to offset the costs of the reflectorization process.

Both the Iowa and North Carolina studies are sensitive to the possibility that the kind of people who purchase license plates early in the changeover period are less accident prone. A weak correlation of this type could easily explain the small differences in accident statistics. Thus, reflectorized vehicles in both the Iowa and North Carolina studies may experience less accident involvement than non-reflectorized vehicles because the latter group, for economic reasons, may experience more nighttime street parking. Also, nighttime rear-end accidents may involve more intoxicated drivers who, for economic reasons, typically obtain plates late in the changeover period and also tend not to drink in the relative safety of the home. It is commonly known that drinking style (what, where, and how much) is associated with family income. In addition, if income is associated with when people choose to purchase plates, then those who delayed purchase in Iowa and North Carolina may constitute a high risk group and ultimately experience more accidents of every kind or nighttime, rear-end only.

In research investigations where human behavior is an important factor, subtle, indirect correlations such as the one just discussed can shape or even dominate the research results. This is why randomization is so important; it greatly reduces the chances of unwanted factors creeping in and contaminating the study findings.

The North Carolina study itself contains evidence that a more general social behavior hypothesis is warranted. Consider Table 1. The North Carolina researchers point to the finding that Group 2 is struck less at night than Group 1, and that Group 4 is struck less at night than Group 3. This they interpret to mean that reflectorized plates are responsible for the reduced nighttime accident proportions of these groups.

TABLE 1

Various Reflectorization Accident Categories and their Nighttime, Rear-End Accident Experience; North Carolina Data

Group No.	Status of Striking Vehicle	Status of Struck Vehicle	Proportion of Collisions Which Occur at Night
1	Unreflectorized	Unreflectorized	0.351
2	Unreflectorized	Reflectorized	0.313
3	Reflectorized	Unreflectorized	0.327
4	Reflectorized	Reflectorized	0.269

Table I also reveals that Groups 2 and 3 have comparable night, rear-end accident experience. Thus, reflectorized vehicles are struck by unreflectorized vehicles about as much as unreflectorized are struck by reflectorized (0.313 compared to 0.327). From these data, one cannot conclude that the plate status of the struck vehicle is relevant to the probability of a night, rear-end collision.

The hypothesis which explains the accident experience of all groups in the North Carolina study is that while reflectorized vehicles tend to be involved in relatively fewer night, rear-end collisions, it does not matter whether or not they are striking or struck and hence the reflectorized group is less accident prone per se. We shall proceed with this as a hypothesis and see how closely we can reconstruct the study results. If the probability of an unreflectorized vehicle striking another unreflectorized vehicle in the rear at night is 0.351, then the probability of an unreflectorized vehicle being involved in a night, rear-end collision is $\sqrt{0.351} = 0.594$. Similarly, if the probability of a reflectorized vehicle striking another reflectorized vehicle in the rear at night is 0.269, then the probability of a reflectorized vehicle being involved in a night, rear-end collision is $\sqrt{0.269} = 0.518$. This is what we would calculate under the general social behavior hypothesis. A test of the reasonableness of this hypothesis is the resulting accuracy in estimating heterogeneous crashes (one vehicle reflectorized and the other not). Multiplying the reflectorized and the unreflectorized probabilities we find that 0.594 x 0.518 = 0.308. This the predicted probability of either a reflectorized vehicle striking an unreflectorized one or an unreflectorized vehicle striking a reflectorized one. From the North Carolina data, we pool the heterogeneous accidents and find that the probability of either a reflectorized vehicle striking an unreflectorized one or vice-versa is:

$$\frac{0.313 + 0.327}{2} = 0.320$$

This is reasonably close to the predicted value of 0.308 computed under the general hypothesis of unequal risk groups.

The above calculations were intended to provide a rough, intuitive estimate of the validity of the hypothesis of unequal sample risk groups. A more exact least squares fit to the general behavioral hypothesis was conducted and gave the estimates of night, rear-end accidents shown in Table 2.

TABLE 2

Predicted (Numerator) vs Actual (Denominator) Night, Rear-End Accident Incidence for Reflectorized and Non-Reflectorized Groups Under the General Behavioral Hypothesis (North Carolina Data)

Status of Striking Vehicle	Status of Struck Vehicle	
	Reflectorized	Non-Reflectorized
Reflectorized	$\frac{72}{72}$	$\frac{82}{87}$
Non-Reflectorized	$\frac{86}{87}$	$\frac{193}{193}$

Sum of absolute differences between actual and predicted accidents = 6.

Table 3 shows the predicted accident incidence under the hypothesis that the reflectorization status of the vehicle is the controlling variable.

TABLE 3

Predicted (Numerator) vs Actual (Denominator) Night, Rear-End Accident Incidence for Reflectorized and Non-Reflectorized Groups Under the Reflectorization Hypothesis (North Carolina Data)

Status of Striking Vehicle	Status of Struck Vehicle	
	Reflectorized	Non-Reflectorized
Reflectorized	$\frac{78}{72}$	$\frac{91}{87}$
Non-Reflectorized	$\frac{81}{87}$	$\frac{189}{193}$

Sum of absolute differences between actual and predicted accidents = 20.

We note that the general behavioral hypothesis of different accident risk groups resulting from demand purchasing of reflectorized plates predicts the North Carolina accident incidence more accurately (residual error = 6) than the reflectorization hypothesis (residual error = 20). Under these circumstances, it would be difficult to prefer the reflectorization hypothesis since it produces more error in the predication process.

Since all of the North Carolina data tend to support the more general behavioral hypothesis, it is to be preferred over the more narrow reflectorization hypothesis which is consistent with only part of the data set. Thus, the North Carolina data do little to show a safety advantage for reflectorized plates, however, they do demonstrate the pitfalls that bedevil a non-randomized research design.

Only two extraneous factors are needed to explain the apparent accident reduction potential of reflectorized plates discussed previously:

1. Either night accidents have been declining as a percentage of total accidents or
2. People who purchase license plates early in the changeover period tend to be involved in fewer accidents at night.

These are both very realistic hypotheses in terms of what is known of social behavior and long-term trends in accident statistics.

C. Randomized Simultaneous Investigations: Australia and Tasmania.

In 1975, data from Australia and Tasmania became available. As with the North Carolina investigation, the accident statistics were compiled for the samples during the change-over period. Thus, during the survey period, both reflectorized and non-reflectorized vehicles were on the road in proportions which depended upon how much time had elapsed since the onset of the change-over period. However, in contrast to Iowa and North Carolina, these investigations may be considered to have randomly allocated reflectorized plates since there was no choice as to the purchase date of the new plates. New plates were issued only on the vehicle registration date aniversary — a procedure which should prevent biases from entering the study group.

In the Australian and Tasmanian report (7) the authors correctly decide to consider only night, rear-end accidents for which one vehicle had reflectorized plates and the other did not. Thus we have two possibilities: 1) a reflectorized vehicle strikes a non-reflectorized vehicle; and, 2) a non-reflectorized vehicle strikes a reflectorized vehicle. If reflectorization is effective in reducing night, rear-end accidents, a greater proportion of reflectorized vehicles should strike non-reflectorized vehicles than vice-versa. The combined Australian and Tasmanian data show that slightly more (4) reflectorized vehicles were struck. Therefore, the authors conclude that there was no evidence to support the conclusion that reflectorized plates reduce night, rear-end accidents.

Of the investigations thus far discussed, the Australian and Tasmanian experiment designs are the most satisfactory since they probably eliminate the influence of extraneous factors. However, the data set was small (1315 collisions) so that no definitive conclusion is possible.

The largest and most conceptually thorough of all the investigations to date is that conducted by Virginia (8). The accident experience of 100,000 without reflectorized plates and 100,000 with reflectorized plates were compared. All vehicles were selected in a manner intended to guarantee random allocation of the reflectorized plates. From this study group, it was found that during the study year (497) non-reflectorized vehicles were involved in night, rear-end accidents while 475 reflectorized vehicles shared the same fate. The difference of 22 was not considered statistically significant by the author.

Most of the controversy over the Virginia report concerns its finding that the difference of 22 accidents between the two groups was not statistically significant at the 0.05 level. Critics (1, 9), while not able to show that the difference **is** statistically significant at 0.05, disagree with the formulation of the research hypothesis. The validity of this criticism notwithstanding, the Virginia report fails to find anything other than a small difference in the accident experience of the two groups. Some critics argue that *if* this difference is real (it would have been considered real if statistical significance had been demonstrated) the effect is large enough to warrant reflectorized plates on a cost-benefit basis (10, 11). This conclusion is based on a cost-benefit analysis in which the cost of reflectorization is compared with the cost of accidents presumeably prevented with plate reflectorization. The conclusions are particularly sensitive to the cost inputs; a point which engenders considerable controversy. Most of the criticisms of the Virginia study become irrelevant if we *assume* the accident difference of 22 to be real and then proceed to a cost-effectiveness study of this benefit. Cost-effectiveness is the superior decision basis since it does not evaluate a fatality or injury in dollars. It merely compares the costs of various programs in achieving the same accident reduction benefit.

COST - EFFECTIVENESS

In discussing Cost-effectiveness, Campbell and Rouse (6), who support plate reflectorization programs, say:

> Some may rightfully object to this advance cost procedure on the grounds that almost any outcome can be forced, depending solely on the estimated dollar cost for a fatal accident. How can one go about setting a dollar value on a human life ? The answer is of course, that one cannot. Therefore, cost-benefits analysis is best in choosing between two programs. (cost effectiveness)
>
> Suppose that state planners must choose between two programs each of which must produce a 10% accident reduction to "break even." If one program actually produces an 8% reduction and the other produces only a 5% reduction, then obviously the latter program should give way to the former. In this comparative situation, there is no need to try to place a dollar value on agony or grief, it is only necessary to assume that the same values apply (whatever they are) in each case, and therefore, the program that returns the greatest portion of the dollar investment is also one that gives the greatest return in preserving the incalculable value of human lives.

Also, in his discussion of roadside safety programs, Glennon (12) states that,

> A highway department administrator who is faced with the arduous task of improving roadside safety on a statewide basis must make decisions on the nature of the roadside environment desired, while he is subjected to constraints that affect his decisions. Generally the principal constraint is that of limited funds. With no funding limitations the administrator would certainly provide a flat roadside free of rigid objects close to the edge of the traveled way. In this situation, the administrator has few decision-making problems. In the real world, however, the administrator rarely works with unlimited funds. Therefore, he strives for a strategy that allows the greatest benefits with available funds.
>
> The basis of cost-effectiveness analysis is that alternative methods are available for reaching an objective, and each alternative requires resources and produces benefits. A cost-effectiveness analysis systematically examines costs and effectiveness (using some dimensional measure) of alternative methods for accomplishing the objective.

For the sake of argument, we shall assume that the night, rear-end accident differences between reflectorized and non-reflectorized simultaneous samples are "real," i.e., that they are not artifacts of statistical fluctuation and represent authentic accident rates which can be expected with a reflectorization program. This approach sidesteps much of the criticism of the Virginia study since it does not raise the issue of statistical significance. Simultaneous samples are selected because they should be free of the influence of the possible time trends previously discussed. In the case of the North Carolina study, the accident statistics which pertain to one vehicle reflectorized and one not are also included since these data should be free of any bias contributions due to social behavior in plate purchasing. Thus, we pool all data from Virginia, Australia, Tasmania and part of North Carolina for a cost-effectiveness study assuming that these data are indicative of effects of plate reflectorization (Table 4). For cost-effectiveness purposes, we will compare plate reflectorization with: 1) two to three lane widening, 2) four to five lane widening, and, 3) high accident intersection skid proofing from both an experience and theoretical point of view.

TABLE 4

Yearly Nightime, Rear-End Accidents

Study	Control Group (No Reflectorized License Plates)	Experimental Group Reflectorized License Plates)	Difference (Control — Experimental)
Virginia (1971)	497	475	22
North Carolina (1968)	87	87	0
Australia (1975)	58	55	3
Tasmania (1975)	42	49	-7
Total	684	666	18

$\frac{18}{684}$ = 2.63 percent estimated reduction in accidents with reflectorized plates.

Cost - Benefit Analysis of Fully-Reflectorized License Plates

Assuming observed effects are "real" the Virginia, North Carolina, Australia and Tasmania data are combined to estimate the reduction in night, rear-end accidents attributable to fully reflectorized plates*. It should be recalled that the Virginia data are generated from a completely randomized statistical design. This was not true of any of the other studies. However, North Carolina, Australia, and Tasmania data were used when they pertained to populations for which one vehicle in a night, rear-end collision was reflectorized and the other was not. This particular data subset should not be subject to potential biasing effects of non-random time and space distributions of reflectorized plates to motorists in the experimental and control groups.

Estimation of Night, Rear-End Accidents in Michigan

For 1974 state trunklines only, we find that 33.9 percent of all accidents occur at night. Further, we find that 26.8 percent of all accidents are rear-ends. Assuming no night, rear-end interaction, we estimate that 9.08 percent of all accidents are night, rear-end. In 1974, there were 324,763 total reported accidents in Michigan for all road systems. Therefore, we estimate 29,505 were night, rear-end, of which 2.63 percent, or 776, conceivably could have been prevented had vehicles been equiped with reflectorized plates. For a three year plate, this amounts to 2,328 accidents assuming no degradation of plate effectiveness.

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*Data from the other studies were not included because of either the non-random manner in which they were collected or the potential interference of trends in "before-after" comparisons.

Estimation of the Number of Potentially Preventable Accidents per $10,000 of Reflectorization Investment.

In 1974 there were 9,138,634 license plates issued. Each plate would require about 0.5 square feet of reflectorized sheeting. At an estimated cost in 1976 dollars of about $1.00 per square foot for a No. 2 grade sheeting, a three-year reflectorized plate issue would add about $4,569,317 in additional plate production cost. This does not take into account equipment capitalization and maintena ce. If over a three-year plate life a $4,569,317 reflectorization investment could prevent 2,328 accidents, we find that $10,000 could prevent about five accidents on a proportionate basis.

Cost - Benefit Analysis for Intersection Two to Three Lane Widening.

1.	Number of Projects Improved	17
2.	Yearly Accidents Reported Before Improvement	140
3.	Yearly Accidents Reported after Improvement	89
4.	Before - After Reported Accident Difference per Year	51
5.	Adjusted Before - After Reported Accident Difference per Year*	40
6.	Benefit Lifetime in Years	20/60**
7.	Estimated Benefit Life Accident Reduction Assuming no Growth in Traffic	800/2400
8.	Total Project Cost in 1965-1970 Dollars	468,000
9.	Estimated Total Cost in 1976 Dollars Assuming 10% Annual Inflation	1,005,000
10.	Estimated Accident Reduction Over Program Life per $10,000 Investment of 1976 Dollars	8.0/24.0

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*For technical statistical reasons, the reported before-after difference is considered an optimistic estimate. Consequently, a reduction of 20 percent in accident benefit was made for correction purposes.

**Calculated for 20 year and 60 year anticipated service life.

Cost - Benefit Analysis for Four to Five Lane Widening.

1.	Number of Projects Improved	13
2.	Yearly Accidents Reported Before Improvement	405
3.	Yearly Accidents Reported After Improvement	303
4.	Before-After Reported Accident Difference per Year	102
5.	Adjusted Before-After Reported Accident Difference per Year*	82
6.	Benefit Lifetime in Years	20/60
7.	Estimated Benefit Life Accident Reduction Assuming no Growth in Traffic	1640/4920
8.	Total Project Cost in 1965-1970 Dollars	1,268,000
9.	Estimated Total Cost in 1976 Dollars Assuming 10% Annual Inflation	2,738,000
10.	Estimated Accident Reduction over Program Life per $10,000 Investment of 1976 Dollars	6.0/18.0

*For technical statistical reasons, the reported before-after difference is considered an optimistic estimate. Consequently, a reduction of 20 percent in accident benefit was made for correction purposes.

Cost - Benefit Analysis for High Accident Intersection Resurfacing

1.	Number of Projects Improved	124
2.	Yearly Accidents Reported Before Improvement	4193
3.	Yearly Accidents Reported After Improvement	3689
4.	Before - After Reported Accident Difference Per Year	504
5.	Adjusted Before - After Reported Accident Difference*	403
6.	Benefit Lifetime in Years	5
7.	Estimated Benefit Life Accident Reduction Assuming no Growth in Traffic**	1007
8.	Estimated Total Cost of the 124 Projects in 1976 Dollars***	1,140000
9.	Estimated Accident Reduction Over Program Life per $10,000 Investment of 1976 Dollars	8.6

*For technical statistical reasons, the reported before-after difference is considered an optimistic estimate. Consequently, a reduction of 20 percent accident benefit was made for correction purposes.

**Assuming also a five year linear decline in the resurfacing skid coefficient.

***Assumes 1,000 lin ft of resurfacing of 2.3 lanes, each 12 ft wide at $3.00 per sq yd on a multiple project bid basis.

Cost - Benefit Analysis of High Accident Intersection Resurfacing Using a Wet Accident Prediction Model.

In 1974 there were 53,000 reported intersection accidents on the state Trunkline system of which about 200 were fatal and 15,000 involved injury. This is in contrast to night, rear-end accidents which in 1974 amounted to about 6,000 on the Trunkline system. An estimated 18 of these were fatal and about 2,500 involved injury. Because intersection accidents are so numerous, it is important that intersection safety programs receive special attention. For this purpose an intersection wet surface accident model has been developed by the Department. It is based on a mathematical relationship between surface friction (skid number), local wet time computed from rainfall, and intersection hazard as measured by dry surface accident statistics. Use of this model in a second cost - benefit analysis of intersection resurfacing is presented for comparison purposes with the preceding analysis.

From the 1974 high accident intersection lists compiled by the Department, 31 locations were selected. These selections averaged 4.7 lanes and each had a skid coefficient equal to or less than 0.35. Using local weather data, together with typical resurfacing skid coefficients and monthly dry surface accident totals, wet accident incidence was estimated using the following wet intersection prediction model:

$$\left(\frac{WA}{TA}\right)_i = \left[\theta_{1i} \left(\frac{WH}{TH}\right)_i\right]^{\theta_{2i}(\mu^3 - \mu) + \theta_{3i}(\mu^2 - \mu) + \mu}$$

where $\left(\frac{WH}{TH}\right)_i$ is the wet accident percentage for month i,

$\left(\frac{WH}{TH}\right)_i$ is the wet hour percentage for month i and μ is the average intersection skid coefficient taken in the wheel trakes. The $\Theta's$ are fitting parameters computed for each month.

The model has been developed from an analysis of approximately 40,000 intersection accidents in Michigan over a period of 11 years. With this data set it has been demonstrated that the model has statistically significant prediction power.

Resurfacing Using Sand - Asphalt Mixes

Sand - Asphalt mixes are common resurfacing materials for which skid coefficient time histories are readily available (Figure 2). Depending on the traffic volume, the skid coefficient of this resurfacing material should provide accident reduction benefits for about five years. The sand-asphalt resurfacing skid coefficient time history, together with dry surface accident statistics and local wetness data provided the data input for the model. Over a five year period, the model predicted an accident reduction of about 600 for the 31 locations if they were resurfaced with sand-asphalt mixes. Table 5 summarizes the accident and cost estimates. Also presented in Table 5 is an analysis of accident reduction benefits using a sandstone resurfacing aggregate. This is a less common material and the skid coefficient time history may be unrealistic because of relatively low traffic volumes through the intersections chosen for resurfacing. Nevertheless it is presented to show that judicious selection of materials may improve intersection resurfacing benefits over those presently obtained with sand-asphalt mixes.

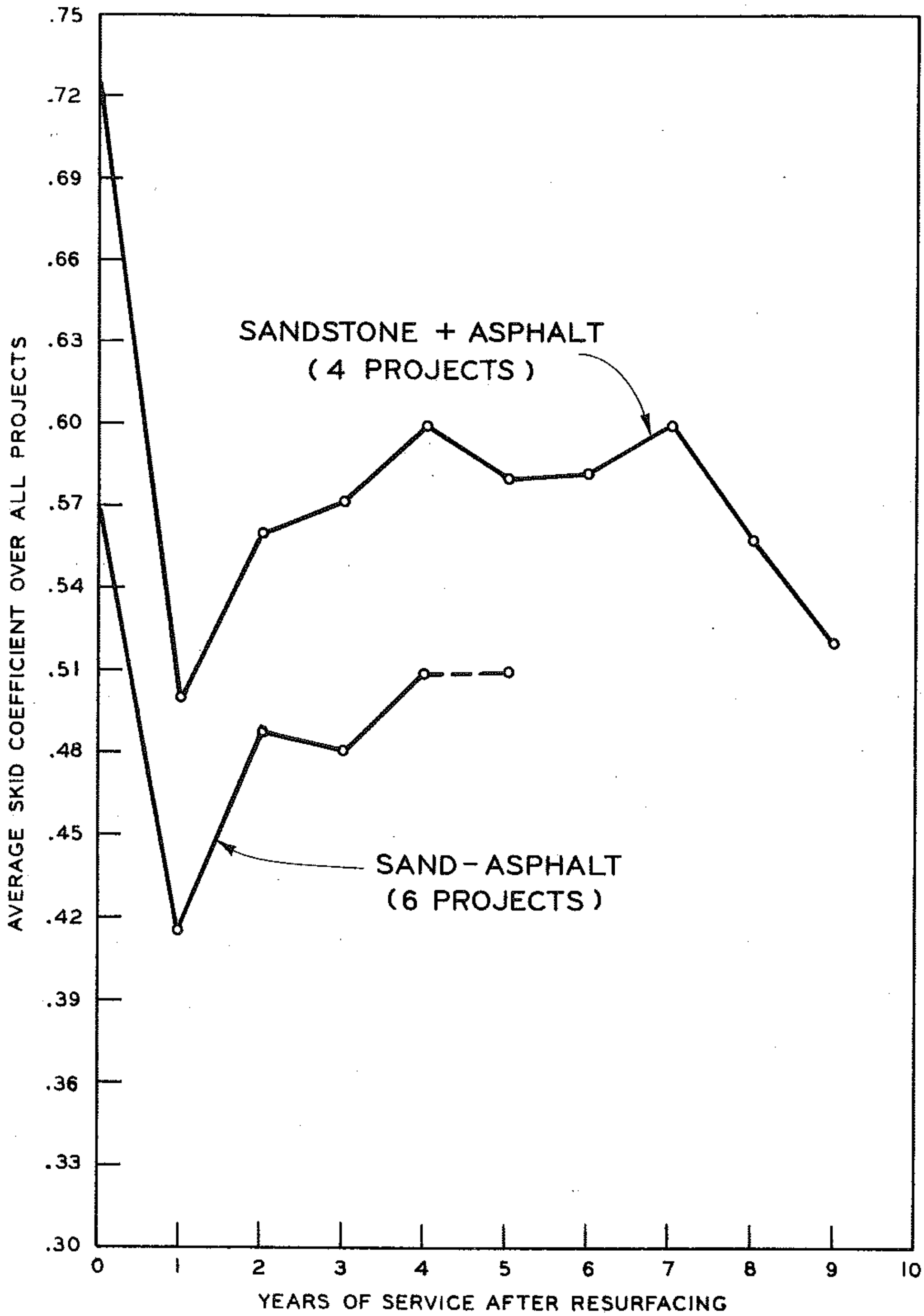

Figure 2. Skid coefficient histories of two resurfacing materials.

TABLE 5

High Accident Resurfacing Using
Accident Prediction Model

	Sand-Asphalt	Sandstone
Number of Projects Improved	31	31
Five-Year Wet Surface Accident Total With no Resurfacing (Model Estimate)	2,200	2,200
Five-Year Wet Surface Accident Total After Resurfacing (Model Estimate)	1,600	400
Estimated Benefit - Life Accident Reduction	600	1,800
Benefit Lifetime, Years	5	9
Average Number of lanes per project	4.7	4.7
Total Program Cost in 1976 Dollars*	285,200	285,200
Estimated Accident Reduction Over Program Life per $10,000 Investment in 1976 Dollars	20	60

*Assumes 1,000 lineal feet of resurfacing of 2.3 lanes, each 12-feet wide @ $3.00 per square yard on a multiple project bid basis.

CONCLUSIONS

It can be seen in Table 6 that all existing safety programs examined yield superior accident reduction benefits to those presumed for plate reflectorization. The range in relative effectiveness depends upon the program considered and the anticipated service life of the improvement. Of the programs considered, it appears that selective high accident intersection resurfacing may yield the greatest dollar pay-off in accident reduction: the estimated reduction being up to four times greater than that presumed possible from a license plate reflectorization program. The estimate of 8.6 accidents prevented per $10,000 investment in prior programs is lower than the model's estimate of 10 accidents. This is because the model considered only intersections of fairly low skid coefficient (less than 0.351). The projects actually resurfaced, however included higher skid coefficients and on occasion, extended non-intersection roadway for which accident reduction may be somewhat less than that of intersections. If service lifetimes greater than 20 years are assumed, then the widening programs would be most effective since their benefit accrues while the cost remains fixed. For example, 60 year service life for 2-3 lane widening would be nearly five times as effective as reflectorized plates.

Most of the studies reviewed do not generate "clean" data, hence, decisions on plate reflectorization should not be based on them. Some studies appear to present higher quality data and this was combined to provide an overall estimate of plate reflectorization accident reduction potential. When this combined estimate was compared on a dollar investment basis with other, well understood safety programs in a cost-effectiveness study, plate reflectorization could not deliver enough benefit to warrant more than a low priority.

TABLE 6

ACCIDENT REDUCTIONS FOR VARIOUS SAFETY PROGRAMS

Program	Term of Investment, yrs	Estimated Number of Accidents Prevented per $10,000 Investment	Accident Reduction Compared to Fully Reflectorized License Plates	
			20 yr life	60 yr life
Fully Reflectorized License Plates [1]	3	5	1.00	1.00
4 to 5 Lane Widening	20	6	1.2	3.6
2 to 3 Lane Widening	20	8	1.6	4.8
High Accident [2] Intersection Resurfacing	5	20	4.0	4.0
High Accident [3] Intersection Resurfacing	5	8.6	1.8	1.8

[1] Data combined from the Virginia, North Carolina, Australia, and Tasmania studies. Analysis does not consider capitalization costs or three year reflectance degradation.

[2] Based on before and after field studies and assuming linear decline of skid resistance.

[3] Sand-asphalt using 1974 weather and skid data as input to wet accident prediction model.

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