Safety Migration, the Influence of Traffic Volumes, and Other Issues in Evaluating Safety Effectiveness—Some Findings on Conversion of Intersections to Multiway Stop Control

BHAGWANT N. PERSAUD

ABSTRACT

Five issues of interest to safety management in general are addressed in the context of an examination of the safety effect of converting intersections from one-street-stopped to multiway stop control. On the first issue, the results support a long-held belief that the more accidents a site is expected to have, the more effective a safety measure is likely to be. This means that for affected measures, effectiveness (percent reduction in accidents) should not be specified as a single accident reduction factor as is currently the practice. Next, on the much debated question of whether improved safety at treated sites leads to a degradation in safety elsewhere, the findings suggest that this safety migration may indeed exist. Accordingly, safety benefits at treated sites should be weighed against any resulting degradation in safety elsewhere. On the other three issues, the findings are somewhat contrary to common belief. First, there is no evidence that conversion of intersections to multiway stop control is effective only for certain ranges of total entering volumes; neither is it apparent that effectiveness depends on how this volume is split among the approaches. Second, a learning period after conversion does not appear to be detrimental to safety. Finally, effectiveness does not decline as the use of this measure becomes widespread. Although all of these issues are addressed for a specific measure, some of the findings might be quite general.

Effective management of safety on a system requires sound knowledge of how the system reacts to the implementation of measures that affect safety--whether safety increases or decreases and by how much. In providing this information, several important issues need to be addressed--issues that have surfaced in evaluation studies because of a belief that, in some way, they are important considerations in safety evaluation. Five such issues are addressed in this paper in the context of an examination of the safety effect of converting one-street-stopped intersections to multiway (all-way) stop control. [See Persaud et al. (1) for more details.] These issues are presented in Figure 1 as questions of interest to safety management.

Issues 1 and 2 have been given the expanded coverage they deserve in other publications (2,3) and will not be addressed in any detail here. Issue 1 results from an apparent consensus among traffic engineers that a safety measure is more effective at locations where many accidents occur than at locations where few accidents occur--a belief that is often reflected in warrants. Issue 2 relates to the controversial question of whether improved safety where a measure is applied results in a degradation in safety elsewhere on a system. Issue 3 is based on a belief that the safety effect of certain measures depends on certain characteristics of traffic volume; for conversion to multiway stop control, the characteristics of interest are the total traffic volumes entering an intersection and how this volume is shared among the intersection approaches. Although in this paper the spotlight is shared by these three issues, the other two are no less important. A common belief that it takes time for drivers to get used to a change in traffic control forms the basis for Issue 4. The final issue to be addressed stems from a concern that traffic control tends to be disregarded if it is considered excessive or unwarranted; if this is so, then the safety effect of a measure will decline as its use becomes widespread.

The knowledge on these issues often comes from simple comparisons of accident records before and after the implementation of safety measures. The foundations of this knowledge have been shaken by researchers, such as Hauer (paper appears elsewhere in this Record), who have shown that such comparisons can lead to erroneous conclusions. Hauer presents details of an improved method for estimating safety effectiveness, and, therefore, for addressing these issues. In examining these issues as they relate to the conversion of intersections to multiway stop control, the intent was that, by removing any doubts as to the propriety of the methodology, some meaningful and forceful conclusions would emerge. In so doing, this work also serves as an illustration of the potential of the new method of analysis.

DATA

In undertaking a study such as this, a sufficiently elaborate data set is as important as the quality of

Transport Safety Studies Group, Department of Civil Engineering, University of Toronto, Toronto, Ontario M5S 1A4, Canada.

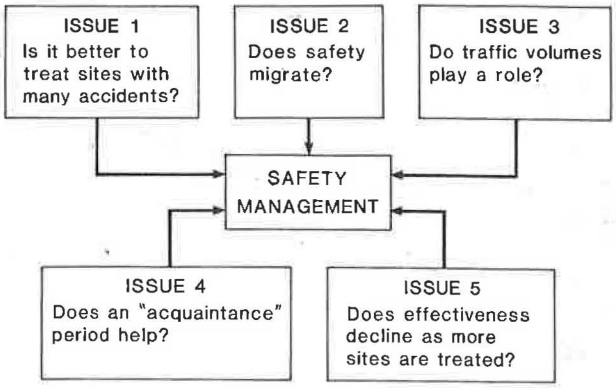

FIGURE 1 Illustrating the issues.

the methods of analysis. The main data set used, a rare find as it turned out, was provided by Ebbecke (4) in a thesis in which he examined the effect of converting 222 intersections of one-way streets from one-street-stopped control to multiway stop control. These conversions were implemented in Philadelphia, Pennsylvania, during the 4-year period from 1970 to 1973. The size of the conversion program can be observed in Table 1, which gives the number of intersections in the study area by type of control. The 222 conversions are reflected by the numbers in this table.

TABLE 1 Types of Intersection Control in Study Area

Control Type	Number of Intersections in Year Beginning 1970	1974
One-street-stopped	419	191
All-streets-stopped	99	321
Traffic signal	375	381
Total	893	893

METHODOLOGY AND OVERALL RESULTS

In examining all of the issues, the percentage reduction in accidents was estimated for intersections grouped in various ways according to the issue being addressed. To obtain these estimates, it was necessary to compare the number of accidents that would have been expected in the "after" period without the conversions with the number actually recorded. Hauer (paper appears elsewhere in this Record) demonstrates that it is usually incorrect to assume that the number of accidents recorded "before" is a reasonable estimate of the number expected to occur after. This common pitfall generally leads to overestimates of treatment effectiveness; that it can also lead to erroneous conclusions about the issues being addressed here provided the main motivation for this work.

To estimate $T(x)$, the number of accidents expected to occur in the after period had the conversion not taken place at an intersection that recorded x accidents in the before period, the following expression, taken from Hauer was used:

$$T(x) = x + [(\bar{x}/s^2)(\bar{x} - x)] \quad (1)$$

where $\bar{x}$ is the sample mean of accidents of a given type in a population of similar one-street-stopped intersections during the before period, and s^2 is the sample variance.

For the results presented in this paper, $\bar{x}$ and s^2 were estimated by first calculating the sample mean and variance of accidents at one-street-stopped intersections grouped in total entering volume ranges of 0 to 999, 1,000 to 1,999, and so on. A weighted least-squares regression line fitted to these "data points" thus provided estimates of $\bar{x}$ and s^2 for any one-street-stopped intersection given its total entering volume. [In earlier work (1,2), traffic volume was accounted for in a different manner. Accordingly, the numerical results presented here are slightly different from those reported previously; the conclusions, however, remain the same.]

In order to provide a backdrop for the discussion of the issues, the estimates of effectiveness obtained in the preceding manner are reported in Table 2 (Column 1) for various accident categories. Also shown (Column 2) are the biased estimates obtained by merely comparing the before and after accident records.

TABLE 2 Safety Effect of Conversion to Multiway Stop Control

Accident Type	Percent Reduction Unbiased 1	Biased 2
Total	45	54
Injury	73	81
Right-angle	79	83
Rear-end	17	33
Fixed-object	−31	−4
Pedestrian	39	46

Although these numbers are of interest in themselves, discussing them here will detract from the main issues. The reader interested in such discussion and further details is referred to the full report on this study (1).

ISSUE 1: ARE SAFETY MEASURES MORE EFFECTIVE WHERE MANY ACCIDENTS OCCUR?

As indicated earlier, this issue has been given generous coverage in a recent paper (2) and will be only briefly addressed here. Its importance is verified by the Manual on Uniform Traffic Control Devices (MUTCD) (5,p.24B), which specifies that one of the conditions that warrant a multiway stop sign is "An accident problem, as indicated by five or more reported accidents of a type susceptible of correction by a multiway stop installation in a 12-month period...." Part of the basis for such a warrant appears to be a widespread belief that the percentage reduction in accidents (effectiveness) or the accident reduction factor for such a measure is greater at locations where many accidents occurred than at those where few occurred.

A limited number of empirical studies of measures such as traffic signal and pedestrian crossing installation (6-10) appear to support this belief. However, a shadow of doubt may have been cast on this evidence by the many sources [see Hauer and Persaud (11), for example] that have shown that laws of chance alone can cause accidents to decrease at sites where unusually large numbers of accidents occur before treatment and increase at sites with few or no accidents before. (This phenomenon has become known as regression-to-the-mean.) It is possible, therefore, to wrongly conclude on the basis of simple before-and-after comparisons that a measure is effective only for sites with numbers of accidents larger than some number. It is not clear whether the studies mentioned earlier had accounted for changes due to chance. Because the methods for doing so have become available and the Philadelphia data set was suitably substantial, it appeared natural to engage in a reexamination of this issue.

The 222 converted intersections were grouped according to the number of accidents recorded in the 2 years before conversion. For each intersection in a group, the number of accidents expected to occur without conversion was estimated by using the method described earlier. The sum of these estimates was compared with what was recorded 2 years after conversion to produce an aggregate effectiveness for that group. Effectiveness (percent reduction in accidents), by accident type for each group, was then plotted against the expected number of accidents (without conversion) for the average intersection in that group (Figure 2). Exponential type functions were fitted to these estimates. These plots clearly support the belief that the more accidents expected to occur at a site, the larger the safety effect of a measure is likely to be.

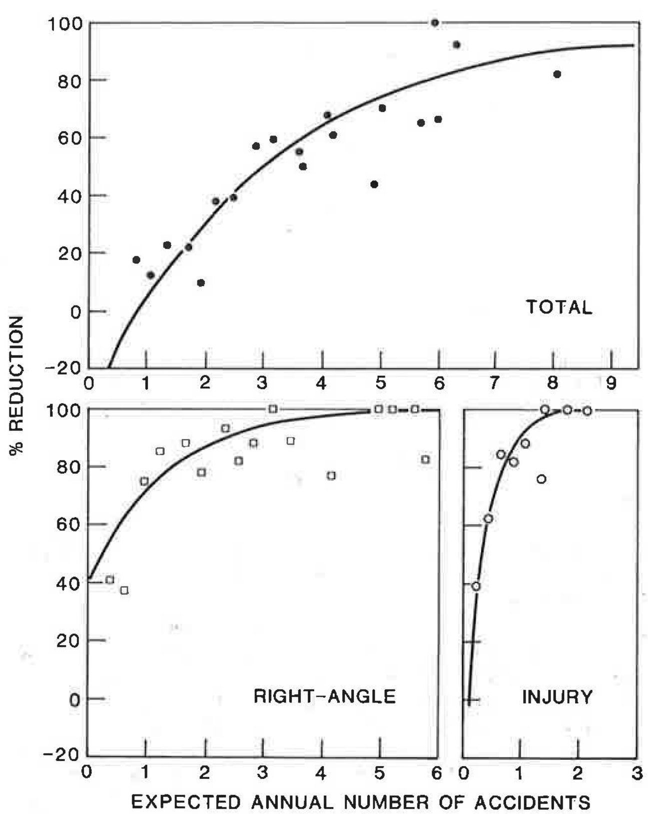

FIGURE 2 Effectiveness versus expected number of accidents–Philadelphia.

This conclusion is further supported by results obtained in a parallel study (12) of intersections converted from two-way to four-way stop control in San Francisco. In Figure 3, taken from this reference, the data points are more scattered because in this case only 49 intersections were converted. In spite of this noise, the message is quite clear;

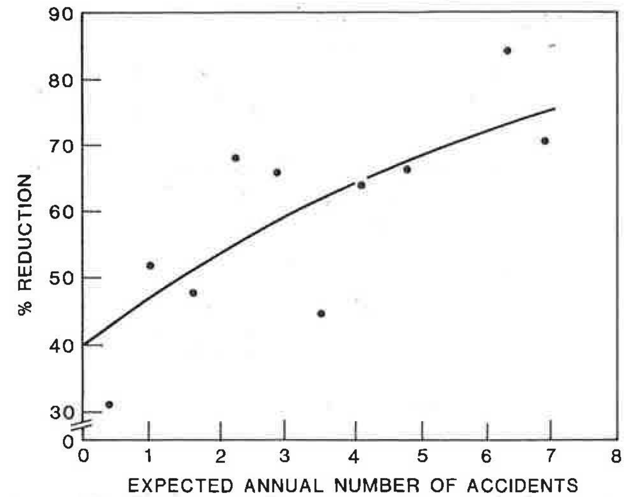

FIGURE 3 San Francisco data: effectiveness versus expected number of accidents–total accidents.

effectiveness of the conversions increases as the expected number of accidents at an intersection increases.

For affected measures, such as conversion to multiway stop control, there are two important implications of the finding on this issue. First, because different applications of this measure can lead to different accident reduction factors (depending on the expected number of accidents before treatment), effectiveness should be specified by its relationship to expected number of accidents rather than as a single accident reduction factor as is currently the practice. Second, the benefits (total reduction in accidents) of treating systems that are expected to have many accidents can be much larger than would be the case if constant effectiveness were assumed; for affected measures, this implication would favor more investment on high-accident systems than would have been the case with a constant effectiveness assumption.

The question remains: Why does effectiveness increase with expected number of accidents? Several explanations are possible [and are discussed (2)], but, despite the relative richness of the data set, there is insufficient evidence from this study to justify any of them. This void presents an interesting challenge for future research on this subject.

ISSUE 2: DOES SAFETY MIGRATE?

Like Issue 1, this issue has been given detailed coverage elsewhere (3) and will be only briefly addressed here. The issue arises from a belief by many safety professionals that an improvement in safety at a treated site leads to a degradation in safety elsewhere in the neighborhood of that site--a phenomenon that has become known as migration of safety. [The term "accident migration" has also been used and, more recently, the unusual term "(un)safety migration" has been suggested (3).] Obtaining insights is complicated because laws of chance alone can cause fewer accidents to occur at treated sites (usually those where many accidents occur) after than before; the converse will happen at untreated (low accident) sites. Taken together, these changes can be incorrectly construed as evidence that safety has migrated.

In one of the few papers on this subject, Boyle and Wright (13) found that a substantial portion of the accidents prevented at treated blackspots in

London, England, had apparently migrated to surrounding sites (generally within one block). This work has been subject to debate in the literature (14-22), and perhaps more to come. The last five exchanges (18-22) constitute a fascinating debate on whether laws of chance (regression-to-the-mean) could have caused an increase in accidents at the untreated surrounding sites, as Stein (18) and McGuigan (20,22) have claimed, or a reduction, as Boyle and Wright (19,21) have claimed. In the original paper (13), the authors apparently compromised by not accounting for regression-to-the-mean at all and attributed the accident increase at the surrounding sites to safety migration. The overall result of this debate is that there is still a thirst for knowledge on this issue.

Conversion of intersections from two-way to multiway stop control provides an almost ideal setting for studying this phenomenon. In setting the stage, Ebbecke (4,p.50) claimed that although multiway stop conversion in Philadelphia reduced accidents by about 50 percent where installed, "the total area accidents are not being reduced, they are just being rearranged." The problem with this conclusion is that Ebbecke apparently did not account for changes due to chance. Because his data set provided the means for doing so, it appeared in order to engage in a reexamination.

To address the issue of safety migration, the effect of the 61 conversions in 1969 was examined. Table 3 gives the changes in numbers of accidents that followed these conversions. Column 1 shows that 219 accidents were recorded at the 61 converted intersections in the 1-year period before conversion and 72 were recorded in the 1-year period after conversion--an apparent reduction of 147 accidents. Using Equation 1, it was estimated that 168 (not 219) accidents would have been recorded at these intersections in the after period had they not been converted. The unbiased change is a reduction of 96 accidents. Equivalent numbers for the 277 unconverted one-street-stopped intersections indicate an (unbiased) increase of 82 accidents. This means that most of the accidents prevented at the converted intersections had apparently migrated to the unconverted intersections.

TABLE 3 Accidents at Converted and Unconverted Intersections

	Converted Intersections 1	Unconverted Intersections 2
Number of intersections	61	277
Accidents recorded before	219	445
Accidents expected after	168	493
Accidents recorded after	72	575
Unbiased change	96	−82

Because there appears to be some support for the existence of safety migration, it might be useful to mention three potential explanations for these results. First, drivers may have been compensating for the reduced accident risk at the converted intersections by being less cautious elsewhere. Second, as Ebbecke suggested (4), it may be that the accident increases at unconverted intersections may be due to confused drivers who were uncertain as to whether those intersections were converted as well. Finally, the apparent migration of safety might have resulted from a redistribution of traffic as drivers sought to avoid the increased delay at the multiway stops. Although this redistribution was not evident in the traffic data provided by Ebbecke, it should be recognized that to explain a change as subtle as the increase of 82 accidents at 277 intersections, better detail is needed than is provided by the usual traffic surveys. These explanations and the implications of safety migration are explored in greater depth in the expanded paper (3).

ISSUE 3: DO TRAFFIC VOLUMES PLAY A ROLE?

Two related issues fall under the broad umbrella of the question of the role of traffic volumes. In a review of the literature on conversion to multiway stop control, Hauer (23) indicated that a belief exists that this measure is more effective when implemented on intersecting roads where the traffic volumes are nearly equal and the total of these volumes is between 6,000 and 12,000 vehicles per day. This belief is in part reflected by the Manual on Uniform Traffic Control Devices (MUTCD) (5,p.24B-3), which specifies that multiway stop control "...should ordinarily be used only where the volume of traffic on the intersecting roads is approximately equal" and that one of the conditions warranting a multiway STOP sign installation is "the total vehicular volume entering the intersection from all approaches must average at least 500 vehicles per hour for any 8 hours of an average day,..." (5,p.24B-4). An upper volume limit is indicated by Syrek (24), who found that four-way-stopped intersections with entering volumes larger than 12,000 vehicles per day had a higher accident rate than two-way-stopped intersections with similar entering volumes. As Hauer (23) points out, there are grounds for questioning the methods of analysis that may have been used in the studies on which these beliefs are based. It is therefore useful that the Philadelphia data provided an opportunity to remove these suspicions and gain some insights into the two traffic-related issues.

To examine the influence of total entering volumes, intersections were grouped in total entering volume ranges of 1,000. In Figure 4, effectiveness is shown by accident type for intersections in each of these volume groups. Although there is no clear

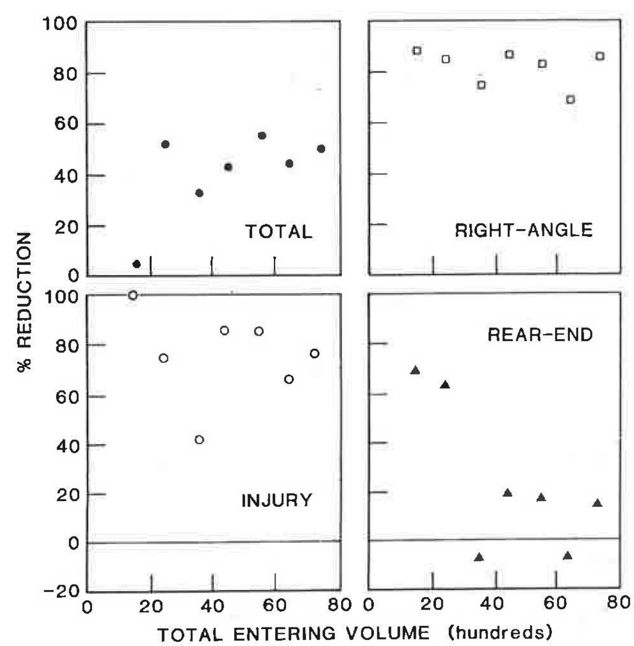

FIGURE 4 Effectiveness versus total entering volume.

trend for total accidents, it is quite clear that this measure can be just as effective for total entering volumes less than 6,000 per day as it is for larger volumes. The same can be said for right-angle accidents. For rear-end accidents, however, the picture is quite different; for this category, it appears that effectiveness decreases as total entering volume increases and can be negative at volumes larger than 6,000 vehicles per day. It is perhaps prudent to examine this trend in the light of findings on the effect of volume share.

To gain insights on the effect of traffic volume share, intersections were grouped in minor road volume share ranges of 5 percent. Figure 5 shows effectiveness values by accident category for intersections in each group. The plots for total and right-angle accidents show that, contrary to common belief, this measure is no more effective when the approach volumes are nearly equal than when they are unbalanced. Once again the rule confirming exception is rear-end accidents; for this category, it appears that effectiveness increases as minor road volume share increases but does not have a positive value until the minor road volume share exceeds 25 percent. Taken together, this finding and the earlier conclusion that effectiveness for rear-end accidents decreases with increasing traffic, produce an issue of considerable interest. It should be noted that the proportion of rear-end accidents is so small in this case that the dependence of effectiveness for rear-end accidents on these traffic characteristics is concealed when effectiveness for total accidents is examined.

Care must be taken in concluding on the overall issue of the role of traffic volumes. Two traffic characteristics have been examined and found to have little or no influence on the effectiveness of conversion of intersections to multiway stop control, except for the rear-end accident category. This does not necessarily mean that traffic volumes do not play a role. Certainly there could be other factors, other exposure measures for example, which could have an influence. Perhaps the changes in safety on a specific approach should be related to the traffic on that approach. Unfortunately, the Philadelphia data do not permit this type of analysis.

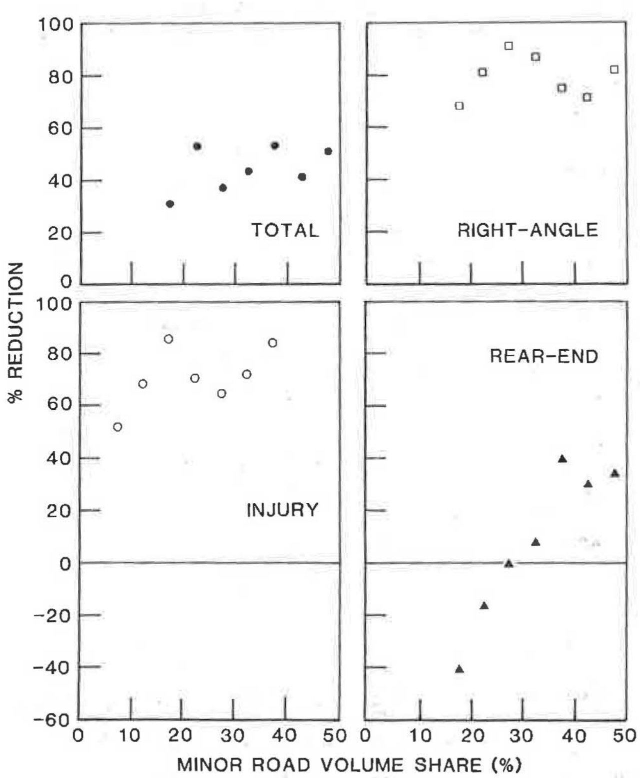

FIGURE 5 Effectiveness versus minor road volume share.

ISSUE 4: DOES AN ACQUAINTANCE PERIOD HELP?

It is often claimed that it takes time for drivers to become acquainted with a change in traffic control and therefore the initial period following conversion should be omitted from analysis of the safety effect of the change. If this claim were to apply to conversion to multiway stop control, then it could be expected that this measure would be less effective during some initial period than it would be later on. To examine this issue, effectiveness for each category of accidents was calculated based on an after period beginning 6 months after conversion. The results, given in Table 4, are compared with the effectiveness estimates based on an after period commencing immediately after conversion. From this comparison, it is clear that it makes little difference if a 6-month acquaintance period is allowed.

TABLE 4 Effectiveness with Acquaintance

	Percentage Reduction for Acquaintance Period	
Accident Category	0 Months	6 Months
Total	45	43
Injury	73	65
Right-angle	79	76
Rear-end	17	14
Fixed-object	−31	−40
Pedestrian	39	44

It is concluded, therefore, that even if it does take time for drivers to get used to multiway stop conversions, safety is not reduced during this learning period.

ISSUE 5: DOES EFFECTIVENESS DECLINE AS MORE SITES ARE CONVERTED?

This issue has an interesting background with respect to the multiway stop conversion program in Philadelphia. In a study of 57 intersections converted early in the program, Heaney (25) reported that total accidents were reduced by 87 percent. For the subsequent conversion program, 222 intersections were studied by Ebbecke (4) who reported a 55 percent reduction. On this basis, Ebbecke claimed that the safety effect decreased as more intersections were converted. However, the intersections studied by Ebbecke were selected in a somewhat haphazard fashion, whereas the intersections studied by Heaney were selected mainly on the basis of a poor accident record. It is therefore possible that the larger reductions reported by Heaney were a result of a regression-to-the-mean effect that is larger than that for Ebbecke's data. This concern has to remain as speculation because the data used in Heaney's study are not available. However it was possible to examine the same issue by using the data for the intersections studied by Ebbecke. Table 5 gives effectiveness values for these conversions by accident category according to the year of conversion.

TABLE 5 Effectiveness by Year of Conversion

	Percentage Reduction for Conversions Done in			
Accident Category	1970 74 Sites	1971 67 Sites	1972 38 Sites	1973 43 Sites
Total	45	43	50	50
Injury	74	67	79	73
Right-angle	76	82	82	80
Rear-end	23	30	−23	21
Fixed-object	−27	−43	−15	−33
Pedestrian	30	45	50	35

For each category, the effectiveness estimates vary from year to year but, however isolated, they do not support the claim that effectiveness decreases as multiway stop control proliferates in an area. Because it is fairly common practice to test a new measure at a few high-accident locations, there is an important lesson to be learned from the Philadelphia experience: without accounting for regression-to-the-mean, it is possible to wrongly conclude that effectiveness declines with subsequent implementation of the measure.

SUMMARY

Several issues of interest to safety management have been addressed in the context of an examination of the effect of conversion of one-street-stopped intersections to multiway stop control. For this measure, one belief--that effectiveness increases as the expected number of accidents at an intersection increases--was confirmed. On the controversial question of safety migration, the findings lend support to the belief that a measure that improves safety at one location can cause a degradation in safety elsewhere. For the other three questions, the findings are somewhat contrary to common belief. First, there is no evidence that this measure is only effective for certain ranges of total entering volumes; neither is it apparent that effectiveness depends on how this volume is split among the approaches. Second, safety is not reduced during a learning period after conversion. Finally, the novelty of this measure does not appear to wear off as its use becomes widespread.

All of the issues examined need to be addressed with respect to other safety measures as well, using improved methods of analysis such as those used in this study. The data set used in this study is more suited to this analysis than most that are available in practice; yet, many questions remain unanswered, the main reason being that this analysis was conducted so long after the conversion program. If there is a lesson to be learned, it is that when future safety measures are planned, a conscious effort should be made to gather the type of data required to more fully explore these and related issues.

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