The Safety Effect of Conversion To All-Way Stop Control

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ABSTRACT

Past studies documenting the safety effect of converting intersection traffic control to all-way stops have consistently shown impressive accident reductions. Because, ordinarily, it was high-accident locations that were converted, it was difficult to know how much of the reduction was real and how much was an artifact of regression-to-the mean. Data from three recent studies were reanalyzed and debiased. In addition, a new data set was assembled and examined. Analysis revealed that, although somewhat inflated, the reductions reported in the earlier studies were quite real and were confirmed by the new data. The empirical information contained in the data sets was captured in likelihood functions and the four functions were joined. Taken individually, the four data sets showed reductions in total accidents ranging from 37 to 62 percent. The joint likelihood function indicates a most likely accident reduction of 47 percent in total accidents.

A number of studies in which an attempt has been made to estimate the safety effect of all-way stops have been conducted in the past. Because the conversion of high-accident intersections was examined in virtually all of these studies, the reported estimates of effectiveness are biased (inflated) by an unknown amount. The source of this bias and methods for its removal are explained in a companion paper, "New Directions for Learning About the Safety Effect of Measures," elsewhere in this Record.

The safety effect of conversion from two-way to all-way stop control at both urban and rural intersections was examined. To obtain unbiased estimates of safety effectiveness, the reported estimates were first cleansed of bias. This was done by using the data from three recent studies. In addition, a new data set was assembled and analyzed to determine the safety effect of the conversion to all-way stop control at 79 intersections in Toronto. The data and results of this analysis are described in this paper. The circumstances and factors affecting the safety effect of all-way stops (such as traffic flow, flow balance, and number of past accidents) are examined separately in a second companion paper, "Safety Migration, Influence of Traffic Volumes, and Other Issues in Evaluating Safety Effectiveness--Some Findings on Conversion of Intersections to Multiway Stop Control," elsewhere in this Record.

It appears both desirable and feasible to assemble and join the information contained in several data sets in order to represent the total current state of knowledge. The likelihood function is used for this purpose. Its application to the four data sets is discussed.

REVIEW

A summary of a review of past studies is given in Table 1. In assessing the accuracy of the various estimates contained in the table it should be noted that studies covering a large number of intersections tend to provide more reliable results. For the same reason estimates for right-angle, injury, and total accident categories are generally more accurate than for the less frequent accident categories (rear-end, pedestrian, etc.). Estimates have not been cleansed of selection-bias and may, therefore, be inflated by some unknown amount. If this source of inaccuracy is disregarded, the following general conclusion can be drawn immediately: safety benefits of conversion to all-way stop sign control are consistent and reductions in accidents considerable (in the 50 to 90 percent range for both total and injury accidents).

The next four sections are devoted to a reanalysis of the three most recent data sets and to the analysis of a newly assembled set. The aim is to obtain estimates of safety effects that are free of bias.

SAN FRANCISCO

The earliest study for which the original data were available was documented in a report published in 1974 by the San Francisco Department of Public Works (2). The report was titled "Study of High Accident Intersections" and included the results of a 1-year before-and-after comparison of accidents occurring at 49 intersections converted from two-way to four-way stop control during the 5-year period running from 1969 to 1973. A 71 percent drop in total accidents was reported in the study. The reduction in right-angle and injury accidents appeared to be as high as 88 and 81 percent.

As the title of the report indicates, intersections were slated for conversion on the basis of a history of many accidents. This criterion for site selection invariably leads to inflated apparent effectiveness due to regression-to-the-mean.

The first task, therefore, was to determine to what extent the results were biased and to remove the bias that was found.

Debiasing involves comparison of the number of accidents occurring after conversion with the number of accidents expected to occur had no conversion taken place (rather than comparing the number of recorded "after" accidents with the number of accidents recorded during the "before" period).

An asymptotically unbiased estimator for the expected number of accidents [$\xi_2(x)$] was developed earlier and is described in the paper "New Direc-

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TABLE 1 Summary of Findings and Estimates of Percent Reduction in Accidents (*1*)

Reference	McEachern 1949	Syrek 1955	Wenger 1958	Leisch et al. 1967	Hammer 1968	Heany 1970	San Francisco 1974	Ebbecke 1976	Briglia 1981
No. of intersections	38	420	38	29	6	57	49	222	10
City	Four	Los Angeles	St. Paul	Chicago, San Francisco, New York, Toronto	California	Philadelphia	San Francisco	Philadelphia	Michigan (rural)
Right-angle			75%		84%		88%	83%	75%
Rear-end			-20%		-30%		-60%	33%	48%
Left-turn				(Gives regression			50%		39%
Head-on	(Number and	(Gives accident rates	67%	equations that de-					
Turning-vehicle	severity	by major and minor	33%	pend on several					
Fixed-object	decrease)	road, ADT)	50%	independent				-4%	
Pedestrian				variables)			67%	48%	
Injury			52%		81%	91%	81%	81%	77%
Total			56%		73%	87%	71%	54%	61%

tions for Learning About the Safety Effect of Measures" elsewhere in this Record. The appropriateness of the estimates was checked by comparing them with the average number of recorded after accidents [M(x)], as extracted from a larger population of unchanged two-way stop controlled intersections. Therefore, it was not only necessary to have the before-and-after accident data for the converted sites but also accident data from all similar sites that were not so converted.

In early 1983 San Francisco officials were approached and their cooperation solicited in supplying the data used in their 1974 study. Although the 1-year before-and-after accident data for the 49 intersections converted from two-way to four-way stop control were still on file, the accident data covering the study period for all nonconverted intersections in San Francisco were no longer available. The closest dates for which data were obtainable were the 4 years from 1974 through 1977. This was supplied in hard copy along with a list of all intersections controlled by two-way stop signs. From the hard copy information pertaining to the 4,681 accidents that occurred during the 1974 to 1977 period at 1,142 intersections with two-way stop control was extracted.

The estimator $\varepsilon_2(x)$ provided good estimates and a comparison was made between the expected number of accidents and those observed at the treated sites in the after period. This was done for six accident types (right-angle, rear-end, left-turn, pedestrian, injury, and total). The results are given in Table 2.

It should be noted that Column 4 is derived from a simple before-and-after comparison and therefore gives biased estimates of percent accident reduction. The correct results are given in Column 5. Thus, for example, in calculating the reduction in total accidents, 130 (Column 3), computed using $\varepsilon_2(x)$ and corrected for exposure, should be used rather than 172 (Column 1). (Both volume changes at the treated sites and changes in numbers of accidents across the larger population of similar but unchanged sites were taken into account.) In this case the biased estimate (71 percent) is close to the unbiased estimate (62 percent) because the reduction is large. When speaking in terms of percent, it matters little whether the reduction is from 172 to 50 or from 130 to 50.

Estimates for total, right-angle, and injury accidents are fairly reliable, whereas others are not. The likelihood function, discussed later in this paper, was used to describe estimate reliability.

PHILADELPHIA

The second data set was obtained from Philadelphia. During the mid-1960s, residents of several Philadelphia neighborhoods resorted to barricading streets in order to force City Hall to install traffic signals at particular intersections. Perhaps initially triggered by accidents at these sites, these actions gradually lost their safety-related motivation and acquired the air of general community unrest. As an alternative to costly signal installation, the decision was made in 1967 to use all-way stop control to placate the escalating public demand for traffic signals. During the next 8 years Philadelphia engaged in an extensive program to convert intersections to all-way stop control.

In his master's thesis, Ebbecke (4) reported the results of a 2-year before-and-after study on the safety effect of the conversion of 222 intersections of one-way streets to all-way stop control. The results showed a decrease of 55 percent in total accidents; right-angle and injury accidents decreased by 83 and 81 percent, respectively.

Because the original public pressure was related to perceived high-accident occurrence, there was

TABLE 2 Safety Effect by Accident Type in San Francisco (*3*)

Accident Type	(1) Number of Before Accidents	(2) Number of After Accidents	(3) Expected Number of After Accidents	(4) [(1) - (2)]/(1) Apparent Percent Reduction	(5) [(3) - (2)]/(3) Unbiased Percent Reduction
Right-angle	129	16	93	88	83
Rear-end	10	16	4	-60	-300
Left-turn	14	7	10	50	30
Pedestrian	6	2	6	67	67
Injury	48	9	35	81	74
Total	172	50	130	71	62

TABLE 3 Safety Effect by Accident Type in Philadelphia (*5*)

Accident Type	(1) Number of Before Accidents	(2) Number of After Accidents	(3) Expected Number of After Accidents	(4) [(1) - (2)]/(1) Apparent Percent Reduction	(5) [(3) - (2)]/(3) Unbiased Percent Reduction
Right-angle	726	126	558	83	77
Rear-end	151	101	123	33	18
Pedestrian	139	75	123	46	39
Fixed object	254	266	200	-4	-33
Injury	313	60	226	81	73
Total	1,329	616	1,072	54	43

again reason to suspect a bias in the results of a simple before-and-after comparison.

An appendix to Ebbecke's thesis included accident data for all intersections in the study area, as well as for the converted sites. It was relatively straightforward to recode the information from hard copy and to proceed in the same manner as for the San Francisco data. Recoding of the data yielded information about 8,934 accidents at 893 intersections from 1968 to 1975.

As in the case of the San Francisco data, the estimates of the expected number of after accidents [$\xi_2(x)$] corresponded well to the average number of after accidents recorded at the larger population of untreated sites. The estimates were then compared to the recorded number of after accidents at the treated sites. Table 3 gives the results for the major accident types.

MICHIGAN

The studies reviewed thus far have dealt with urban intersections. The third data set reexamined addressed the effect of four-way stop control at intersections of low-volume, high-speed rural roads in Michigan.

In 1981 the Michigan Department of Transportation published a report (6) documenting the change in accidents as a result of converting 10 rural intersections from two-way to four-way stop control over a 7-year period from 1971 to 1977. Total accidents were reported to have fallen by 61 percent while right-angle accidents were reduced by 75 percent.

The 10 converted intersections had been identified as having persistent right-angle accident patterns, and for most of these locations, several less restrictive measures, such as "stop ahead" signs and flashers had been tried without success.

Here again, with a history of many accidents as a reason for conversion, there is danger of regression-to-the-mean biasing results.

Accident data for the converted sites for 2- and 3-year before-and-after periods were appended to the original report. The Michigan Department of Transportation provided additional information in the form of a computer tape that contained accident data for all rural two-lane, two-way, nonsignalized intersections on Michigan's state trunkline system for the years 1974 through 1976. On the 8,578 intersections across rural Michigan, 12,569 accidents were recorded during those 3 years.

Estimates of expected number of accidents [$\xi_2(x)$] were compared with the average recorded after accidents for the large body of untreated sites. Again, there was good correspondence between the two sets of values.

The data in Table 4 show the results of the comparison between the expected and recorded after accidents.

TORONTO

The last data set examined was from the city of Toronto. Computer tapes containing details of all intersection accidents that occurred in Toronto between 1973 and 1983 were examined. From the 408,040 records originally supplied, information about 16,059 accidents occurring at 1,279 nonsignalized intersections was extracted. For the effectiveness evaluation, 79 intersections were selected that had undergone conversion from two-way to four-way stop control between 1975 and 1982.

Reexamination of the proposal files indicated that 28 of the 79 intersections were converted because of a history of high numbers of accidents. An additional 15 intersections were converted to improve safety.

Following the procedure used in the three earlier analyses, the estimate of expected number of after accidents was compared with those recorded for the larger population of sites. Again the estimates proved good. Comparing the estimates to the recorded after accidents generated Table 5.

Finally, what remained to be done was to amalgamate the four separate sets of results into a coherent whole.

TABLE 4 Safety Effect by Accident Type in Michigan (*1*)

Accident Type	(1) Number of Before Accidents	(2) Number of After Accidents	(3) Expected Number of After Accidents	(4) [(1) - (2)]/(1) Apparent Percent Reduction	(5) [(3) - (2)]/(3) Unbiased Percent Reduction
Right-angle	146	36	102	75	65
Rear-end	44	23	28	48	18
Left-turn	18	11	9	39	-28
Injury	118	27	70	77	61
Total	277	108	230	61	53

TABLE 5 Safety Effect by Accident Type in Toronto (*8*)

Accident Type	(1) Number of Before Accidents	(2) Number of After Accidents	(3) Expected Number of After Accidents	(4) [(1) - (2)]/(1) Apparent Percent Reduction	(5) [(3) - (2)]/(3) Unbiased Percent Reduction
Right-angle	175	85	170	51	50
Rear-end	56	26	33	54	22
Left-turn	17	12	17	29	29
Pedestrian	1	2	3	−100	33
Injury	75	9	62	88	63
Total	331	172	286	48	40

LIKELIHOOD FUNCTIONS

Because automobiles, drivers, and intersections across North America have a good deal in common, it is not unreasonable to expect the safety effect of a treatment to be similar in Michigan, Philadelphia, San Francisco, and Toronto. However, there is much that is unique to each of the four regions, and it is those unique elements that might limit the degree of similarity.

To emphasize similarity, difference, and accuracy, the results of the four data sets will be juxtaposed in this section. Next, the four estimates will be combined into a single estimate of percent accident reduction by accident type.

The likelihood function was the chosen tool of analysis. For a more detailed discussion of the workings of the likelihood function, see "New Directions for Learning About the Safety Effects of Measures" elsewhere in this Record. The horizontal axis of the plots in Figure 1 gives the various possible values for percent reduction in total accidents. The ordinate gives the relative likelihood for the percent reduction. The most likely percent reduction is the point at which the likelihood function has a value of 1.

Thus, for example, in Figure 1a (total accidents, San Francisco) the most likely percent reduction is 62 percent; the relative likelihood of anything outside 40 to 80 percent is negligible. Note that the likelihood function for Philadelphia (Figure 1b) is much more compact, mainly reflecting the fact that it is based on more information (222 intersections as opposed to 49 in San Francisco).

The joy of using likelihood functions is their ability not only to store all empirical information and present it in a clear manner, but also to easily accumulate information as it becomes available. This

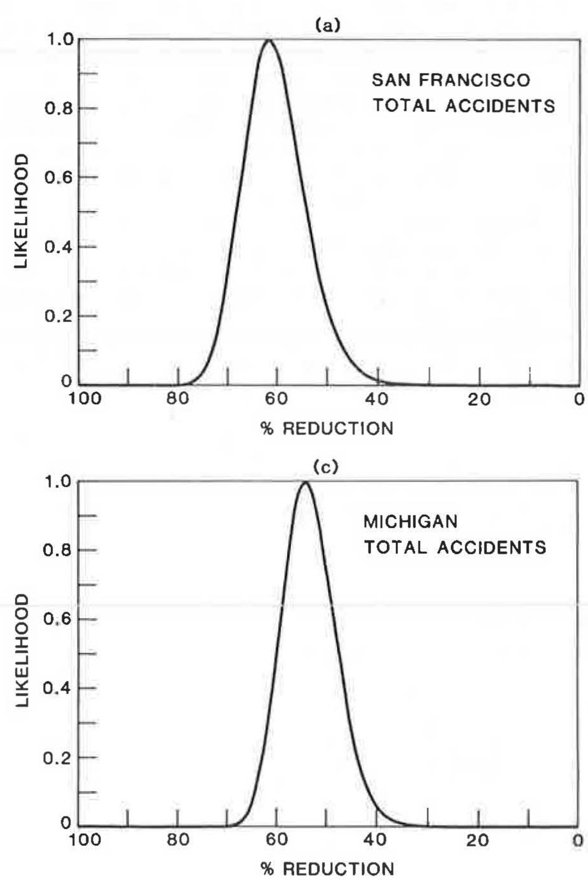

FIGURE 1 Likelihood functions for total accidents.

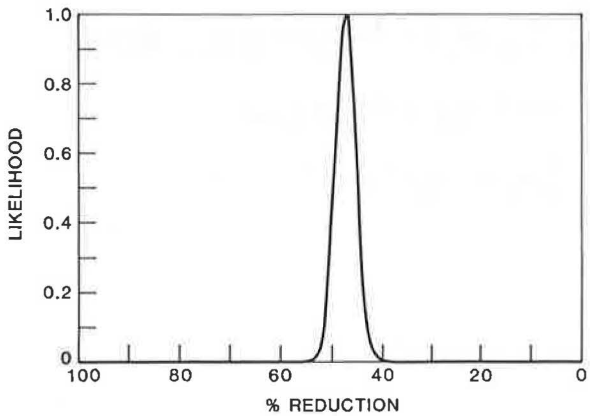

FIGURE 2 Combined likelihood function for total accidents.

can be done simply by multiplying the corresponding ordinates (or adding their logarithms). Because of this facility the functions for each of the data sets were joined to produce a joint estimate of countermeasure effectiveness. This joint likelihood function for total accidents appears in Figure 2. The data in Table 6 give the most likely values for percent accident reduction for all four data sets and for the combined set.

TABLE 6 Most Likely Percent Accident Reductions

Accident Type	San Francisco	Philadelphia	Michigan	Toronto	Combined
Right-angle	84	78	64	48	72
Rear-end	−305	20	19	22	13
Left-turn	33	–	−7	25	20
Pedestrian	66	40	–	42	39
Fixed object	–	−30	–	–	–
Injury	74	74	62	63	71
Total	62	47	59	37	47

SUMMARY AND CONCLUSIONS

The goal of this work was to estimate the safety effect of converting intersection control from two-way to all-way stop control. A review of available empirical evidence revealed fairly consistent and impressive safety effectiveness. However, because in many cases high-accident locations were treated, estimates were inflated to an uncertain extent.

Three recent data sets were reanalyzed to obtain unbiased effectiveness estimates. An additional set of data from Toronto was assembled and examined. Tables 2-5 give detailed unbiased estimates of effectiveness for each case.

The four data sets were represented by likelihood functions and were combined. The combined most likely estimates of effectiveness are given in Table 6. It appears that the conversion to all-way stop control may be expected to reduce total accidents by 47 percent with right-angle and injury accidents dropping by 72 and 71 percent, respectively.

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