Study of the Effect of Two-Way Left-Turn Lanes on Traffic Accidents

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ABSTRACT

The purpose of this investigation was twofold: (a) to determine the safety-effectiveness of two-way left-turn lanes (TWLTLs) and (b) to determine the cost-effectiveness of TWLTLs. The study includes statistical as well as economic analyses. Accident data were collected for 31 roadway sections, 15 five-lane and 16 three-lane sections, for 2 years before and 2 years after the improvements (addition of the TWLTL) were made. Statistical tests were applied on total accidents as well as affected accidents (rear-end, left turn, and sideswipes), their rates, and their severity. Statistically significant reductions were found in accidents, their rates, and their severity. An economic analysis was also performed, including benefit-cost ratios and cost-effectiveness values (cost per accident reduced). The only benefit considered was saving in accidents. The results of economic analysis along with those of statistical analysis indicate that the TWLTL is an economic safety improvement to the conventional two- and four-lane urban roadways along which extensive commercial development has taken place.

Traffic volumes have generally increased on urban roadways in recent years. The commercial development of land adjacent to these roadways has created demand for access to these abutting properties, thereby increasing left- (and right-) turning movements. The increasing traffic volumes coupled with increased turning movements have created capacity as well as safety problems. Furthermore, the acquisition of rights-of-way for new construction or extensive reconstruction of the existing roadway is usually not practical. Under these circumstances, the two-way left-turn lane (TWLTL) becomes a desirable addition to the conventional two- and four-lane roadway systems.

Sawhill and Neuzil (1) reported on what appears to be the first installation of a TWLTL by Seattle in November 1952. Three sections of roadways were examined to study the accident experience and operational characteristics, such as signing and markings. Ray (2) examined the operational efficiency of the TWLTL in serving the abutting properties. Koltnow (3) found that these lanes work well because of driver acceptance, and he suggested some end treatments to mark for them. Shaw and Michael (4) used considerations such as delay time and accident rates (involving left-turning vehicles) as warrants for justifying the cost of a median lane. Hoffman (5) examined the accident experience on four sections of roadways in Michigan. Although no indication of statistical testing was apparently made, the results in terms of accident reduction were impressive. Finally, Nemeth (6) presented a state-of-the-art report of TWLTLs that included a survey of expert opinion, a literature review, field study results, and implementation guidelines. Walton et al. (7) also presented a detailed investigation of the relevant literature and a comparison of the accident experience of a TWLTL with that of a channelized one-way left-turn median lane.

The concept of a TWLTL, also known as bidirectional turn lane or center (median) lane, was initially developed to increase the capacity of urban roadways. The TWLTL allows simultaneous left turns from the center lane by vehicles traveling in the opposite direction (Figure 1). Vehicles from either direction of the traffic flow enter the center lane to make a left turn, thereby removing themselves from the through lanes. This increases the capacity of the through lanes, reduces vehicular conflicts, and enables traffic to move smoothly. In addition, the potential for rear-end, left-turn, and sideswipe accidents (considered affected by the TWLTL) is reduced. Illinois has used the TWLTL by constructing it on both two-lane (to three-lane) and four-lane (to five-lane) roads.

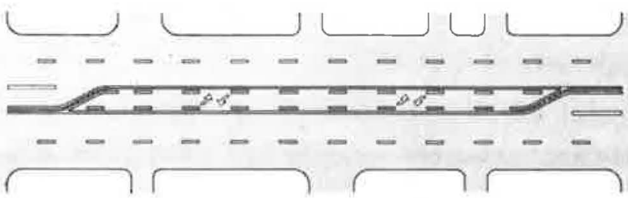

FIGURE 1 TWLTL median pavement marking.

The TWLTL offers at least two other advantages. It provides an emergency lane that may be used to bypass traffic accidents and stalled vehicles and it allows emergency vehicles to more quickly arrive at the scene of an accident.

There are possible disadvantages of the TWLTL. The head-on collision is a primary concern among those considering the installation of a TWLTL. However, this type of collision has been proven in every study, including this one, to be an uncommon occurrence (1,6,7). Another doubt raised about the installation of such lanes on high-volume roadways is that the left-turning drivers at midblock may not find an acceptable or sufficient gap in the opposing through traffic to permit the turning maneuver, which consequently may increase accidents or cause disruptions in the flow of opposing traffic. However, this study and the study by Walton et al. (7) do not support that contention. Finally, there may be some confusion in the motorists' mind concerning the use of these lanes, especially during the initial period after construction. This confusion is greatest among some out-of-state drivers because the installation of these lanes is not common throughout the United States (1). However, studies (2,3,6) indicate that public acceptance of this practice is favorable and complaints are minimal.

The purpose of this report is two-fold: (a) to determine the safety-effectiveness of the TWLTL in reducing accidents and their severity, and (b) to determine the cost-effectiveness of the TWLTL (benefit-cost ratios and cost per accident reduced).

Thirty-one sections were studied: 15 five-lane and 16 three-lane improvements (adding the TWLTL). Accident data and traffic volume data were obtained for 2 years before and 2 years after the improvements were made.

Total accidents as well as affected accidents (rear-end, left turn, and sideswipes), their rates, and their severity were tested for statistically significant difference from the before period to the after period. The Wilcoxon test and the Paired t-test at the 95 percent confidence level were used for this purpose.

Because statistically significant results were obtained, an economic analysis was also performed. The benefit-cost ratios and cost-effectiveness values (cost per accident reduced) were calculated.

EVALUATION METHODOLOGY

An experimental design before-and-after comparison was adopted to determine the effect of TWLTLs on various measures of effectiveness (MOEs). The period covered by the study is 2 years before and 2 years after the improvement was made. The changes in various MOEs were tested for statistical significance. An economic analysis was performed if the results were found to be significant.

Selection of Study Sites

The following criteria, basically drawn from the report by Sawhill and Neuzil (1) were used to select the study sites.

1. A minimum of change in traffic volume, traffic control, or adjacent land use should occur during the period of study. In this way the effect of the TWLTL on traffic accidents could be determined without the influence of other factors.
2. The sections that include other major improvements or major reconstruction should not be considered. Also, the sections that require only striping or small expenditures should not be included.
3. At least 2-year before and 2-year after accident data should be available in order to reduce large variations in these data because of weather fluctuations and chance occurrences.
4. The minimum length of a study section should be 0.25 mile.

Originally, all sites that included a TWLTL were obtained. A statewide survey indicated that there were 49 five-lane and 48 three-lane sections throughout the state (Illinois). The criteria previously listed were then applied to obtain the final list of study sites. Thus several sections that included major improvements in addition to the installation of a TWLTL (e.g., installation of right-turn lane or reconstruction of a bridge) were dropped from further consideration. Some sections were rejected because sufficient accident data in the after period (2 years) were not available. Other sections only one or two blocks in length were not considered.

The accident experience at a location was not a factor in the selection of study sites. However, portions of 11 (of the 15) five-lane and 4 (of the 16) three-lane sections experienced higher than statewide average accident rates in the before period. This is so because some of these sections were constructed as safety projects, which required the site to be a high-accident location (HAL). (By definition, a HAL is a location at which the accident rate exceeds a critical statewide accident rate, determined by a rate quality control method.)

The Student's t-test was applied to test whether the mean reductions in accident rates for HALs versus non-HALs are different. The results of statistical significance at the 95 percent confidence level are given in Table 1.

TABLE 1 Significance of HALs Versus Non-HALs

	Five Lanes		Three Lanes	
	Yes/No	t	Yes/No	t
TA rates	No	1.47	Yes	2.91
FA + PI (TA) rates	No	0.34	No	1.58
TA affected rates	Yes	2.60	No	1.69
FA + PI affected rates	No	1.58	No	1.01

Note: TA = total accident, FA = fatal accident, and PI = personal injury accident.

The results indicated that there was no statistical difference between HALs and non-HALs, except that

1. For five-lane sections the mean reduction in affected accident rates for HALs was significantly higher than that for non-HALs, and
2. For three-lane sections the mean reduction in total accident (TA) rates for HALs was significantly higher than that for non-HALs.

Although statistically significant results were obtained in these two cases, their validity cannot be fully ascertained because of two reasons.

1. The sample size is small and there is imbalance in the number of projects in the two groups.
2. The five-lane sections include 11 HALs versus 4 non-HALs. Conversely, the three-lane sections include only 4 HALs versus 12 non-HALs. In spite of this disproportionate mix, statistically significant reductions in accidents and their severity were obtained for both five- and three-lane improvements, as discussed later in this paper.

Data Collection

Only sections meeting all four criteria previously listed were included in this study. Overall, 31 sections were studied, 15 being five-lane sections (from four lanes before to five lanes after), and 16 being three-lane sections (from two lanes before to three lanes after). The total length of the five-lane sections is 11.29 miles and for three-lane sections it is 7.36 miles. Traffic volumes ranged from an average daily traffic (ADT) of 10,600 to 25,000 for five-lane sections and from 4,200 to 21,300 for three-lane sections.

Accident and traffic volume data for each project are given in Tables 2 and 3 for five- and three-lane sections, respectively. In each case the data are tabulated to give the total accidents (TA) by severity and the affected accident rates, as well as total severity rates and affected severity rates. The accident data are for 2 years, whereas traffic volumes and accident rates are annual averages. For

TABLE 2 Accident and Traffic Volume Data for Five-Lane Sections

SEC. NO.	YEARS	ADT	DVM	ALL ACCIDENTS TA	PD	PI	FA	TA RATE	FA & PI RATE	AFFECTED ACCIDENTS TA	PD	PI	FA	AFF. TA RATE	AFF. FA & PI RATE
* 1	73-74	10,600	7,102	145	102	43	0	2,797	829	24	19	5	0	463	96
	78-79	12,150	8,141	118	80	38	0	1,986	639	22	18	4	0	379	67
* 2	76-77	11,000	5,940	65	53	12	0	1,499	277	25	19	6	0	577	138
	80-81	12,450	6,723	27	23	4	0	550	82	5	3	2	0	102	41
* 3	76-77	12,150	4,253	43	33	10	0	1,386	322	20	17	3	0	645	97
	80-81	12,500	4,375	48	32	16	0	1,503	501	7	3	4	0	220	125
4	76-77	12,300	19,557	116	89	27	0	813	189	30	23	7	0	210	49
	80-81	13,500	21,465	58	42	16	0	371	102	11	9	2	0	70	13
* 5	74-75	13,400	5,226	144	105	38	1	3,775	1,022	21	14	7	0	551	183
	78-79	15,100	5,889	93	71	22	0	2,164	512	12	12	0	0	279	0
* 6	72-73	14,500	7,250	81	63	18	0	1,531	340	46	37	9	0	869	170
	77-78	21,750	10,875	50	36	14	0	630	176	20	18	2	0	252	25
7	76-77	15,000	7,950	52	35	17	0	896	293	13	8	5	0	224	86
	79-80	15,000	7,950	42	33	9	0	724	155	3	2	1	0	52	17
* 8	75-76	16,300	22,983	365	274	90	1	2,176	542	117	98	18	1	698	113
	78-79	16,800	23,688	214	156	58	0	1,238	335	75	56	19	0	434	110
* 9	77-78	20,000	16,000	109	82	27	0	933	231	48	34	14	0	411	120
	80-81	18,900	15,120	41	24	17	0	372	154	11	7	4	0	100	36
*10	74-75	20,850	11,885	109	61	48	0	1,257	553	88	51	37	0	1,014	426
	77-78	22,500	12,825	127	80	47	0	1,357	502	94	58	36	0	1,004	385
11	77-78	23,000	34,730	116	77	39	0	458	154	46	33	13	0	182	51
	80-81	22,000	33,220	56	41	15	0	231	62	30	21	9	0	124	37
12	76-77	23,000	8,280	66	44	22	0	1,092	364	17	13	4	0	281	66
	80-81	24,200	8,712	89	69	20	0	1,399	314	24	17	7	0	378	110
*13	72-73	23,625	10,868	169	130	39	0	2,130	492	100	78	22	0	1,261	277
	76-77	24,050	11,063	167	124	43	0	2,068	532	84	70	14	0	1,040	173
*14	71-72	24,000	27,360	385	281	104	0	1,928	521	146	115	31	0	731	155
	76-77	27,900	31,806	370	265	105	0	1,594	452	112	91	21	0	483	90
*15	75-76	25,000	11,750	128	93	35	0	1,493	408	83	58	25	0	968	291
	79-80	26,900	12,643	119	90	29	0	1,290	314	48	38	10	0	520	108

* High-Accident Locations

TABLE 3 Accident and Traffic Volume Data for Three-Lane Sections

SEC. NO.	YEARS	ADT	DVM	ALL ACCIDENTS TA	PD	PI	FA	TA RATE	FA & PI RATE	AFFECTED ACCIDENTS TA	PD	PI	FA	AFF. TA RATE	AFF. FA & PI RATE
1	76-77	4,200	1,722	4	1	3	0	318	238	3	1	2	0	239	159
	80-81	3,800	1,558	0	0	0	0	0	0	0	0	0	0	0	0
2	76-77	6,900	1,725	15	10	5	0	1,191	397	2	2	0	0	159	0
	80-81	6,900	1,725	11	7	4	0	874	318	1	1	0	0	79	0
3	72-73	8,200	7,134	48	35	13	0	922	250	13	9	4	0	250	77
	77-78	8,550	7,438	43	31	12	0	792	221	11	8	3	0	203	55
4	74-75	8,400	2,100	9	7	1	1	587	130	3	3	0	0	196	0
	78-79	8,500	2,125	5	3	2	0	322	129	2	1	1	0	130	65
5	74-75	8,500	2,465	14	7	7	0	778	389	13	7	6	0	722	333
	77-78	9,200	2,668	4	3	1	0	205	51	3	3	0	0	154	0
6	76-77	8,550	3,078	7	4	3	0	312	134	3	1	2	0	134	89
	80-81	8,600	3,132	6	4	2	0	265	88	4	3	1	0	177	44
7	73-74	10,000	4,300	27	25	2	0	860	64	18	17	1	0	573	32
	76-77	11,050	4,751	23	17	6	0	663	173	11	7	4	0	317	115
8	72-73	10,600	4,346	8	6	2	0	252	63	2	0	2	0	63	63
	76-77	11,500	4,715	13	9	4	0	378	116	4	4	0	0	116	0
9	73-74	10,700	4,708	19	17	2	0	553	58	0	0	0	0	0	0
	76-77	10,900	4,796	18	14	4	0	514	114	1	0	1	0	29	29
*10	76-77	11,000	7,150	49	38	11	0	939	211	20	16	4	0	383	77
	79-80	12,200	7,930	35	26	9	0	605	156	3	1	2	0	52	35
11	76-77	11,700	6,318	45	37	8	0	976	174	7	6	1	0	152	22
	79-80	10,300	5,562	52	45	7	0	1,281	173	10	9	1	0	246	24
*12	72-73	13,500	7,155	55	42	13	0	1,053	249	21	15	6	0	402	115
	75-76	14,200	7,526	38	29	9	0	692	164	17	13	4	0	310	73
13	72-73	15,900	11,130	108	83	24	1	1,329	307	29	23	6	0	357	74
	75-76	16,700	11,690	109	78	31	0	1,277	363	29	19	10	0	340	17
14	77-78	16,150	4,684	52	32	19	1	1,521	585	21	12	8	1	614	263
	80-81	16,700	4,843	35	19	16	0	990	453	13	10	3	0	368	85
*15	76-77	16,100	8,050	74	49	25	0	1,259	425	40	24	16	0	680	272
	80-81	16,000	8,000	23	17	6	0	394	103	12	7	5	0	205	85
*16	77-78	20,500	9,020	130	93	37	0	1,974	562	27	13	14	0	410	213
	80-81	21,100	9,284	60	39	21	0	885	310	9	8	11	0	133	15

* High-Accident Locations

the purpose of this study, the accident rate, severity, and severity rates are defined as follows:

$$\text{Accident rate} = (\text{Number of accidents} \times 10^8)/[(\text{ADT} \times \text{length}) \times 365] \quad (1)$$

$$\text{Severity} = \text{Personal injury accidents} + \text{Fatal accidents} \quad (2)$$

$$\text{Severity rate} = [(\text{Fatal} + \text{injury accidents}) \times 10^8]/[(\text{ADT} \times \text{length}) \times 365] \quad (3)$$

The same daily vehicle miles (ADT x length) of travel were used for all accident rate calculations.

Measures of Effectiveness

The following MOEs were considered to determine the effectiveness of the TWLTL in terms of reduction in accidents and their severity:

1. Total accidents,
2. Total accident rates,
3. Total fatal and injury accidents (severity),
4. Total fatal and injury accident rates,
5. Total affected accidents (rear-end, left turn, and sideswipe),
6. Total affected accident rates,
7. Total affected fatal and injury accidents, and
8. Total affected fatal and injury accident rates.

Expected Result

The expected result was a decrease from the before period to the after period for each MOE.

Statistical Testing

The Wilcoxon matched-pair signed-rank test and the Paired t-test were used to determine the significance of change in the MOEs. In addition, the unaffected accidents (total minus affected) were also tested. All tests were one-tailed and were performed at the 95 percent confidence level. The work by Siegel (8) was used for the application of the Wilcoxon test, and the work by Haber and Runyon (9) was used for the application of the t-test. The results of statistical tests are included in the Results section of this report.

ECONOMIC ANALYSIS

The economic analysis was performed because statistically significant reductions in accidents were obtained for both five- and three-lane sections. The economic analysis used future benefits and costs in constant dollars. For the purpose of this study, an interest rate of 8 percent was used. It was assumed that the improvement would last 15 years, except that the pavement would be in need of resurfacing in 7.5 years (it was also assumed the pavement was in need of resurfacing at the time of the improvement). The salvage value of the improvements was assumed to be zero.

Cost of Projects

All project costs were standardized to the 1977 base year. The Illinois construction price index (1977 base = 100.00) calculated by the Bureau of Design, Illinois Department of Transportation (IDOT) was used. The Illinois index is patterned after the index used by the FHWA. Thus the standardized costs for both five- and three-lane improvement projects were as follows:

	Cost ($)	
	Five Lanes	Three Lanes
Total	3,678,000	2,254,380
Affected	3,126,500	2,254,380

The affected costs were obtained by subtracting from the total cost the cost of additional work other than the construction of the TWLTL, such as traffic signal installation and so forth. (No additional work was included in the three-lane improvements.)

Accident Benefits

The accident benefits are based on the accident costs calculated by the Division of Traffic Safety (DTS) of IDOT. These costs are derived from the National Safety Council (NSC) accident costs for the year 1977. The NSC costs by severity were converted to cost per accident. Thus the cost per accident for 1977 used in the calculation was $3,590.

The following two approaches were considered for economic analysis: benefit/cost analysis, and cost-effectiveness analysis.

Benefit/Cost Analysis

The benefit/cost (B/C) ratio is a ratio of accident benefits to project construction costs, both standardized in constant dollars. Only savings in accidents are considered as benefits of these improvements. Other benefits, such as improved mobility and driving comfort, savings in time and fuel, and reduction in air pollution, are not considered here, but will be treated in a separate report. The ratio indicates the number of times the expenditures on construction of these projects are returned to society in terms of benefits in preventing traffic accidents.

The B/C ratios were calculated by the two methods: equivalent uniform annual benefits to costs, and present worth of benefits to costs (both methods yield the same results). The following equation, based on annual benefits to costs method and adopted from the FHWA (10), illustrates the input variables used in the calculation of B/C:

$$B/C = (A_s \times A_c)/[I(CR_n^i) + K - T(SF_n^i)] \quad (4)$$

where

- A_s = number of accidents saved,
- A_c = cost per accident,
- I = initial implementation cost,
- K = net annual and operating costs,
- T = terminal value (assumed zero),
- i = interest rate (assumed 8 percent),
- n = service life of improvement (assumed 15 years),
- CR = capital recovery factor, and
- SF = sinking fund factor.

Of the various factors listed, a sensitivity analysis of the B/C ratio was conducted with regard to those factors for which certain values were assumed (i.e., i = 8 percent, n = 15 years, and T = 0). To conduct the sensitivity analysis, the B/C ratios for both five- and three-lane sections (total accidents) were calculated by varying

1. i from 6 to 20 percent (1 percent increment),
2. n from 10 to 20 years (2.5-year increment), and
3. T from 0 percent (of I) to 20 percent (10 percent increments).

Cost-Effectiveness Analysis

The cost-effectiveness analysis indicates the cost of saving one accident. Like the B/C ratio, the cost-effectiveness (C/E) values were calculated by the two methods (both methods yield the same results). The following equation, based on an annual benefits to costs method and adopted from the FHWA (10), was used to calculate C/E values:

$$C/E = [I(CR_n^i) + K - T(SF_n^i)]/A_s \quad (5)$$

The results of the economic analysis are included in the following section.

RESULTS

Statistical

The results of the statistical tests regarding the mean reduction in each MOE for both five- and three-lane sections from the before to the after periods are given in Table 4.

All test results were significant at the 95 percent confidence level (one-tailed) by both Wilcoxon and Paired t-test, except for the FA + PI accidents for three lanes by Paired t-test, which was significant at the 94.3 percent level.

The reductions by type of affected accidents are given in Table 5.

The test results indicated that

1. For five-lane sections the left-turn and rear-end (combined) accidents, and sideswipe same-direction accidents, were reduced significantly; and
2. For three-lane sections no significant reduction in all three types of accidents was found.

However, when all affected accident types are considered collectively, the accident reductions for both five- and three-lane sections were statistically significant, as indicated by the data in Table 4.

The mean difference (before versus after) in the unaffected (total minus affected) accident rates, their severity, and property damage (PD) rates were also tested. The results of statistical significance at the 95 percent confidence level (two-tailed) are given in Table 6. No statistically significant reductions were obtained except for total unaffected accident rates.

Economic

B/C Ratios

The B/C ratios for total as well as affected accidents on both five- and three-lane sections with i =

TABLE 4 Total Accident Reduction

	5-LANE					3-LANE				
MOE	Before	After	Percent Reduction	t	T′	Before	After	Percent Reduction	t	T′
TA	2,093	1,619	22.6	2.82	15.0	664	475	28.5	2.30	20.5
TA Rate	24,164	17,477	27.7	3.35	12.0	14,824	10,137	31.6	3.33	12.0
FA + PI	571	453	20.7	2.93	13.5	178	134	24.7	1.68	34.5
FA + PI Rate	6,537	4,832	26.1	2.99	12.0	4,236	2,932	30.8	2.35	31.0
TA Affected	824	558	32.3	4.55	5.0	222	130	41.4	2.65	18.0
TA Affected Rate	9,085	5,428	40.2	4.91	4.0	5,334	2,859	46.4	3.17	19.0
FA + PI Affected	207	135	34.8	3.85	6.0	73	36	50.7	2.00	24.0
FA + PI Affected Rate	2,318	1,337	42.3	3.67	10.0	1,789	742	58.5	2.28	29.0

Note: The tests of significance are as follows: for Paired t-statistic, t ⩾ 1.76 for five lanes (df = 14) and t ⩾ 1.75 for three lanes (df = 15); for Wilcoxon statistic, T′ ⩽ 30 for five lanes (number of sites = 15) and T′ ⩽ 35 for three lanes (number of sites = 16).

TABLE 5 Accident Reduction by Type

	Five Lanes				Three Lanes			
Type	Before	After	Percent Reduction	t	Before	After	Percent Reduction	t
Left turn	275	185	32.7	1.77 (left turn and rear-end)	55	53	3.6	1.28 (left turn and rear-end)
Rear-end	352	227	35.5		133	59	55.6	
Sideswipe (same direction)	181	134	26.0	1.95	15	9	40.0	0.91
Sideswipe (opposite direction)	16	12	25.0	0.77	18	9	50.0	1.73

Note: Some of the rear-end accidents might have occurred as a result of left-turn movement by some vehicles. Therefore, the left-turn and rear-end accidents should be considered together. Thus the reduction in left-turn and rear-end accidents (combined) was 34.3 percent for five-lane and 40.4 percent for three-lane sections.

TABLE 6 Unaffected Accident Reduction

	Five Lanes				Three Lanes			
	Before	After	Percent Reduction	t	Before	After	Percent Reduction	t
Unaffected TA rate	15,315	12,059	21.3	1.76	9,491	7,299	23.1	2.32
Unaffected FA + PI rate	4,278	3,500	18.2	1.59	2,436	2,191	10.1	1.02
Unaffected PD rate	11,034	8,559	22.4	1.58	7,055	5,288	25.0	1.99

8 percent, n = 15 years, and T = 0 (salvage value) are given in the following table:

Accidents	B/C Ratio Five Lanes	Three Lanes
Total	2.65	1.31
Affected	1.59	0.63

The results of the sensitivity analyses on B/C ratios with various interest rates (i), service life of improvement (n), and percent salvage values (T) are given in Tables 7-9 and shown in Figures 2-4.

From the data in Tables 7-9 it becomes clear that the B/C values for five-lane sections remain well above acceptable level of 1.00 with various interest rates, service lives, and salvage values.

TABLE 7 Interest Rate and B/C Ratio

i (%)	B/C Ratio Five Lanes	Three Lanes
6	3.00	1.48
7	2.82	1.39
8	2.65	1.31
9	2.51	1.24
10	2.37	1.18
11	2.24	1.12
12	2.13	1.06
13	2.01	1.00
14	1.91	0.95
15	1.84	0.92
16	1.74	0.87
17	1.66	0.83
18	1.59	0.79
19	1.52	0.76
20	1.48	0.75

TABLE 8 Service Life and B/C Ratio

n (yr)	B/C Ratio Five Lanes	Three Lanes
20.0	3.03	1.49
17.5	2.86	1.41
15.0	2.65	1.31
12.5	2.40	1.19
10.0	2.10	1.05

TABLE 9 Salvage Rate and B/C Ratio

T (%)	B/C Ratio Five Lanes	Three Lanes
20	2.83	1.40
10	2.74	1.35
0	2.65	1.31

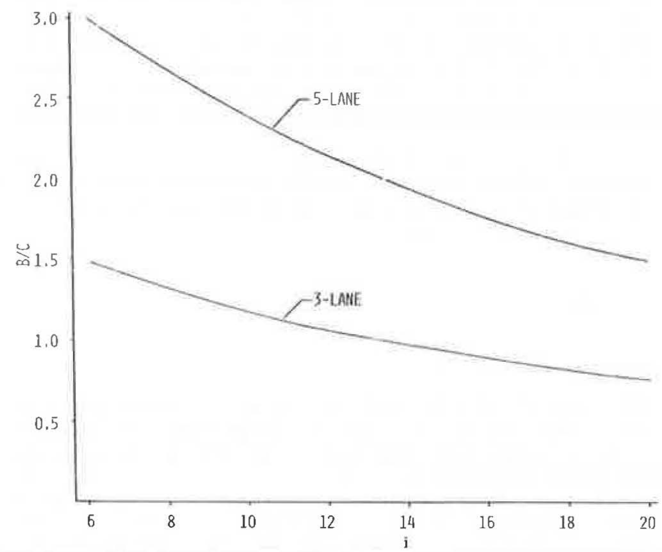

FIGURE 2 Interest rates versus B/C ratio.

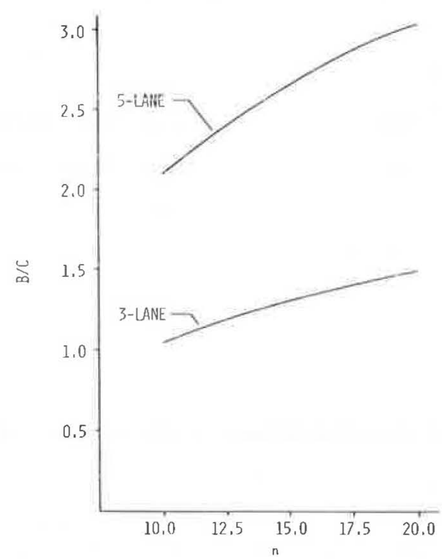

FIGURE 3 Service life versus B/C ratio.

However, the B/C values for three-lane sections becomes only marginally greater than 1.00 when the interest rates are 12 percent and higher and the service life of improvement is 10 years and lower. The B/C values for three-lane sections remain fairly high even with no salvage value. However, it must be remembered that the only benefit considered in this B/C analysis is saving in traffic accidents.

C/E Analysis

The C/E values for total as well as affected acci-

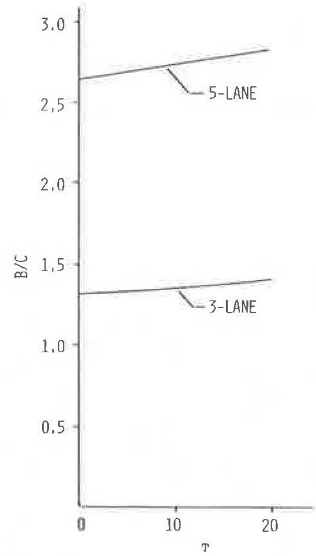

FIGURE 4 Salvage value versus B/C ratio.

dents on both five- and three-lane sections with i = 8 percent, n = 15 years, and T = 0 (salvage value) are given in the following table:

	C/E Values ($)	
Accidents	Five Lanes	Three Lanes
Total	1,352	2,730
Affected	2,254	5,733

CONCLUSIONS AND RECOMMENDATIONS

Based on the statistical and economic analysis of the TWLTL, the following conclusions are drawn.

1. The total accidents, their rates, and their severity for both five- and three-lane sections were reduced significantly after the installation of a TWLTL.
2. The affected accidents, their rates, and their severity were reduced significantly. The left-turn, rear-end, and sideswipe accidents were also reduced substantially.
3. The unaffected (total minus affected) accident rates were reduced significantly for both five- and three-lane improvements. However, their severity was not reduced.
4. The five-lane improvements are cost effective if only accident reduction benefits are considered, with varying interest rates, service lives, and salvage values.
5. The three-lane improvements are cost effective if only accident reduction benefits are considered, with interest rates less than 12 percent, service lives longer than 10 years, and salvage values greater than or equal to 0 percent.

Overall, the TWLTL is found to be both safety and cost effective. In urban areas, where heavy demand for access to the abutting properties exists, the TWLTL becomes a desirable addition to the two- and four-lane urban roadways from safety and economic points of view.

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