70

AN EVALUATION OF 4-WAY STOP SIGN CONTROL

Report TSD-466

TRAFFIC and SAFETY DIVISION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS
AND TRANSPORTATION

MICHIGAN DEPARTMENT
OF
TRANSPORTATION

AN EVALUATION OF 4-WAY STOP SIGN CONTROL

Report TSD-466

By
Peter M. Briglia, Jr.
Safety Programs Unit

February 1981

ACKNOWLEDGEMENTS

The author wishes to acknowledge the helpful assistance provided by the following employees of the Traffic and Safety Division, Michigan Department of Transportation:

G. R. Etelamaki	W. T. Lebel
B. R. Hagerty	S. J. Levin
R. G. Lariviere	S. D. Lingeman

TABLE OF CONTENTS

LIST OF TABLES

Abstract

This report evaluates the effects resulting from changing operational control at several intersections from 2-way to 4-way stops. Accident experience, vehicle operating costs, travel time, fuel consumption, and vehicle emissions were compared for ten intersections, eight having three years and two having two years of "before" and "after" data.

The total numbers of property damage only accidents, injury accidents, injuries, fatal accidents and deaths for the ten intersections were reduced. The total number of accidents of each type (i.e., angle, rear-end, etc.) for eight of the ten intersections was also reduced. Except for the property damage accident rates at two intersections, all other accident rates were reduced. Statistical tests to determine the significance of these reductions were employed and are discussed in the text. The annual savings resulting from reduced accidents at the ten intersections was $760,200 (1979 price levels).

The additional motor vehicle operating costs (fuel, tires, engine oil, maintenance, and depreciation) totalled $913,700 per year. The additional travel time was 208,800 hours per year. The additional fuel consumption was 440,300 gallons per year, and excess annual vehicle emissions totalled 1,287,500 pounds of carbon monoxide, 79,200 pounds of hydrocarbons, and 83,000 pounds of nitrogen oxides.

Nine of the ten intersections experienced low to moderate traffic volumes. All but one included at least one high-speed approach. None were in urban or suburban areas. The single high volume intersection contributed approximately 30 percent of the total vehicle operating costs, travel time, fuel consumption, and vehicle emissions. With high volumes, the increases in operating cost, delay, fuel consumption, and vehicle emissions make this type of intersection control less feasible. At moderate or low volumes (daily approach volume less than 13,000 vehicles) where operating costs are less and where a traffic study indicates that a 4-way stop will substantially reduce the number and severity of accidents, the 4-way stop can be a cost-effective method of intersection control.

Introduction

Many of the techniques normally used to correct accident problems at high speed, low volume, rural intersections have not proven effective. The 4-way stop, previously considered as an intersection control applicable only in moderate volume, low speed, urban-suburban environments, was utilized at several such locations and is the subject of this report.

Ten 4-way stop sign controlled intersections were evaluated to determine the effects of this control compared to the 2-way stops they replaced. All but one of these intersections involved high speed roads; all but one were moderate or low volume intersections; and none was located in an urban area. The factors evaluated were accident experience, motor vehicle operating costs, travel time, fuel consumption, and air quality impacts. The ten intersections, their locations, dates of 4-way stop installation, and a brief description of each follow:

1. M-13 @ M-57, Genesee County, 2-21-74
   Four trunkline approaches - rural
   Daily approach volume - M-13 (3217), M-57 (5650)
   Posted speed - 55 mph

2. M-52 @ M-57, Saginaw County, 2-6-74
   Four trunkline approaches - rural
   Daily approach volume - M-52 (3900), M-57 (5417)
   Posted speed - 55 mph

3. M-50 @ M-52, Lenawee County, 12-22-75
   Four trunkline approaches - rural
   Daily approach volume - M-50 (6550), M-52 (6350)
   Posted speed - 55 mph

4. US-45 @ M-28, Ontonagon County, 12-5-77
   Four trunkline approaches - village
   Daily approach volume - US-45 (1512), M-28 (2340)
   Posted speed - US-45 (55 mph), M-28 (45 mph)

5. M-15 @ M-81, Saginaw County, 8-13-74
   Four trunkline approaches - two approaches divided - rural
   Daily approach volume - M-15 (3567), M-81 (5200)
   Posted speed - 55 mph

6. M-20 @ M-120, Oceana County, 1-8-75
   Three trunkline approaches - one village approach
   Daily approach volume - M-20 (3442), M-120 (3666)
   Posted speed - 35 mph

7. M-106 @ M-52, Ingham County, 4-8-77
   Three trunkline approaches - one village approach
   Daily approach volume - M-106 (4154), M-52 (3758)
   Posted speed - M-106 West (30 mph), M-106 North (55 mph), M-52 East (30 mph)

8. US-27BR @ US-27BR, Gratiot County, 10-12-72
Two trunkline approaches (one right-turn lane channelized) - two county primary approaches
Daily approach volume - US-27BR (4000), US-27BR (4733)
Posted speed - 55 mph

9. M-15 @ M-46, Tuscola County, 3-16-76
Four trunkline approaches (skewed) - village
Daily approach volume - M-15 (4400), M-46 (5500)
Posted speed - M-15 (40 mph), M-46 (45 mph)

10. M-47 @ M-58, Saginaw County, 12-17-71
Three trunkline approaches - one county primary approach
Daily approach volume - M-47 (10,667), M-58 (22,600)
Posted speed - M-47 (55 mph), M-58 (35 mph)

Accident Frequency

Three years of "before" and "after" accident data were evaluated for all intersections except US-45 at M-28 and M-106 at M-52. Two years of "before" and "after" data were used for these intersections due to their more recent installation of 4-way stops. The complete accident data for all ten intersections are shown in Appendix A.

The total number of accidents at the eight locations for which three years of "before" data were available was 230. One hundred and two of these were injury accidents and ten were fatal accidents. There were 89 accidents, including 25 injury accidents, and one fatal accident in the "after" period at these locations. The one fatal accident in the "after" period was a rear-end accident.

The total number of accidents at the two locations for which only two years of "before" data were available was 47. Six of these were injury accidents and one was a fatal accident. There were 19 accidents, one injury accident and no fatal accidents in the two years "after."

The number of accidents, injuries, and deaths expected to occur in the "after" period was projected using the corresponding number in the "before" period and the rates of change of these factors for the entire state (Table 1). Injuries and deaths were used instead of injury accidents and fatal accidents because of the availability of data on statewide trends for these factors. Chi-square tests were used to determine whether the overall reductions in observed versus expected values were significant (Appendix B). The reductions in accidents per year and injuries per year were statistically significant at the 99.9 percent confidence level. The reduction in deaths per year was not statistically significant due to the low numbers involved.

Table 1
Expected and Observed Annual Accidents, Injuries, and Deaths

Location	Accidents/Year			Injuries/Year			Deaths/Year		
		After			After			After	
	Before	Expected	Observed	Before	Expected	Observed	Before	Expected	Observed
M-15 @ M-46	11.3	13.5	4.0	3.3	4.0	1.0	0.7	0.8	0.3
M-13 @ M-57	13.3	13.5	5.0	16.0	14.6	3.3	1.0	0.9	0
M-15 @ M-81	9.7	9.9	4.0	14.0	12.7	4.0	1.3	1.1	0
M-50 @ M-52	14.3	15.3	1.7	12.3	12.1	1.3	0.3	0.3	0
M-52 @ M-57	12.0	12.2	2.7	11.7	10.6	1.7	1.3	1.1	0
US-45 @ M-28	10.5	11.5	3.0	2.5	2.8	0	0.5	0.5	0
M-47 @ M-58	6.0	5.9	7.0	5.0	4.0	1.7	0	0	0
US-27BR @ US-27BR	10.0	10.4	3.0	9.3	8.1	2.0	0.3	0.3	0
M-106 @ M-52	13.0	14.3	6.5	2.0	2.2	0.5	0	0	0
M-20 @ M-120	3.3	3.5	2.3	1.3	1.3	0.0	0	0	0

Table 2 shows the number of accidents, by type, for the eight intersections for which three years of "before" and "after" data were available. Table 3 shows the same information for the two intersections for which two years of data were available.

Table 2
Number of Accidents By Type
For Eight 4-Way Stop Intersections

Type	Before (3 yrs.)	After (3 yrs.)	Percent Reduction
Angle	136	34	75.0
Rear-End	41	22	46.3
Left-Turn	17	9	47.1
Right-Turn	3	2	33.3
Other	33	22	33.3
Total	230	89	61.3

Table 3
Number of Accidents By Type
For Two 4-Way Stop Intersections

Type	Before (2 yrs.)	After (2 yrs.)	Percent Reduction
Angle	10	2	80.0
Rear-End	3	1	66.7
Left-Turn	1	2	+
Right-Turn	1	1	0
Other	32	13	59.4
Total	47	19	59.6

+Percentage increase

With the exception of left-turn and right-turn accidents shown for the two intersections (Table 3), the installation of 4-way stop signs reduced all major types of accidents at these intersections. A Chi-square test utilizing a 5x2 contingency table was performed to assess the significance of these reductions (Appendix B). The reduction in accidents at the eight intersections in Table 2 was statistically significant at the 97.5 percent confidence level. The overall reduction in collisions at the two intersections in Table 3 was not statistically significant due to the low numbers involved.

Accident Rates

Table 4 shows the yearly accident rates per million vehicles for all ten intersections. Two intersections experienced increases in property damage only accident rates. All other accident rates were reduced or remained the same.

The significance of the reduction in accident rates was evaluated using t-tests. The overall reductions in total accident rates, injury accident rates, and fatal accident rates were statistically significant at the 95 percent confidence level. The overall reduction in property damage only accident rates was statistically significant at the 90 percent confidence level (Appendix B).

Table 4
Accident Rates (Accidents/MV/Year)

Location	Total Accidents Before	Total Accidents After	Total Accidents Percentage Reduction	PDO Accidents Before	PDO Accidents After	PDO Accidents Percentage Reduction
M-15 @ M-46	3.45	1.11	67.8	2.74	0.74	73.0
M-13 @ M-57	4.37	1.54	64.8	1.97	1.13	42.6
M-15 @ M-81	3.12	1.25	59.9	0.75	0.63	16.0
M-50 @ M-52	3.35	0.35	89.6	1.87	0.21	88.8
M-52 @ M-57	4.08	0.78	80.9	2.04	0.39	80.9
US-45 @ M-28	7.72	2.13	72.4	6.25	2.13	65.9
M-47 @ M-58	0.64	0.58	9.4	0.39	0.44	12.8+
US-27BR @ US-27BR	1.84	0.94	48.9	0.55	0.84	52.7+
M-106 @ M-52	4.51	2.25	50.1	3.99	2.08	47.9
M-20 @ M-120	1.34	0.90	32.8	0.94	0.90	4.3

Location	Injury Accidents Before	Injury Accidents After	Injury Accidents Percentage Reduction	Fatal Accidents Before	Fatal Accidents After	Fatal Accidents Percentage Reduction
M-15 @ M-46	0.61	0.28	54.1	0.10	0.09	10.0
M-13 @ M-57	2.08	0.41	80.3	0.33	0	100.0
M-15 @ M-81	2.15	0.63	70.7	0.22	0	100.0
M-50 @ M-52	1.40	0.14	90.0	0.08	0	100.0
M-52 @ M-57	1.81	0.39	78.5	0.23	0	100.0
US-45 @ M-28	1.10	0	100.0	0.37	0	100.0
M-47 @ M-58	0.25	0.14	44.0	0	0	0
US-27BR @ US-27BR	1.20	0.10	91.7	0.09	0	100.0
M-106 @ M-52	0.52	0.17	67.3	0	0	0
M-20 @ M-120	0.40	0	100.0	0	0	0

+Percentage Increase

Savings From Accident Reductions

Table 5 shows the savings resultant from accident reductions at the ten intersections. The net annual savings was $760,200 based on National Safety Council cost estimates for 1979 at $870 per property damage accident, $6,200 per injury accident, and $160,000 per fatal accident.

Table 5
Savings From Accident Reduction

Location	PDO Acc. Reduction/ Savings ($)	Inj. Acc. Reduction/ Savings ($)	Fatal Acc. Reduction/ Savings ($)	Net Savings ($)	Net Annual Savings ($)
M-15 @ M-46	19/16,530	3/18,600	0/0	35,130/3 yrs.	11,700
M-13 @ M-57	7/6090	15/93,000	3/480,000	579,090/3 yrs.	193,000
M-15 @ M-81	1/870	14/86,800	2/320,000	407,670/3 yrs.	135,900
M-50 @ M-52	21/18,270	16/99,200	1/160,000	277,470/3 yrs.	92,500
M-52 @ M-57	14/12,180	12/74,400	2/320,000	406,580/3 yrs.	135,500
US-45 @ M-28	11/9570	3/18,600	1/160,000	188,170/2 yrs.	94,100
M-47 @ M-58	5/4350+	2/12,400	0/0	8,050/3 yrs.	2,700
US-27BR @ US-27BR	2/1740+	12/74,400	1/160,000	232,660/3 yrs.	77,600
M-106 @ M-52	11/9570	2/12,400	0/0	21,970/2 yrs.	11,000
M-20 @ M-120	0/0	3/18,600	0/0	18,600/3 yrs.	6,200
				Total Net Annual Savings =	$760,200

+Increased costs from increase in accidents.

Vehicle Operating Costs

Additional vehicle operating costs consisted of the cost of stopping instead of continuing at the initial speed and the cost of idling. The cost of stopping included fuel, tires, engine oil, maintenance, and depreciation. The cost of idling included all of the above except tires. The cost of speed changes is dependent upon approach speed with the cost of 1000 speed changes from 55 mph to a stop and return to 55 mph, for example, being $30.75[1]. The cost of 1000 hours of idling was $312.64[2]. The percentage of vehicles stopped and the delays for the "before" and "after" periods are shown in Table 6. The percentage of vehicles stopped in the "before" period was based on the proportion of traffic on the less heavily traveled road. The average delays per stopped vehicle were estimated from back-up delay studies for two of the intersections, M-50 at M-52 and M-47 at M-58. The increased number of vehicles stopped and the increased delay are shown in Table 7.

Table 6
Traffic Volumes and Vehicular Delays
Before and After 4-Way Stop Control

Location	Daily Approach Volume[3]		Volumes Stopped Percent		Average Delay per Stopped Vehicle, Sec.	
	Before	After	Before	After	Before	After
M-15 @ M-46	9,000	9,900	45.6	100	25	16
M-13 @ M-57	8,350	8,867	40.9	100	25	16
M-15 @ M-81	8,483	8,767	47.5	100	25	16
M-50 @ M-52	11,733	12,900	43.2	100	25	16
M-52 @ M-57	8,067	9,317	45.9	100	25	16
US-45 @ M-28	3,725	3,852	36.9	100	25	16
M-47 @ M-58	25,720	33,267	27.0	100	25	16
US-27BR @ US-27BR	9,933	8,733	35.6	100	25	16
M-106 @ M-52	7,900	7,912	48.1	100	25	16
M-20 @ M-120	6,833	7,108	48.8	100	25	16

[1] "Procedure for Estimating Highway User Costs, Fuel Consumption, and Air Pollution," by U.S. Dept. of Transportation, Federal Highway Administration, Office of Traffic Operations, March 1980, pg. 13.

[2] Ibid., pg. 15.

[3] The traffic stream is assumed to be 100 percent passenger cars.

Table 7
Annual Number of Vehicle Stops and Periods of
Delay Before and After
4-Way Stop Control

Location	Number of Vehicles Stopped (1000s)			Vehicular Stopped (Idling) Delay (1000 Hours)		
	Before	After	Increase	Before	After	Increase
M-15 @ M-46	1498	3614	2116	10.4	16.1	5.7
M-13 @ M-57	1247	3236	1989	8.7	14.4	5.7
M-15 @ M-81	1471	3200	1729	10.2	14.2	4.0
M-50 @ M-52	1850	4709	2859	12.8	20.9	8.1
M-52 @ M-57	1352	3401	2049	9.4	15.1	5.7
US-45 @ M-28	502	1406	904	3.5	6.2	2.7
M-47 @ M-58	2535	12142	9607	17.6	54.0	36.4
US-27BR @ US-27BR	1291	3188	1897	9.0	14.2	5.2
M-106 @ M-52	1387	2888	1501	9.6	12.8	3.2
M-20 @ M-120	1217	2594	1377	8.5	11.5	3.0

Table 8 shows the calculations performed to determine the additional cost of stopping ($879,600/year), the additional cost of idling ($34,100/year), and the total additional motor vehicle operating cost ($913,700/year). The references cited on page 6 used 1975 price levels. Costs were updated to 1979 price levels using the change in the Consumer Price Index.

Table 8
Annual Motor Vehicle Operating Costs (1979 Price Levels)

Location	Additional Costs of Stopping ($)	Add. Costs of Idling ($)	Total Add. Motor Veh. Oper. Costs ($)
M-15 @ M-46	69,700	2,400	72,100
M-13 @ M-57	83,600	2,400	86,000
M-15 @ M-81	72,700	1,700	74,400
M-50 @ M-52	120,200	3,500	123,700
M-52 @ M-57	86,100	2,400	88,500
US-45 @ M-28	30,400	1,200	31,600
M-47 @ M-58	257,200	15,600	272,800
US-27BR @ US-27BR	79,700	2,200	81,900
M-106 @ M-52	46,600	1,400	48,000
M-20 @ M-120	33,400	1,300	34,700
	$879,600	$ 34,100	$ 913,700

Vehicle Travel Time

Total additional vehicle travel time is comprised of the additional time required to stop instead of continuing at the initial speed and the additional time spent idling at a stop. The time to slow from 55 mph to a stop and to return to 55 mph, for example, was 5.84[4] hours per 1000 speed change cycles. The delay due to idling was discussed in the previous section and is shown in Table 7.

Table 9 tabulates the hours used for speed changes instead of continuing at the initial speed (129,100 hours/year), hours of vehicle delay (79,700 hours/year), and total additional hours of vehicle travel time (208,800 hours/year).

Table 9
Annual Vehicle Travel Time (Hours/Year)

Location	Hours for Speed Change Cycle	Hours of Delay	Total Additional Hours of Vehicle Travel Time
M-15 @ M-46	10,300	5,700	16,000
M-13 @ M-57	11,600	5,700	17,300
M-15 @ M-81	10,100	4,000	14,100
M-50 @ M-52	16,700	8,100	24,800
M-52 @ M-57	12,000	5,700	17,700
US-45 @ M-28	4,500	2,700	7,200
M-47 @ M-58	40,400	36,400	76,800
US-27BR @ US-27BR	11,100	5,200	16,300
M-106 @ M-52	7,000	3,200	10,200
M-20 @ M-120	5,400	3,000	8,400
	129,100	79,700	208,800

Fuel Consumption

Additional fuel consumption consisted of the fuel used in stopping instead of continuing at the initial speed and that for increased idling.

For example, the additional fuel consumed per 1000 speed changes from 55 mph to stop and back to 55 mph was 18.5[5] gallons per 1000 speed changes. The additional fuel for idling was 650[6] gallons per 1000 hours.

[4]Procedure for Estimating Highway User Costs, Fuel Consumption, and Air Pollution, op. cit, pg. 14.

[5]Ibid., pg. 17.

[6]Ibid., pg. 15

Table 10 shows the additional fuel consumed in stopping instead of continuing at the initial speed (388,300 gal/year), idling (52,000 gal/year), and the total consumed (440,300 gal/year).

Table 10
Annual Fuel Consumption (Gallons/Year)

Location	Additional Fuel Consumption Due to Stopping	Add. Fuel Consumption Due to Idling (650 gal/1,000 Veh. Hours)	Total Add. Fuel Consumption
M-15 @ M-46	30,500	3,700	34,200
M-13 @ M-57	36,800	3,700	40,500
M-15 @ M-81	32,000	2,600	34,600
M-50 @ M-52	52,900	5,300	58,200
M-52 @ M-57	37,900	3,700	41,600
US-45 @ M-28	13,300	1,800	15,100
M-47 @ M-58	114,200	23,700	137,900
US-27BR @ US-27BR	35,100	3,400	38,500
M-106 @ M-52	20,700	2,100	22,800
M-20 @ M-120	14,900	2,000	16,900
	388,300	52,000	440,300

Vehicle Emissions

The increase of the three major automobile exhaust products (i.e. carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x)) due to the installation of 4-way stops was investigated. As in the previous discussions, the effects of both stopping and idling were investigated.

Table 11 shows the total additional annual emissions of the three products after installation of 4-way stop signs (CO = 1,287,500 pounds/yr; HC = 79,200 pounds/yr; NO_x = 83,000 pounds/yr). These quantities indicate the magnitude of the additional emissions attributable to 4-way stop sign control at these intersections. While any increase in emissions may be assumed detrimental, their significance was not evaluated.

Table 11
Total Annual Air Quality Impacts (lbs./year)

Location	Carbon Monoxide (CO) Emissions	Hydrocarbon (HC) Emissions	Nit[illegible] Emissions
M-15 @ M-46	94,500	6,100	6,600
M-13 @ M-57	129,300	7,500	8,300
M-15 @ M-81	110,000	6,300	7,100
M-50 @ M-52	185,500	10,700	11,800
M-52 @ M-57	132,700	7,700	8,500
US-45 @ M-28	42,400	2,700	2,900
M-47 @ M-58	365,100	24,300	22,900
US-27BR @ US-27BR	122,600	7,100	7,900
M-106 @ M-52	65,100	4,000	4,200
M-20 @ M-120	40,300	2,800	2,800
	1,287,500	79,200	83,000

Conclusions

Table 12 presents a summary of the effects of installation of 4-way stop control at the 10 intersections studied in this report. These intersections experienced a reduction of 77 property damage accidents, 82 injury accidents, and 10 fatal accidents. This reduction resulted in an annual savings of $760,200.

However, these 4-way stops resulted in additional vehicle operating costs of $913,700 per year for the 10 intersections. Vehicular travel time increased 208,800 hours per year, fuel consumption increased by 440,300 gallons per year, and exhaust emissions increased by 1,287,500 pounds of carbon monoxide (CO) per year, 79,200 pounds of hydrocarbons (HC) per year, and 83,000 pounds of oxides of nitrogen (NO_x) per year.

Four-way stop signs were installed at these intersections to reduce accidents which were occurring with 2-way stop sign control. Unlike traffic signals, which generally experience an increase in accidents following installation, the total number of accidents and the number of accidents of all types, decreased with installation of 4-way stop control.

The increased costs associated with 4-way stops are substantial. With high intersection approach volumes, these cost increases are greater than resultant savings in reduction of accidents. However, at low or moderate volumes, where a traffic study indicates that a 4-way stop will substantially reduce the number or severity of accidents, the 4-way stop can be a cost-effective method of intersection control. Further improvement in fuel economy and emission controls should reduce the adverse fuel consumption and air quality effects, making the 4-way stop a more feasible option.

Table 12
Summary

Location	Study Period Before (Yrs)	Study Period After (Yrs)	PDO Accident Reduction (% Red. in Rate)	Inj. Acc. Red. (% Red. in Rate)	Fat. Acc. Red. (% Red. in Rate)	Annual Acc. Savings ($/yr)[1]	Annual Add. Veh. Oper. Costs ($/yr)[1]	Annual Add. Veh. Travel Time (hrs/yr)	Annual Add. Fuel Con. (Gal/yr)	Annual Air Quality Impacts (lbs/yr) CO	HC	NO_x
M-15 @ M-46	3	3	19(73.0)	3(54.1)	0(10.0)	$ 11,700	$ 72,100	16,000	34,200	94,500	6,100	6,600
M-13 @ M-57	3	3	7(42.6)	15(80.3)	3(100.0)	193,000	86,000	17,300	40,500	129,300	7,500	8,300
M-15 @ M-81	3	3	1(16.0)	14(70.7)	2(100.0)	135,900	74,400	14,100	34,600	110,000	6,300	7,100
M-50 @ M-52	3	3	21(88.8)	16(90.0)	1(100.0)	92,500	123,700	24,800	58,200	185,500	10,700	11,800
M-52 @ M-57	3	3	14(80.9)	12(78.5)	2(100.0)	135,500	88,500	17,700	41,600	132,700	7,700	8,500
US-45 @ M-28	2	2	11(65.9)	3(100.0)	1(100.0)	94,100	31,600	7,200	15,100	42,400	2,700	2,900
M-47 @ M-58	3	3	5(12.8)+	2(44.0)	0(0.0)	2,700	272,800	76,800	137,900	365,100	24,300	22,900
US-27BR @ US-27BR	3	3	2(52.7)+	12(91.7)	1(100.0)	77,600	81,900	16,300	38,500	122,600	7,100	7,900
M-106 @ M-52	2	2	11(47.9)	2(67.3)	0(0.0)	11,000	48,000	10,200	22,800	65,100	4,000	4,200
M-20 @ M-120	3	3	0(4.3)	3(100.0)	0(0.0)	6,200	34,700	8,400	16,900	40,300	2,800	2,800
			Net = 77	82	10	$760,200	$ 913,700	208,800	440,300	1,287,500	79,200	83,000

+ = Increase

[1] 1979 Price Levels

Recommendations for Further Study

The following recommendations for further study can be made concerning 4-way stop signs:

1. The unanticipated reduction in rear-end accidents at these intersections after installation of 4-way stop control should be monitored and other 4-way stop intersections should be studied to determine if this can be expected in all cases.

2. Low speed, high volume, urban or suburban intersections, which were not investigated in this study, should be studied to determine any generalizations which could be drawn concerning 4-way stop control.

3. Information on 4-way stop performance in other areas of the country, if available, should be combined with information from the above studies to provide firm guidelines for the use of 4-way stop control.

Appendix A
Number of Accidents By Type

APPENDIX A
Number of Accidents By Type

M-47 @ M-58

	Before 68	Before 69	Before 70	Before Tot	After 73	After 74	After 75	After Tot
Angle	2	5	7	14	2	2	2	6
Rear End	1	1	0	2	2	1	2	5
Left Turn	0	0	0	0	2	0	1	3
Right Turn	0	0	0	0	0	0	0	0
Other	1	1	0	2	3	4	0	7
Total	4	7	7	18	9	7	5	21
PDO	3	4	4	11	8	5	3	16
Inj. Acc.	1	3	3	7	1	2	2	5
# Inj.	1	7	7	15	1	2	2	5
Fat. Acc.	0	0	0	0	0	0	0	0
# Killed	0	0	0	0	0	0	0	0

M-15 @ M-46

	Before 73	Before 74	Before 75	Before Tot	After 77	After 78*	After 79*	After Tot
Angle	7	4	5	16	1			3
Rear End	3	4	2	9	1			3
Left Turn	1	0	1	2				1
Right Turn	1	0	0	1	1			2
Other	4	1	1	6				3
Total	16	9	9	34	3	6	3	12
PDO	12	6	9	27	1	5	2	8
Inj. Acc.	3	3	0	6	2	2	1	3
# Inj.	7	3	0	10	2	0	1	3
Fat. Acc.	1	0	0	1	0	1	0	1
# Killed	2	0	0	2	0	1	0	1

M-15 @ M-81

	Before 71	Before 72	Before 73	Before Tot	After 75	After 76	After 77	After Tot
Angle	10	3	5	18	3	4	2	9
Rear End	1	2	1	4	1	1	0	2
Left Turn	1	2	0	3	0	1	0	1
Right Turn	0	0	0	0	0	0	0	0
Other	3	0	1	4	0	0	0	0
Total	15	7	7	29	4	6	2	12
PDO	3	3	1	7	1	4	1	6
Inj. Acc.	11	3	6	20	3	2	1	6
# Inj.	22	6	14	42	7	3	2	12
Fat. Acc.	1	1	0	2	0	0	0	0
# Killed	1	3	0	4	0	0	0	0

*Accidents unavailable on a yearly basis.

	M-13 & M-57								M-52 @ M-57								M-50 @ M-52							
	Before				After				Before				After				Before				After			
	71	72	73	Total	75	76	77	Total	71	72	73	Total	75	76	77	Total	72	73	74	Total	76	77	78	Total
Angle	8	6	14	28	2	1	4	7	0	6	9	15	1	0	2	3	13	9	6	28	0	1	0	1
Rear End	0	3	3	6	2	3	1	6	1	4	4	9	0	0	0	0	5	2	0	7	0	0	2	2
Left Turn	1	0	0	1	0	2	0	2	2	4	1	7	0	1	0	1	0	0	1	1	0	0	0	0
Right Turn	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	0	0	0	0
Other	1	3	1	5	0	0	0	0	1	2	1	4	0	4	0	4	4	1	1	6	0	1	1	2
Total	10	12	18	40	4	6	5	15	4	16	16	36	1	5	2	8	22	13	8	43	0	2	3	5
PDO	4	6	8	18	4	2	5	11	2	9	7	18	1	2	1	4	15	5	4	24	0	1	2	3
Inj. Acc.	5	6	8	19	0	4	0	4	2	6	8	16	0	3	1	4	7	7	4	18	0	1	1	2
# Inj.	13	10	25	48	0	10	0	10	8	8	19	35	0	4	1	5	19	14	4	37	0	3	1	4
Fat. Acc.	1	0	2	3	0	0	0	0	0	1	1	2	0	0	0	0	0	1	0	1	0	0	0	0
# Killed	1	0	2	3	0	0	0	0	0	1	3	4	0	0	0	0	0	1	0	1	0	0	0	0

	US-45 @ M-28						US-27BR @ US-27BR								M-52 @ M-106						M-20 @ M-120							
	Before			After			Before				After				Before			After			Before				After			
	75	76	Total	78	79	Total	69*	70*	71	Total	73*	74*	75	Total	75	76	Total	78	79	Total	72	73	74	Total	76	77	78	Total
Angle	1	3	4	0	0	0				11				3	3	3	6	2	0	2	2	2	2	6	0	0	2	2
Rear End	1	0	1	0	0	0				3				3	2	0	2	1	0	1	0	0	1	1	0	0	1	1
Left Turn	1	0	1	0	0	0				3				1	0	0	0	1	1	2	0	0	0	0	0	0	0	0
Right Turn	0	1	1	0	0	0				0				0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Other	7	7	14	5	1	6				3				2	7	11	18	2	5	7	0	0	3	3	2	0	2	4
Total	10	11	21	5	1	6	3	10	7	20	1	3	5	9	12	14	26	7	6	13	2	2	6	10	2	0	5	7
PDO	9	8	17	5	1	6	2	2	2	6	1	3	4	8	12	11	23	6	6	12	1	0	6	7	2	0	5	7
Inj. Acc.	1	2	3	0	0	0	1	7	5	13	0	0	1	1	0	3	3	1	0	1	1	2	0	3	0	0	0	0
# Inj.	1	4	5	0	0	0	4	18	9	28	0	0	6	6	0	4	4	1	0	1	1	3	0	4	0	0	0	0
Fat. Acc.	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
# Killed	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*Accidents unavailable on a yearly basis.

Appendix B
Statistical Analysis

Statewide Accident Trends

Location	Midpoint of Before Period	Accidents (x1,000)	Injuries (x1,000)	Deaths	Midpoint of After Period	Accidents (x1,000)	Injuries (x1,000)	Deaths	Percentage Change Accidents	Injuries	Deaths
M-15 @ M-46	1974	324.8	141.1	1875	1978	389.2	169.2	2076	+0.198	+0.199	+0.107
M-13 @ M-57	1972	359.7	178.9	2258	1976	365.6	162.8	1955	+0.016	-0.09	-0.134
M-15 @ M-81	1972	359.7	178.9	2258	1976	365.6	162.8	1955	+0.016	-0.09	-0.134
M-50 @ M-52	1973	350.8	169.5	2213	1977	374.7	166.3	1950	+0.068	-0.019	-0.119
M-52 @ M-57	1972	359.7	178.9	2258	1976	365.6	162.8	1955	+0.016	-0.09	-0.134
US-45 @ M-28	1975	333.6	147.3	1811	1979	366.4	162.6	1849	+0.098	+0.104	+0.021
M-47 @ M-58	1969	331.2	175.4	2487	1974	324.8	141.1	1875	-0.019	-0.196	-0.246
US-27BR @ US-27BR	1970	313.7	161.7	2177	1974	324.8	141.1	1875	+0.035	-0.127	-0.139
M-106 @ M-52	1975	333.6	147.3	1811	1979	366.4	162.6	1849	+0.098	+0.104	+0.021
M-20 @ M-120	1973	350.8	169.5	2213	1977	374.7	166.3	1950	+0.068	-0.019	-0.119

Accidents

Location	Before Period (Accidents/yr.)	After Period Expected (Accidents/yr.)	After Observed (Accidents/yr.)	$\frac{(O-E)^2}{E}$
M-15 @ M-46	11.3	13.5	4.0	6.7
M-13 @ M-57	13.3	13.5	5.0	5.4
M-15 @ M-81	9.7	9.9	4.0	3.5
M-50 @ M-52	14.3	15.3	1.7	12.1
M-52 @ M-57	12.0	12.2	2.7	7.4
US-45 @ M-28	10.5	11.5	3.0	6.3
M-47 @ M-58	6.0	5.9	7.0	0.21
US-27BR @ US-27BR	10.0	10.4	3.0	5.3
M-106 @ M-52	13.0	14.3	6.5	4.3
M-20 @ M-120	3.3	3.5	2.3	0.4
				$X^2 = 51.61$

$df = (10-1)(2-1) = 9$

$P < 0.001$ There is a statistically significant difference in the After expected and After observed.

Injuries

Location	Before Period (Injuries/yr.)	After Period Expected (Injuries/yr.)	After Period Observed (Injuries/yr.)	$\frac{(O-E)^2}{E}$
M-15 @ M-46	3.3	4.0	1.0	2.2
M-13 @ M-57	16.0	14.6	3.3	8.7
M-15 @ M-81	14.0	12.7	4.0	6.0
M-50 @ M-52	12.3	12.1	1.3	9.6
M-52 @ M-57	11.7	10.6	1.7	7.5
US-45 @ M-28	2.5	2.8	0	2.8
M-47 @ M-58	5.0	4.0	1.7	1.3
US-27BR @ US-27BR	9.3	8.1	2.0	4.6
M-106 @ M-52	2.0	2.2	0.5	1.3
M-20 @ M-120	1.3	1.3	0.0	1.3

$X^2 = 45.3$

$df = (10-1)(2-1) = 9$

$P < 0.001$ There is a statistically significant difference in the After expected and After observed.

Deaths

Location	Before Period (Deaths/yr.)	After Period Expected (Deaths/yr.)	After Period Observed (Deaths/yr.)	$\frac{(O-E)^2}{E}$
M-15 @ M-46	0.7	0.8	0.3	0.3
M-13 @ M-57	1.0	0.9	0	0.9
M-15 @ M-81	1.3	1.1	0	1.1
M-50 @ M-52	0.3	0.3	0	0.3
M-52 @ M-57	1.3	1.1	0	1.1
US-45 @ M-28	0.5	0.5	0	0.5
M-47 @ M-58	0	0	0	0
US-27BR @ US-27BR	0.3	0.3	0	0.3
M-106 @ M-52	0	0	0	0
M-20 @ M-120	0	0	0	0

$X^2 = 4.5$

$df = (10-1)(2-1) = 9$

$0.75 < P < 0.90$ There is no statistically significant difference in the After expected and After observed.

Number of Accidents by Type
For Eight 4-Way Stop Intersections

Type	Before	After	Total
Angle	136	34	170
R-end	41	22	63
L-turn	17	9	26
Rt-turn	3	2	5
Other	33	22	55
Total	230	89	319

	Before	After
Angle	$\frac{170}{319} \times 230 = 122.6$	$\frac{170}{319} \times 89 = 47.4$
R-end	$\frac{63}{319} \times 230 = 45.4$	$\frac{63}{319} \times 89 = 17.6$
L-turn	$\frac{26}{319} \times 230 = 18.7$	$\frac{26}{319} \times 89 = 7.3$
Rt-turn	$\frac{5}{319} \times 230 = 3.6$	$\frac{5}{319} \times 89 = 1.4$
Other	$\frac{55}{319} \times 230 = 39.7$	$\frac{55}{319} \times 89 = 15.3$
	230	89

OBS	EXP	OBS-EXP	$(OBS-EXP)^2$	$\frac{(OBS-EXP)^2}{EXP}$
136	122.6	13.4	179.56	1.46
34	47.4	13.4	179.56	3.79
41	45.4	4.4	19.36	0.43
22	17.6	4.4	19.36	1.10
17	18.7	1.7	2.89	0.15
9	7.3	1.7	2.89	0.40
3	3.6	0.6	0.36	0.1
2	1.4	0.6	0.36	0.26
33	39.7	6.7	44.89	1.13
22	15.3	6.7	44.89	2.93
319	319			$X^2 = 11.75$

$df = (5-1)(2-1) = 4$

$0.01 < P < 0.025$

∴ significant difference in before and after

Number of Accidents By Type
For Two 4-Way Stop Intersections

Type	Before	After	Total
Angle	10	2	12
R-end	3	1	4
L-turn	1	2	3
R-turn	1	1	2
Other	32	13	45
Total	47	19	66

	Before	After
Angle	$\frac{12}{66} \times 47 = 8.55$	$\frac{12}{66} \times 19 = 3.45$
R-end	$\frac{4}{66} \times 47 = 2.85$	$\frac{4}{66} \times 19 = 1.15$
L-turn	$\frac{3}{66} \times 47 = 2.14$	$\frac{3}{66} \times 19 = 0.86$
R-turn	$\frac{2}{66} \times 47 = 1.42$	$\frac{2}{66} \times 19 = 0.58$
Other	$\frac{45}{66} \times 47 = 32.05$	$\frac{45}{66} \times 19 = 12.95$
	47.0	19.0

OBS	EXP	OBS-EXP	$(OBS-EXP)^2$	$\frac{(OBS-EXP)^2}{EXP}$
10	8.55	1.45	2.10	0.25
2	3.45	1.45	2.10	0.61
3	2.85	0.15	0.0225	0.008
1	1.15	0.15	0.0225	0.02
1	2.14	1.14	1.3	0.61
2	0.86	1.14	1.3	1.51
1	1.42	0.42	0.18	0.13
1	0.58	0.42	0.18	0.31
32	32.05	0.05	0.0025	0.0001
13	12.95	0.05	0.0025	0.0002
66	66.0			$X^2 = 3.45$

$df = (5-1)(2-1) = 4$
$0.975 < P < 0.99$
No significant difference in Before and After

JOB DEF= ******
PROC DEF= TOTAL
DATA DEF= PETE
ANALYSIS= TTEST
DATA SET= 1 OBSERVATIONS: 80 READ, 20 PROCESSED.

Analysis of Total Accident Rates

VARIABLE	RATE
SAMPLE 1	
SAMPLE SIZE	10
MEAN	3.44200
VARIANCE (UNBIASED)	3.96204
STANDARD DEVIATION	1.99049
SAMPLE 2	
SAMPLE SIZE	10
MEAN	1.18300
VARIANCE (UNBIASED)	0.39240
STANDARD DEVIATION	0.62642
VARIANCE RATIO (F)	10.09691
CONFIDENCE LEVEL	0.99900

EQUAL POPULATION VARIANCES - POOLED-T

VARIANCE ESTIMATE	2.17722
DEGREES OF FREEDOM	18
TEST STATISTIC	3.42334
TWO-TAIL SIGNIF	0.00303

95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

LOWER LIMIT	0.87264
UPPER LIMIT	3.64536

UNEQUAL POPULATION VARIANCES - BEHRENS-FISHER PROBLEM

VARIANCE ESTIMATE	0.43544
DEGREES OF FREEDOM	11
TEST STATISTIC	3.42334
TWO-TAIL SIGNIF	0.00569

95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

LOWER LIMIT	0.80661
UPPER LIMIT	3.71139

```
 JCB DEF= ******
PROC DEF=    PDO
DATA DEF=   PETE
ANALYSIS=  TTEST
DATA SET=      1        OBSERVATIONS:     80 READ,     20 PROCESSED,
```

Analysis of Property Damage Only Accident

```
VARIABLE                          RATE

SAMPLE 1
SAMPLE SIZE                         10
MEAN                           2.14900
VARIANCE (UNBIASED)            3.30537
STANDARD DEVIATION             1.81807

SAMPLE 2
SAMPLE SIZE                         10
MEAN                           0.94900
VARIANCE (UNBIASED)            0.44268
STANDARD DEVIATION             0.66534

VARIANCE RATIO (F)             7.46677
CONFIDENCE LEVEL               0.99689

EQUAL POPULATION VARIANCES - POOLED-T

   VARIANCE ESTIMATE           1.87402
  DEGREES OF FREEDOM                18
      TEST STATISTIC           1.96010
    TWO-TAIL SIGNIF            0.06565

  95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

         LOWER LIMIT          -0.08621
         UPPER LIMIT           2.48621

UNEQUAL POPULATION VARIANCES - BEHRENS-FISHER PROBLEM

   VARIANCE ESTIMATE           0.37480
  DEGREES OF FREEDOM                11
      TEST STATISTIC           1.96010
    TWO-TAIL SIGNIF            0.07580

  95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

         LOWER LIMIT          -0.14747
         UPPER LIMIT           2.54747
```

```
  JOB DEF=  ******
 PROC DEF=  INJURY
 DATA DEF=    PETE
 ANALYSIS=  TTEST
 DATA SET=       1        OBSERVATIONS:     80 READ,     20 PROCESSED.
```

Analysis of Injury Accident Rates

```
VARIABLE                              RATE

SAMPLE 1
SAMPLE SIZE                             10
MEAN                               1.15200
VARIANCE (UNBIASED)                0.49211
STANDARD DEVIATION                 0.70150

SAMPLE 2
SAMPLE SIZE                             10
MEAN                               0.22600
VARIANCE (UNBIASED)                0.04032
STANDARD DEVIATION                 0.20079

VARIANCE RATIO (F)                12.20637
CONFIDENCE LEVEL                   0.99952

EQUAL POPULATION VARIANCES - POOLED-T

   VARIANCE ESTIMATE               0.26621
  DEGREES OF FREEDOM                    18
      TEST STATISTIC               4.01313
     TWO-TAIL SIGNIF               0.00082

  95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

         LOWER LIMIT               0.44123
         UPPER LIMIT               1.41077

UNEQUAL POPULATION VARIANCES - BEHRENS-FISHER PROBLEM

   VARIANCE ESTIMATE               0.05324
  DEGREES OF FREEDOM                    10
      TEST STATISTIC               4.01313
     TWO-TAIL SIGNIF               0.00247

  95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

         LOWER LIMIT               0.41187
         UPPER LIMIT               1.44013
```

```
 JOB DEF=  ******
PROC DEF=  FATAL
DATA DEF=   PETE
ANALYSIS=  TTEST
DATA SET=      1        OBSERVATIONS:      80 READ,      20 PROCESSED,
```

Analysis of Fatal Accident Rates

```
VARIABLE                              RATE

SAMPLE 1
SAMPLE SIZE                             10
MEAN                               0.14200
VARIANCE (UNBIASED)                0.01888
STANDARD DEVIATION                 0.13742

SAMPLE 2
SAMPLE SIZE                             10
MEAN                               0.00900
VARIANCE (UNBIASED)                0.00081
STANDARD DEVIATION                 0.02846

VARIANCE RATIO (F)                23.31413
CONFIDENCE LEVEL                   0.99997

EQUAL POPULATION VARIANCES - POOLED-T

   VARIANCE ESTIMATE               0.00985
  DEGREES OF FREEDOM                    18
      TEST STATISTIC               2.99695
     TWO-TAIL SIGNIF               0.00774

  95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

         LOWER LIMIT               0.03976
         UPPER LIMIT               0.22624

UNEQUAL POPULATION VARIANCES - BEHRENS-FISHER PROBLEM

   VARIANCE ESTIMATE               0.00197
  DEGREES OF FREEDOM                    10
      TEST STATISTIC               2.99695
     TWO-TAIL SIGNIF               0.01341

  95.00 CONFIDENCE INTERVAL ON MEAN(1)-MEAN(2)

         LOWER LIMIT               0.03412
         UPPER LIMIT               0.23188
```