BENEFIT-COST ANALYSIS OF A SPEED SIGNAL FUNNEL

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The objective of this research was to establish an estimate of the economic feasibility of modifying an intersection traffic control system to incorporate a speed signal funnel. An appropriate high-speed intersection currently under traffic-actuated control was selected for this evaluation. Data on traffic volumes, delays, approach speed profiles, and accident experience were gathered for the study site so future costs of retaining the present control system could be estimated. A speed signal funnel incorporating three variable-message speed signals was then designed for each of the two major approaches at the intersection. Estimates specifying equipment costs, maintenance costs, vehicle operation costs, time costs, and accident costs were developed for the proposed speed signal funnel. The economic desirability of the speed signal funnel was determined by means of an incremental benefit-cost ratio. It was found that the speed signal funnel yielded benefit-cost ratios ranging from 1.5:1.0 to as high as 12.0:1.0 depending on the assumptions underlying the computation.

•ALTHOUGH experiments have been conducted with the speed signal funnel concept in the United States, only cursory investigation (7) has been performed to determine the economic feasibility of this type of intersection control system. It is the purpose of this study to establish an index, in the form of an incremental benefit-cost ratio, that will be appropriate for comparing a speed signal funnel with other potential highway improvement projects. The analyses reported relate to the expected costs and benefits associated with retaining the existing standard control devices at a signalized intersection and the expected costs and benefits if the intersection is converted to speed signal funnel control.

PREVIOUS STUDIES

An extensive report of experiments concerning modification of vehicle approach speeds at signalized intersections is given by von Stein (11). As early as 1954, he had installed various combinations of presignals and variable-message speed signals for intersection traffic control in Germany. He recommended that a series of three speed-advisory messages be used along each intersection approach of roadways with an approach speed of about 45 mph. With this traffic control system, a driver approaching a signalized intersection encounters several signals advising him of the correct speed to assume in order to arrive at the intersection during the green phase.

The only significant installation involving the speed signal concept in the United States was the traffic pacer installed in Warren, Michigan, by the General Motors Research Laboratories in 1961 (1, 9). The traffic pacer incorporated 33 speed signals, 11 presignals, and nine intersection traffic signals located throughout a 4-mile length of divided four-lane expressway.

It was reported that the traffic pacer reduced the average trip time and the average number of stops of a vehicle traveling through the test section as compared to a past system and a progressive system. A detailed accident comparison was not presented; however, a general comparison with the accident trend within the county and for a

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similar parallel roadway indicated a substantial improvement in the accident experience for the traffic pacer route.

A more detailed economic analysis of the traffic pacer installation was subsequently performed by Hulbert (7) in 1964. His study evaluated road user benefits for the main route northbound traffic only, without consideration of accident costs. It was assumed that side road traffic was unaffected by the traffic pacer. Hulbert found that the rate of return offered by investing in the traffic pacer installation was as high as 1,350 percent when compared to the past system. The data from this study are summarized in Appendix A, where it is shown that the incremental benefit-cost ratio for the traffic pacer may have reached a value of 72.2:1.0.

Computer simulation studies of the speed signal funnel were performed by Dare (3, 4) in 1968. In these studies the feasibility of combining variable-message speed signals with a semi-actuated controller was explored. It was found that a speed signal funnel could function successfully with a semi-actuated controller provided proper vehicle detection devices were utilized on the minor approach. These studies showed that the signal funnel could theoretically eliminate vehicle stoppages at the intersection. An economic analysis of this system was not performed.

STUDY SITE

To determine the benefits and costs to be expected from a signal funnel installation, we selected an isolated high-speed signalized intersection for detailed evaluation. The intersection is a four-leg intersection formed by Colo-121 and West 80th Avenue at the north city limit of Arvada, Colorado. It is located in a rapidly developing rural-urban transition area with gently rolling topography.

Colo-121 is a divided four-lane highway with separate left- and right-turn lanes at the intersection. The north approach has a posted 60-mph speed limit to a point approximately $\frac{1}{4}$ mile north of the intersection, where the speed limit is reduced to 50 mph. The south approach has a limit of 50 mph for more than 1 mile preceding the intersection.

West 80th Avenue is a two-lane, two-way arterial street with 45-mph speed limits decreasing to 25 mph near the intersection. Its approaches are widened at the intersection to facilitate right-turn vehicle movements. Current signalization is a two-phase, fully actuated controller with adjustments as given in Table 1.

The 1971 ADT and peak-hour volumes obtained by field studies are shown in Figure 1. Truck traffic was found to range from 2 to 5 percent, 4 percent being a typical value during daytime periods.

A summary of the accident experience during the years 1961-1964 and 1967-1971 is given in Table 2. During the former time period, traffic was controlled by a two-way stop; after 1964 the intersection was regulated by two-phase signalization. The broadside collision was the predominate accident type in 1961-1964, while the turning movement and broadside collisions were most frequent in 1967-1971.

SIGNAL FUNNEL DESIGN

Planning and Design

Numerous interrelated factors must be considered in planning and installing a speed signal funnel. It is essential that the advance variable-message speed signals be properly located in advance of the intersection. This problem has been explored to a certain extent by Breuning (2), and he has shown total funnel length to be primarily dependent on the following:

1. The unimpeded approach speed of the vehicles,
2. The slower approach speed advised to vehicles, and
3. The red phase duration on approaches with funneled traffic.

In practice, one must also consider the traffic volumes and capacity of the intersection; the sequence of the phases at the intersection; and speed signal and intersection signal visibility limitations arising from roadway alignment, driver response, and vehicular deceleration characteristics.

The first phase of the design process in this study was to evaluate the ability of the study intersection to accommodate the anticipated traffic demands. Figure 2 shows the projected 1972 ADT values and the peak-hour volumes as determined by extrapolating volume trends for the location and applying adjustment factors to recognize additional traffic generated by proposed nearby shopping centers.

An intersection capacity study indicated that, with the current intersection geometrics and signal phasing, several traffic movements would be operating at level of service D or E during peak hours in 1972. It was concluded that additional turning lanes on both the east and west approaches would achieve smoother operation during peak hours. Furthermore, capacity and safety factors necessitated the introduction of protected left-turn signal phases for the north, south, and east approaches.

The selection of a cycle length and optimum phasing sequence for the intersection controller was then considered. After cycle lengths ranging from 60 to 90 sec and several potential phasing sequences were explored, it was determined that a 70-sec cycle incorporating the phase sequence shown in Figure 3 would provide operation at level of service B or C for all movements.

Variable-Message Speed Signals

The number and placement of the variable-message speed signals and the speeds displayed are critical aspects of the speed signal funnel design. An approximate location for the outermost speed signal may be determined from the relationship developed by Breuning (2):

$$S = T_r V_1 \frac{V_2}{V_1 - V_2}$$

where

S = length of speed signal funnel, ft;
T_r = red phase length, sec;
V_1 = free-flow speed, fps; and
V_2 = slowest advised speed, fps.

This relationship assumes that drivers will adopt the slower speed at the speed signal location and progress toward the intersection at a constant velocity. In reality, the adjustment to the slower speed may not occur exactly at the point of the speed signal. It is more likely that a driver will react to a slower advised speed at some distance prior to the variable-message speed signal and then continue to decelerate to the slower speed for a considerable distance after he has passed the speed signal location. This gradual deceleration to the slower speed would result in his arriving at the intersection several seconds prior to appearance of the green phase. To compensate for the gradual vehicle deceleration pattern, we increased the speed signal funnel lengths given by Breuning's equation as necessary to prevent the early arrival from occurring.

The number of speed signals installed on an approach is a problem remaining to be explored in further detail. It is recognized that drivers must receive sufficient information to properly regulate their progress, but they must not be overwhelmed by the advisory speed messages to the extent that a confusing siutation is created. For lengthy funnels at high-speed intersections, von Stein (11) has illustrated and recommended the installation of three speed signals on an approach. It was therefore decided that, for this preliminary analysis, selective placement of three speed signals on the north and south approaches at the study site would be appropriate.

Figure 4 shows the profile of Colo-121, the location of the speed signals, and the sequence of speeds to be displayed on the speed signals. The intermediate speed signals are located according to a somewhat irregular spacing to permit better visibility as drivers travel through the system and to provide speed information to drivers entering from minor side streets.

Table 1. Present fully actuated controller timing.

Route	Adjustment	Time (sec)
Colo-121	Minimum green	15
	Maximum green	40
	Extension	15
	Amber	5
	All red	2
West 80th Avenue	Minimum green	14
	Maximum green	30
	Extension	7
	Amber	4
	All red	2

Table 2. Accident experience summary.

Period	Months	Accidents	Persons Injured	Fatalities
1961-1964	41	13	23	1
1967-1971	44	21	9	5

Figure 1. 1971 peak-hour volumes and ADT.

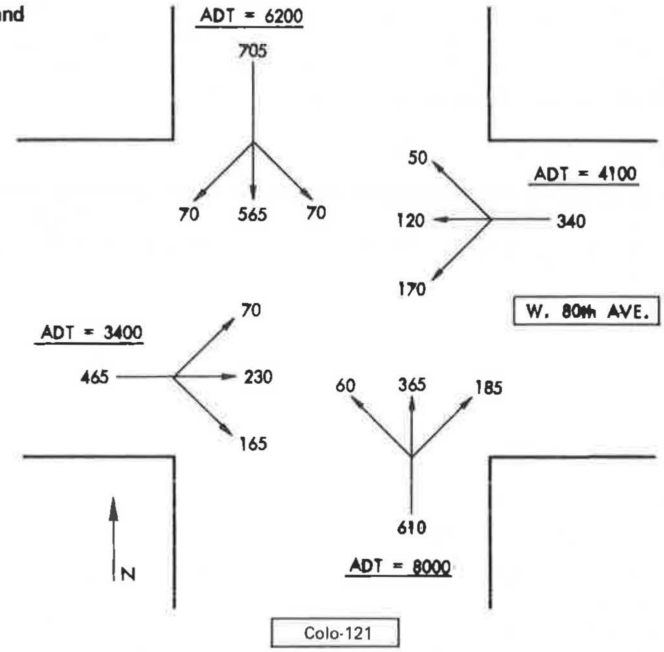
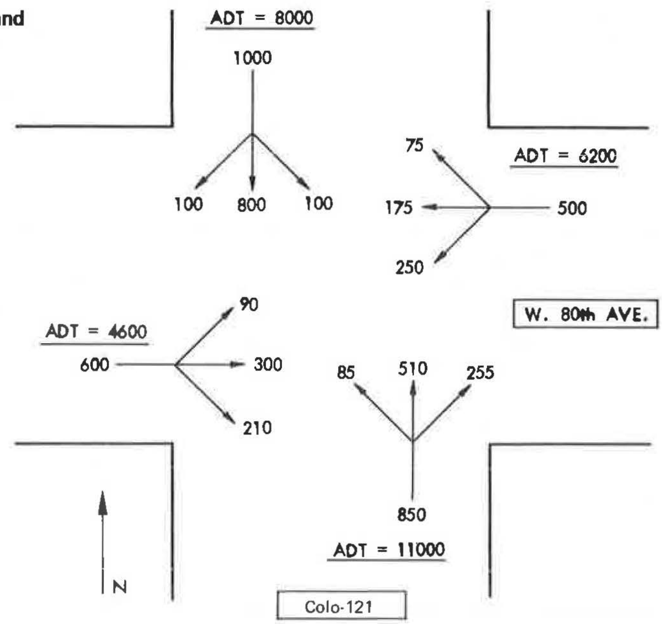


Figure 2. 1972 peak-hour volumes and ADT.



BENEFIT-COST EVALUATION

A detailed economic analysis was performed to determine the feasibility of installing the proposed speed signal funnel as compared to continuing with the existing two-phase, fully actuated control at the intersection. An interest rate of 6 percent was selected, and the following factors were evaluated for both control systems:

1. Highway costs—capital expenditures, maintenance cost, and equipment operation cost; and
2. Road user costs—motor vehicle running cost, motor vehicle idling cost, travel time costs, and accident costs.

Due to the controversial nature of certain cost factors, such as the value of a driver's time and the actual cost of an automobile accident, several benefit-cost ratios were calculated.

Speed Signal Funnel Installation Costs

The initial expenditures (in 1971 costs) required for the multibulb variable-message speed signals, the poles and mast arm mountings, a new pretimed multiphase controller, installation, and roadway widening were as follows:

Item	Cost (dollars)
Pretimed signalization	8,500
Poles and mast arms (six required)	2,400
Speed signals (six required)	10,200
Installation	2,400
Supplementary signs	1,000
Widening W. 80th Avenue	18,000
Total	42,500

The equivalent annual costs corresponding to the initial investments and the necessary roadway widening on West 80th Avenue and maintenance and operation are given in Table 3. Data in Table 3 represent 1971 costs.

Road User Cost Estimates

To formulate an incremental benefit-cost ratio required that road user costs for both the present system and the proposed speed signal funnel be predicted. Field studies of the existing fully actuated signal system served as the basis for estimating future road user costs associated with continued use of the present equipment. Field data were taken by sampling procedures to estimate vehicular delay at the intersection, and car-following studies were conducted to determine vehicular deceleration patterns and travel times. Vehicle running costs and travel time costs of commercial vehicles were estimated for all possible movements against all possible signal indications for a distance equal to 1 mile before the intersection on Colo-121 and ¼ mile before the intersection on West 80th Avenue. A total daily road user expense was determined for each movement with the existing situation by utilizing vehicle operation and time costs as tabulated by Winfrey (12). The annual total costs of vehicular operation and driver time were estimated for retaining the present control system in 1972 by applying a factor of 365 days/year and a ratio of 1972 ADT to 1971 ADT to the 1971 daily costs and summing for all possible traffic movements at the intersection. The 1972 accident costs were estimated according to a potential conflict model developed in Appendix B. The results of these road user cost analyses as well as the annual maintenance cost are as follows:

Figure 3. Proposed signal phasing for intersection controller (70-sec cycle).

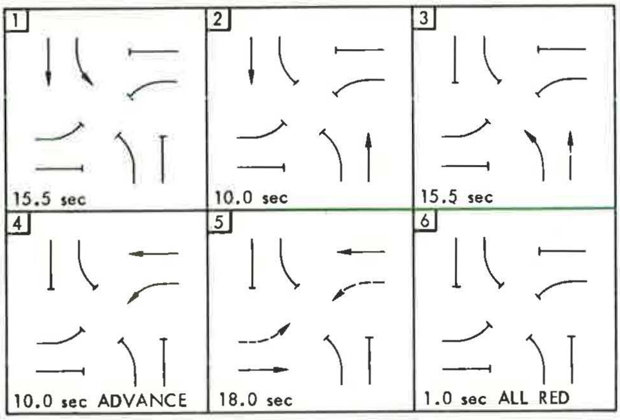


Figure 4. Profile view and speed signal location on Colo-121.

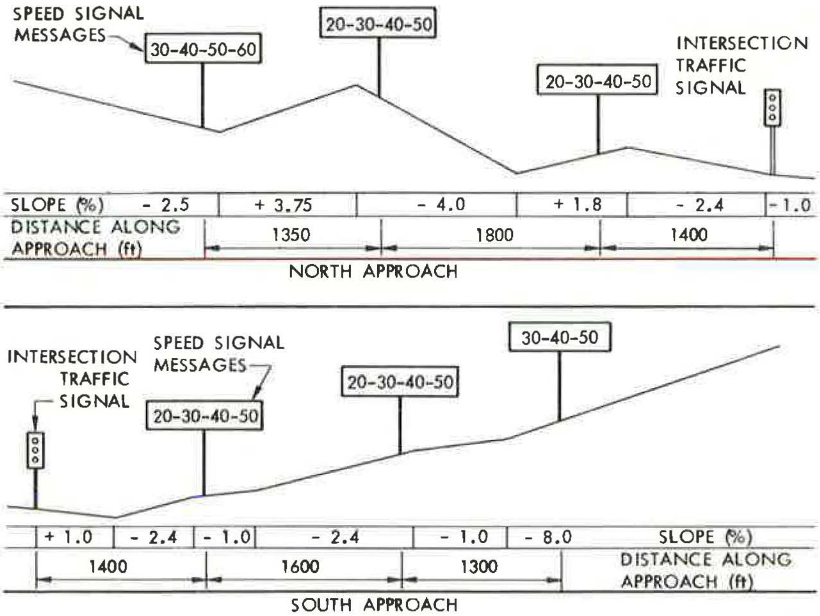


Table 3. Equivalent annual cost of investment and operation at an interest rate of 6 percent.

Item	Service Life (years)	Salvage Value (dollars)	Annual Cost (dollars)
Widening West 80th Avenue	20	0	1,570
Equipment and installation	8	0	3,950
Annual operation and maintenance	–	–	2,350
Total			7,870

Table 4. Incremental benefit-cost evaluation.

Cost Sources Included	Benefit-Cost Ratio
Investment, maintenance, vehicle operation	4.1
Investment, maintenance, vehicle operation, travel time	1.5
Investment, maintenance, vehicle operation, travel time, direct accident cost	2.6
Investment, maintenance, vehicle operation, travel time, direct and indirect accident cost	9.3
Investment, maintenance, vehicle operation, direct and indirect accident cost	12.0

Cost Source	Amount (dollars)
Vehicle operation	1,031,600
Travel time	258,000
Accident direct cost	16,800
Accident direct and indirect cost	108,800
Operation and maintenance	1,000

The road user costs for the proposed speed signal funnel were developed in the same manner as for the present system although field data were not available for an actual installation. Each traffic movement was analyzed, and the costs were tabulated on a daily basis. It was assumed that drivers on Colo-121 would accept the speed advisory messages, thus eliminating stops on the high-speed route. An accident prediction model was developed for the speed signal system and this is described in Appendix B. The estimated annual road user costs for the speed signal funnel are given below:

Cost source	Amount (dollars)
Vehicle operation	1,003,600
Travel time	276,000
Accident direct cost	8,700
Accident direct and indirect cost	55,000
Operation and maintenance	2,350

A comparison of costs for the present system and for the funnel reveals that the funnel could be expected to reduce vehicle operation and accident costs; however, it would cause a slight increase in maintenance and travel time costs.

Incremental Benefit-Cost Evaluation

It is possible to compute several different benefit-cost ratios for any highway improvement project, depending on certain assumptions such as which road user costs to include, the placement of the maintenance costs (numerator versus denominator) in the computation, and the interest rate that is selected. The benefit-cost ratios given in Table 4 were calculated according to the AASHO (10) procedure where an interest rate of 6 percent has been assumed. This table shows that, for all types of cost combinations commonly used in calculating the incremental benefit-cost ratio, the speed signal funnel installation is economically justified when compared to continued operation with the present system. As expected, the largest benefit-cost ratio is obtained when vehicle operation, direct and indirect accident costs, maintenance, and investment costs are included in the analysis. The effect of including travel time costs in any of the computations is to slightly reduce the ratio.

CONCLUSIONS AND DISCUSSION

This investigation has demonstrated the economic feasibility of installing speed signal funnels on the two major approaches at a specific signalized intersection. It was found that the benefit-cost ratio for the proposed change would be no lower than 1.5 to 1.0 and may be as high as 12.0 to 1.0 depending on the factors included in the computations.

In support of the change to the speed signal funnel it seems worthwhile to mention several other environmental factors that tend to favor the installation but that were not rigorously evaluated. Specifically, it would seem reasonable to anticipate a reduction in traffic noise level if the funnel is installed, inasmuch as main route vehicles would not be forced to stop and then completely regain speed at the intersection. It would also seem reasonable to anticipate a reduction in vehicle exhaust emissions inasmuch as the speed signal funnel would facilitate smoother vehicular operation.

This study has, of necessity, relied on estimates of equipment costs, installation costs, maintenance costs, and road user costs for a specific location. A different location may not yield similar benefit-cost ratios due to several possible sources of variation. It is obvious that different traffic volumes could cause noticeable changes in road user benefits. Another factor that could cause considerable variability is the adequacy of the intersection capacity and the necessity for widening the approaches at the intersection. In this study it was thought advisable to widen the two minor route approaches to gain needed intersection capacity and to permit smoother flow during peak hours. These additional construction costs for the roadway widening penalized the speed signal funnel in this evaluation, and this may not be a pertinent cost at other locations. Additional costs were also assessed against the speed signal funnel due to the change to a new multiphase pretimed traffic controller, without the recognition of any salvage value for the currently used equipment. If this change had not been required, substantially higher benefit-cost ratios would have been obtained favoring the speed signal funnel.

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APPENDIX A

ECONOMIC EVALUATION OF TRAFFIC PACER

In 1964 Hulbert (7) reported an economic evaluation of the northbound flow through the General Motors traffic pacer installation. The analysis determined the rate of return on the extra investment for the traffic pacer compared to a past system and for the traffic pacer compared to a progressive system.

The additional initial investment required for the traffic pacer when compared to the past system is $36,600, whereas the additional initial investment for the traffic pacer when compared to the progressive system is $32,000. Additional annual maintenance and operation costs would be $2,000 and $1,200 more than for the past and progressive systems respectively. The reported amounts are 50 percent of the actual expenditures because the road user benefits were estimated for the northbound flow only. Annual road user costs are given in Table 5. Separate analyses were performed for time costs estimated for commercial traffic only and time costs estimated for all main route traffic. Accident costs were not included in the evaluation.

The rate of return on the extra investment was calculated on a 10-year equipment life with negligible salvage values. Excluding extra-market costs, the rate of return on the traffic pacer was 1,000 and 380 percent over the past and progressive systems respectively. Including extra-market costs, the rate of return on the pacer was 1,350 and 360 percent over the other systems. It is apparent that the extra investment in the traffic pacer yields a high rate of return for all reported comparisons.

To perform a benefit-cost evaluation using traffic pacer data required that an interest rate be assumed so that all costs may be expressed in terms of equivalent annual costs. The equivalent annual cost for extra investment in the traffic pacer (interest rate = 6 percent) was $4,970 and $4,350 when compared to the past and progressive systems. Table 6 gives the benefit-cost rates determined according to the procedure recommended by AASHO (10). These computations yield high benefit-cost ratios, indicating that the traffic pacer system is definitely the preferred system of the three evaluated.

APPENDIX B

ACCIDENT PREDICTION MODEL

To predict the number and severity of accidents expected in 1972, it was decided to develop an accident exposure model based on 1969-1970 volume and accident records for the study site. The information included in the modeling process was (a) the number of accidents of each type and severity reported in the base period, 1969-1970; (b) the average annual number of vehicle exposures corresponding to each accident type in the base period; and (c) the expected annual number of vehicle exposures for each type of accident with the two control systems for the year 1972, based on 1972 traffic projections. The expected number of 1972 accidents with each system was estimated by multiplying the base period accidents by the ratio of 1972 vehicle exposures to the corresponding base period vehicle exposures.

In estimating the number of accident exposures, we evaluated each traffic movement on each approach to determine the average number of exposures per signal cycle. This was converted to an annual number of exposures by estimating the number of signal cycles to occur within a 1-year period. The results of the accident exposure modeling process are given in Table 7 by accident type for the intersection control systems being compared. The data given in Table 7 indicate a general reduction in accident exposure with the speed signal funnel, with the exception of the sideswipe collision. The increase in potential for sideswipe collisions reflects the assumption that, with the speed signal funnel, traffic will flow in more tightly grouped platoons, and there may be a greater opportunity for a sideswipe or lane-change accident with vehicles in platoons than with random flow. The projected 1972 accident experience by type and severity of accident is given in Table 8. Miscellaneous accidents were estimated by applying a factor of 20 percent to the subtotal, inasmuch as miscellaneous accidents were 20 percent of the subtotal in the 1969-1970 base period.

Two separate evaluations of the cost of the projected 1972 accidents were then performed. The first evaluation utilized only the direct costs for each type and severity of accident according to the recent findings in Texas (6). The results of the direct cost

Table 5. Annual road user costs.

System	Market Cost[a] (dollars)	Market Plus Extra-Market Cost[b] (dollars)
Past	1,267,500	2,051,500
Progressive	992,200	1,665,000
Pacer	869,500	1,548,500

[a]Includes vehicle operation costs for all vehicles and time costs for commercial vehicles.
[b]Includes vehicle operation costs and time costs for all vehicles.

Table 6. Traffic pacer incremental benefit-cost evaluation.

	Benefit-Cost Ratio	
Systems Compared	Excluding Extra-Market Costs	Including Extra-Market Costs
Pacer and past	57.1	72.3
Pacer and progressive	22.1	21.0

Table 7. Accident exposures.

Accident Type	Average Exposures per Year During 1969 and 1970	Projected 1972 Exposures	
		Present System	Signal Funnel
Rear end	1,770,000	2,910,000	960,000
Right angle	890,000	1,180,000	840,000
Sideswipe	430,000	840,000	2,270,000
Turning	2,610,000	5,030,000	2,340,000
Total	5,700,000	9,960,000	6,410,000

Table 8. 1972 accident experience prediction.

	Projected 1972 Accidents	
Accident Type and Severity	Present System	Signal Funnel
Rear end, PDO	1.5	0.5
Right angle, PDO	0.5	0.5
Sideswipe, PDO	1.0	2.0
Sideswipe, INJ		0.5
Turning, PDO	4.5	2.0
Turning, INJ	1.5	0.5
Turning, FAT	1.0	0.5
Subtotal	10.0	6.5
Misc., PDO	1.5	1.5
Misc., INJ	0.5	—
Total	12.0	8.0

Note: PDO = property damage only, INJ = injury, and FAT = fatal accident.

Table 9. Estimated 1972 accident costs.

	Direct Costs (dollars)		Direct and Indirect Costs (dollars)	
Accident Type and Severity	Present System	Signal Funnel	Present System	Signal Funnel
Rear end, PDO	450	150	450	150
Right angle, PDO	200	200	200	200
Sideswipe, PDO	250	500	250	500
Sideswipe, INJ		650		4,000
Turning, PDO	1,350	600	1,350	600
Turning, INJ	2,850	950	12,000	4,000
Turning, FAT	10,200	5,100	90,000	45,000
Misc., PDO	550	550	550	550
Misc., INJ	950	—	4,000	—
Total	16,800	8,700	108,800	55,000

evaluation are given in Table 9. Both direct and indirect costs were considered in the second evaluation, where values of $8,000 for each injury and $90,000 for each fatality were applied as drawn from the recent U. S. Department of Transportation Automobile Insurance and Compensation Study (5). The data reported in Table 9 were included in several of the incremental benefit-cost analyses of this investigation.