Benefit Analysis for Sketch Planning of Highway Improvements

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A streamlined procedure for evaluating the user benefit from highway improvements was demonstrated. The focus of the procedure was on roadway improvements that included changes in intersection design for the reduction of travel delay. The procedure was synthesized from existing literature primarily for sketch planning analysis; however, its application at more detailed levels of analysis is also appropriate. The procedure simplifies and improves previous methods of estimating the benefit from intersection improvements through the application of delay estimation techniques. A variety of policy and design alternatives can be easily evaluated. Estimation of the benefit derived from upgrading a two-lane roadway to a four-lane cross section with appropriate improvements in the intersection design was used as a case study. Given assumptions regarding the intersection design for the base and the improved condition, and an assumed average daily traffic increasing from 15,000 vehicles in Year 1 to 26,300 vehicles in Year 20, the benefit-cost ratio of the upgrade was estimated to be between 3.6 and 4.5. Ninety-six percent of the benefit originated in the reduction in travel time resulting from adding a lane to each intersection approach.

The objectives of this study were to synthesize a quick-response procedure for evaluating the potential benefit attributable to roadway improvements at the sketch planning level, and to demonstrate the use of the procedure with a generic example. Decision makers and the public generally demand the exhibition of benefit-cost ratios in excess of 1.0 before the acceptance of roadway improvement plans. Local transportation officials are often required to demonstrate the general benefit associated with a class of projects before gaining acceptance for the inclusion of these projects in the regional transportation plan. It is also valuable to know the conditions under which improvement becomes economically viable so that implementation can be made with the proper timing.

This evaluation technique was intended as a guide for planning and decision making. The approach was designed to present a conservative estimate of benefit. The result can be considered the potential minimum attributable to the general class of roadway improvements described.

The procedure and its application were developed in response to a request from the Pima County Department of Transportation in Tucson, Arizona, in support of long-range planning activities.

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ESTIMATION OF ROADWAY IMPROVEMENT BENEFITS

Procedures for the calculation of road user benefits are well documented in the *AASHTO Manual on User Benefit Analysis of Highway and Bus Transit Improvements (1)* and its parent document NCHRP Report 133 *(2)*. The basic methods described in these reports are sound. However, these procedures base the calculation of benefits on highway user cost curves that were developed in the late 1960s, and on estimates of delay based on volume-capacity (v/c) ratios derived from the 1965 version of the *Highway Capacity Manual* (HCM) *(3)*. The vehicle running cost and speed curves presented in the AASHTO Manual and NCHRP Report 133 are also based on v/c ratios derived using procedures from the 1965 HCM.

Using the 1965 HCM, the estimate of intersection delay can be seriously in error. This error is primarily a result of an approach v/c ratio calculation that fails to consider the differential demand for lane utilization (specifically with regard to exclusive turn lanes), which normally exists at an intersection. Where lane demand is not distributed in a manner similar to lane capacity, for example, where turning movements are relatively low, the approach v/c ratio and delay do not equal the corresponding lane v/c ratio and delay. Hence, it is inappropriate to evaluate intersection delay using the v/c ratio for the entire approach. A cursory evaluation of the case study described in this paper using the 1965 HCM procedures revealed virtually no benefit from improvement because the approach v/c ratios were too low for the base condition. This lack occurred even though the predominant lane demand far exceeded lane capacity. The benefit calculation procedures presented in the AASHTO Manual are also needlessly detailed for sketch planning application.

A flow chart describing the basic elements of the procedure is given in Figure 1. The procedure follows the methods described in the AASHTO Manual and NCHRP Report 133, except that the changes in vehicle travel time and vehicle operating cost were based on the 1985 HCM *(4)* and other reports *(5, 6)*. The procedure is relatively streamlined, produces rational results, can be applied manually in a reasonable amount of time, and can easily be adapted for computer applications. The following section details the elements of Figure 1 through a case study.

Existing and Improved Roadway and Traffic Conditions

The initial phase of the evaluation procedure is the definition of

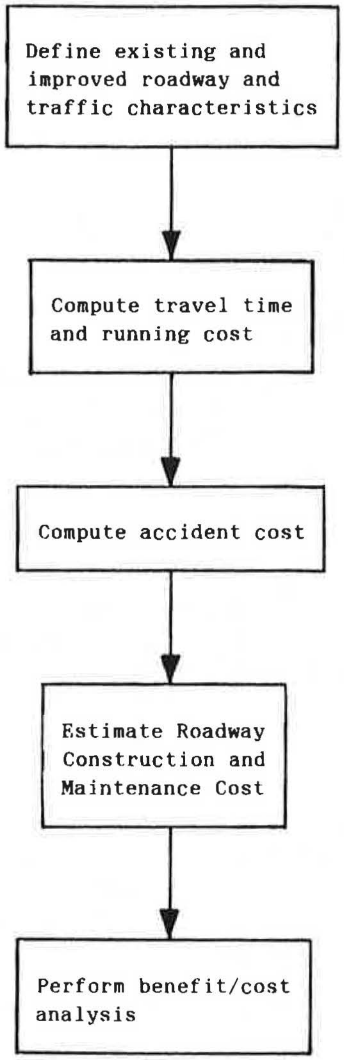

FIGURE 1 Procedural steps for benefit-cost analysis.

characteristics of the existing and improved roadway. The general improvement type considered in this analysis is the upgrade of a (one-way) two-lane cross section to a four-lane roadway with commensurate intersection improvements.

The primary characteristics of the two- and four-lane roadways assumed for the case study were as follows:

- 12-ft lanes with adequate improved shoulders;
- Straight, level tangent section (no horizontal or vertical curves);
- 1 mi in length;
- Major intersections separated by at least 1 mi;
- Signalized major intersections; and
- Uninterrupted flow between major intersections.

The intersection approaches of the two-lane roadway were assumed to consist of one through lane and one exclusive left- or right-turn lane. The intersection approaches of the four-lane improved roadway were assumed to consist of two through lanes and exclusive left- and right-turn lanes. The assumption that the roadway was straight and level was conservative in that this would yield less benefit than an analysis that included alignment improvements.

Intersection signalization for both the two- and four-lane roadway was assumed to have the following characteristics:

- 60-sec cycle length;
- Green-to-cycle time ratio of 0.5; and
- Two-phase signalization (i.e., no exclusive turn phases).

The signalization assumptions represented simplifications designed to reduce the number of computations that were required in the delay calculation. These assumptions also were conservative in that a longer cycle length would have increased the average intersection delay on the two-lane roadway more than on the four-lane. The two-phase signal assumption facilitated intersection capacity calculations, and was a conservative assumption in that protected turn phases generally increase average delay if the through movement dominates.

For this study, both the existing and improved roadway were assumed to have an initial average daily traffic (ADT) of 15,000 vehicles per day. This volume represented a situation where the intersection approaches of the roadway would be nearing capacity.

Review of available data indicated that in general the Pima County roadways have been experiencing between 4 and 5 percent annual traffic growth rate over the past 5 years. It was doubtful that this rate of growth would continue for the next 20 years, and, therefore, 4 to 5 percent was viewed as the upper limit of actual annual growth for this study. The hypothesized growth rate was taken as a uniform 3 percent per year for the 20-year analysis period, resulting in a final ADT value of 26,300 vehicles per day.

Review of available data also indicated that approximately 9 percent of the ADT occurred during the peak hours of the day on Pima County roads and that a 60/40 directional split of traffic in the peak hours was a reasonable approximation. For Year 1, this condition resulted in a peak-hour demand of 810 vehicles per hour (vph) and 540 vph in the peak and off-peak directions, respectively. Corresponding values were 1,420 and 947 vph for Year 20.

The temporal distribution of traffic volume could be modeled effectively assuming that the ADT occurred over an 18-hr day consisting of 2 peak hours and 16 off-peak hours. This assumption was made to facilitate computational procedures, and in recognition of the extremely low traffic volumes that occur during the remaining 6 hr of the 24-hr day. Off-peak traffic volumes were assumed uniform throughout the day with a 50/50 directional split. This assumption resulted in directional demands of 390 and 684 vph for off-peak hours in Years 1 and 20, respectively. The model consisted of 618 peak hours and 5,952 off-peak hours per year, when adjusted for weekend days and holidays, which were assumed to contain 1 peak hour of traffic and 17 nonpeak hours each.

Traffic flow was assumed to consist only of passenger cars. This assumption was made to facilitate capacity and delay computations, and it ultimately generated a conservative estimate of user benefits, because the presence of trucks in the traffic stream reduces intersection capacity and increases delay per vehicle. These changes would result in a more detrimental scenario for the base condition and in more benefit being attributed to the improved roadway. Also, because a higher value for travel time is generally associated with truck travel, a unit reduction in delay would be worth more.

Turning movements were assumed to be 10 percent of the approach volume for both right and left turns. This assumption was deemed adequate for sketch planning analysis.

The assumptions regarding ADT, the directional distribution of traffic, and the percentage of traffic during the peak hours were such that the traffic during the peak hour on the two-lane roadway reached the intersection capacity in the ninth year of the analysis period. The assumption regarding the temporal distribution of demand beyond the ninth year was critical to the analysis. An assumption that the directional distribution would change once the intersection reached capacity would have been unrealistic, and would have biased the result in favor of the base condition. Assuming that traffic was diverted away from the intersection would have implied that adjacent facilities were available, and argued for a systems analysis of the problem. The point of this analysis was to determine the benefit of an isolated improvement under the assumption that the demand would increase as hypothesized. Therefore, it was assumed that traffic volumes would continue to grow under the initial hypothesis, resulting in significant queuing and increase in delay in both the peak and off-peak hours for the base condition.

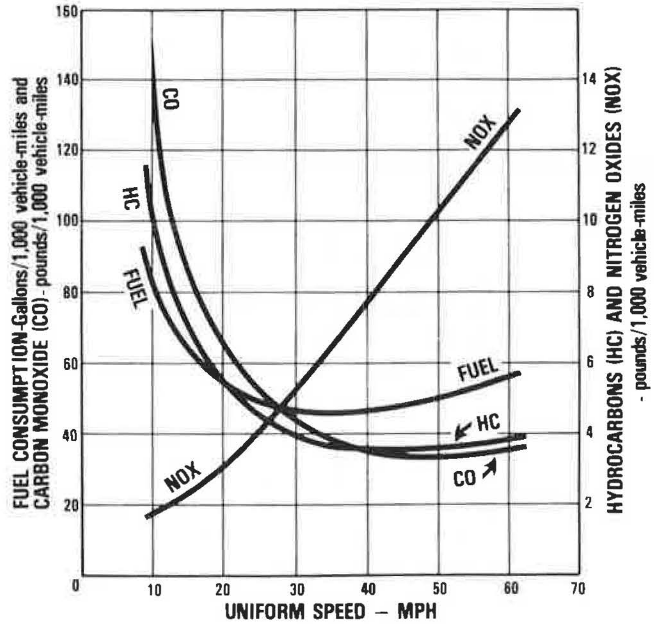

FIGURE 2 Fuel consumption and emissions of carbon monoxide, hydrocarbons, and nitrogen oxides from driving 1,000 mi at various uniform speeds (for light-duty vehicles) *(5)*.

Travel Time and Running Costs

Vehicle travel time and running costs were determined following the steps outlined in Table 1. The analysis was performed for the peak and off-peak hours, with the peak hour analysis being directional. The average approach speed was determined based on the demand volumes using the 1985 HCM procedures for two-lane and multilane roadways. The base and improved condition design speeds were 50 and 60 mph, respectively. This assumption was required to estimate travel speeds on the roadway.

The running cost factor at constant speed was determined using the fuel consumption curve shown in Figure 2, taken from a report by Dale *(5)*. The fuel consumption rate taken from Figure 2 multiplied by the cost per gallon of fuel ($1.00 for purposes of this study) represented the cost of fuel per 1,000 veh-mi of travel. This was factored to represent the total running cost of vehicle operation at a constant speed based on the proportion of the total that was the cost of fuel. The AASHTO Manual indicates the following equation can be used to update the running cost curves presented in that document:

$$M = 0.28(CF) + 0.01(CO) + 0.05(CT) + 0.27(CM) + 0.39(CA) \quad (1)$$

where

M = updating multiplier;
CF = ratio of the 1985 to 1970 consumer price index for private transportation, gasoline, regular and premium;

TABLE 1 TRAVEL PARAMETERS FOR TWO-LANE ROADWAY, YEAR 1

	Peak Period		
	Peak Direction	Off-Peak Direction	Off-Peak Period
Average tangent speed (mph)	45	45	45
Running time at tangent speed (hr/1,000 mi)	22.2	22.2	22.2
Fuel consumption rate (gal/1,000 veh-mi)	48	48	48
Running cost factor ($/1,000 veh-mi)	123.07	123.07	123.07
Stopped time delay (hr/1,000 veh)	3.78	2.28	1.97
Total intersection delay (hr/1,000 veh)	4.91	2.96	2.56
Added cost due to delay ($/1,000 veh)	11.49	8.46	7.03
Total time (hr/1,000 veh)	27.11	25.16	24.76
Total cost ($/1,000 veh)	134.56	131.53	130.10
Annual travel (veh-mi, millions)	0.500	0.334	2.321
Annual travel time (hr, thousands)	13.57	8.40	57.47
Annual running cost ($, thousands)	67.35	43.89	302.00

CO	=	ratio of the 1985 to 1970 consumer price index for private transportation, motor oil, premium;
CT	=	ratio of the 1985 to 1970 consumer price index for private transportation, tires, new, tubeless;
CM	=	ratio of the 1985 to 1970 consumer price index for private transportation, automobile repairs and maintenance; and
CA	=	ratio of the 1985 to 1970 consumer price index for private transportation, automobiles, new.

The coefficients in Equation 1 represent the proportion of total running cost that was contributed by each element of the relationship. In 1970, the cost of fuel represented 28 percent of the total running cost of a passenger car. The consumer price indices shown in the adjoining table indicate that as a result of the differential rate of inflation for the elements of Equation 1, the cost of fuel was approximately 39 percent of the running cost in 1985.

	CPI	
Category	*1970*	*1985*
Fuel	120.0	375.8
Oil	147.1	268.3
Tires	122.4	174.0
Maintenance	147.5	359.4
Automobiles	131.2	217.5

In this table, the column elements are normalized to a value of 100.0 for the year 1967. The factor 0.39 was then applied to the fuel consumption rate from Figure 2 to determine the 1985 running cost factor for automobiles.

$$RCF = (FCR)(FC)/0.39 \qquad (2)$$

where

RCF	=	running cost factor (dollars per 1,000 veh-mi),
FCR	=	fuel consumption rate (gallons per 1,000 veh-mi) (Figure 2), and
FC	=	cost of fuel (dollars/gal).

The calculation of stopped time delay was based on the operational procedures described in Chapter 9 of the 1985 HCM. For this analysis, random arrival was assumed as the arrival type. The total delay per vehicle, which includes the delay due to slowing down and accelerating to the average running speed, was calculated as

$$TDPV = 1.3(SDPV) \qquad (3)$$

where $TDPV$ is total intersection delay per vehicle and $SDPV$ is stopped delay per vehicle.

The average delay per vehicle for the base and improved condition is presented in the adjoining table for the Years 1 and 20 of the analysis period.

	Peak Hours		*Off-Peak Hours*	
	Two Lanes (sec)	*Four Lanes (sec)*	*Two Lanes (sec)*	*Four Lanes (sec)*
Year 1	11.4	6.8	7.1	6.2
Year 20	461.0	13.8	50.8	6.8

As indicated, the base condition intersection breaks down, causing extensive delays during the final years of the analysis period. The peak hour condition is simulated to be so poor that the estimated average stopped delay during the off-peak hours increased from 10 to 50 sec per vehicle.

The increase in the delay in the off-peak hour resulting from queuing during the peak hour was estimated using the procedures detailed in NCHRP Report 133. The time to dissipate the queue built up during the peak period was calculated as the fraction

$$QDT = D(PHV - C)/(C - OPHV) \qquad (4)$$

where

QDT	=	time required to dissipate the queue (hr),
D	=	duration of the peak period (hr),
PHV	=	peak hour demand volume (vph),
C	=	peak hour intersection capacity (vph), and
$OPHV$	=	off-peak hour demand volume (vph).

The increase in the average delay in the off-peak period was calculated using the expression

$$IOPD = (QDT/OD)(PHD - OPHD) \qquad (5)$$

where

$IOPD$	=	increase in off-peak period stopped delay (sec/veh),
PHD	=	average peak period stopped delay (sec/veh),
$OPHD$	=	average off-peak period stopped delay (sec/veh), and
OD	=	duration of the off-peak period (hr).

The total delay per vehicle was calculated as the additional time required to traverse the roadway section exceeding the time required at a constant running speed. The total travel time was the sum of the time at the running speed and the total intersection delay.

The added running cost due to intersection delay was assumed to be only the additional fuel cost resulting from vehicle stops, speed changes, and idling. The additional fuel consumed from stops, speed changes, and idling was determined using information presented by Dale *(5)* and Ismart *(6)*. Figure 2 represents the curves for fuel consumption and emission rates at a constant travel speed. Similar graphs were presented for the incremental emission rates due to vehicle speed changes.

Ismart *(6)* also presented a series of equations to calculate the incremental fuel consumption and emissions based on the average stopped time delay at an intersection. The following are relationships for the incremental fuel consumption due to stopping, speed changes, and idling.

1. Stopping:

$$AFC1 = [0.5497 \log (1.3SDPV) - 0.1404](TTEI)(FCR/1{,}000) \quad (6)$$

2. Speed changes:

$$AFC2 = [(TTEI)(FCR)(0.04SDPV + 0.03)]/[(3{,}600)(HPSC)] \quad (7)$$

3. Idling:

$$AFC3 = (TTEI/3{,}600)(SDPV)(0.65) \quad (8)$$

where

$AFC1, AFC2, AFC3$ = additional fuel consumption due to stops, speed changes, and idling, respectively (gal),
$TTEI$ = total traffic entering the intersection (veh),
FCR = fuel consumption rate for speed changes *(5, 6)*, and
$HPSC$ = time in hours for 1,000 speed changes [see Ismart *(6)*].

The total additional fuel consumption resulting from intersection delay is the sum of $AFC1$, $AFC2$, and $AFC3$. The total additional cost due to intersection delay was calculated as the additional fuel consumption factored by the price per gallon of gasoline. Equation 7 was ignored for the case in which all of the vehicles entering the intersection stopped. For speed changes, it was assumed that the average speed reduction was one-half of the average running speed. Similar equations for the incremental vehicle emissions resulting from intersection delay were also presented by Ismart *(6)*.

Costs of Accidents

The primary source of the required accident data was the Pima County Traffic Accident Statistics *(7)*. Accident statistics from July 1982 through June 1985 were reviewed for 259 two-lane and 29 four-lane Pima County roadway segments that had not been altered by construction during the time period represented by the data. The accident rates for the roadway segments were 1.48 and 1.46 accidents per million vehicle miles (MVM) for the two- and four-lane roadways, respectively.

The accident rate for intersections was determined separately. Intersections with geometrics similar to those assumed for the base and improved conditions were identified, and the accident rates were calculated and expressed as the number of accidents per million vehicles entering (MVE) the intersection. The accident rates for six intersections on two-lane roadways and four intersections on four-lane roadways were 1.46 and 1.22 accidents per MVE, respectively. These rates were assumed to remain constant throughout the duration of the analysis period. The accident rates for the roadway segment and the intersection were summed to represent a total accident rate.

The computed accident rates represent the unadjusted values for reported accidents. The property damage (PD) accident rate was increased by a factor of 2.5 to account for the incidence of unreported accidents. This increase, which assumes that only 40 percent of PD accidents were reported, is consistent with guidelines for default values given in the literature *(1, 2)*.

The accident rates were stratified by accident severity to adjust the aggregate rate for the underreporting of PD accidents. This stratification was accomplished using the data available in the Arizona Traffic Accident Summary for 1982 through 1984 *(8–10)*. The percentages of reported accidents on Pima County roads that were fatalities (F), personal injuries (PI), and property damages (PD) were determined from the data. The PD accident rate was adjusted for underreporting. These accident rates appear in Table 2.

The monetary values for accidents were based on 1984 National Safety Council estimates *(10)*. These values were adjusted upwards by 3.75 percent to represent 1985 values due to the increase in the general consumer price index from 1984 to 1985. The cost of PD accidents was adjusted further to include the cost of unreported accidents that were estimated to have a cost equal to 60 percent of the reported PD accidents based on data in the AASHTO Manual. Therefore, the costs reported in Table 2 represent the total cost per accident by severity type.

Roadway Construction and Maintenance Costs

Based on Pima County records, the recent cost of upgrading a two-lane roadway to four lanes has been between \$2 and \$2.5 million/mi. This cost includes earthwork, grading, structures, paving, design, the purchase of right-of-way, and construction inspection.

The annual maintenance cost of two-lane roadways has been approximately \$4,100/mi. This cost includes a chip seal every 5 years, shoulder maintenance, and the upkeep of traffic control devices and pavement markings.

As a modest simplification, the average maintenance cost per year for the four-lane roadway was assumed to be \$5,800/mi. Maintenance cost for a new four-lane roadway was estimated at approximately \$2,200/mi per year for the first 10 years. This represents the cost of the upkeep of the roadside, traffic control devices, and pavement markings. After the first 10 years, it was assumed that the roadway would require chip sealing at 5-year intervals, increasing the annual maintenance cost to \$9,400/mi for the remaining 10 years of the analysis period.

Benefit-Cost Analysis

The case study considered those road user benefits attributable to the reduction in vehicle operating cost, travel time, and accidents. The change in roadway maintenance was also considered on the benefit side of the ledger, although this is not a direct user benefit. Maintenance benefits were included in the case study to evaluate the potential impact of this on total benefit.

TABLE 2 ACCIDENT RATES AND COST OF ACCIDENTS BY ACCIDENT TYPE

	Accident Type[a]			
	F	PI	PD	Total
Unadjusted accident rate (%)	0.9	39.4	59.7	100.0
Unadjusted accident rate (MVM or MVE):				
Two-lane	0.028	1.158	1.754	2.940
Four-lane	0.026	1.056	1.600	2.680
Adjusted accident rate (%)	0.5	20.8	78.7	100.0
Adjusted accident rate (MVM or MVE):				
Two-lane	0.028	1.158	4.384	5.570
Four-lane	0.026	1.056	3.998	5.080
Adjusted cost per accident ($)	228,500	9,600	960	—

[a]F = Fatal, PI = Personal Injury, PD = Property Damage.

Benefits were computed using the consumer's surplus approach:

$$\text{Benefits} = (P0 - P1)[(V0 + V1)/2] \quad (9)$$

where

$P0$ = cost per vehicle under the existing condition,
$P1$ = cost per vehicle under the improved condition,
$V0$ = traffic volume under the existing condition, and
$V1$ = traffic volume under the improved condition.

The total value of travel time was based on an assumed value $5.00/hr. The annual running and accident costs were used to determine the average cost per vehicle. Resulting benefits for two- and four-lane roadways are presented in Table 3. A comparison of the alternatives is presented in Table 4. Average annual change in running and accident costs, highway maintenance, and value of travel time were used to compute the present worth of benefits. The present worth factors were selected based on an interest rate of 7 percent (the interest rate of the March 1986 Pima County sewer revenue bonds). The residual value of the improved condition was ignored.

The summary of the economic indices from the analysis is summarized in the following list.

Item	*Amount*
Cost and time value reductions ($, thousands)	
Year 1	
Running and accident cost	−19.33
Vehicle travel time value	59.70
Year 20	
Running and accident cost	210.59
Vehicle travel time value	2,142.00
Annual increase in benefits	
Running and accident cost	7.09
Vehicle travel time value	103.43
Present (1986) total worth of benefits	
Running and accident cost	344.76
Highway maintenance cost	−18.00
Vehicle travel time value	8,795.00
Total	9,121.76
Highway investment cost ($, thousands)	2,000.00–2,500.00
Benefit-cost ratio	4.5–3.6
Value of travel time ($/hr)	0.95–1.20

The benefit-cost ratio was between 4.5 and 3.6 for an improvement costing between $2 and $2.5 million, respectively. For the assumed demand volumes, these figures are the minimum benefit-cost ratios expected from improvements of this type, because alignment improvements and the effect of trucks on the

TABLE 3 SUMMARY OF USER COST AND TIME REDUCTIONS

	Year 1		Year 20	
	Two-Lane	Four-Lane	Two-Lane	Four-Lane
Vehicle time (hr, thousands)	136.91	121.97	648.15	219.72
Running cost ($, thousands)	715.24	745.09	1,501.20	1,318.03
Accident cost ($, thousands)	119.62	109.10	209.79	191.32
Annual traffic volume (veh, millions)	5.48	5.48	9.60	9.60
Average costs and travel time				
Vehicle time (hr/1,000 veh)	25.00	22.28	67.52	22.89
Running cost ($/1,000 veh)	130.64	136.09	156.38	137.30
Accident cost ($/1,000 veh)	21.85	19.93	21.85	19.93

TABLE 4 BENEFITS RESULTING FROM WIDENING TO FOUR-LANE ROADWAY

	Year 1	Year 20
Reduction in Unit Costs and Time		
Vehicle time (hr/1,000 veh)	2.72	44.63
Running cost ($/1,000 veh)	–5.45	19.08
Accident cost ($/1,000 veh)	1.92	1.92
Total Time and Cost Reductions		
Vehicle time (hr, thousands)	14.90	428.40
Running cost ($, thousands)	–29.84	183.16
Accident cost ($, thousands)	10.51	18.43
Value of passenger car time ($, thousands)	73.50	2,142.00

delay and on running cost calculations are ignored. The value of travel time that would result in a benefit-cost ratio of 1.0 is between $0.95/hr and $1.20/hr. This range represents the value of travel time where benefits equal costs.

Ninety-six percent of the benefits generated by the improvement are a result of the reduction in travel time. The benefits resulting from the reduction in running costs and accident costs are minor. The running cost on the improved roadway increases relative to the base condition because of the increased running speed, and traffic volumes are too low to generate appreciable benefits in running cost at the intersection. The accident rates between the base and improved condition are not significantly different, and, therefore, these benefits are not a significant portion of the total cost savings. The difference in the accident rates was consistent with that found in the literature *(1)* for the type of roadways considered.

The estimates of annual fuel consumption and vehicle emissions are presented in Table 5. The improved roadway results in a 5 percent increase in fuel consumption in Year 1 due to increased operating speed, and a 26 percent reduction in Year 20. Carbon monoxide, hydrocarbon, and nitrogen oxide emissions are estimated to increase slightly in Year 1, and to decrease by 57, 51, and 7 percent, respectively, in Year 20.

SUMMARY AND CONCLUSIONS

The recent developments in procedures for evaluating intersection capacity and delay at the operational level have significantly improved planning analysis of improvement benefits as well. The computational procedures presented in the AASHTO Manual and NCHRP Report 133 can be effectively streamlined, particularly for the evaluation of improvements that involve major intersection changes. These computational procedures can be improved significantly by use of the delay calculation procedures presented in the 1985 HCM *(4)* and the updated data by Dale *(5)*. Also, the computational procedures presented by Ismart *(6)* significantly improve the ease of calculating the changes in fuel consumption and vehicle emissions from an intersection improvement.

The delay and benefit calculations can be further simplified by ignoring the influence of trucks and by alignment improvements at the sketch planning level. However, if trucks and alignment improvements are considered to represent a significant contribution to benefits, these factors can effectively be considered using the procedures described in the 1985 HCM.

Assumptions regarding traffic signalization need not be design specific and are only required to be realistic in terms of the intersection type being evaluated. However, the benefits of improved signal timing and signal synchronization can be evaluated as well.

Other policy and design alternatives can be easily evaluated using this procedure. For example, the benefits of staggered work hours could be tested by varying the temporal distribution of the ADT. The benefits of carpooling could be evaluated by reducing the demand volume during the peak hour. As a design alternative, the benefits of replacing at-grade intersections with grade separations could also be estimated.

The evaluation procedure also provided other valuable information than the alternatives being considered. From the case study, it became clear that the use of exclusive turn lanes on the intersection approach of a two-lane highway effectively extends the capacity of the roadway to accommodate an ADT of between 15,000 and 16,000 vehicles, depending on the percent of turning movements and the temporal distribution of the demand. Exclusive turn lanes appear as an excellent intermediate improvement. At more than approximately 18,000 vehicles per day, intersection delay during the peak hour becomes extreme and extends into the off-peak period on the two-lane roadway even with the use of exclusive turn lanes.

The benefit generated by the improved roadway condition is dominated by the reduction in travel time, unless the improvement is specifically designed to reduce accidents. Running cost did not become significant for the traffic volumes assumed in this analysis. Therefore, for traffic volume and improvement conditions similar to those of the case study, benefits due to the reduction in accidents and vehicle running cost can be ignored. The change in maintenance cost was also minor, and for sketch planning evaluation this change can be ignored as well.

TABLE 5 ANNUAL FUEL CONSUMPTION AND VEHICLE EMISSIONS

	Year 1			Year 20		
	Two-Lane	Four-Lane	Difference	Two-Lane	Four-Lane	Difference
Fuel (gal, thousands)	307.3	322.5	+15.2	782.4	576.5	–205.9
Emissions						
CO (lb, thousands)	314.8	317.1	+2.3	1,386.6	590.7	–795.9
HC (lb, thousands)	28.0	28.0	0	104.7	51.4	–53.3
NO (lb, thousands)	57.5	65.7	+8.2	125.1	117.0	–8.1

REFERENCES

1. *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements 1977.* American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1978.
2. D. A. Curry and D. G. Anderson. *NCHRP Report 133: Procedures for Estimating Highway User Costs, Air Pollution and Noise Effects.* HRB, National Research Council, Washington, D.C., 1972.
3. *Special Report 87: Highway Capacity Manual.* HRB, National Research Council, Washington, D.C., 1965.
4. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.
5. C. W. Dale. *Procedure for Estimating Highway User Costs, Fuel Consumption and Air Pollution.* FHWA, U.S. Department of Transportation, March 1980 (revised April 1981).
6. D. Ismart. Mobile Source Emissions and Energy Analysis at an Isolated Intersection. In *Transportation Research Record 842,* TRB, National Research Council, Washington, D.C., 1982, pp. 5–10.
7. *Traffic Accident Statistics.* Traffic Engineering Division, Pima County Department of Transportation and Flood Control District, Tucson, Ariz., Oct. 1985.
8. *Arizona Traffic Accident Summary 1982.* Traffic Engineering Section, Arizona Department of Transportation, Phoenix, 1983.
9. *Arizona Traffic Accident Summary 1983.* Traffic Engineering Section, Arizona Department of Transportation, Phoenix, 1984.
10. *Arizona Traffic Accident Summary 1984.* Traffic Engineering Section, Arizona Department of Transportation, Phoenix, 1985.

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