Application of a User Cost Model To Measure During and After Construction Costs and Benefits: Highway Widening Projects

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Because many highways in Texas are being widened to expedite traffic, motorists are asking questions about the cost impacts of such highway improvements. This study is designed to determine the user costs and benefits, both during and after construction, of widening a highway located in an urban area. A 10.79-km (6.7-mi) section of U.S. Highway 80 in Longview, Texas, a city with a population of 70,311 in 1990, was selected for study. The highway section was upgraded recently with a two-way continuous left-turn lane and curbs and gutters within the existing right of way. In addition, a new interconnecting signal system was installed. The total cost of the project was $9.5 million. The Heem-III benefit-cost model was used to determine the benefits to motorists. Benefits were calculated as the sum of delay savings, accident reductions, and vehicle operating cost savings, discounted over a 20-year period. Instrumented vehicle runs indicated that motorist delay was reduced as a result of optimal signal timing implemented during the widening construction and reduced stops as lanes were no longer blocked by left-turning vehicles. The accident rate fell steadily from the time that construction began. Projected maintenance costs were subtracted from projected benefits, and the resulting difference is divided by the cost of construction to obtain the benefit-cost ratio. The total benefit-cost ratio for the whole project is $7.82, which means that motorists are receiving benefits worth $7.82 for every dollar spent on the project.

The Texas Department of Transportation (TxDOT) continually is faced with the responsibility of providing safe and congestion-free highways. One of the principal ways that TxDOT is accomplishing this task is by widening and adding travel lanes to existing highways. In many cases, these highways are widened enough to install a continuous two-way left-turn lane in the median, and curbs and gutters at the margins.

The benefits to motorists of an improved highway can be classified into three general categories: delay savings, accident reductions, and vehicle operating cost savings. Many methods and techniques are available to calculate these benefits, but, in general, such calculations are based on some change in the before and after situation the motorists face, putting a dollar value on those changes, and calculating those dollar values over the life of the improvement. These benefits are then discounted to the present and compared with the construction cost. If the user benefits are greater than the costs, then it is a beneficial project. This study is unique in that impacts of the proposed improvements during construction are also calculated.

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The study focuses on the widening of U.S. Highway 80 (Marshall Avenue) in Longview, Texas. To reduce traffic congestion, three major intersections were widened in 1974. Two additional major intersections were widened in 1986. In 1987, a continuous left-turn lane was proposed between Fisher and Eastman roads along Marshall Avenue, which includes the five widened intersections. That same year, a study was conducted to estimate the benefits of creating a continuous left-turn lane on Marshall Avenue (Buffington et al., unpublished data). Travel times, speed changes, left-turning movements, and lane volumes were documented fully. The study estimated a benefit-cost ratio of $3.47 for the proposed improvement. The proposed improvement was approved and went to contract in fall 1989, and it was completed in fall 1991. The current study is a follow-up study and was initiated before construction so that the construction period could be monitored and the cost impacts to users before, during, and after construction could be estimated. Similar data were collected during and after construction. Also, construction activity, such as lane closures and expenditures, were monitored. Therefore, a complete impact analysis of costs and benefits before, during, and after construction can be performed.

CALCULATION OF DELAY SAVINGS

Delay savings are calculated as the dollar value of motorist time savings resulting from the highway improvement. They are calculated using the following formula as a guideline:

$$\text{Savings} = \text{length} \times \text{volume} \times \left(\frac{1}{\text{speed}_{\text{No Median}}} - \frac{1}{\text{speed}_{\text{With Median}}}\right) \times \text{value of time}$$

where

savings = hourly delay savings ($1,000/hr);
length = section length (1.61 × km) (mi);
volume = hourly traffic volume by lane (thousands of cars);
$\text{speed}_{\text{No Median}}$ = speed under previous conditions, no median [1.61 × km/hr (mph)];
$\text{speed}_{\text{With Median}}$ = speed under current conditions, with median [1.61 × km/hr (mph)]; and
value of time = the weighted average of truck and car value of time ($/hr).

Traffic Volume

Traffic volume is calculated as average daily traffic (ADT). Detailed ADT for 1986 was collected from TxDOT maps along the section of U.S. Highway 80 that was widened. Also, the Texas Transportation Institute (TTI) collected ADT data annually before, during, and after construction for calculating construction-period impacts. In addition, TxDOT provided a projected ADT for 2006 for this section of highway. Because there was no indication that the traffic would follow a specific growth pattern in the future, the difference between the 1986 and 2006 values was divided by 20 to obtain an annual increase in ADT. Various multiples of this value were added to the 1986 figure to obtain an estimated ADT for more recent years.

The estimated ADT is slightly higher than that established by the TTI counters, which show the ADT remaining nearly flat during the construction period. The construction period benefits may be slightly overstated, but TxDOT projections for the long term seem reasonable.

For the major route, which is Marshall Avenue, the ADT for the segment with the least volume was used as the current through ADT, and the difference between the actual segment volume and the current ADT was entered as local ADT. The ADT calculated for the minor routes, or cross streets, was put in directly as estimated. In addition to the current ADT, a projected ADT is required for calculating future benefits.

The ADT was further broken down into hourly volumes by lane using traffic counters placed in several locations along the highway. The number of vehicles passing each location over a 24-hr period was counted. These were accumulated into hourly totals and applied to the overall average ADT along the section to give average hourly traffic volumes by lane.

Traffic Speed

Speeds before, during, and after construction were determined by instrumented vehicle runs along the study section of U.S. Highway 80. To compare speeds before and after construction, speeds were compared with the default speeds of the HEEM-III model, a benefit-cost computer program developed by TTI (*1*). If they differed, default speeds were changed to represent actual measured speeds. The HEEM-III model then was used to calculate vehicle operating costs and savings. Speeds used in the model reflected the effects of construction activities, including increased congestion caused by the lane closures.

Value of Time

On the basis of a TTI study using a speed-choice model and the latest data for Texas, the HEEM-III model assumes that the car value of time is $9.52 per hour per person and that the truck value of time is $22.63 per hour per person (*2*). Intersection or interchange delay is calculated using the delay equations for selected highway situations discussed by Memmott (*1*).

The model calculates the delay on an hourly basis for each direction on both the major and minor routes for each route segment. These calculations are repeated for a 24-hr period for both the unimproved and newly widened road sections. The difference between the sum of the before and after costs is the motorist benefit. These calculations are repeated for each year of the analysis. Unreasonable delays are precluded by calculations that modify the lower and upper parts of the curve. Delay equations are based on optimal signal timing and phasing, and the calculated delay can be modified for less than ideal conditions by using an intersection delay adjustment factor. These factors are modified on the basis of vehicle travel time and the number of stops recorded by instrumented vehicles, which are summarized in Table 1.

Additional delay can be caused by vehicles that are queued behind a vehicle waiting to make a left turn from the median lane. Without a median, vehicles attempting to make left turns at mid-block driveways or intersections without a left-turn bay will have to wait for a gap in the oncoming traffic to make the turn. Vehicles may have to wait behind the turning vehicle if there is insufficient space within the shoulder lane to pass the vehicle. These situations could be eliminated with a continuous left-turn median.

Reduction in delay stops from queuing vehicles was estimated using several runs with an instrumented vehicle through the length of the study highway section. The number of stops made by an

TABLE 1 Instrumented Vehicle Travel Time, Speed, and Stops on Runs Through Study Project[a]

		Stops		Travel		
Year	Runs	At Lights	Mid-Block[b]	Time (min)	Speed (km/h)[c]	Approach Speed (km/h)[c]
1987	99	10	3	14.91	43.44	58.57
1990	93	16	1	15.30	42.29	52.08
1991	76	19	1	14.60	44.32	57.49
1992	90	4	0	12.30	52.61	67.35

[a] An average of 30 runs per day on Thursday, Friday, and Saturday Between 6:00 a.m. and 10:00 p.m. each day of each year studied.

[b] Stops per run rounded off to appropriate whole number.

[c] 1 mi. = 1.61 km.

TABLE 2 Number of Accidents per Year, Study Area, 1984–1992

Year	Fatal	Injury	Property Damage Only	Total
1984	2	165	300	467
1985	2	171	251	424
1986	2	157	271	430
Average	2	164	274	440
Percent	0.45	37.27	62.28	100.00
1989	1	88	122	211
1990	1	109	132	242
1991	0	93	107	200
1992 (January - August)	1	50	63	114
1992 Annualized	1	75	95	171
Average	1	91	114	206
Percent	0.49	44.17	55.34	100.00

instrumented vehicle decreased with the addition of a continuous left-turn lane, as can be seen from the information in Table 1. The runs were not sufficient to estimate the effects on an hourly basis, however, so daily traffic using the median lanes was used to estimate the savings. It was assumed that all of this delay would be eliminated with continuous left-turn medians.

VEHICLE OPERATING COSTS

Additional vehicle operating costs are incurred when motorists slow down and stop at intersections, including costs associated with running and idling as vehicles wait for a signal to turn and the queue to dissipate. Average running speed is the most important variable in the latter calculation, and HEEM-III's calculation for it is based on the 1985 *Highway Capacity Manual.* Speed calculations for volume/capacity above capacity are taken from a TTI study on delay (*3,4*). Equations are presented by Memmott (*1*).

The vehicle operating cost equation for the segments and intersections were estimated from Zaniewski et al. (*5*) and updated in 1990. The vehicle operating costs were summed and then adjusted for the pavement condition using the formula presented by Memmott (*1*), taken from the *Highway Performance Monitoring System Analytical Process* (*6*). A pavement condition of 4.5 is used as the base for the adjustment.

ACCIDENT REDUCTION SAVINGS

The numbers and types of accidents on Marshall Avenue between 1984 and 1986 and from 1989 to 1992 are given in Table 2. The table indicates that there were fewer accidents between 1989 and 1992 than there were between 1984 and 1986.

Present research assumes that the continuous left-turn lane will reduce the number of accidents involving turning vehicles. Table 3 gives the number of accidents involving turns during the construction period and almost a year after the construction period. The postconstruction period data resemble that for 1990, and it is not clear that turning accidents were affected by the construction.

There is also a question of whether the construction caused additional accidents. In Table 4, accidents in the construction zone are divided into those that were construction related and those that were not. Only a small percentage of the construction zone accidents were construction related.

With the HEEM-III model, accident costs are calculated by multiplying the accident rate by the cost per accident. The accident rate, which is given in Table 5, is then adjusted by the accident adjustment factor. The accident adjustment factor is based on the total accident rate of the study area over various time periods, with the preconstruction period (1984 to 1988) representing the base rate of 1.0. Accident rates for highway segments are taken

TABLE 3 Number of Accidents on Marshall Avenue Involving Turning Vehicles

Year	Left-Turn	Right-Turn
1989	19	14
1990	34	16
1991	18	21
1992 (Jan - Aug)	20	10
1992 (Annualized)	30	15

Source: TxDOT

from the *Highway Performance Monitoring System Analytical Process* (*6*). Accident rates for intersections, interchanges, and railroad grade crossings were estimated from Texas accident rate tapes from 1981 to 1986 (Table 6). Costs per accident were taken from a TTI study of accident costs by Rollins and McFarland (*7*). All operating and accident costs are updated to July 1990 and are presented in Table 7. The model estimates that accident costs will be reduced by $4,276,420 over a 20-year period between 1993 and 2012.

CALCULATION OF MOTORIST BENEFITS OVER THE ANALYSIS PERIOD

Three types of benefits are analyzed. The first type is the benefit or lack of benefit associated with the construction. Benefits related to early completion of the project (in 2 years instead of the estimated 3 years) are a second type. The last type is those benefits received after construction, as compared with those received before construction. Benefits calculated following project completion are presented in Table 7.

HIGHWAY IMPROVEMENT COST

Two types of costs are associated with highway construction: the construction costs themselves and the costs of maintaining the highway. The actual cost of the Interstate 80 widening construction was $9,544,420. Future highway costs are associated with overlays, striping, and routine maintenance. These costs are projected to be $350,000 for this project; they are presented in Table 7. There may be additional costs for maintaining traffic control devices that were not included in this analysis, so total costs may be understated.

SUMMARY OF BENEFITS AND COSTS

The benefit-cost ratio for the continuous left-turn lane is the total discounted user benefits less maintenance costs divided by the

TABLE 4 Distribution of Accidents in Construction and Maintenance Areas

Year	Construction Zone		Maintenance Zone	
	Non-Construction Related Accident	Construction Related Accident	Non-Maintenance Related Accident	Maintenance Related Accident
1989	2	0	0	0
1990	94	3	1	0
1991	55	2	0	0

Source: TxDOT

TABLE 5 Urban Accident Rates and Costs in Texas

	Freeway	Divided	Undivided
Accident Rates[a]	244	565	616
Cost per Accident	13,360	12,570	9,170

Source: HEEM-III: Revised Highway Economic Evaluation Model Version 1.0

[a] Accident Rates per 161 Million Vehicle Kilometers

TABLE 6 Urban Accident Rates in Texas

Accident Rates	PDO	Injury	Fatal
At Grade Stop	0.9393	0.5165	0.0102303
At Grade Signal	0.4648	0.2145	0.0020001
Interchange	0.0879	0.0518	0.0014806

Source: HEEM-III: Revised Highway Economic Evaluation Model Version 1.0

[a] Accident rates per urban intersection per 1,610 vehicle lane kilometers

TABLE 7 Summary of Discounted Benefits, Costs, and the Benefit-Cost Ratio, 1992

Motorist Benefits	Construction Period	Early Completion	Before vs. After	Total
	(Thousands of Dollars)			
Delay Savings	-3,969.43	6,695.95	61,563.10	64,289.62
Reduced Vehicle Operating Cost	191.85	193.22	5,532.95	5,918.02
Accident Reduction	317.35	162.04	4,276.42	4,755.81
Total	-3,460.23	7,051.21	71,372.47	74,963.45
Less Maintenance Costs	-50.00	-30.00	-270.00	-350.00
Benefits - Maintenance Costs	-3,510.23	7,021.21	71,102.47	74,613.45
Construction Costs				9,544.42
Benefit-Cost Ratio				7.82

construction costs:

$$\text{B/C ratio} = \frac{(\text{benefits} - \text{maintenance costs})}{\text{construction costs}}$$

The discount rate used in this study is 8 percent. The benefit-cost ratio estimated in 1992 is

$$\text{B/C ratio} = (\$74{,}963{,}450 - \$350{,}000)/\$9{,}544{,}420 = \$7.82$$

$$\text{Net present value} = \$74{,}963{,}450 - \$350{,}000 - \$9{,}544{,}420 = \$65{,}069{,}030$$

A benefit-cost ratio of $7.82 means that the motorists are receiving $7.82 of benefit for every dollar spent on the project. This is a beneficial project from the standpoint of the motorist because the benefits are greater than the costs by a substantial margin. As indicated in Table 7, finishing the construction a year earlier created benefits of $7,021,210, which more than compensated for the negative user-cost impacts incurred during the 2 years of construction, which totalled $3,510,230.

As indicated earlier, the preliminary study estimated a benefit-cost ratio of $3.47 using an earlier version of the HEEM benefit-cost model. This study used HEEM-III, which gives more accurate estimates of vehicle delays and operating costs.

SUMMARY

The addition of a continuous left-hand turn lane can result in three types of motorist benefits: delay savings, accident reductions, and vehicle operating cost savings. This report includes estimates of motorist benefits related to the widening of Marshall Avenue in Longview. Delay savings were estimated using the reduced number of stops along the study section as recorded by instrumented vehicle runs. Vehicle operating savings were calculated using the HEEM-III benefit-cost model. The number of accidents along the study section fell as the construction started, and this trend continued during and after construction. Overall, the findings indicate considerable user benefits over the cost of highway improvement, even after subtracting the negative impacts of construction.

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