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16. Abstract

The Texas A&M Transportation Institute undertook an economic analysis to compare the costs of maintaining a typical Texas low-volume road in an energy-impacted area in its current state versus widening and maintaining the road; converting it to an improved, emulsified asphalt surface (IEAS); or rehabilitating the low-volume road for short-term oil/gas field traffic. For each option, three different cost scenarios were considered. For each cost scenario, the analysis shows that converting the road to an IEAS is the lowest-cost alternative among the four options considered.

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AN ECONOMIC ANALYSIS OF FOUR OPTIONS FOR DEALING WITH LOW-VOLUME ROADS IN ENERGY-IMPACTED AREAS OF TEXAS

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INTRODUCTION

In recent years, the technology of hydraulic fracturing (fracking) has given new life to oil and natural gas formations considered to be too low in productivity for exploitation (*1*). The rapid expansion of this technology has given the nation a better economic position in the world market with respect to the availability and quantity of energy. Texas alone has over half of the drilling rigs in the United States and 25 percent of the rigs in the world. Over 15,000 total wells were completed in 2012, and 40.1 million barrels of crude were produced in November 2012 (*2*).

However, with high oil production comes a great deal of movement of materials to and from drilling sites. Equipment, saltwater, fracking sand, drilling mud, and crude oil are just some of the items requiring transport in fracking operations. For instance, it can take as much as 320,000 gallons of water for 1 year's fracking of a single well. The water is hauled to the well site, and about 60 percent is hauled away. This means that many trucks are hauling equipment and servicing wells in a given area. The roads that these trucks use were designed for much lighter traffic loads and fewer vehicles than are currently being applied. Thus, the agency responsible for the maintenance and operations of those roads must respond rapidly to cope with these conditions with the resources it has available.

BACKGROUND

As the state highway and farm-to-market road systems in Texas have evolved over the last 100 years, there has been a steady progression from unsurfaced roads to gravel- or limestone-surfaced roads, and then to hard-surfaced roads that are predominantly either hot-mix asphalt or surface treatments and seal coats. When these roads were originally designed and built, and throughout various periods of rehabilitation, the expected traffic was considered in terms of the number of vehicles and the number of heavy commercial vehicles. For most roads, this meant the traffic used in design consisted of low numbers of locally operated vehicles and relatively few heavy loads associated with agriculture or oil well drilling and development. The traffic demands for these roads allowed for relatively narrow widths of 18 to 22 feet.

Since the institution of fracking of shale formations to release oil and natural gas in the early 2000s, there has been an exponential increase in the numbers of both vehicles and heavily loaded vehicles in the Eagle Ford Shale area, Permian Basin, and Barnett Shale. The total number of vehicle trips needed varies between 1000 and 4000 for each well for completion and early operation, and about 13,000 wells are completed statewide in a 1-year period. This traffic involves drilling equipment, freshwater for fracking, fracking sands, drilling muds, fracking compressors, fracking saltwater, production water, crude oil, pipe sections, drill stems, and tanks. The magnitude of loads and the number of loads are far beyond the capacity of the pavement structures in rural Texas. The result is a rapidly deteriorating pavement system and a lack of funding to keep up with the repairs and adjustments necessary to safely carry the traffic in the short term.

The challenge to the Texas Department of Transportation (TxDOT) is ascertaining the safest and most cost-effective strategy to deal with the rising deterioration of roads in the oil/gas-affected regions of the state. In order to accomplish this, TxDOT placed the Texas A&M Transportation Institute (TTI) under contract to examine the feasibility of four different strategies in the short term (10 years) and long term (20 years).

OBJECTIVE

This study examined the general short-term and long-term economics associated with low-volume road repair in areas of Texas affected by oil and gas production.

SCOPE

In order to accomplish the objective, the research team set out four realistic alternatives for a general case of a road consisting of 2 inches of asphalt pavement over 6 inches of flexible base, with a paved width of about 21 feet on average. These options were:

A. Maintaining the pavement in its current surfaced condition for 5 years to allow the initial well development and production to occur, followed by rehabilitating the pavement and then maintaining it for the next 15 years, assuming the following options:
    1. No widening of the existing roadway for the oil/gas initial production and exploitation phase.
    2. Widening of the existing road to 28 feet to maintain safe conditions.
B. Providing an improved, emulsified asphalt surface (IEAS), and widening the road and maintaining it as an IEAS road for 5 years. An IEAS is comprised of a high-quality flexible base material with asphalt emulsion scarified into the top 1 to 2 inches to provide a bound, non-dusting surface. Once the asphalt emulsion is mixed with the surface of the flexible base, it is compacted to provide a smooth surface. The asphalt emulsion provides a cohesive and somewhat water-resistant surface that will require less maintenance than an unbound granular surface layer. The IEAS is expected to perform for a period of 5 years, after which a new asphalt pavement structure will be constructed and maintained for the next 15 years.
C. Constructing a rehabilitated pavement designed for oil/gas production traffic for 5 years and maintaining the pavement for the next 15 years.

Costs per centerline mile for various construction, rehabilitation, and maintenance activities at different times in a pavement's life were identified from TxDOT district and maintenance staff, TxDOT bid records and estimates, and reliable sources of literature. The team estimated high costs, medium costs, and low costs for each activity in order to provide a spread of possible costs.

Using the accepted engineering economics approaches of computing the present worth (PW) and equivalent uniform annual costs (EUAC) of all activities, researchers compared the economic viability of the four alternatives and the initial costs to understand the immediate impact on TxDOT budgets.

ASSUMPTIONS

Highway costs vary widely depending upon safety improvements, material availability, structural capacity requirements, bid competition, and transport costs. The cost figures used for construction, maintenance, and rehabilitation activities represent the best assessment from TxDOT staff, published values, TxDOT historical costs, and the judgment of the research team.

The initial structure selected for this analysis consists of a 2-inch asphalt surface over 6 inches of flexible base. While this is not representative of all low-volume roads in Texas, it is considered a typical pavement structure for such roads. As mentioned earlier, this type of design is intended for a traffic mix that is mostly (about 90 percent) passenger vehicles and less than about 10 percent heavy vehicles. In addition to load-bearing and performance considerations, it was assumed that the road would have an initial width of 21 ft that would be widened to 28 ft in order to provide improved edge support and to better accommodate traffic wander and safety.

Two types of economic analyses were performed for this study. A PW cost analysis presents the total discounted cost for each option. This type of analysis is often used for options being evaluated over the same time frame. Secondly, an EUAC is presented to show the annual cost of each option. Two time frames were selected for evaluation: a short-term evaluation of 10 years and a long-term evaluation of 20 years. For the economic analysis, a discount rate of 4 percent was used as typical of what is normally applied in pavement life-cycle cost analysis.

The costs and timing of the four options are presented in Tables 1 through 4. The costs shown in these tables are non-discounted or present costs. Values for the various activities were selected based on the corresponding range of costs compiled from a variety of sources listed in Appendix A of this report. The detailed life-cycle cost analysis for each option and each cost scenario is presented in Appendix B.

Table 1. Costs and Timing for Option A1: Maintain Existing Pavement Condition without Initial Widening of Road.

Year	Activity	Range of Non-discounted Costs ($ per Centerline Mile)		
		Low	Medium	High
0	Heavy maintenance (spot repair of edges and no additional width/strength to edge)	35,000	50,000	75,000
1–4	Annual heavy maintenance (mostly repeat of previous treatment), $/yr	35,000	50,000	75,000
5	Major maintenance/rehabilitation (scarify entire pavement, add 6 inches of base across width, and extend width to 28 ft)	225,000	300,000	400,000
6–11	Annual routine maintenance, $/yr	600	1,000	4,000
12	Seal coat	30,000	40,000	50,000
13–18	Annual routine maintenance, $/yr	600	1,000	4,000
19	Seal coat	30,000	40,000	50,000
20	Final routine maintenance	600	1,000	4,000

Table 2. Costs and Timing for Option A2: Maintain Existing Pavement Condition and Widen Road.

Year	Activity	Range of Non-discounted Costs ($ per Centerline Mile)		
		Low	Medium	High
0	Initial heavy maintenance (widen to 28 ft and add 6 inches of base)	150,000	225,000	300,000
1–4	Annual moderate maintenance (spot repairs in existing pavement), $/yr	10,000	15,000	25,000
5	Major maintenance/rehabilitation (remix entire pavement, add 6 inches of base across width, and seal-coat entire pavement)	175,000	225,000	350,000
6–11	Annual routine maintenance, $/yr	600	1,000	4,000
12	Seal coat	30,000	40,000	50,000
13–18	Annual routine maintenance, $/yr	600	1,000	4,000
19	Seal coat	30,000	40,000	50,000
20	Final routine maintenance	600	1,000	4,000

Table 3. Costs and Timing for Option B: Convert the Pavement to IEAS.

Year	Activity	Range of Non-discounted Costs ($ per Centerline Mile)		
		Low	Medium	High
0	Convert to IEAS	35,000	40,000	175,000*
1–4	Annual IEAS maintenance, $/yr	10,000	17,000	22,000
5	Major maintenance/rehabilitation	125,000	150,000	175,000
6–11	Annual routine maintenance, $/yr	600	1,000	4,000
12	Seal coat	30,000	40,000	50,000
13–18	Annual routine maintenance, $/yr	600	1,000	4,000
19	Seal coat	30,000	40,000	50,000
20	Final routine maintenance	600	1,000	4,000

*The high end of the IEAS is an indication of the uncertainty associated with this alternative.

Table 4. Costs and Timing for Option C: Rehabilitate the Pavement for Short-Term Oil/Gas Field Traffic.

Year	Activity	Range of Non-discounted Costs ($ per Centerline Mile)		
		Low	Medium	High
0	Rehabilitation	350,000	500,000	800,000
1–4	Annual moderate maintenance, $/yr	3,000	6,000	20,000
5	Overlay (2 inches)	40,000	100,000	175,000
6–11	Annual routine maintenance, $/yr	400	1,000	4,000
12	Seal coat	30,000	40,000	50,000
13–18	Annual routine maintenance, $/yr	400	1,000	4,000
19	Seal coat	30,000	40,000	50,000
20	Final routine maintenance	400	1,000	4,000

LIFE-CYCLE COST ESTIMATES

Comparisons of the PW costs for the four options for each of the cost scenarios and time periods are given in Table 5 and displayed graphically in Figure 1. Comparing the options by cost scenario, researchers found Option C (rehabilitate the pavement for short-term oil/gas field traffic) to be the most expensive, followed by Options A1 (maintain the existing pavement condition without initially widening the road) and A2 (maintain the existing pavement condition and widen the road). Options A1 and A2 are cost comparable. For a given cost scenario, Option B (convert the pavement to an IEAS) is the most attractive alternative.

Note that different combinations of the cost scenarios can occur in practice. In this regard, Table 5 shows that the low-cost scenario of Option C approaches the high-cost scenario of Option B and the medium-cost scenarios of Options A1 and A2. The optimal alternative depends on factors that affect cost variability, as noted previously.

Table 5. Comparisons of PW Cost for Options Considering Low, Medium, and High Cost (in $1000 per Centerline Mile).

Option	Low-End Costs		Medium Costs		High-End Costs	
	10 Years	20 Years	10 Years	20 Years	10 Years	20 Years
Option A1, Maintain Existing Pavement Condition without Initially Widening Road	296	372	411	514	597	742
Option A2, Maintain Existing Pavement Condition and Widen Road	291	356	415	500	611	745
Option B, Convert Pavement to IEAS	146	200	193	261	372	465
Option C, Rehabilitate Pavement for Short-Term Oil/Gas Field Traffic	386	418	599	660	990	1,083

Table 6 and Figure 2 show the EUAC for the three cost alternatives for short-term and long-term periods. Again, for a given cost scenario, Option B is the lowest-cost alternative, and Option C is the most expensive. Options A1 and A2 are estimated to be equivalent to one another and are substantially lower in cost than Option C. The trends between the short-term and long-term costs are different in the EUAC compared to the PW analysis. This is because the PW analysis is a total discounted cost over the entire 10- or 20-year period, so it presents a greater cost for 20 years. The EUAC is an annualized cost, so the high costs associated with oil/gas field activities in years 1 through 5 are spread over more years in the 20-year analysis. However, the comparison between the options for a given cost scenario is the same regardless of whether PW or EUAC is used to evaluate the data.

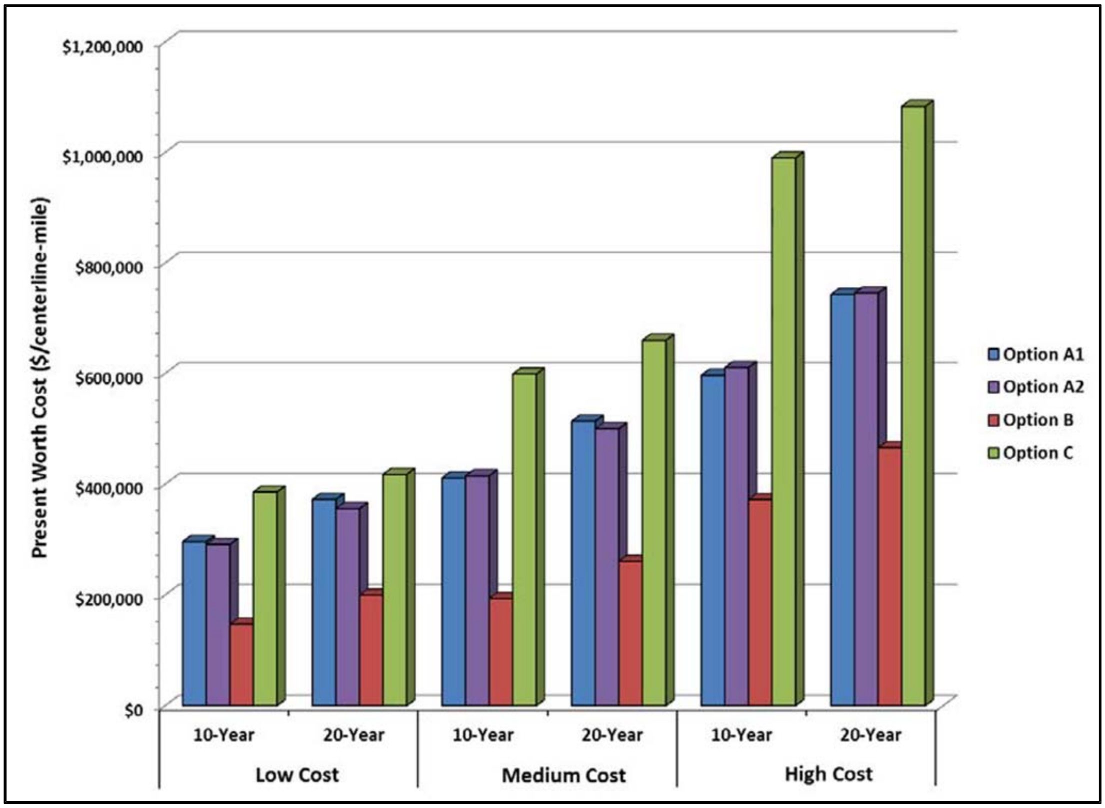

Figure 1. PW Costs for Options Considering Low, Medium, and High Costs per Centerline Mile.

Table 6. Comparisons of EUAC for Options Considering Low, Medium, and High Cost (in $1000 per Centerline Mile).

Option	Low-End Costs		Medium Costs		High-End Costs	
	10 Years	20 Years	10 Years	20 Years	10 Years	20 Years
Option A1, Maintain Existing Pavement Condition without Initially Widening Road	37	27	51	38	74	55
Option A2, Maintain Existing Pavement Condition and Widen Road	36	26	51	37	75	55
Option B, Convert Pavement to IEAS	18	15	24	19	46	34
Option C, Rehabilitate Pavement for Short-Term Oil/Gas Field Traffic	48	31	74	49	122	80

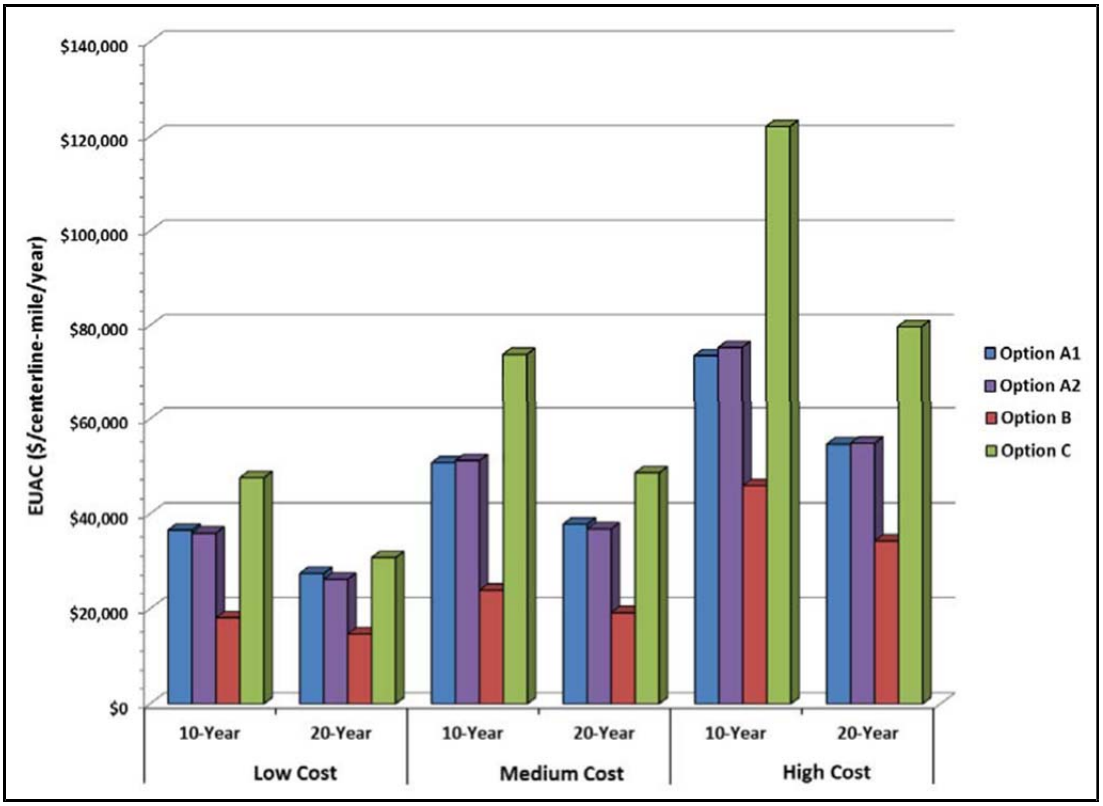

Figure 2. EUAC for Options Considering Low, Medium, and High Costs per Centerline Mile.

DISCUSSION OF OTHER CONSIDERATIONS

The engineering economics analysis estimated that there is an advantage in converting existing pavements to an IEAS in oil- and gas-field-impacted areas, where it likely would be more expensive to rehabilitate the pavements to handle the initial traffic of oil and gas field development and early operation. Maintaining the existing pavements either with or without widening would fall in between these two alternatives. There are, however, considerations beyond the economics associated with only construction, rehabilitation, and maintenance. Table 7 lists some of these considerations, which deal with issues such as safety and user costs not considered in the economic analysis.

Table 7. Considerations beyond Pavement Activities.

Option	Advantages	Disadvantages
Option A1, Maintain Existing Pavement Condition without Initially Widening Road	1. Avoidance of long-term traffic disruptions associated with construction in B or C 2. Better lane delineation than B 3. Higher posted speed than B 4. Better resistance to weather impact than B	1. Safety concerns with non-widened road 2. Numerous maintenance operations disrupting traffic in short intervals 3. Safety associated with maintenance operations 4. Greater roughness than C 5. Greater vehicle maintenance costs than B or C
Option A2, Maintain Existing Pavement Condition and Widen Road	1. Better safety due to widened roadway than A1 2. Better resistance to weather than A1 or B 3. Higher posted speed than B 4. Avoidance of long-term traffic disruptions associated with construction in B or C	1. Numerous maintenance operations disrupting traffic in short intervals 2. Safety associated with maintenance operations 3. Greater roughness than C 4. Greater vehicle maintenance costs than B or C
Option B, Convert Pavement to IEAS	1. Possibly shorter maintenance operations than A1, A2, or C 2. Restoration of ride easier than A1, A2, or C 3. Less edge damage than A1	1. Numerous maintenance operations to maintain road, causing traffic disruptions 2. Susceptibility to weather 3. Reduced posted speed compared to A1, A2, or C 4. Worse lane delineation than A1, A2, or C 5. Potentially greater user costs with slower speeds 6. Greater roughness than C
Option C, Rehabilitate Pavement for Short-Term Oil/Gas Field Traffic	1. Fewer public complaints about roughness or dust generation 2. Higher posted speeds 3. Best vehicle control 4. Best stopping distance 5. Better visibility than B 6. Not as susceptible to weather as B	

CONCLUSIONS

For a given cost scenario, the economic analyses of the four alternatives show that the lowest-cost strategy for handling oil/gas field development and production within the first 5 years of operations is to convert the roadway to an IEAS with a widened roadway (Option B). The next most economically viable and safe approach is to widen the roadway and maintain the current pavement structure (Option A2). Option A1 had essentially the same cost as A2 without the improved safety of a widened road during the oil/gas initial production and exploitation phase. Option C was the most expensive alternative. In the short term (10 years), the anticipated PW for Option B is approximately \$193,000 per centerline mile compared to Option C at \$600,000, and Options A1 and A2 at about \$410,000 per centerline mile.

There are considerations beyond the economics of pavement construction, rehabilitation, and maintenance in the selection of a strategy for a particular roadway. Road user costs associated with construction or maintenance delays and roughness need to be considered along with the most important consideration, roadway safety.

REFERENCES

(1) Lucas, Tim. Fall 2011. "In the Midst of a Fracking Firestorm." *Duke Environment Magazine.* Duke Nicholas School of the Environment, Chapel Hill, North Carolina. http://www.nicholas.duke.edu/dukenvironment/f11/in-the-midst-of-a-fracking-firestorm. Accessed 10:14 a.m. on February 16, 2013.

(2) Barer, David. January 30, 2013. "How Much Oil Is Texas Producing? (Plenty.)" State Impact, National Public Radio. http://stateimpact.npr.org/texas/2013/01/30/how-much-oil-is-texas- producing-plenty/. Accessed 10:26 a.m. on February 16, 2013.

(3) Texas Department of Transportation. September 26, 2013. *Maintenance Cost for Selected Roads in Live Oak, Dimmit, La Salle, Zavala, Reeves and Culberson Counties.* TxDOT Maintenance Division Summary, Texas Department of Transportation, Austin, Texas.

(4) Humphries, S., Broughton, B., and Humphries, E. 2013. *Costs Associated with Conversion of Surfaced Roads to Unsurfaced Roads.* Project Summary Report 0-6677-S, Texas State University–San Marcos.

(5) Passmore, L. G. 2013. *Impact of Energy Sector and Heavy Commercial Development—Action Plan and Summary for Roads to Unpaved.* Prepared for TxDOT Maintenance Division, Pavement Asset Management Team. AMD Engineering, Lubbock, Texas.

(6) Quiroga, C., Fernando, E., Wimsatt, A., Newcomb, D., Stockton, B., and Epps, J. October 2012. *Estimation of Additional Investment Needed to Support Energy Industry Activity in Texas.* TxDOT Administration Research Work Order 24, Texas A&M Transportation Institute, College Station, Texas.

(7) Jahren, C. T., Smith, D., Thorius, J., Rukashaza-Mukome, M., White, D., and Johnson, G. 2005. *Economics of Upgrading an Aggregate Road.* Minnesota Department of Transportation, St. Paul, Minnesota.

(8) Munn, B. September 26, 2013. *Maintenance Information.* Texas Department of Transportation, requested by John Bohuslav, TxDOT San Antonio District.

(9) Figueroa, C., Fotsch, S., and Haddock, J. 2013. *Assessment Procedures for Paved and Unpaved Roads.* Report No. SP-28-2013, Indiana Local Technical Assistance Program, West Lafayette, Indiana.

(10) Churchill, N., Lachance, R., and Henry, C. Undated. *Unpaved Roads Study.* Report of Town of Richmond, Maine. http://www.maine.gov/mdot/csd/mirc/documents/pdf/Richmond1993PavedvsGravelStudy.pdf. Accessed 15:25 p.m. on October 3, 2013.

(11) Stacks, D. September 26, 2013. *Project Plan Sheets and Bid Estimates.* Texas Department of Transportation, San Antonio District.

APPENDIX A
REFERENCES FOR PAVEMENT ACTIVITIES

Table A.1. Cost Estimate—Routine/Heavy Maintenance.

Activity	Representative Cost, $/Centerline Mile		Reference
	Typical	Representative Range	
Paved Roadway with Relatively Low Traffic (Relatively Good Condition)	500*	300–1800	TxDOT (*3*)
	6,300		Humphries et al. (*4*)
	3,100	700–6,400	Passmore (*5*)
	1,200	900–2,000	Quiroga et al. (*6*)
	1,000	200–2,100	Jahren et al. (*7*)
	4,700*		TTI
Paved Roadway with Relatively High Truck Traffic	50,000	20,000–150,000	Passmore (*5*)
	20,000*	3,000–50,000	TxDOT (*3*)
	5,700*	2,000–35,000	Munn (*8*)
	3,000*	1,000–5,000	Quiroga et al. (*6*)
	50,000		TTI
Unsurfaced Roadway with Relatively Low Truck Traffic	750	300–2,000	Jahren et al. (*7*)
	1,700	1,500–2,700	Figueroa et al. (*9*)
	2,500	2,000–5,000	Figueroa et al. (*9*)
	3,500	2,500–6,000	Figueroa et al. (*9*)
Unsurfaced Roadway with Relatively High Truck Traffic	17,000	10,000–30,000	Passmore (*5*)
	6,100		Humphries et al. (*4*)
	7,000	1,500–10,000	Churchill et al. (*10*)
Widen to 28 ft, and Add Base and Two-Course Surface Treatment	200,000	180,000–235,000	TxDOT Districts—San Angelo, Corpus Christi, and Yoakum

***** Based on a review of TxDOT maintenance records for pavements with an average width of 21 ft.

Table A.2. Cost Estimate—Conversion from Paved to Non-paved Road.

Activity	Representative Costs, $/Centerline Mile		Reference
	Typical	Representative Range	
Scarify, Widen, Add Base, and Compact	40,000		Passmore (*5*)
	7,650		Humphries et al. (*4*)
	42,000		Figueroa et al. (*9*)
	50,000	40,000–70,000	TTI

Table A.3. Cost Estimate—Conversion from Non-paved to Paved Road.

Activity	Representative Costs, $/Centerline Mile		Reference
	Typical	Representative Range	
Rework Base and Add Two-Course Surface Treatment	150,000		Figueroa et al. (*9*)
	165,000	120,000–175,000	TTI

Table A.4. Cost Estimate—Rehabilitation.

Activity	Representative Costs, $/Centerline Mile		Reference
	Typical	Representative Range	
Widen, Stabilize, and Add Base and Two-Course Surface Treatment	500,000	300,00–800,000	Passmore (*5*)
	425,000	350,000–500,000	Stacks (*11*)
	500,000	250,000–1,000,000	Quiroga et al. (*6*)

APPENDIX B
DETAILED PRESENT WORTH COST ANALYSES

Table B.1. Detailed Economic Analysis for Option A1, Low-Cost Scenario.

Discount Rate	4%	Low			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Heavy Maintenance	$35,000	1.0000	$35,000	
1	Continued Heavy Maintenance	$35,000	0.9615	$33,654	
2	Continued Heavy Maintenance	$35,000	0.9246	$32,359	
3	Continued Heavy Maintenance	$35,000	0.8890	$31,115	PW at
4	Continued Heavy Maintenance	$35,000	0.8548	$29,918	5 Years
5	Major Maint./Rehabilitation	$225,000	0.8219	$184,934	$162,046.33
6	Routine Maintenance	$600	0.7903	$474	
7	Routine Maintenance	$600	0.7599	$456	
8	Routine Maintenance	$600	0.7307	$438	PW at
9	Routine Maintenance	$600	0.7026	$422	10 Years
10	Routine Maintenance	$600	0.6756	$405	$296,337.20
11	Routine Maintenance	$600	0.6496	$390	
12	Seal Coat	$30,000	0.6246	$18,738	
13	Routine Maintenance	$600	0.6006	$360	
14	Routine Maintenance	$600	0.5775	$346	
15	Routine Maintenance	$600	0.5553	$333	
16	Routine Maintenance	$600	0.5339	$320	
17	Routine Maintenance	$600	0.5134	$308	
18	Routine Maintenance	$600	0.4936	$296	PW at
19	Seal Coat	$30,000	0.4746	$14,239	20 Years
20	Routine Maintenance	$600	0.4564	$274	$372,575.58

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.2. Detailed Economic Analysis for Option A1, Medium-Cost Scenario.

Discount Rate	**4%**	**Medium**			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Heavy Maintenance	$50,000	1.0000	$50,000	
1	Continued Heavy Maintenance	$50,000	0.9615	$48,077	
2	Continued Heavy Maintenance	$50,000	0.9246	$46,228	
3	Continued Heavy Maintenance	$50,000	0.8890	$44,450	
4	Continued Heavy Maintenance	$50,000	0.8548	$42,740	
5	Major Maint./Rehabilitation	$300,000	0.8219	$246,578	PW at 5 Years $231,494.76
6	Routine Maintenance	$1,000	0.7903	$790	
7	Routine Maintenance	$1,000	0.7599	$760	
8	Routine Maintenance	$1,000	0.7307	$731	
9	Routine Maintenance	$1,000	0.7026	$703	
10	Routine Maintenance	$1,000	0.6756	$676	PW at 10 Years $411,281.07
11	Routine Maintenance	$1,000	0.6496	$650	
12	Seal Coat	$40,000	0.6246	$24,984	
13	Routine Maintenance	$1,000	0.6006	$601	
14	Routine Maintenance	$1,000	0.5775	$577	
15	Routine Maintenance	$1,000	0.5553	$555	
16	Routine Maintenance	$1,000	0.5339	$534	
17	Routine Maintenance	$1,000	0.5134	$513	
18	Routine Maintenance	$1,000	0.4936	$494	
19	Seal Coat	$40,000	0.4746	$18,986	
20	Routine Maintenance	$1,000	0.4564	$456	PW at 20 Years $513,808.28

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.3. Detailed Economic Analysis for Option A1, High-Cost Scenario.

Discount Rate	4%	High			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Heavy Maintenance	$75,000	1.0000	$75,000	
1	Continued Heavy Maintenance	$75,000	0.9615	$72,115	
2	Continued Heavy Maintenance	$75,000	0.9246	$69,342	
3	Continued Heavy Maintenance	$75,000	0.8890	$66,675	
4	Continued Heavy Maintenance	$75,000	0.8548	$64,110	
5	Major Maint./Rehabilitation	$400,000	0.8219	$328,771	PW at 5 Years $347,242.14
6	Routine Maintenance	$4,000	0.7903	$3,161	
7	Routine Maintenance	$4,000	0.7599	$3,040	
8	Routine Maintenance	$4,000	0.7307	$2,923	
9	Routine Maintenance	$4,000	0.7026	$2,810	
10	Routine Maintenance	$4,000	0.6756	$2,702	PW at 10 Years $596,714.75
11	Routine Maintenance	$4,000	0.6496	$2,598	
12	Seal Coat	$50,000	0.6246	$31,230	
13	Routine Maintenance	$4,000	0.6006	$2,402	
14	Routine Maintenance	$4,000	0.5775	$2,310	
15	Routine Maintenance	$4,000	0.5553	$2,221	
16	Routine Maintenance	$4,000	0.5339	$2,136	
17	Routine Maintenance	$4,000	0.5134	$2,053	
18	Routine Maintenance	$4,000	0.4936	$1,975	
19	Seal Coat	$50,000	0.4746	$23,732	
20	Routine Maintenance	$4,000	0.4564	$1,826	PW at 20 Years $742,790.20

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.4. Detailed Economic Analysis for Option A2, Low-Cost Scenario.

Discount Rate	**4%**	**Low**			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Heavy Maintenance	$150,000	1.0000	$150,000	
1	Moderate Maintenance	$10,000	0.9615	$9,615	
2	Moderate Maintenance	$10,000	0.9246	$9,246	
3	Moderate Maintenance	$10,000	0.8890	$8,890	
4	Moderate Maintenance	$10,000	0.8548	$8,548	
5	Major Maint./Rehabilitation	$175,000	0.8219	$143,837	PW at 5 Years $186,298.95
6	Routine Maintenance	$600	0.7903	$474	
7	Routine Maintenance	$600	0.7599	$456	
8	Routine Maintenance	$600	0.7307	$438	
9	Routine Maintenance	$600	0.7026	$422	
10	Routine Maintenance	$600	0.6756	$405	PW at 10 Years $291,235.28
11	Routine Maintenance	$600	0.6496	$390	
12	Seal Coat	$30,000	0.6246	$18,738	
13	Routine Maintenance	$600	0.6006	$360	
14	Routine Maintenance	$600	0.5775	$346	
15	Routine Maintenance	$600	0.5553	$333	
16	Routine Maintenance	$600	0.5339	$320	
17	Routine Maintenance	$600	0.5134	$308	
18	Routine Maintenance	$600	0.4936	$296	
19	Seal Coat	$30,000	0.4746	$14,239	
20	Routine Maintenance	$600	0.4564	$274	PW at 20 Years $355,731.85

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.5. Detailed Economic Analysis for Option A2, Medium-Cost Scenario.

Discount Rate	4%	Medium			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Heavy Maintenance	$225,000	1.0000	$225,000	
1	Moderate Maintenance	$15,000	0.9615	$14,423	
2	Moderate Maintenance	$15,000	0.9246	$13,868	
3	Moderate Maintenance	$15,000	0.8890	$13,335	
4	Moderate Maintenance	$15,000	0.8548	$12,822	
5	Major Maint./Rehabilitation	$225,000	0.8219	$184,934	PW at 5 Years $279,448.43
6	Routine Maintenance	$1,000	0.7903	$790	
7	Routine Maintenance	$1,000	0.7599	$760	
8	Routine Maintenance	$1,000	0.7307	$731	
9	Routine Maintenance	$1,000	0.7026	$703	
10	Routine Maintenance	$1,000	0.6756	$676	PW at 10 Years $415,202.93
11	Routine Maintenance	$1,000	0.6496	$650	
12	Seal Coat	$40,000	0.6246	$24,984	
13	Routine Maintenance	$1,000	0.6006	$601	
14	Routine Maintenance	$1,000	0.5775	$577	
15	Routine Maintenance	$1,000	0.5553	$555	
16	Routine Maintenance	$1,000	0.5339	$534	
17	Routine Maintenance	$1,000	0.5134	$513	
18	Routine Maintenance	$1,000	0.4936	$494	
19	Seal Coat	$40,000	0.4746	$18,986	
20	Routine Maintenance	$1,000	0.4564	$456	PW at 20 Years $500,117.42

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.6. Detailed Economic Analysis for Option A2, High-Cost Scenario.

Discount Rate	4%	High			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Heavy Maintenance	$300,000	1.0000	$300,000	
1	Moderate Maintenance	$25,000	0.9615	$24,038	
2	Moderate Maintenance	$25,000	0.9246	$23,114	
3	Moderate Maintenance	$25,000	0.8890	$22,225	
4	Moderate Maintenance	$25,000	0.8548	$21,370	
5	Major Maint./Rehabilitation	$350,000	0.8219	$287,674	PW at 5 Years $390,747.38
6	Routine Maintenance	$4,000	0.7903	$3,161	
7	Routine Maintenance	$4,000	0.7599	$3,040	
8	Routine Maintenance	$4,000	0.7307	$2,923	
9	Routine Maintenance	$4,000	0.7026	$2,810	
10	Routine Maintenance	$4,000	0.6756	$2,702	PW at 10 Years $610,865.45
11	Routine Maintenance	$4,000	0.6496	$2,598	
12	Seal Coat	$50,000	0.6246	$31,230	
13	Routine Maintenance	$4,000	0.6006	$2,402	
14	Routine Maintenance	$4,000	0.5775	$2,310	
15	Routine Maintenance	$4,000	0.5553	$2,221	
16	Routine Maintenance	$4,000	0.5339	$2,136	
17	Routine Maintenance	$4,000	0.5134	$2,053	
18	Routine Maintenance	$4,000	0.4936	$1,975	
19	Seal Coat	$50,000	0.4746	$23,732	
20	Routine Maintenance	$4,000	0.4564	$1,826	PW at 20 Years $745,199.08

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.7. Detailed Economic Analysis for Option B, Low-Cost Scenario.

Discount Rate	**4%**	**Low**			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Convert to IEAS	$35,000	1.0000	$35,000	
1	Maintain IEAS	$10,000	0.9615	$9,615	
2	Maintain IEAS	$10,000	0.9246	$9,246	
3	Maintain IEAS	$10,000	0.8890	$8,890	
4	Maintain IEAS	$10,000	0.8548	$8,548	
5	Major Maint./Rehabilitation	$125,000	0.8219	$102,741	PW at 5 Years $71,299
6	Routine Maintenance	$600	0.7903	$474	
7	Routine Maintenance	$600	0.7599	$456	
8	Routine Maintenance	$600	0.7307	$438	
9	Routine Maintenance	$600	0.7026	$422	
10	Routine Maintenance	$600	0.6756	$405	PW at 10 Years $146,881
11	Routine Maintenance	$600	0.6496	$390	
12	Seal Coat	$30,000	0.6246	$18,738	
13	Routine Maintenance	$600	0.6006	$360	
14	Routine Maintenance	$600	0.5775	$346	
15	Routine Maintenance	$600	0.5553	$333	
16	Routine Maintenance	$600	0.5339	$320	
17	Routine Maintenance	$600	0.5134	$308	
18	Routine Maintenance	$600	0.4936	$296	
19	Seal Coat	$30,000	0.4746	$14,239	
20	Routine Maintenance	$600	0.4564	$274	PW at 20 Years $199,635

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.8. Detailed Economic Analysis for Option B, Medium-Cost Scenario.

Discount Rate	4%	Medium			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Convert to IEAS	$40,000	1.0000	$40,000	
1	Maintain IEAS	$17,000	0.9615	$16,346	
2	Maintain IEAS	$17,000	0.9246	$15,717	
3	Maintain IEAS	$17,000	0.8890	$15,113	
4	Maintain IEAS	$17,000	0.8548	$14,532	
5	Major Maint./Rehabilitation	$150,000	0.8219	$123,289	PW at 5 Years $101,708
6	Routine Maintenance	$1,000	0.7903	$790	
7	Routine Maintenance	$1,000	0.7599	$760	
8	Routine Maintenance	$1,000	0.7307	$731	
9	Routine Maintenance	$1,000	0.7026	$703	
10	Routine Maintenance	$1,000	0.6756	$676	PW at 10 Years $193,431
11	Routine Maintenance	$1,000	0.6496	$650	
12	Seal Coat	$40,000	0.6246	$24,984	
13	Routine Maintenance	$1,000	0.6006	$601	
14	Routine Maintenance	$1,000	0.5775	$577	
15	Routine Maintenance	$1,000	0.5553	$555	
16	Routine Maintenance	$1,000	0.5339	$534	
17	Routine Maintenance	$1,000	0.5134	$513	
18	Routine Maintenance	$1,000	0.4936	$494	
19	Seal Coat	$40,000	0.4746	$18,986	
20	Routine Maintenance	$1,000	0.4564	$456	PW at 20 Years $260,733

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.9. Detailed Economic Analysis for Option B, High-Cost Scenario.

Discount Rate	4%	High			
Year	Activity	Total Cost	PW Factor	Present Worth	
0	Convert to IEAS	$175,000	1.0000	$175,000	
1	Maintain IEAS	$22,000	0.9615	$21,154	
2	Maintain IEAS	$22,000	0.9246	$20,340	
3	Maintain IEAS	$22,000	0.8890	$19,558	
4	Maintain IEAS	$22,000	0.8548	$18,806	
5	Major Maint./Rehabilitation	$175,000	0.8219	$143,837	PW at 5 Years $254,858
6	Routine Maintenance	$4,000	0.7903	$3,161	
7	Routine Maintenance	$4,000	0.7599	$3,040	
8	Routine Maintenance	$4,000	0.7307	$2,923	
9	Routine Maintenance	$4,000	0.7026	$2,810	
10	Routine Maintenance	$4,000	0.6756	$2,702	PW at 10 Years $372,235
11	Routine Maintenance	$4,000	0.6496	$2,598	
12	Seal Coat	$50,000	0.6246	$31,230	
13	Routine Maintenance	$4,000	0.6006	$2,402	
14	Routine Maintenance	$4,000	0.5775	$2,310	
15	Routine Maintenance	$4,000	0.5553	$2,221	
16	Routine Maintenance	$4,000	0.5339	$2,136	
17	Routine Maintenance	$4,000	0.5134	$2,053	
18	Routine Maintenance	$4,000	0.4936	$1,975	
19	Seal Coat	$50,000	0.4746	$23,732	
20	Routine Maintenance	$4,000	0.4564	$1,826	PW at 20 Years $465,472

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.10. Detailed Economic Analysis for Option C, Low-Cost Scenario.

Discount Rate	4%	Low			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Rehabilitation	$350,000	1.0000	$350,000	
1	Moderate Maintenance	$3,000	0.9615	$2,885	
2	Moderate Maintenance	$3,000	0.9246	$2,774	
3	Moderate Maintenance	$3,000	0.8890	$2,667	
4	Moderate Maintenance	$3,000	0.8548	$2,564	
5	Overlay (2 Inches)	$40,000	0.8219	$32,877	PW at 5 Years $360,890
6	Routine Maintenance	$400	0.7903	$316	
7	Routine Maintenance	$400	0.7599	$304	
8	Routine Maintenance	$400	0.7307	$292	
9	Routine Maintenance	$400	0.7026	$281	
10	Routine Maintenance	$400	0.6756	$270	PW at 10 Years $385,837
11	Routine Maintenance	$400	0.6496	$260	
12	Seal Coat	$30,000	0.6246	$18,738	
13	Routine Maintenance	$400	0.6006	$240	
14	Routine Maintenance	$400	0.5775	$231	
15	Routine Maintenance	$400	0.5553	$222	
16	Routine Maintenance	$400	0.5339	$214	
17	Routine Maintenance	$400	0.5134	$205	
18	Routine Maintenance	$400	0.4936	$197	
19	Seal Coat	$30,000	0.4746	$14,239	
20	Routine Maintenance	$400	0.4564	$183	PW at 20 Years $417,755

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.11. Detailed Economic Analysis for Option C, Medium-Cost Scenario.

Discount Rate	4%	Medium			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Rehabilitation	$500,000	1.0000	$500,000	
1	Moderate Maintenance	$6,000	0.9615	$5,769	
2	Moderate Maintenance	$6,000	0.9246	$5,547	
3	Moderate Maintenance	$6,000	0.8890	$5,334	
4	Moderate Maintenance	$6,000	0.8548	$5,129	
5	Overlay (2 Inches)	$125,000	0.8219	$102,741	PW at 5 Years $521,779
6	Routine Maintenance	$1,000	0.7903	$790	
7	Routine Maintenance	$1,000	0.7599	$760	
8	Routine Maintenance	$1,000	0.7307	$731	
9	Routine Maintenance	$1,000	0.7026	$703	
10	Routine Maintenance	$1,000	0.6756	$676	PW at 10 Years $598,825
11	Routine Maintenance	$1,000	0.6496	$650	
12	Seal Coat	$40,000	0.6246	$24,984	
13	Routine Maintenance	$1,000	0.6006	$601	
14	Routine Maintenance	$1,000	0.5775	$577	
15	Routine Maintenance	$1,000	0.5553	$555	
16	Routine Maintenance	$1,000	0.5339	$534	
17	Routine Maintenance	$1,000	0.5134	$513	
18	Routine Maintenance	$1,000	0.4936	$494	
19	Seal Coat	$40,000	0.4746	$18,986	
20	Routine Maintenance	$1,000	0.4564	$456	PW at 20 Years $660,256

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.

Table B.12. Detailed Economic Analysis for Option C, High-Cost Scenario.

Discount Rate	**4%**	**High**			
Year	**Activity**	**Total Cost**	**PW Factor**	**Present Worth**	
0	Rehabilitation	$800,000	1.0000	$800,000	
1	Moderate Maintenance	$20,000	0.9615	$19,231	
2	Moderate Maintenance	$20,000	0.9246	$18,491	
3	Moderate Maintenance	$20,000	0.8890	$17,780	
4	Moderate Maintenance	$20,000	0.8548	$17,096	
5	Overlay (2 Inches)	$175,000	0.8219	$143,837	PW at 5 Years $872,598
6	Routine Maintenance	$4,000	0.7903	$3,161	
7	Routine Maintenance	$4,000	0.7599	$3,040	
8	Routine Maintenance	$4,000	0.7307	$2,923	
9	Routine Maintenance	$4,000	0.7026	$2,810	
10	Routine Maintenance	$4,000	0.6756	$2,702	PW at 10 Years $989,975
11	Routine Maintenance	$4,000	0.6496	$2,598	
12	Seal Coat	$50,000	0.6246	$31,230	
13	Routine Maintenance	$4,000	0.6006	$2,402	
14	Routine Maintenance	$4,000	0.5775	$2,310	
15	Routine Maintenance	$4,000	0.5553	$2,221	
16	Routine Maintenance	$4,000	0.5339	$2,136	
17	Routine Maintenance	$4,000	0.5134	$2,053	
18	Routine Maintenance	$4,000	0.4936	$1,975	
19	Seal Coat	$50,000	0.4746	$23,732	
20	Routine Maintenance	$4,000	0.4564	$1,826	PW at 20 Years $1,083,212

Note: Present worth costs at 5-, 10-, and 20-year periods include residual value of most recent rehabilitation.