8   Life-Cycle Cost Analysis

8.1   Introduction

The purpose of this life-cycle cost analysis (LCCA) chapter is to set forth guidelines for comparing alternative design strategies on an economic basis. Concepts of engineering economics are used to calculate the net present value of costs for each of the alternatives being considered, including not only first cost but also any preservation, rehabilitation, and reconstruction costs over the analysis period.

Both federal and state guidelines recommend such analyses. Prior to 1998, federal legislation mandated such studies for projects over a certain value. The requirement was removed in 1998, but Federal Regulations now requires that economic considerations be given to alternative combinations of materials during pavement design.[23] At the state level, Alaska Statute 19.10.160 provides, in part, "Design for proposed major upgrade and new construction projects for highways in federally recognized metropolitan planning areas must be conducive to safety, durability, and economy of maintenance …" [24] Also, life cycle cost analysis is addressed several times in the DOT&PF Preconstruction Manual including: 1) definition of Value Engineering—Section 450.16; 2) items included in the design study report—Section 450.5.1; 3) use of surface treatments—Section 1180.3.2; 4) use of binder courses—Section 1180.4; and, 5) use of stabilized base courses—Section 1180.5.

The chapter is divided into three parts. In the first, seven steps in the analysis process are recommended, including establishing alternative design strategies, determining performance periods and activity timing, estimating agency and user costs, developing cash flow diagrams, computing net present value of costs for each alternative, performing a sensitivity analysis, and analyzing the results and reevaluating strategies. The second section contains an example that analyzes the costs of two hypothetical projects by utilizing the seven suggested steps, using a spreadsheet as the means of calculation. The third part describes the LCCA module within the AKFPD 2.0 software.

Many factors impact the selection of a design strategy, including safety, local needs, available materials, environmental concerns, and appearance. Economic considerations are but one of the factors in such a decision. The method outlined here provides a rational, straightforward means for analyzing the initial and future costs of pavement construction.

Keep in mind that some social, safety or political issues may not be quantifiable according to the standard economic analysis concepts presented in this chapter. Such issues may nevertheless weigh heavily – even critically – on selecting a pavement design alternative. Be aware of all decision-making issues, in addition to life cycle cost analysis; then be prepared to defend your selected design alternative on all accounts.

8.2   Recommended Steps in the Analysis Process

The steps suggested here are based on a condensed and modified version of the eight-step process set forth in *Life Cycle Cost Analysis in Pavement Design: In Search of Better Investment Decisions*.[25]

8.2.1   Establish alternative design strategies

The process begins during the technical design, when the various design alternatives have been identified sufficiently that their costs can be reasonably estimated. The strategy of each alternative is a combination of initial pavement design and associated future preservation, rehabilitation, and reconstruction activities. Typically, two or three such strategies will have been identified; thus, there is a need to compare them on an economic basis. For consistency, it is essential that all strategies be set forth for the same analysis period. It is recommended that a 35-

year analysis period be used, a length of time usually enough to include several major activities in the rehabilitation and reconstruction cycle. Moreover, a 35-year analysis period is the minimum recommended by the Federal Highway Administration and has been accepted by the Alaska DOT&PF administration for application in life cycle cost analyses for all pavement design strategies. It is not expected that the pavement's predicted service life will be exactly 35 years or some simple fraction thereof; Chapter 2 of this manual sets forth policies for design lives for various types of projects. A pavement with remaining life at the end of the 35-year analysis period will have a salvage value that will be incorporated into the analysis.

All pavement design strategies must include consideration for work zone requirements during initial construction and any subsequent activities. Traffic control, detours, temporary drainage, environmental monitoring and control, and other efforts may both add to the agency's costs and have major impacts on the traveling public in the form of user costs. Work planning can reduce user costs through such strategies as confining field work to periods of low traffic and working the job in small segments rather than impacting traffic flow through the entire work zone during the entire construction period. Further consideration is given to user costs in the section on estimating agency and user costs.

8.2.2 Determine performance periods and activity timing

Having identified the scope and nature of the activities for each alternative in step one, we then must estimate their performance periods: how long they will last. Performance life of both the initial construction and any subsequent preservation, rehabilitation and reconstruction activities has a major impact on the life cycle cost analysis results. Determination of performance periods then leads to specifying activity timing: when, relative to the time of initial construction, each subsequent activity will take place. If an initial pavement construction (at "year 0") is expected to last fifteen years, with an overlay to be placed after that performance period, it follows that the first overlay is planned for "year 15." Chapter 2 of this manual provides guidance for the planning of performance periods.

8.2.3 Estimate agency and user costs

The purpose of the life cycle cost analysis is to compare alternative design strategies; thus, only *differences* in cash flows among the alternatives need be considered in estimating initial and future costs.

Agency costs include all costs incurred by DOT&PF (or owner agency) over the life of the project. These costs include planning, design, and contract administration; construction; traffic control; environmental monitoring and control; and any other costs paid for from the project budget. Note that these costs are present not only for initial construction but also future preservation, rehabilitation, and reconstruction activities. Often routine annual preservation is not included in life cycle cost analysis of competing design alternatives; the rationale is that the cost of such preservation is likely not to vary greatly among the alternatives and thus can be ignored in an analysis whose purpose is to compare the differences between alternatives. The method presented here can easily accommodate significant differences in annual preservation costs for the various alternative strategies if such differences have been identified. However, AKFPD does consider annual maintenance or preservation costs to reduce potential confusion as to whether or not to include it.

At the end of the analysis period (usually 35 years, as recommended above), in most cases the pavement will have some remaining value. A recommended approach to determining the pavement's salvage value is to use the cost of the most recent rehabilitation and/or reconstruction activity, if it still has some remaining life, and determine its remaining value based on the proportion of its life that remains. For example, suppose $800,000 is spent at year 32 on an overlay whose total performance life is predicted to be eight years. Therefore, at year 35 (the end of the analysis period), five of its eight years remain. Thus, it is reasonable to find that the pavement's salvage value is

$$\left(\frac{5}{8}\right) \times (\$800,000) = \$500,000$$

A full treatment of user costs would try to recognize differences in operating costs throughout the 35-year analysis period due to variations among the various alternative strategies. It is recommended that such costs not be

included, under the assumption that they are essentially the same for any of the alternatives. This assumption is based on an expected DOT&PF management requirement that all allowable strategies must provide driving surfaces of similarly acceptable quality-levels during the entire 35-year analysis period. In other words, all acceptable alternatives must provide similarly good driving surfaces regardless of age.

Turning to work zone user costs during the initial construction and subsequent rehabilitation and reconstruction periods, three types of costs are recognized: user delay costs, vehicle operating costs, and crash costs. Recognizing these costs reflects the fact that, during periods of construction, preservation and rehabilitation, the capacity of the highway is restricted, and normal traffic flow is disrupted. Figure 8.1 produced using software developed by the Asphalt Pavement Alliance [26] and updated to 2018 dollars can be used to estimate work zone user costs. The work zone user costs recognized by this graph include extra vehicle operating costs while changing speed and being stopped, and the user time costs of changing speed, traveling more slowly than normal and being stopped. The total cost estimate is a function of the type of roadway (urban or rural), whether work is conducted during the day or night, the estimated AADT, the number of work zone lane miles, and the number of days during which construction is underway. For example, a five-mile work zone, two lane, rural project with an AADT of 6000, a project duration of 40 days, and all work performed during the day would have an estimated work zone user cost of

$$\left(\frac{\$125}{1,000\ AADT - lane\ mile - day}\right) \times (6{,}000\ AADT) \times (10\ lane\ miles) \times (40\ days) = \$300{,}000$$

Other means of estimating user work zone costs would be 1) hand calculations based on the designer's knowledge of local conditions, or 2) direct use of the software that is the basis of the graph shown here or other similar software. However, for the sort of estimate needed for a legitimate life cycle cost analysis, it is believed that the graph will produce sufficiently accurate results with minimum effort.

Whether or not to include work zone user costs at all is both a philosophical and a practical matter. Some would suggest that they should not be included, since the primary consideration is the agency's budget, which nowhere reflects such costs. On the other hand, the agency's sole purpose is to act as the proxy for the public benefit, so the counterargument suggests that the agency ought to give serious attention to such costs. From a practical standpoint, some elements of these costs are difficult to estimate, and some, even if easily obtained, would have a minor impact on the overall cost.

Crash costs are usually excluded from the analysis because they are random events. While work zones do have higher crash rates, on average they may represent a minor element in the user cost picture; however, one fatality, when it occurs, is certainly a catastrophic event.

There are many arguments in favor of limiting the number of construction events and keeping the duration of the events that do occur as short as possible. From the user standpoint, these include crash potential; health issues from dust, noise, anger, and stress; delays; increased vehicle operating costs; and loss or cessation of business. From the agency's point of view, fewer and shorter construction events can lead to better public relations and greater certainty in material and labor costs. By including work zone user costs in the life cycle cost analysis, this element will be recognized; other things being equal, the alternative with the fewest and/or shortest construction events ought to be favored.

It is important that all costs be estimated in real, or present day, or time zero, dollars. Thus, the costs shown in Figure 8.1 are in real, time zero dollars. The calculation of present value using the discount rate, to be explained below, assumes that all cash flows are in present day dollars, rather than in actual, or inflated, or nominal dollars. Thus, all costs should be those that would apply at the time of the project's first capital expenditure, without adding the effects of inflation.
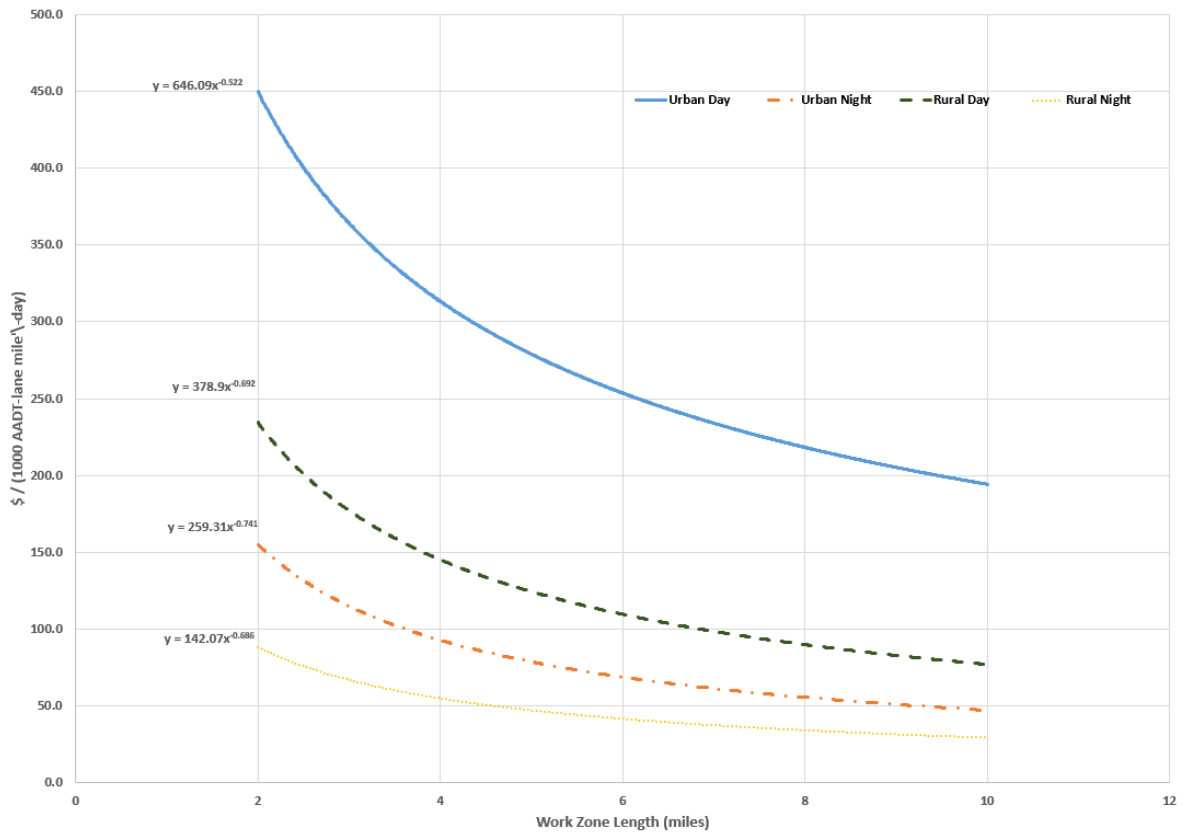
Figure 8-1 Work Zone User Delay Cost Estimates

8.2.4 Develop cash flow diagrams

A cash flow diagram is a simple graphical device for showing when, in time, the various cash flows associated with an alternative are expected to take place. Generally, the beginning of the cash flow period is taken as "time 0," or "year 0." The time scale of years is laid out horizontally, with each significant cash flow shown as an arrow at the year when it is expected to take place. Although each cash flow takes place during a non-instantaneous period of time, it is assumed that each occurs at one point in time. Cash flows occurring during a year are assumed to take place at the end of that year. The suggested convention is that costs, both to the agency and to the public, are shown as upward arrows, while any cash flows that are benefits, such as salvage values, are shown as downward arrows.

The following cash flow diagram represents a project whose initial cost, occurring during the year prior to year 0, is $2,000,000; whose periodic costs, occurring just prior to or at years 14 and 28, are $650,000 each; and whose salvage value, occurring at year 35, is $500,000:
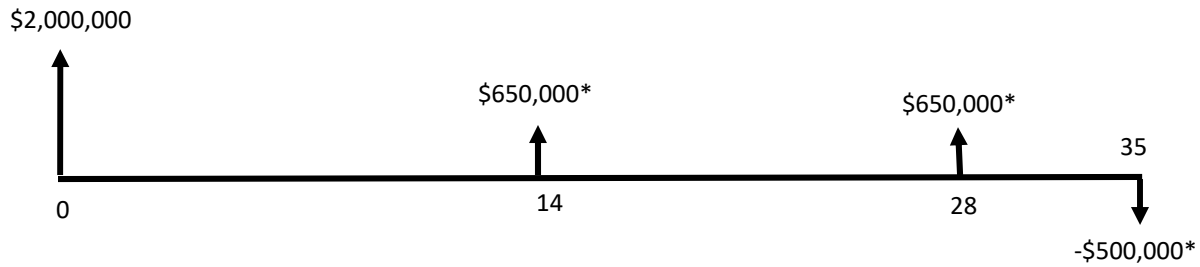
Figure 8-2 Sample Cash Flow Diagram

*Note that these cash flows are stated in real, or present day, or time zero, dollars.

Note that the length of each arrow is roughly proportional to its value, although this convention is often not followed very strictly.

8.2.5 Compute net present value of costs for each alternative

In order to compare the economic consequences of the various alternatives on a common basis, present value analysis is used. This method allows alternatives with different cash flow values and patterns to be compared in a way that reflects the time value of money. The net present value (NPV) is the discounted monetary value of the expected positive and negative cash flows, found by summing the discounted future cash flows using an appropriate discount rate and then adding the initial, time zero, cost. The result can be thought of as the amount that would be needed at the beginning of the project to fund the initial and future net costs, if any unspent amounts were invested at the given discount rate until needed. The alternative with the lowest net present value is considered the most attractive from an economic standpoint.

Two methods are available to perform the analysis, the deterministic method, and the probabilistic method. The former utilizes single values of each input variable and determines a single value of net present value for each alternative strategy. The latter considers several of the inputs as random variables and thus utilizes probability distributions and simulation to generate a distribution of possible values of net present value for each alternative. For simplicity, it is recommended that the deterministic method be used. Furthermore, it is recommended that such an approach be accompanied by a sensitivity analysis to give some measure of confidence in the results.

The present value of a future cash flow is found from the following formula:

$$PV = \frac{CF}{\left(1 + i_{dis}\right)^n} \text{ , where}$$

PV = Present value,

CF = Cash flow at year n,

i_{dis} = discount rate in decimal form, and

n = year at which cash flow occurs.

This formula is used to find the present value of each cash flow, and the individual present values are totaled to

find the net present value. Note that the present value of the initial cost is that cost itself, since it occurs at time 0 $(n = 0)$, and the value of $(1 + i_{dis})^0$ will always be 1, regardless of the value of i_{dis}

Suppose one of the cash flows that is expected to take place for a certain design strategy is a rehabilitation at year 14 that is estimated to cost $650,000. If we use a discount rate of 4%, the calculation is as follows:

$$PV = \frac{\$650,000}{(1+.04)^{14}} = \$375,359, \text{ rounded, say, to } \$375,400$$

This calculated value is the time zero equivalent of the future cash flow. It can be thought of as the amount that would have to be invested at time zero in a fund earning 4% per annum in order to have $650,000 in the fund at the end of year 14.

As one more example, consider the $500,000 salvage value calculated earlier. Since this value occurs at the end of the 35-year analysis period, we can find its time zero equivalent as

$$PV = \frac{-\$500,000}{(1+.04)^{35}} = -\$126,700$$

Note that this value is negative because it has value to the owner and thus tends to reduce the cost of the project.

The results of the NPV calculations depend upon the assumed value of the discount rate. When the analyst uses real, or year zero, costs for all cash flows, as recommended above, the value of i in the formula for present value must be the discount rate, which does not include the assumed rate of inflation. The relationship among interest rate, discount rate and inflation rate are approximately the following:

Discount rate ≈ Interest rate − Inflation rate .

Over many years, the difference between the interest rate on a 10-year U.S. Government Treasury note (a seemingly appropriate measure of the public's opportunity cost of money) and the inflation rate has been consistently between 3 and 5%. However, the Office of Management (OMB) recommends a real interest rate annually in OMB Circular A-94 [27]. This rate is used to represent an estimate of the average rate of return on private investment before taxes and after inflation.

The cash flow diagram for an alternative shows the assumed initial and future cash flows for that alternative; note once again that cash flows will be in real, or time zero, dollars. From the diagram, one can identify each cash flow and its assumed time of occurrence; application of the present value formula is then straightforward.

One method for performing the net present value calculations is to use a spreadsheet; that method is illustrated in Section 8.3. Such a technique is especially useful if a sensitivity analysis is performed; varying each desired input parameter, once the spreadsheet is populated with cash flow values, is uncomplicated and efficient. Other ways to carry out the calculations include hand calculations and the inclusion of life cycle cost analysis within the pavement design module. This last feature is illustrated in Section 8.4.

8.2.6 Perform a sensitivity analysis

The costs utilized in these analyses are only estimates, even though we have eliminated any consideration of inflation. The further we investigate the future, the less confidence we have in those estimates. Thus, it is

important that the analyst have some notion of how sensitive the recommendation is to variations in the input variables. If the cost of an overlay at year 12 (in real dollars) for the preferred alternative were 20% higher than estimated, and all other costs remain as estimated, would the recommendation change? What if the life of a new type of pavement turns out to be 10 years instead of 15; would such a condition cause the cost analysis to favor the other alternative? Or, if we paid a premium for the initial construction to be done at night, would there be enough savings in road user costs to justify such a scheme?

Using a spreadsheet, the user can vary selected input values to study questions such as these to determine some notion of confidence in the recommendation resulting from the initial analysis. The analyst will have to decide which input values should be studied in this way, based on her/his knowledge of which cost values are likely to be different from those assumed in the initial analysis.

The sample hypothetical analysis in section 8.3 gives an example of a simple sensitivity study that may suggest a helpful approach.

8.2.7 Analyze results and reevaluate strategies

After the calculations have been completed, the results must be analyzed and interpreted. In some cases, it may suffice to state which of the alternatives appears to be most economically attractive, based on the calculations. Perhaps the percent difference between two strategies will be stated. In some cases, the results may be so close as to indicate that factors other than economics will decide the preferred alternative. Results of the sensitivity analysis may play a significant part in identifying a recommendation. It is important to analyze the agency cost and user cost results separately, at least initially, and interpret them considering the relative importance that each is given in making a final recommendation.

Lastly, the designer/analyst must determine whether the results indicate that adjustments or modifications to the alternative strategies should be made prior to the final design decision. Perhaps the initial construction should be changed, or rehabilitation methods modified. Perhaps the analysis has indicated excessive user costs during construction, so that construction times, both initially and in the future, should be substantially reduced. Following such adjustments, further economic analysis may be warranted.

8.3 Sample Hypothetical Analysis

Suppose it is proposed to repave an eight-mile section of two-lane rural highway. Two alternative design strategies (Section 8.2.1) have been developed. The subbase would be the same for either alternative and is thus ignored in the life cycle cost analysis. Alternative #1 includes a 3" asphalt concrete pavement and a 4" stabilized base course. In the future, annual preservation will be performed. Major rehabilitation will consist of a thick overlay, while a complete reconstruction will include a pavement structure exceeding the quality of the original (year 0) construction.

Alternative #2 consists of a 2" asphalt concrete pavement and an 8" base course. Future work includes routine annual preservation, minor rehabilitation with a thin overlay, and a major reconstruction with the same design as the original project.

The performance periods and activity timing (Section 8.2.2) for each of these alternatives are shown in the following table.

Table 8-1 Performance Periods and Activity Timing for Sample Project

	Alternative #1	Alternative #2
Initial Structure	3" asphalt concrete + 4" stabilized base	2" asphalt concrete + 8" base
Initial Construction	Year 0	Year 0
Routine Preservation	Annually	Annually
Rehabilitation	Major rehabilitation @ years 15 & 25 (thick overlay)	Minor rehabilitation @ years 15, 20 & 25 (thin overlay)
Reconstruction	Complete rebuild at year 32, lasting 20 years	Major rebuild at year 30, lasting 15 years

Estimated costs (Section 8.2.3) are given in Table 8.2 shown below. Note that these are always stated as *real*, or *year zero*, costs. (It is not necessary to account for future inflation when listing future costs because of the *real* 4% discount rate that will be used in the analysis). User costs were obtained using Figure 8.1, Work Zone User Delay Cost Estimates, assuming daytime work for an eight-mile, two lane rural highway, and an assumed number of project days appropriate to the type of work. For example, for Alternative #1, if the initial construction requires 150 days, the AADT is 4500, and the value from the graph is 90, the calculated work zone user delay cost is $972,000.

Table 8-2 Estimated Costs for Sample Project

	Alternative #1	Alternative #2
Agency costs		
Initial construction		
Engineering & contract administration	$1,300,000	$900,000
Construction	$7,500,000	$5,500,000
Traffic control	$200,000	$170,000
Rehabilitation (overlays)		
Engineering & contract administration	$500,000	$350,000
Construction	$3,100,000	$1,900,000
Traffic control	$140,000	$80,000
Reconstruction		
Engineering & contract administration	$1,500,000	$1,100,000
Construction	$9,200,000	$6,400,000
Traffic control	$200,000	$170,000
User costs		
Initial construction	$1,026,000	$1,373,800
Rehabilitation	$457,900 (Year 15) $549,500 (Year 25)	$419,800 (Year 15) $489,400 (Year 20) $475,200 (Year 25)
Reconstruction	$1,404,000 (Year 32)	$1,814,400 (Year 30)

The costs of routine preservation are assumed to be equal for both alternatives and are therefore not included in the analysis. If this is not the case, it would be necessary to include such preservation costs for the years when they are expected to occur. To find the salvage value for each alternative, using the pro-rated life method, we proceed as follows:

For Alternative #1, the $10,900,000 reconstruction cost at year 32 (shown in Table 8.3 and Figure 8.3) has a 20-

year life. Thus, at year 35, its value will be $\left(\dfrac{17}{20}\right) \times (\$10,900,000) = \$9,265,000$.

For Alternative #2, the $7,670,000 reconstruction cost at year 30 (shown in Table 8.3 and Figure 8.4) has a 15-year life. Thus, at year 35, its value will be $\left(\dfrac{10}{15}\right) \times (\$7,670,000) = \$5,113,333$, say, $\$5,113,000$.

From the above activity timing and cost estimates, we can develop the following cash flow table and the <u>cash flow diagrams</u> (Section 8.2.4) shown in Figures 8.3 and 8.4

Table 8-3 Cash Flow Table for Sample Project

Year	Alt #1 Agency Cost	Alt #1 User Cost	Alt #2 Agency Cost	Alt #2 User Cost
0	$9,000,000	$1,030,300	$7,570,000	$1,373,800
15	$3,740,000	$457,900	$2,330,000	$419,800
20			$2,330,000	$461,700
25	$3,740,000	$549500	$2,330,000	$503,700
30			$7,670,000	$1,923,300
32	$10,900,000	$1,488,200		
35	-$9,265,000		-$5,113,000	
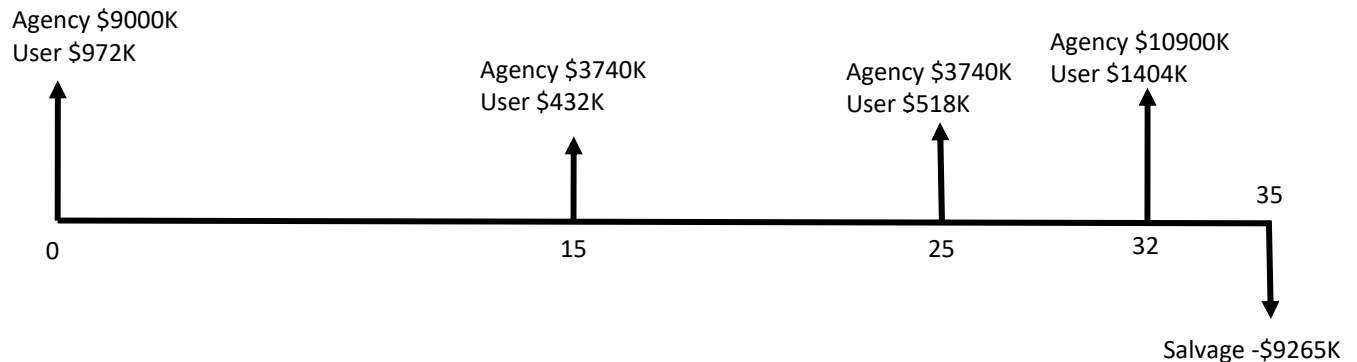
Figure 8-3 Cash Flow Diagram for Alternative #1

Agency $7570K
User $1296K

Agency $2330K
User $396K

Agency $2330K
User $436K

Agency $2330K
User $475K

Agency $7670K
User $1814K

35

15   20   25   30

Salvage = -$5113K
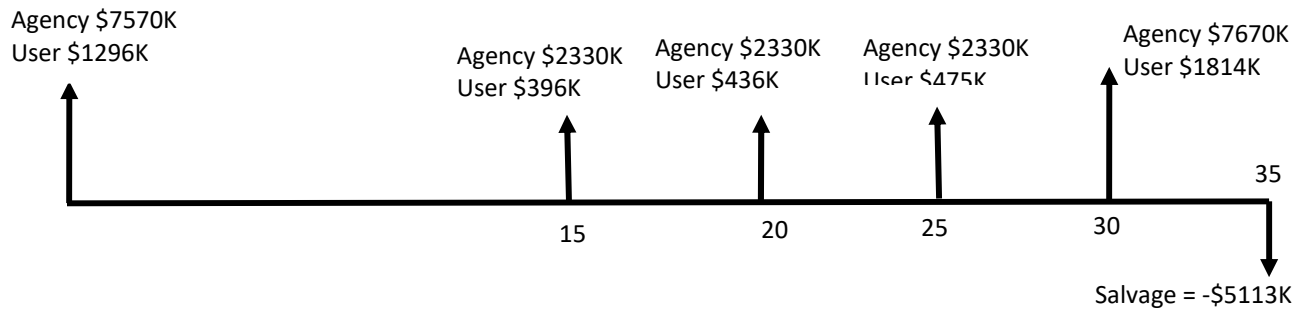
Figure 8-4 Cash Flow Diagram for Alternative #2

Computation of net present value for each alternative (Section 8.2.5) is based on the cash flow diagrams and a discount rate of 4%. We have separated the agency and user costs. The following spreadsheet shows the results of the analysis, which uses a simple $(1+i)^{-n}$ formula to calculate present value for each cash flow.

Table 8-4 Spreadsheet Output from Sample Hypothetical Analysis

Sample Hypothetical Life Cycle Cost Analysis						Discount Rate = 4%		
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
Year	Alt #1 Agency Cost	PV Alt #1 Agency Cost	Alt #1 User Cost	PV Alt #1 User Cost	Alt #2 Agency Cost	PV Alt #2 Agency Cost	Alt #2 User Cost	PV Alt #2 User Cost
0	$9,000,000	$9,000,000	$1,030,300	$1,030,300	$7,570,000	$7,570,000	$1,373,800	$1,373,800
15	$3,740,000	$2,076,689	$457,900	$254,256	$2,330,000	$1,293,766	$419,800	$233,100
20					$2,330,000	$1,063,382	$461,700	$210,714
25	$3,740,000	$1,402,937	$549,500	$206,164	$2,330,000	$874,022	$503,700	$188,946
30					$7,670,000	$2,364,804	$1,923,300	$592,989
32	$10,900,000	$3,107,132	$1,488,200	$424,223				
35	-9,265,000	-2,347,894			-5,113,000	-1,295,713		
Column Sums		$13,238,864		$1,914,943		$11,870,261		$2,599,549
Sum, NPV Agency & User Costs				$15,153,807				$14,469,810

For this hypothetical example, Alternative #2 appears to be preferred. If only agency costs are considered (NPV of $13,238,863 v. $11,870,261), #2 is clearly the more economical with an NPV about $1.5 million less than that of #1. If user costs are included, the preference is still for #2, but by considerably less (an NPV difference of about $720,000). If user costs are considered particularly important, the agency might decide on Alternative #1.

A graphical presentation might be helpful as a visual means of seeing the results. Figure 8.5 summarizes the results of the basic analysis.
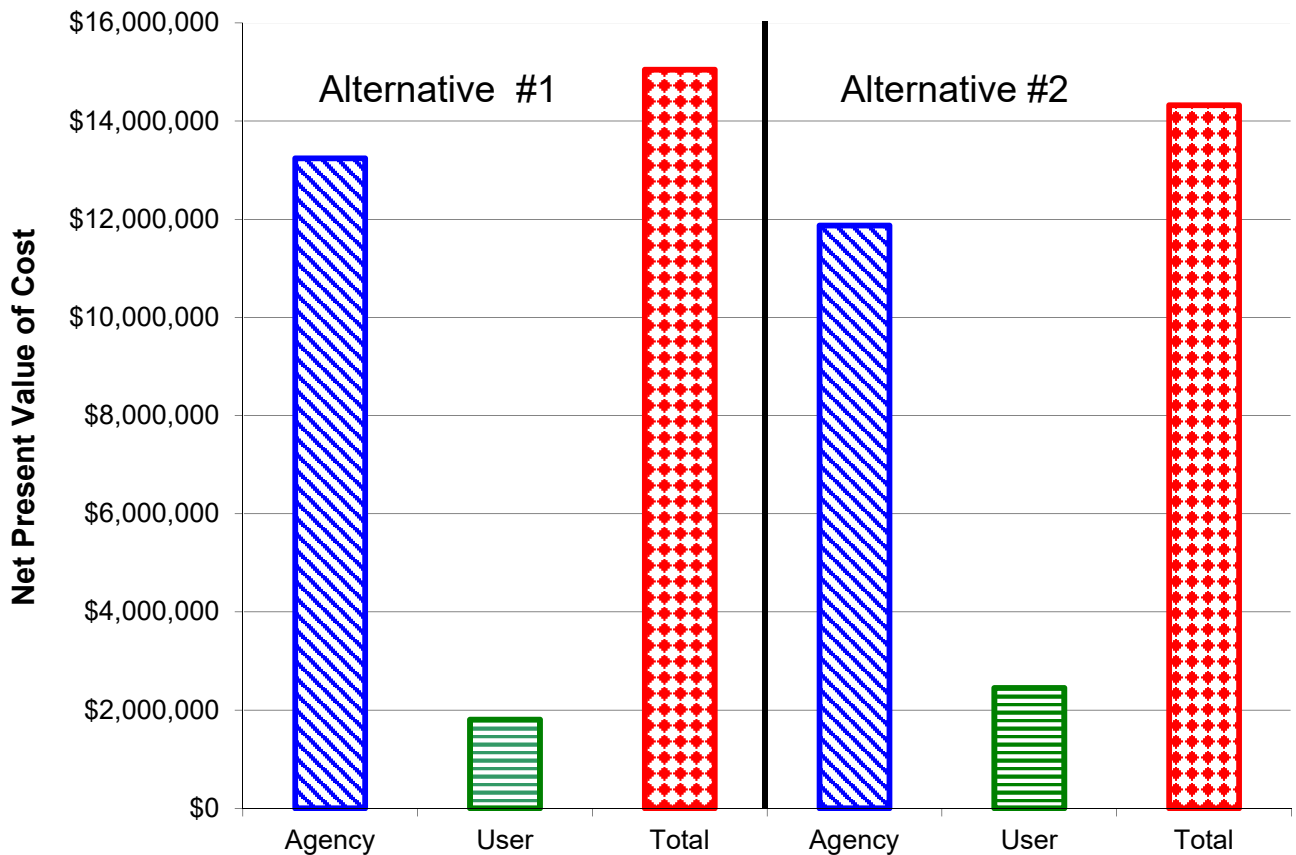
Figure 8-5 Graphical Comparison of NPV of Alternatives #1 and #2

A <u>sensitivity analysis</u> (Section 8.2.6) considers one of the input parameters, the year zero agency costs. One approach to studying the sensitivity of the year zero agency costs is to vary each by, say, 10% and determine whether the recommendation would change. There are many possible combinations:

- increasing both by 10%;

- increasing Alternative #1 by 10% and keeping Alternative #2 at its original value (as for example, if Alternative #1 is a relatively untried design whose construction costs are not well understood);

- decreasing one by 10% and increasing the other by 10%; and so forth.

Once the spreadsheet contains the original cost values, it is relatively easy to vary the values and identify their effects. Caution is advised that the number of combinations analyzed be kept to a manageable number representing likely actual costs.

- For our example, Table 8.5, we show four variations in the year zero agency costs:
- increase both alternatives by 10%; decrease both alternatives by 10%;
- decrease Alternative #1 by 10% while increasing Alternative #2 by 10%;
- increase Alternative #1 by 10% while decreasing Alternative #2 by 10%.

Using the 4% discount rate, the results are as follows:

Table 8-5 Results of Sensitivity Analysis for Sample Project

	Both Alternatives +10%	Both Alternatives -10%	Alt#1 -10%; Alt #2 +10%	Alt#1 +10%; Alt#2 -10%
NPV Alt#1 Agency Costs	$14,562,750	$11,914,977	$11,914,977	$14,562,750
NPV Alt #1 User Costs	$2,106,396	$1,723,415	$1,723,415	$2,106,396
Sum NPV Alt #1 Costs	**$16,669,146**	**$13,638,392**	**$13,638,392**	**$16,669,146**
NPV Alt#2 Agency Costs	$13,057,287	$10,683,235	$13,057,287	$10,683,235
NPV Alt #2 User Costs	$2,2,859,504	$2, 2,339,595	$2,662.826	$2,339,595
Sum NPV Alt #2 Costs	**$15,916,791**	**$13,022,829**	**$15,720,113**	**$13,022,829**

Focusing only on the sum of agency and user costs, the results show that Alternative #2 is favored for three of the four cases under study. Alternative #1 is favored only if the first cost of Alternative #1 decreases by 10% while that of Alternative #2 increases by the same percentage.

The final step is to analyze the results and consider reevaluating the proposed strategies (Section 8.2.7). We have analyzed the results to some extent already. We found that the basic analysis favored Alternative #2 if both agency and user costs are considered. The difference in NPV was $722,802, or about 5.0% of Alternative #2's NPV. Considering only agency costs, Alternative #2 had a NPV of $1,368,602, or 11.5%, less than that for Alternative #1. User costs were higher for Alternative #2 by $645,800, or about 35.7%, compared with those for Alternative #1. Under one scenario considered in the sensitivity analysis, Alternative #1 was favored, and it always had lower user costs. If road user costs are considered especially important for this project, a re-evaluation might study the impact of seeking proposals to perform construction at night in order to reduce road user costs.

8.4   LCCA Using AKFPD

The AKFPD Life Cycle Costing Analysis module computes the present value of a series of costs related to pavement construction, reconstruction, rehabilitation, preservation, and maintenance using the techniques described in this chapter. The LCCA module is a stand-alone module in that it does not ingest data from previous pavement structure analysis. While the module uses a database to store the anticipated life and costs of pavement related costs, it is expected that the user verifies and update these data as appropriate. It is also expected that the user develops realistic strategies for the life cycle of the pavement.

For example, if the remaining pavement life after the design period is less than the 20%, an overlay should not be employed. Consequently, it makes no sense to use an overlay as a strategy.

While developing the life cycle cost for a single strategy is useful, the power of LCCA is in the comparison of multiple strategies. For example, one might ask if investing additional funds now to increase the pavement life from 15 years to 20 years is cost effective. Is it better to overlay the pavement after 10 years or 15 years? Should a preservation strategy be applied and when? The LCCA module automates much of this process, but the user must still develop a series of actions to answer these and other questions.

Once potential strategies are on the table, the Mechanistic Design Module should be used to determine whether these strategies are feasible. If the designer randomly selects activities without ensuring they are likely to perform, LCCA is almost certainly misleading.

The order of the analysis is a personal preference. One could select strategies, perform the LCCA analysis and then run the mechanistic analysis to ensure the strategy meets the design criteria.

The other option is to define the strategy, perform the mechanistic analysis and then perform the LCCA.

For the example presented here, assume that each strategy has been tested to ensure they are feasible.

Step 1. Develop multiple pavement structures using the Excess Fines Method or the Mechanistic Design Method. These pavement structures include those which will be used in scenarios included in the LCCA. Recognize that the initial pavement designs will often dictate the options available in the LCCA. For example, if a minimal pavement design is selected such that less than 20% of the fatigue life is available at the time an overlay is selected, an overlay is not an option. In this case full depth reclamation or similar activity may be appropriate.

The LCCA module is a stand-alone module and can be used separately or attached to a pavement design. Consequently, there are multiple options for entering the LCCA module.

Option a: Open as a New LCCA Project

 Step 2a. Open AKFPD and click on ***Start a New Project***. (Clip 8-1) Entering the LCCA in this way creates a separate file with no pavement design attached.
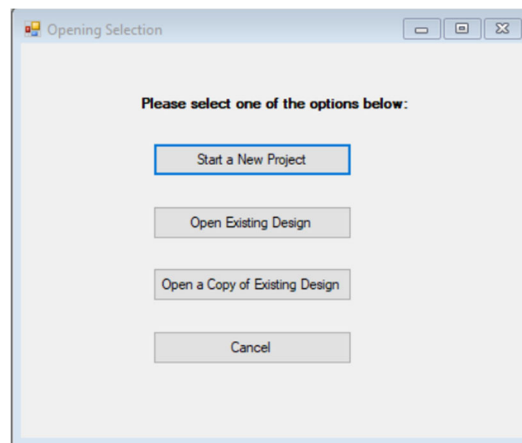
Screen Clip 8-1

Step 3a. Input Project Information and Click on ***LCCA***. (Clip 8-2)
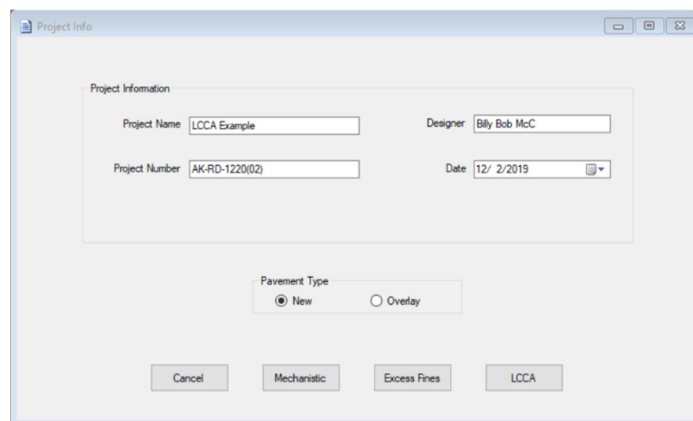
Screen Clip 8-2

Step 4a. Save File. Change name if appropriate. (Clip 8-3)
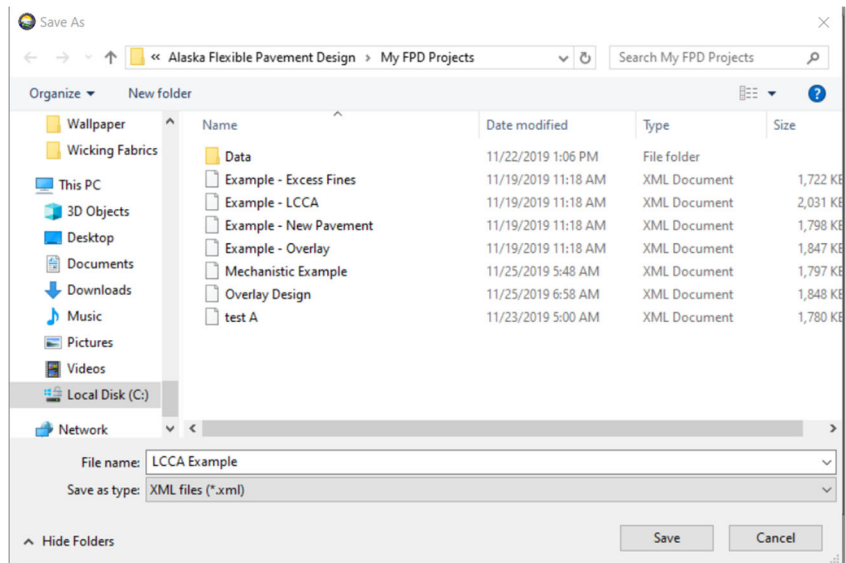
Screen Clip 8-3

Go To Step 5. Attach LCCA analysis to an existing project

Option b: Open LCCA module while attaching to an existing project.

Step 2b: Open AKFPD and click on *Open Existing Project*. (Clip 8-1) *Open Copy of Existing Project* may be used to preserve an unaltered copy of the original project. (Screen Clip 8-1)

Step 3b. Select the desired file. Modify the name to create a new file and click *Open.* (Screen Clip 8-4)
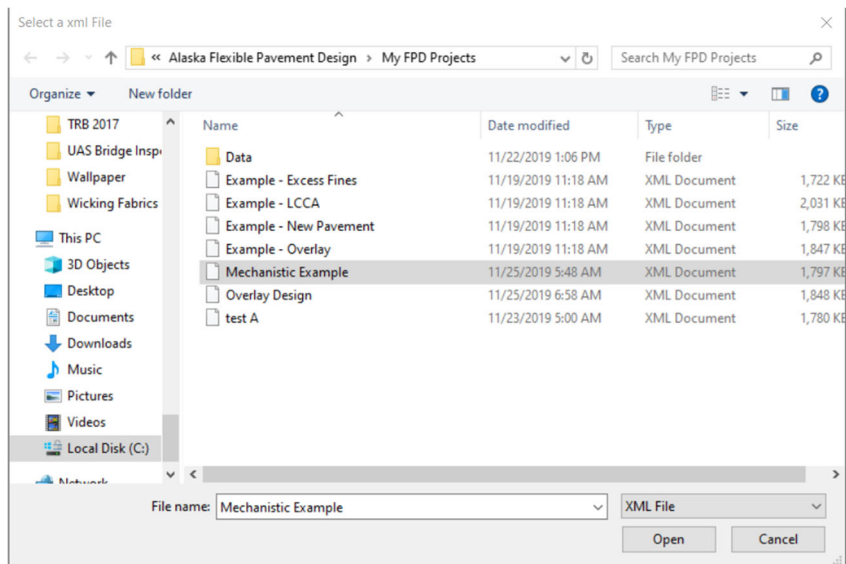
Screen Clip 8-4

Step 4b. If an existing project was used, the project information will be shown. (Clip 8-5)
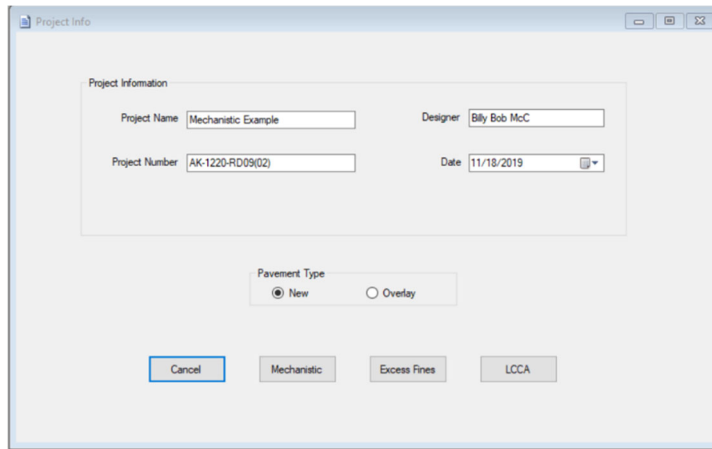
Screen Clip 8-5

Step 5 From this point forward the process will be the same for both approaches. In this case a new project will be used for the example. Complete the project information. The analysis period must be 35 years and the discount rate must be 3%. These values may be changed by directive from the Chief Engineer. Be sure to check the Project Setting (Urban or Rural) and the Work Period. These will impact the user delay costs. The screen should look like Clip 8-6.
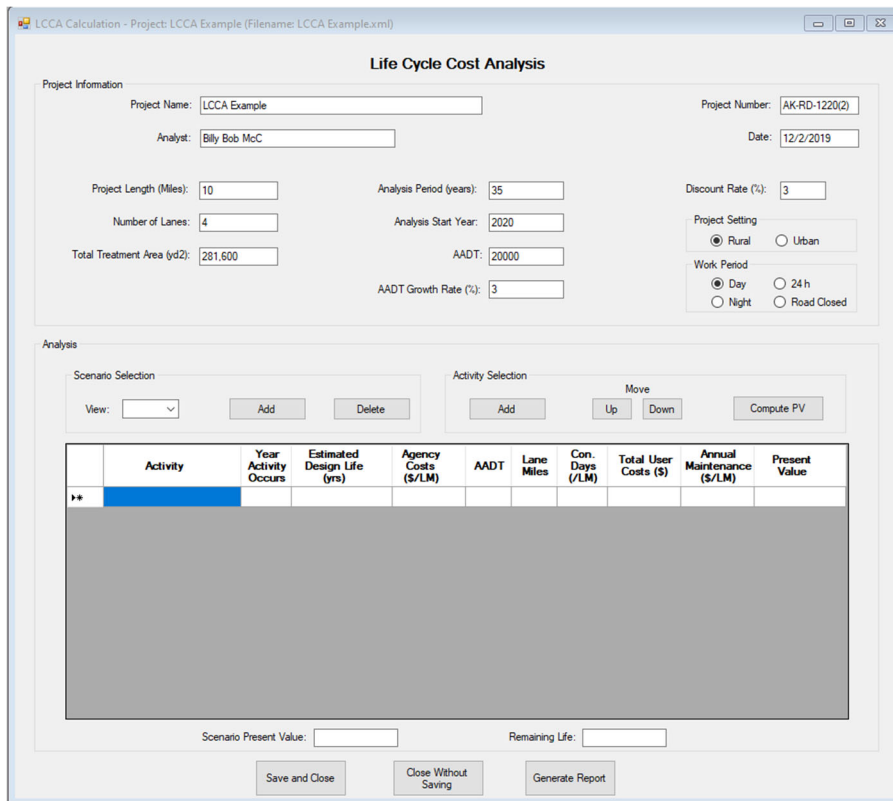
Screen Clip 8-6

Step 6. The first of multiple Scenarios will be developed at this point. Under *Scenario Selection* Box, click on **Add** to create a scenario. You may also remove a scenario by clicking on **Delete**. Once you click on **Add** in the *Scenario Selection* Box, the software will allow activities to be added to the scenario. (Clip 8-6)
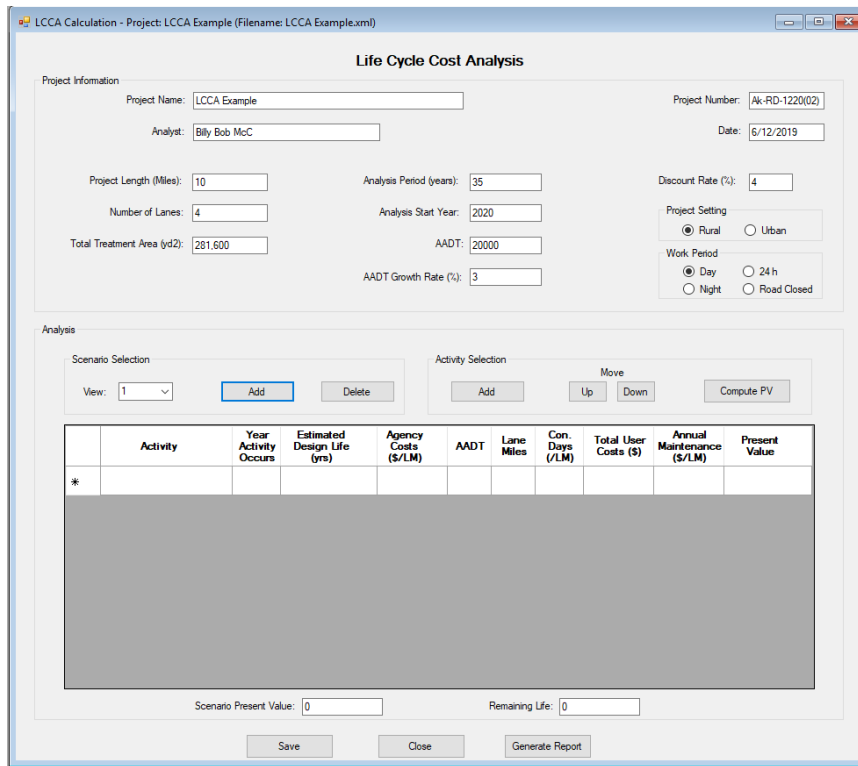
Screen Clip 8-7

Step 7. Enter each activity by clicking on *Add* in the *Activity Selection* Box. A menu of existing alternatives will appear. (Clip 8-8)
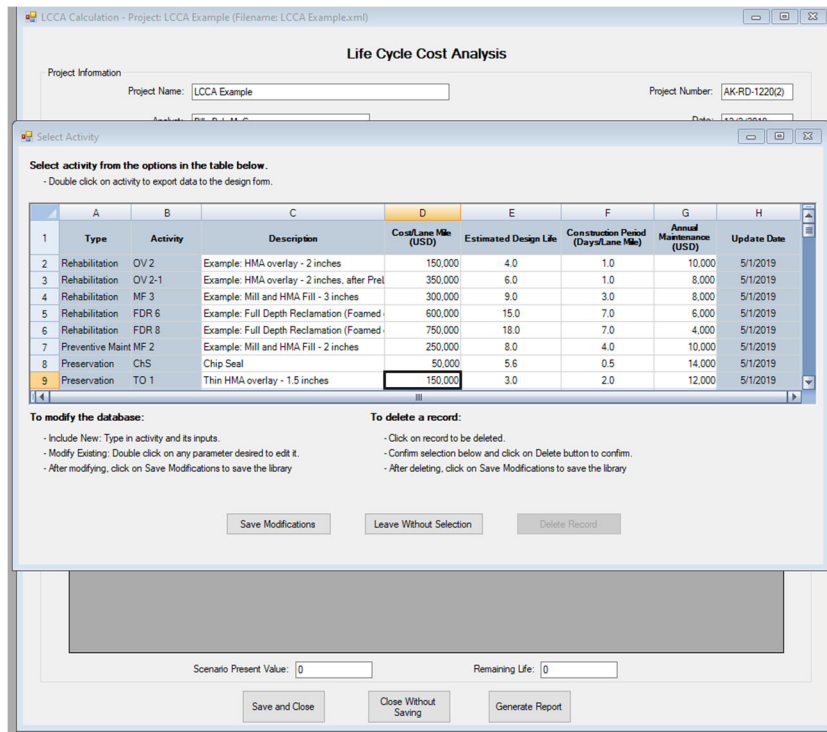
Screen Clip 8-8

Step 8. For purposes of this example, the design calls for reconstruction of the pavement structure with a life of

15 years at a cost of $1,500,000/lane mile. This does not exist in the database, so it must be added. Add a new activity to the database by clicking on the first empty line and enter the data as shown in Clip 8-9. Once the data has been entered, click on **Save Modifications**.

Step 9 Double click on the activity, in this case "Reconstruction."
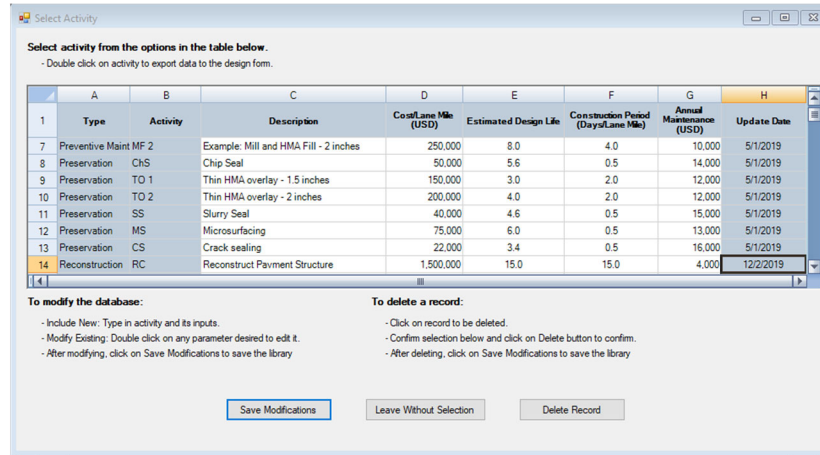
Screen Clip 8-9

The user will be returned to the Life Cycle Cost analysis screen. The Reconstruction activity data has been entered as shown in Clip 8-10.
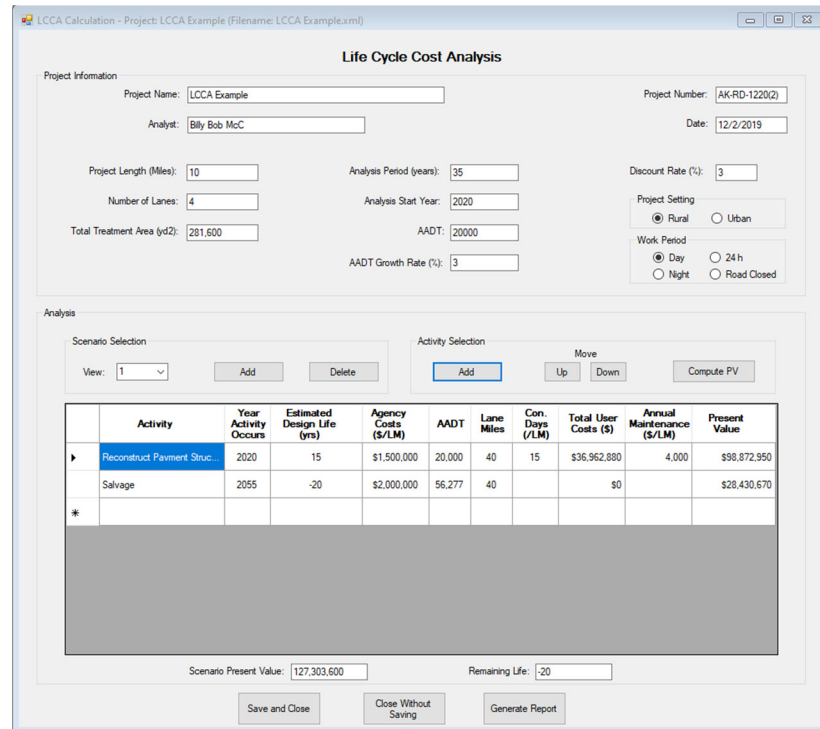
Screen Clip 8-10

Step 10. Repeat Step 7 until the remaining life shown below the table becomes positive (alternatively the estimated design life of the Salvage activity becomes positive), i.e., the sum of the estimated design lives equals or exceeds 35 years. The order of the activities can be altered by highlighting the activity you wish to move and using the buttons labeled "Up" and "Down" to move the activity to the appropriate point. An activity can be deleted by highlighting the activity and hitting the delete key on the keyboard. The completed scenario should look like Clip 8-11.

Screen Clip 8-11

Step 11. Create Scenario 2 by Clicking *Add* in the *Scenario Selection* box.

Screen Clip 8-12

Step 12. Click *Add* under the Activity Selection box. Add Reconstruct Pavement Structure 20-year life as in Step 8. In this example this will be Reconstruct pavement structure with a 20-year life at a cost of $1,700,000/lane-mile and a construction time of 17 days/lane-mile. (Screen Clip 8-13). Click *Save Modifications*.

Screen Clip 8-13

Step 14. Double click on the new activity to add the 20-year reconstruction design to the Scenario 2. Add additional activities to Scenario 2 until the sum of the estimated design lives equals or exceeds 35 years. Scenario 2 should look like Screen Clip 8-13.

Screen Clip 8-14

Step 14. Create Scenario 2 by repeating steps 6-10. The screen for Scenario 2 should look something like Screen Clip 8-15.

Screen Clip 8-15

Step 15. Add as many scenarios as appropriate. Once all scenarios have been added click *Generate Report.* A report will be generated and displayed. See Screen Clip 16.

Alaska DOT&PF Flexible Pavement Design Software, Version 2.0 - Project: LCCA Example (Filename: LCCA Example.xml) - [Workbook: LCCA Example]

File Clipboard Modules View Help

Project Name: LCCA Example		Project Number: AK-RD-1220(2)		Analysis Date: 12/2/2019		AADT:	20000
Design Type: New Design		Project Length: 10 Miles		Discount Rate: 3 %		AADT Annual Growth:	3 %
Designer: Billy Bob McC		No. Lanes: 4		Project Setting: Rural/Day		Analysis Period:	35
						Start Year:	2020

SUMMARY

Scenario	Total Net Present Value (USD)	Rank	Remaining Life (yrs)
2	128,809,744	1	3
1	142,557,936	2	1

DETAILED CALCULATIONS

Scenario	Description of Activity	Year Activity Occurs	Estimated Design Life (yrs)	Agency ($)	AADT	Lane Miles	Days (/LM)	Estimated User Cost ($)	Annual Maintenance ($/LM)	Present Value ($)
1	Reconstruct Pavment Structure	2020	15	60,000,000	20,000	40	15	36,962,880	4,000	98,872,950
	Example: HMA overlay - 2 inches, after PreLevel	2035	6	14,000,000	31,159	40	1	3,839,131	8,000	12,562,930
	Example: Full Depth Reclamation (Foamed or emuls	2041	15	24,000,000	37,206	40	7	32,088,860	6,000	31,690,660
	Salvage	2055	1	-1,600,000	56,277					-568,613
2	Reconstruct Pavement Structure 20 yr	2020	20	68,000,000	20,000	40	17	41,891,270	4,000	112,271,700
	Chip Seal	2040	6	2,000,000	36,122	40	1	2,225,303	14,000	4,019,094
	Example: HMA overlay - 2 inches, after PreLevel	2046	6	14,000,000	43,132	40	1	5,314,256	8,000	9,759,734
	Chip Seal	2052	6	2,000,000	51,502	40	1	3,172,750	14,000	3,114,635
	Salvage	2055	3	-1,000,000	56,277					-355,383

Screen, Clip 8-16

The summary box shows the scenarios ranked from lowest total net present value (NPV) to the highest. In this case the lowest NPV is for Scenario 2. Adding an additional five years to the life of the pavement shown in Scenario 2 requires about ½ inch of additional pavement. However, the impact to the public is delayed by five years and eliminates the final overlay.

Detailed computations are provided so that the user can evaluate the results in detail.

The report can be printed by clicking **File** then **Print**,

8.5   Word of Caution

The validity of Life Cycle Costing is dependent on the quality of input to the analysis. While LCCA module of AKFPD simplifies the computation of life cycle costing, the development of cost data requires considerable effort. There is no escaping the need for good cost data. While the software does not directly aid in the development of high-quality cost data, the embedded data base does provide the ability to record the data which can then be applied to similar projects. In doing so, the designer is afforded the ability to reuse prior work.

The designer must recognize that the initial design will have considerable impact on the future maintenance, preservation, and rehabilitation strategies. For example, a minimal pavement structure may force reconstruction after 15 years, while a heavier pavement structure may allow an overlay after a similar period. Consequently, the designer is encouraged to explore these options to identify the best life cycle cost.

User costs often dominate the LCCA. Over the years, the debate as to whether user costs should or should not be part of the LCCA continues. Some argue that the Departments of Transportation are responsible for the development and maintenance of the State's transportation system and the cost to the user should not be included in the decision process. Others argue that the DOTs are responsible for providing a transportation system for the benefit of the public including the impact to the public for maintenance and construction activities. The Federal Highway Administration supports the latter philosophy and requires that user costs be included in any LCCA for the nation's highway network. As such the designer will be well advised to develop strategies that minimize the impact of construction and maintenance of highways on the public.

A closer look at the example above illustrates this principle. Scenario 1 uses a 15-year life for the initial construction while Scenario 2 uses a 20-year life. In this example, the LCCA is dominated by user costs. Scenario two clearly has a lower impact on the public and consequently has the lower LCCA.

It is unrealistic to assume the scenarios used in the LCCA will be followed exactly. As time passes, technology, funding, and design philosophies change. Perhaps the greatest value of LCCA is to develop an initial design that allows future designs the flexibility to reduce costs. For example, an overlay is likely less expensive than reconstruction, but can only be an option if the initial design allows for the overlay.