Least Cost (Life Cycle) Analysis Microcomputer Program

JOHN M. KURDZIEL

This paper covers the contents and operation of the American Concrete Pipe Association's Least Cost (Life Cycle) Analysis microcomputer program. The program evaluates the costs associated with each alternate pipe material based on their design components and project requirements. The program has a multipl~ screen format similar to spreadsheet software and will operate on any IBM compatible system with MS-DOS operating system of version 2.0 or greater. The Least Cost Analysis program's versatility and ease of use will decrease the time and costs for conducting economic analysis and promote more cost-effective project designs.

Least cost (life cycle) analysis is the selection of a product, or material, based not on its initial cost, but on its total cost over the life of the project. Many articles and papers have been written on this subject, but only a few have provided tools for easily comparing complex alternates. The American Concrete Pipe Association's Least Cost Analysis (LCA) microcomputer program performs multiple economic analyses that enable evaluation of different pipe materials bid as alternates for a project to be carried out.

The program incorporates into the analysis the project design life, material service life, economic factors, and other project-related items such as traffic costs. Total costs are calculated using present worth (PW), annualized costs, or future value methods. Ample help screens are provided throughout the program to assist users in creating the data base. Hard copy documentation of all or part of the analysis may be obtained on execution of the program.

Presented in this paper are the program's functions and capabilities and a discussion of each screen from a design as well as an operational standpoint.

PROGRAM OPERATION

The LCA program has a multiple screen format similar to commercially developed spreadsheet software. It is written in *C* language and targeted for the IBM-XT or compatible microcomputer systems with a minimum of 256 K random access memory using the MS-DOS operating system of version 2.0 or greater.

All input and analysis sections are in front of users at all times. Subscreens assist users in creating and modifying the data set. Help screens are provided for every decision making step. Although default values are provided, the actual input values must be selected by users. The default values are only recommended values and are not automatically defaulted by the program. Copy commands are provided where appropriate to minimize repetitive entering.

Most operations within the subscreens may be selected using the scroll and enter keys. The function keys provide the means for moving from one subscreen to another, calling up help screens, or using the copy commands. This dual operation allows users access to file commands while still maintaining their place in the specific input screen.

The main screen is divided into seven major sections (Figure 1). The main menu provides seven alternatives. These include Project, Design, Economic, Material, Analysis, Files, and Quit. As users scroll through these alternatives, the short help screen, which is located just below the main menu, will change, reflecting descriptive information pertinent to the particular main menu alternative. Once a specific alternative is chosen, users will either enter one of the subscreens or a submenu for further selection. Once in a subscreen or submenu, the short help screen will reflect the descriptive information pertinent to the new screen.

Large help screens are available in these subsections (Figure 2). The help screens provide detailed technical information on the specific item highlighted at the time help is requested. The help information replaces the entire existing menu and screen. Text displayed in this way allows maximum use of screen space and enhances reading without displaying any distracting material. Many of the help screens are over a page in length, but easy review can be accomplished by scrolling up or down through the material. Once users have completed their review of the help screen, the same function key is used to return to the work screen.

After the data for a particular section have been entered, users return to the main menu to enter or modify any additional data, execute the program, request printed output, or manipulate the files.

Program execution is accomplished in the same way as is data input. The only difference is that once the type of analysis has been selected, users must request the execution of the program by entering return when "analyze" is highlighted. This provides users with the option of preselecting the type of analysis without executing the program. Once the program is executed, a comparison of the alternate products analyzed is displayed on the large screen. Total program running time is less than 5 sec.

Hardcopy printouts of either the final design summary or the comparison summary, with comprehensive documentation of all the input and analysis, may be obtained. Documentation printouts are requested under a submenu of the "file" alternative.

American Concrete Pipe Association, 8320 Old Courthouse Road, Vienna, Va. 22180.

MAIN MENU	
SHORT HELP	
MATERIAL SUMMARIES	PROJECT DESIGN
• PROJECT DESCRIPTION • MATERIAL COMPONENTS • HELP SCREENS	ECONOMIC FACTORS TYPE OF ANALYSIS

FIGURE 1 Main screen format.

PROJECT DESCRIPTION

The project description window provides the means for identifying the data base. The information in the project description also appears in the heading of the hard-copy documentation of the project design. Project description includes the project title, project location, designer's name, and the date of the design (Figure 3). Thirty-five spaces are provided for each of the first three headings with eight additional spaces for the date.

PROJECT DESIGN

The program provides the project design alternatives of storm sewer, sanitary sewer, and culverts, which are further classified as Interstate, state primary, state secondary, or local/rural projects.

Once the type of facility is selected, users are requested to enter its design service life. Guidance is provided in both the short help screen and long help screens for selecting this value but the final decision is left to the designer, who must manually enter the number of years. By not hardwiring the input, users maintain complete control over their design and this reduces the risk of the acceptance of erroneous information.

The project design service life is the length of time a specific roadway facility is expected to be in service. Figure 4 is an example of a culvert Interstate project with a 100-year project design life. The service life is normally set by the owner or authority responsible for the project. In cases in which a roadway or facility cannot be disrupted for replacement of the pipe, a project design life of 100 years or greater should be considered. This is typical of heavily traveled urban roadways, Interstate highways, stormwater systems, or sanitary sewers. Special consideration should also be given to installations under high fills or in remote areas with poor access. The selection of an appropriate project design life should reflect the transportation and commercial importance of the roadway, its effect on traffic, and the difficulty of replacement with inherent construction hazards to the traveling public.

As guidelines, ranges for the project design lives of the various types of facilities are provided in the program. Minimum design lives are provided as recommended values in the program's short help screens (Table 1).

ECONOMIC FACTORS

Least cost (life cycle) analysis provides the best means for considering and comparing alternate materials with different service lives. The problem with any economic analysis has always been forecasting interest and inflation rates. Short-term rates vary on a daily basis and are impossible to predict. For long-term rates, however, this problem can be avoided by using the relatively constant long-term ratio between interest and inflation rates.

The differential recommended is that between the producer price index (PPI) and the cost of funds for the borrower in question. The PPI represents the producer prices for materials such as steel mill and concrete products. The historical differential between the PPI and the municipal bonds, prime rate, and treasury bonds is appropriate to use when funding is provided by state and local governments, private firms, and

```
F3-MATERIAL WINDOW
SCROLL THROUGH HELP WITH CURSOR KEYS
                                                    Project Design

MATERIAL SERVICE LIVES

FORWARD:  Different pipe materials have different service lives, which
          depend on the material and the environmental and functional
          conditions of the installation.  The durability of pipe
          materials has been researched by government agencies, states
          and others and numerous reports published.  The service life
          of a pipe material is either specified as a certain number of
          years, or determined as a function of various environmental
          and functional factors.  The recommended values listed in the
          short help screens are based on the durability reports and
          state practices.  Individuals interested in specific informa-
          tion pertaining to a site should consult the appropriate
          reference.  These reports are listed in chronological order by
          State, government and miscellaneous categories.

BIBLIOGRAPHY - STATE CULVERT SURVEYS AND REPORTS

ALABAMA
```

FIGURE 2 Section of a large help screen from material service life window.

```
PROJECT   DESIGN   ECONOMIC   MATERIAL   ANALYSIS   FILES   QUIT
EDIT PROJECT DESCRIPTION WINDOW
                                                              Project Design
      Concrete Pipe Service Life Components                      Storm Sewer
Replace/Install    Maintenance    Rehabilitation    Total        Sanitary Sewer
Life   Costs       Costs          Life   Costs      Years        Interstate
____   ________    _________      ____   ________   ____         State Primary
____   ________    _________      ____   ________   ____         State Secondary
____   ________    _________      ____   ________   ____         Local/Rural
____   ________    _________      ____   ________   ____       Design Life   ____

                                                              Economic Factors
 Project Description                                             Nominal Discount
                                                              _  Real Discount
   Project Title      LCA_Test_Data_File_________________        Federal Funding
                                                                 State Funding
   Project location   American_Concrete_Pipe_Association_        Private Funding
                                                               Interest Rate   _____
   Analyzed by        John_M._Kurdziel___________________

   Date               07/08/87                                Type Of Analysis
                                                                 Present Worth
                                                                 Annualized
                                                                 Future Value
                                                               Analyze ?  YES
```

FIGURE 3 Project description window.

GIVEN: Culvert, interstate project with a 100 year project design life.

```
PROJECT   DESIGN   ECONOMIC   MATERIAL   ANALYSIS   FILES   QUIT
EDIT PROJECT DESIGN LIFE WINDOW
                                                              Project Design
      Concrete Pipe Service Life Components                      Storm Sewer
Replace/Install    Maintenance    Rehabilitation    Total        Sanitary Sewer
Life   Costs       Costs          Life   Costs      Years      ▸ Interstate
____   ________    _________      ____   ________   ____         State Primary
____   ________    _________      ____   ________   ____         State Secondary
____   ________    _________      ____   ________   ____         Local/Rural
____   ________    _________      ____   ________   ____       Design Life   _100

                                                              Economic Factors
 Project Description                                             Nominal Discount
                                                              _  Real Discount
   Project Title      LCA_Test_Data_File_________________        Federal Funding
                                                                 State Funding
   Project location   American_Concrete_Pipe_Association_        Private Funding
                                                               Interest Rate   ___
   Analyzed by        John_M._Kurdziel___________________

   Date               07/08/87                                Type Of Analysis
                                                                 Present Worth
                                                                 Annualized
                                                                 Future Value
                                                               Analyze ?  YES
```

FIGURE 4 Project design window.

federal agencies, respectively (Table 2). Although the economic factor section is based on these assumptions, as with other parts of the program, users completely control the input.

The economic factor section is broken into three steps. The designers first choose whether to use the nominal or real discount rate for the analysis. The nominal discount rate uses current dollars and directly includes an inflation value in its analysis. The real discount rate uses constant dollars and, although it takes inflation into account, a value for inflation does not directly enter into the calculations. For example, if the interest rate was 6 percent and inflation was 4 percent, the nominal discount rate would use the specific values for the interest and inflation rates, whereas the real discount rate would be the differential between the two rates or 2 percent. Choosing one method over another does not affect the final analysis because both yield essentially the same results.

TABLE 1 DESIGN LIFE GUIDELINES

Project	Design Life
Storm sewer system	100 years or greater
Sanitary sewer system	100 years or greater
Interstate culverts	75 to 100 years
Urban culverts	75 to 100 years
State primary culverts	50 to 75 years
State secondary culverts	50 to 75 years
Local/rural culverts	50 years or greater

TABLE 2 HISTORICAL INTEREST-INFLATION RELATIONSHIP

Time Period	Municipal Bonds (%)	Prime Rate (%)	Treasury Bonds (%)
1954–1963	2.08	3.29	2.74
1964–1973	0.81	2.48	1.69
1974–1983	−1.32	2.81	0.55
Average Inflation-interest differential (1954–1983)	0.52	2.86	1.66

NOTE: Differentials represent differences between stated interest rates and the Producer Price Index for the year. All figures are based on annual averages.

EXAMPLE

Given: Interest (i) = 6 percent
Inflation (I) = 4 percent

Nominal Discount Rate

$$\frac{\text{Inflation}}{\text{Interest factor}} = \frac{1 + I}{1 + i}$$

Where $i = 0.06$
$I = 0.04$

$$I/i = \frac{1 + 0.04}{1 + 0.06} = 0.9811$$

Real Discount Rate

$$\frac{\text{Inflation}}{\text{Interest factor}} = \frac{1 + I}{1 + i}$$

Where $i = 0.02$
$I = 0$

$$I/i = \frac{1 + 0}{1 + 0.02} = 0.9804$$

There is less than 0.1 percent difference between the two methods.

The second step is to select the type of funding the borrower will use to finance the project. Generally funding can be classified into one of the three categories: federal, state, or private. If multiple types of funding are used on the project, the institution providing the majority of funding will normally control the analysis. The purpose for providing the type of funding is to assist users in selecting the discount rates associated with their specific type of project (i.e., a municipal project is less costly to finance than a privately funded one).

In the final step, the program provides recommended interest and inflation rates based on the type of discount method and funding selected by the designers. These values are provided as guidance; users must select and input all values to be used in the analysis. The example in Figure 5 shows a project design using a nominal discount rate with federal fund-

```
GIVEN:      Project design using a nominal discount rate with
            federal funding.  Interest is equal to 5% with a 3.5%
            inflation rate.

PROJECT   DESIGN   ECONOMIC   MATERIAL   ANALYSIS   FILES   QUIT
EDIT ECONOMIC FACTORS WINDOW
                                                          Project Design
      Concrete Pipe Service Life Components                  Storm Sewer
Replace/Install    Maintenance   Rehabilitation   Total      Sanitary Sewer
Life  Costs        Costs         Life  Costs      Years    ► Interstate
----  ----------   ----------    ----  ---------- ----       State Primary
----  ----------   ----------    ----  ---------- ----       State Secondary
----  ----------   ----------    ----  ---------- ----       Local/Rural
----  ----------   ----------    ----  ---------- ----     Design Life  _100

                                                          Economic Factors
 Project Description                                      ► Nominal Discount
                                                          _  Real Discount
   Project Title     LCA_Test_Data_File______________     ► Federal Funding
                                                             State Funding
   Project location  American_Concrete_Pipe_Association_     Private Funding
                                                           Interest Rate  _5.00
   Analyzed by       John_M._Kurdziel_________________     Inflation Rate _3.50

   Date              07/08/87                             Type Of Analysis
                                                             Present Worth
                                                             Annualized
                                                             Future Value
                                                           Analyze ?  YES
```

FIGURE 5 Economical factors window.

ing. Interest is equal to 5 percent with a 3.5 percent inflation rate.

MATERIAL SERVICE LIFE

Different pipe materials have different service lives, which depend on the material and the environmental and functional conditions of the installation. The durability of pipe materials has been researched by government agencies, states, and others, and numerous reports have been published. The service life of a pipe material is either specified as a certain number of years or determined as a function of various environmental and operational factors.

The LCA program allows for the analysis of three different product materials simultaneously. Assistance in the form of recommended service lives is provided for concrete and corrugated steel pipes in the short help screens. These values are supplemented with a large help screen, which contains a bibliography of pipe durability studies by various state and governmental agencies. Individuals interested in specific information pertaining to a site should consult the appropriate reference. These reports are listed in chronological order by state, government, and miscellaneous categories. The third alternative, other materials, is used to analyze any other product.

For each material, service life components are listed to assist in calculating the cost and number of rehabilitation and replacement actions necessary for the structure to reach the desired project design life. The service life components are divided into initial installation, maintenance, rehabilitation, and replacement.

Initial installation requires the input of a material service life and the cost of installing the facility. Because a pipe installation normally represents only one part of a project, this cost is usually the project bid price. In the example shown in Figure 6, concrete pipe installation has a bid price of \$500,000 and a material service life of 100 years. Any alternative materials will have similar engineering, mobilization, and traffic control costs, and analysis using the bid prices will yield comparative results. If the material service life at this time, or if subsequent input, equals or exceeds the project design life, the program will inform users that the design life has been met and will not accept any further input for the installation. As with other parts of the program, this restriction can be overridden.

Maintenance is any action taken periodically to ensure that the facility functions as originally intended. Typical maintenance activities for pipe installations include removal of debris, flushing, deposition or silt removal, and repair of localized damage. Actions to maintain or improve the pipe's structural integrity are not considered maintenance activities but are addressed as either rehabilitation or replacement projects.

Maintenance costs in the program are handled as an expense per period or cost per number of years (see Figure 7, in which corrugated pipe installation has a \$400,000 bid cost, a 30-year material service life, and a maintenance cost of \$500 every 5 years). For example, if routine maintenance costs \$1,000 every 5 years, the input would be an expense of \$1,000 for a period equal to 5 years. To consider maintenance as an annual expense, the input would be the annual cost for a period equal to 1 year.

Rehabilitation entails any remedial action taken on a pipe facility to upgrade its structure condition. Rehabilitation actions cannot restore the pipe to its original condition, but may extend its service life by a number of years depending on the type and amount of deterioration. The years the material life is extended should be judged based on the condition of the pipe and the current rate of deterioration. Costs associated

GIVEN: Concrete pipe installation with a bid price of \$500,000 and a material service life of 100 years.

```
CONCRETE    STEEL    GENERAL    QUIT
EDIT CONCRETE PIPE SERVICE LIFE COMPONENTS WINDOW

       Concrete Pipe Service Life Components                 Project Design
Replace/Install      Maintenance     Rehabilitation   Total    - Storm Sewer
Life  Costs          Costs           Life  Costs      Years      Sanitary Sewer
_100  ___500000      _________       ____  _________  _100     ► Interstate
____  _________      _________       ____  _________  ____       State Primary
____  _________      _________       ____  _________  ____       State Secondary
____  _________      _________       ____  _________  ____       Local/Rural
                                                               Design Life  _100

                                                              Economic Factors
                                                              ► Nominal Discount
                                                              _   Real Discount
                                                              ► Federal Funding
                                                                  State Funding
                                                                  Private Funding
                                                                Interest Rate  _5.00
                                                                Inflation Rate _3.50

                                                              Type Of Analysis
                                                                Present Worth
                                                                  Annualized
                                                                  Future Value
                                                                Analyze ?  YES
```

FIGURE 6 Material service life window.

```
GIVEN:      Corrugated pipe installation with a $400,000 bid cost,
            30 year material service life and maintenance cost of
            $500 every 5 years.
```

```
F1-MENU  F3-HELP  F5-MAINTENANCE WINDOW                    Move: Field  Ins: Off
MAINTENANCE EXPENSE (COST PER PERIOD [ $/YEARS])
                                                         Project Design
      Corrugated Steel Pipe Service Life Components         Storm Sewer
Replace/Install      Maintenance    Rehabilitation  Total   Sanitary Sewer
Life  Costs          Costs          Life  Costs     Years  ► Interstate
__30  ___400000           500       ____  ________  __30    State Primary
____  _________      _________      ____  ________  ____    State Secondary
____  _________      _________      ____  ________  ____    Local/Rural
____  _________      _________      ____  ________  ____   Design Life  _100

                                                         Economic Factors
                                                         ► Nominal Discount
                                                         _  Real Discount
                                                         ► Federal Funding
             Maintenance Costs Components                   State Funding
                                                            Private Funding
    Periodic costs -  Period ___5  Expense ______500       Interest Rate  _5.00
                                                           Inflation Rate _3.50

                                                         Type Of Analysis
                                                           Present Worth
                                                            Annualized
                                                            Future Value
                                                          Analyze ?  YES
```

FIGURE 7 Maintenance cost components.

```
F1-MENU  F3-HELP  F5-REHABILITATION WINDOW                 Move: Field  Ins: Off
COST FOR TOTAL REHABILITATION ACTIONS ($)
                                                         Project Design
      Corrugated Steel Pipe Service Life Components         Storm Sewer
Replace/Install      Maintenance    Rehabilitation  Total   Sanitary Sewer
Life  Costs          Costs          Life  Costs     Years  ► Interstate
__30  ___400000      ______500      __10     90187  __40    State Primary
____  _________      _________      ____  ________  ____    State Secondary
____  _________      _________      ____  ________  ____    Local/Rural
____  _________      _________      ____  ________  ____   Design Life  _100

              Rehabilitation Costs Components            Economic Factors
Construction costs  ____50000  Other costs   ______5000  ► Nominal Discount
Traffic costs       ____35187  Total costs   _____90187  _  Real Discount
              Traffic Costs Components                   ► Federal Funding
Work zone length  _____0.50   ADT              ____30000    State Funding
Normal speed      ______55    Work zone speed  _______35    Private Funding
Occupancy rate    _____1.50   Value of time    ____14450   Interest Rate  _5.00
Work time         _____3.00   Detour Required?  Yes No     Inflation Rate _3.50

                                                         Type Of Analysis
                                                           Present Worth
                                                            Annualized
                                                            Future Value
                                                          Analyze ?  YES
```

FIGURE 8 Rehabilitation cost components.

with rehabilitation actions not only include the construction and material costs for the work but any other directly or indirectly related costs, such as easements, engineering, safety, detour roadway deterioration, and traffic-related costs. The example in Figure 8 shows corrugated steel pipe with rehabilitation costs of $50,000 for construction and $5,000 for engineering, safety, and so on. The project roadway has an average daily traffic count of 30,000 vehicles with 1.5 people/vehicle and a normal speed limit of 55 mph, which is reduced to 35 mph during the 3-month construction time and construction zone length of 0.5 mi. The value of time is based on the U.S. Department of Commerce 1986 statistics for per capita income (default value).

Provisions have been made within the program to incorporate traffic-related costs into the analysis. Costs associated with vehicle deterioration, passenger time, and construction-related accidents have been included. Inclusion of these items in the project costs are in accordance with similar analysis procedures such as those presented in the Federal Highway Administration's publication "The Design of Encroachments on Flood Plains Using Risk Analysis" (*2*). Cost of passenger's time is based on the loss of time for the decrease in speed through the construction zone. Vehicle deterioration costs reflect the wear on vehicles from the extra traveling distance for detours. Costs associated with construction-related accidents reflect the number and cost of vehicle accidents through the construction zone, and include property damage, injuries, and fatalities.

Replacement entails the removal of an existing facility and the installation of a new structure. The material life of the replaced facility should equal that of the original material life. Costs associated with replacement actions include all construction and material costs as well as all the direct and indirect costs illustrated under rehabilitation actions. The example in Figure 9 shows a corrugated steel pipe installation with replacement costs as illustrated (see rehabilitation screen for description). In addition, a l-mi detour will be required for the duration of the project. Vehicle operating costs are $0.21/mi (default value). Three accidents are expected with an average cost of $2,500/vehicle in damage. No injuries or fatalities are expected.

Rehabilitation and replacement actions are taken until the project design life is met or exceeded. In the event that the material service life exceeds the required number of years, a residual value will be determined. The residual cost represents the value of extended service. This value appears in the final analysis and hard copy documentation and is subtracted from the overall cost of the particular material.

ANALYSIS

The LCA program allows the economic analysis to be conducted using three different methods: PW, annualized costs, and future value. PW is calculated based on the equivalent costs at the current or present time (see Figure 10, in which analysis is to be conducted using the PW method). In other words, this would be the amount of money needed to be set aside today to meet the desired project design life.

When using the nominal discount rate, present value calculations are made by first inflating estimates of cost expenditures, made in original dollar terms, into the future, to the time that they will be made. These inflated costs are then discounted to present value terms using an appropriate interest rate. The inflation and discount of each future cost or value is done by the equation:

$$PV = A(F)^n$$

where

PV = present value,
A = amount of original cost,
F = inflation (I)/interest (i), $F = [(1 + I)/(1 + i)]$, and
n = period or number of years.

If a real discount rate is used, the future costs are discounted to the present value using the same equation in which the value for inflation is zero and the interest rate represents the difference between the actual interest and inflation rate [i.e., $(i - I)$].

Annualized costs are annual yearly costs or what an agency would have to outlay every year for the life of the project. This may also be computed on a period basis as an outlay every number of months or years by modifying the value of n in the equation:

$$AC = PV\,[i'\,(1 + i')^n/(1 + i')^n - 1]$$

where AC is annualized cost and i' is discount rate.

Future value is simply the cost of the project at a future

```
F1-MENU   F3-HELP   F5-REPLACEMENT WINDOW                    Move: Field   Ins: Off
COST FOR TOTAL REPLACEMENT ACTIONS ($)

      Corrugated Steel Pipe Service Life Components          | Project Design ------
Replace/Install        Maintenance    Rehabilitation   Total |     Storm Sewer
Life   Costs           Costs          Life   Costs     Years |     Sanitary Sewer
__30   ___400000       ______500      __10   ____90187  __40 | ► Interstate
__30      1032400      _________      ____   _________  __70 |     State Primary
____   _________       _________      ____   _________  ____ |     State Secondary
____   _________       _________      ____   _________  ____ |     Local/Rural
                                                             |   Design Life   _100
             Replacement Costs Components                    | Economic Factors
Construction costs   ___500000   Other costs      ___100000  | ► Nominal Discount
Traffic costs        ___432400   Total costs      __1032400  | _   Real Discount
             Traffic Costs Components                        | ► Federal Funding
Work zone length    _____0.50    ADT              _____30000 |     State Funding
Normal speed        ________55   Work zone speed  ________35 |     Private Funding
Occupancy rate      _____1.50    Value of time    _____14450 |   Interest Rate   _5.00
Work time           _____3.00    Detour Required? Yes   No   |   Inflation Rate  _3.50
             Detour Components
Detour length       _____1.00    Running Costs    ______0.21 | Type Of Analysis
Injury rate         _________0   Cost/Injury      _________0 |    Present Worth
Fatality rate       _________0   Cost/Fatality    _________0 |     Annualized
Accident rate       _________3   Cost/Accident    ______2500 |     Future Value
                                                             |   Analyze ?   YES
```

FIGURE 9 Replacement cost components.

date. Costs can be discounted to a future value with the following equation:

$$FV = PV\,(1 + i')^n$$

where FV is future value.

FILES

The file section of the program allows data to be stored and retrieved on either the working diskette or any external directory or subdirectory. The file section has four main functions: retrieve, save, print, and disk/path (Figure 11).

GIVEN: Analysis to be conducted using the present worth method.

```
PROJECT   DESIGN   ECONOMIC   MATERIAL   ANALYSIS   FILES   QUIT
EDIT ANALYSIS WINDOW
-------------------------------------------------------------------- Project Design ------
       Corrugated Steel Pipe Service Life Components                   Storm Sewer
Replace/Install       Maintenance     Rehabilitation     Total        Sanitary Sewer
Life    Costs         Costs           Life   Costs       Years      ► Interstate
__30  ___400000       ______500       __10   ____90187   __40          State Primary
__30  __1032400       ______500       __10   ____90187   __80          State Secondary
__30  __1032400       ______500       ____   _________   _110          Local/Rural
____  _________       _________       ____   _________   ____        Design Life   _100
--------------------------------------------------------------------------------------------
                                                                    Economic Factors
 Project Description                                                ► Nominal Discount
                                                                    _   Real Discount
   Project Title      LCA_Test_Data_File_________________          ► Federal Funding
                                                                        State Funding
   Project location   American_Concrete_Pipe_Association_              Private Funding
                                                                      Interest Rate  _5.00
   Analyzed by        John_M._Kurdziel___________________             Inflation Rate _3.50
                                                                    ------------------------
   Date               07/08/87                                      Type Of Analysis
                                                                    ► Present Worth
                                                                        Annualized
                                                                        Future Value
                                                                      Analyze ?   YES
```

FIGURE 10 Type of analysis window.

```
F1-MENU   F3-HELP                                           Move: Field   Ins: Off
CHOOSE ITEM FROM LIST WITH <Enter> KEY OR TYPE IN FILENAME
-------------------------------------------------------------------- Project Design ------
       Corrugated Steel Pipe Service Life Components                   Storm Sewer
Replace/Install       Maintenance     Rehabilitation     Total        Sanitary Sewer
Life    Costs         Costs           Life   Costs       Years      ► Interstate
__30  ___400000       ______500       __10   ____90187   __40          State Primary
__30  __1032400       ______500       __10   ____90187   __80          State Secondary
__30  __1032400       ______500       ____   _________   _110          Local/Rural
____  _________       _________       ____   _________   ____        Design Life   _100
--------------------------------------------------------------------------------------------
                                                                    Economic Factors
                                                                    ► Nominal Discount
   Filename - C:\LC2\TRB.LCA                                        _   Real Discount
                                                                    ► Federal Funding
   COMMAND.COM    LCCA.EXE       LCCA.HLP       LASTTIME.LCA            State Funding
   SERNUM.EXE     DISTRIB.EXE    STARTUP.EXE    NEW.LCA                 Private Funding
   TRB.LCA                                                            Interest Rate  _5.00
                                                                      Inflation Rate _3.50
                                                                    ------------------------
                                                                    Type Of Analysis
                                                                    ► Present Worth
                                                                        Annualized
                                                                        Future Value
                                                                      Analyze ?   YES
```

FIGURE 11 File window.

The save and retrieve commands provide access to the directory of the operating diskette or subdirectory. All the files on the directory are listed and an existing file can be either saved or retrieved by highlighting the desired file and entering. New files may be created by storing the data under a new file name, which is simply typed in over the file name prompt.

Printing of any program runs is done by selecting the print command for a complete hard copy printout or the print screen for a final design summary (Figure 12). All tabs and spacings have been preselected and arranged so that the hard copy documentation conforms to the standard 8½-in. by 11-in. sheet size for easy inclusion into plans and files. Figure 13 contains a complete hard copy printout of the analysis developed in this paper. Values used in developing the analysis were only intended to illustrate the computational aspects of the program and do not represent any particular project.

The disk/path command allows users to change or specify a specific default drive or subdirectory. If the program is being executed on the hard disk drive and all the data files are being

```
F1-MENU  F3-HELP                                              Move: Field   Ins: Off
ANALYZE PROJECT DESIGN ?
                                                               Project Design
     Corrugated Steel Pipe Service Life Components                Storm Sewer
Replace/Install      Maintenance    Rehabilitation    Total       Sanitary Sewer
Life  Costs          Costs          Life  Costs       Years     ► Interstate
__30  ___400000      ______500      __10  ____90187   __40        State Primary
__30  __1032400      ______500      __10  ____90187   __80        State Secondary
__30  __1032400      ______500      ____  _________   _110        Local/Rural
____  _________      _________      ____  _________   ____     Design Life  _100

                                                               Economic Factors
 Present Value Analysis Results                                ► Nominal Discount
                                                               _  Real Discount
                          Equivalent Costs                     ► Federal Funding
                    Concrete      Steel         Other             State Funding
                                                                  Private Funding
 Installation       ____500000    ____400000    __________0     Interest Rate  _5.00
 Maintenance        ______4994    ______4784    __________0     Inflation Rate _3.50
 Rehabilitation     _________0    _____91510    __________0
 Replace            _________0    ____907154    __________0    Type Of Analysis
 Residual           _________0    ____-81627    __________0    ► Present Worth
 Total              ____504994    ___1321821    __________0       Annualized
                                                                  Future Value
                                                                Analyze ?   YES
```

FIGURE 12 Final design.

```
LEAST COST ANALYSIS ANOTATED LISTING
PAGE 1 OF GENERAL PARAMETERS
PREPARED BY : JOHN M. KURDZIEL


Project Description

   Project Title        - LCA Test Data File
   Project Location     - American Concrete Pipe Association
   Analyzed By          - John M. Kurdziel
   Date                 - 07/08/87

Project Design Parameters

   Type of Facility     - Interstate Culvert
   Project Design Life  = 100 (years)

Economic Factors

   Discount Rate Type   - Nominal Discount Rate
   Type of Funding      - Federal Funding
   Interest Rate        = 5.00 (%)
   Inflation Rate       = 3.50 (%)
```

FIGURE 13 Printout of LCA program.

```
LEAST COST ANALYSIS ANOTATED LISTING
PAGE 1 OF CONCRETE PIPE MATERIAL SERVICE LIFE
PREPARED BY : JOHN M. KURDZIEL


Start of Period (years) =     0
End of Period (years)   =   100

Installation        Life (years) =  100          Costs ($) =    500000
Maintenance                                      Costs ($) =       500
Rehabilitation      Life (years) = Undefined     Costs ($) = Undefined


Maintenance Costs Components

   Period (years) =    5                  Costs ($) =        500


Rehabilitation Costs Components

   Construction Costs ($) = Undefined   Other Costs ($)           = Undefined
   Traffic Costs ($)      = Undefined   Total Costs ($)           = Undefined

   Traffic Costs Components

   Work Zone Length (mi)  = Undefined   ADT (veh/day)             = Undefined
   Normal Speed (mph)     = Undefined   Work Zone Speed (mph)     = Undefined
   Occupancy Rate (#/veh) = Undefined   Value of Time ($/year)    = Undefined
   Work Time (months)     = Undefined

   Detour Is Undefined


Start of Period (years) =     0
End of Period (years)   =    40

Installation        Life (years) =   30          Costs ($) =    400000
Maintenance                                      Costs ($) =       500
Rehabilitation      Life (years) =   10          Costs ($) =     90187


Maintenance Costs Components

   Period (years) =    5                  Costs ($) =        500


Rehabilitation Costs Components

   Construction Costs ($) =     50000   Other Costs ($)           =      5000
   Traffic Costs ($)      =     35187   Total Costs ($)           =     90187

   Traffic Costs Components

   Work Zone Length (mi)  =      0.50   ADT (veh/day)             =     30000
   Normal Speed (mph)     =        55   Work Zone Speed (mph)     =        35
   Occupancy Rate (#/veh) =      1.50   Value of Time ($/year)    =     14450
   Work Time (months)     =      3.00

   Detour Is Not Required


Start of Period (years) =    40
End of Period (years)   =    80

Replacement         Life (years) =   30          Costs ($) =   1032400
Maintenance                                      Costs ($) =       500
Rehabilitation      Life (years) =   10          Costs ($) =     90187
```

FIGURE 13 *continued.*

```
LEAST COST ANALYSIS ANOTATED LISTING
PAGE 2 OF CORRUGATED STEEL PIPE MATERIAL SERVICE LIFE
PREPARED BY : JOHN M. KURDZIEL

Replacement Costs Components

   Construction Costs ($) =    500000   Other Costs ($)             =     100000
   Traffic Costs ($)      =    432400   Total Costs ($)             =    1032400

   Traffic Costs Components

   Work Zone Length (mi)  =      0.50   ADT (veh/day)               =      30000
   Normal Speed (mph)     =        55   Work Zone Speed (mph)       =         35
   Occupancy Rate (#/veh) =      1.50   Value of Time ($/year)      =      14450
   Work Time (months)     =      3.00

   Detour Is Required -- Costs Components

   Detour Length (mi)     =      1.00   Running Costs ($/mile)      =       0.21
   Injury Rate (#)        =         0   Cost/Injury ($/#)           =          0
   Fatality Rate (#)      =         0   Cost/Fatality ($/#)         =          0
   Accident Rate (#)      =         3   Cost/Accident ($/#)         =       2500


Maintenance Costs Components

   Period (years) =    5                Costs ($) =      500


Rehabilitation Costs Components

   Construction Costs ($) =     50000   Other Costs ($)             =       5000
   Traffic Costs ($)      =     35187   Total Costs ($)             =      90187

   Traffic Costs Components

   Work Zone Length (mi)  =      0.50   ADT (veh/day)               =      30000
   Normal Speed (mph)     =        55   Work Zone Speed (mph)       =         35
   Occupancy Rate (#/veh) =      1.50   Value of Time ($/year)      =      14450
   Work Time (months)     =      3.00

   Detour Is Not Required

Start of Period (years) =   80
End of Period (years)   =  110

Replacement       Life (years) =   30          Costs ($) =   1032400
Maintenance                                    Costs ($) =       500
Rehabilitation    Life (years) = Undefined     Costs ($) = Undefined


Replacement Costs Components

   Construction Costs ($) =    500000   Other Costs ($)             =     100000
   Traffic Costs ($)      =    432400   Total Costs ($)             =    1032400

   Traffic Costs Components

   Work Zone Length (mi)  =      0.50   ADT (veh/day)               =      30000
   Normal Speed (mph)     =        55   Work Zone Speed (mph)       =         35
   Occupancy Rate (#/veh) =      1.50   Value of Time ($/year)      =      14450
   Work Time (months)     =      3.00

   Detour Is Required -- Costs Components

   Detour Length (mi)     =      1.00   Running Costs ($/mile)      =       0.21
   Injury Rate (#)        =         0   Cost/Injury ($/#)           =          0
   Fatality Rate (#)      =         0   Cost/Fatality ($/#)         =          0
   Accident Rate (#)      =         3   Cost/Accident ($/#)         =       2500
```

FIGURE 13 *continued.*

LEAST COST ANALYSIS ANOTATED LISTING
PAGE 3 OF CORRUGATED STEEL PIPE MATERIAL SERVICE LIFE
PREPARED BY : JOHN M. KURDZIEL

Maintenance Costs Components

Period (years) = 5 Costs ($) = 500

Rehabilitation Costs Components

Construction Costs ($)	= Undefined	Other Costs ($)	= Undefined
Traffic Costs ($)	= Undefined	Total Costs ($)	= Undefined

Traffic Costs Components

Work Zone Length (mi)	= Undefined	ADT (veh/day)	= Undefined
Normal Speed (mph)	= Undefined	Work Zone Speed (mph)	= Undefined
Occupancy Rate (#/veh)	= Undefined	Value of Time ($/year)	= Undefined
Work Time (months)	= Undefined		

Detour Is Undefined

Present Value Analysis Equivalent Costs ($)

	Concrete	Steel	Other
Installation	500000	400000	0
Maintenance	4994	4784	0
Rehabilitation	0	91510	0
Replacement	0	907154	0
Residual	0	-81627	0
Total	504994	1321821	0

Annualized Value Analysis Equivalent Costs ($)

	Concrete	Steel	Other
Installation	25192	20153	0
Maintenance	252	241	0
Rehabilitation	0	4611	0
Replacement	0	45705	0
Residual	0	-4113	0
Total	25443	66597	0

Future Value Analysis Equivalent Costs ($) (X1000)

	Concrete	Steel	Other
Installation	65751	52601	0
Maintenance	657	629	0
Rehabilitation	0	12034	0
Replacement	0	119292	0
Residual	0	-10734	0
Total	66407	173821	0

FIGURE 13 ***continued.***

stored on a floppy drive or subdirectory, users can specify these parameters using the disk/path command and minimize misplacement of files and excessive inputs.

AVAILABILITY

The LCA program will be made available as a public domain program through the distribution facilities of McTrans, Center for Microcomputers in Transportation. McTrans is the official software distributor and user support center for the Federal Highway Administration. The center provides support to microcomputer users through technical assistance of the software distributed. Costs for public domain programs distributed by McTrans are nominal, covering only their administrative, reproduction, and overhead costs. The LCA program will be only one of a number of programs developed by the American Concrete Pipe Association to be distributed in this way.

SUMMARY

The LCA program evaluates costs associated with each alternate pipe material based on their design components and project requirements. The program allows the maximum amount of freedom in selecting design parameters while providing detailed guidance at every decision making step. Because data entry requires little typing, complex designs may be entered in less than 5 minutes, and multiple runs for parameter studies or sensitivity analysis in a fraction of that time. The LCA program's versatility and ease of use will make life cycle economic analysis easier, decrease government agencies' and consultants' time and costs for analysis, and promote more cost-effective project designs.

REFERENCES

1. W. O. Kerr and B. A. Ryan. Taking the Guesswork Out of Least Cost Analysis. *Consulting Engineer*, March, 1986.
2. *The Design of Encroachments on Flood Plains Using Risk Analysis*. Hydraulics Engineering Circular 17, Office of Hydraulics, Federal Highway Administration, U.S. Department of Transportation, 1980.

DISCUSSION

WAHEED UDDIN
Texas Research and Development Foundation, 6811 Kenilworth Avenue, Riverdale, Md. 20737.

The LCA microcomputer program for pipe type selection is a useful addition to the limited number of user-friendly microcomputer programs for the life cycle cost analysis of highway components. The LCC1 microcomputer program (*1*,*2*) offers a user-friendly approach to analyze life cycle costs for pavement management considering multiple reconstruction, maintenance and rehabilitation treatments, material salvage and extended service life, and different economic scenarios.

The author offers the users both PW and annualized value methods as well as future value analysis to compare the life cycle costs of different pipe material alternatives. It should be recognized that, if correctly performed, PW provides the bench mark against which other methods of evaluation must be judged. The annual equivalent annuity (AE) method will give answers consistent with a bench-mark PW in the absence of inflation and when a uniform inflation is expected over time. The validity of PW and AE are demonstrated when actual (nominal) cash flow and actual (nominal) discount rates are used. Decisions based on real discount rates will be correct only if they are consistent with those obtained using nominal rates. A real rate can be used only with cash flows expressed in base-year prices (i.e., uninflated costs). Similarly, a nominal rate can be used only in conjunction with the actual cash flow expected. There should be no mixing of real and nominal values.

Salvage values are unlikely to have any significant impact on the economic evaluation of alternative strategies. First, they will be similar in value (e.g., similar haulage, labor, and residual value of materials). Second, the cost, when discounted back to present value, is likely to be small, even for modest discount rates. Consideration of the extended value of service life is important for proper life cycle cost comparisons. Both salvage values are provided in the LCA program.

The outputs show a summary of all cost streams and total cost for each alternative. However, it is apparently up to the users to select the least cost alternative based on the total life cycle costs. It will be useful if another output screen is added that rank orders the alternatives on the least cost basis using the following options:

1. All costs.
2. All costs (excluding maintenance, rehabilitation, and replacement costs). This will present a "do-nothing" policy.
3. All costs except road user costs (traffic detour and accident costs). This option can be used to ignore these traffic cost components in the least cost analysis because the program user may not have reliable estimates of the traffic cost components during the service life of the facility.
4. All costs except salvage values.
5. All costs except road user costs and salvage value.

The ranking costs should be provided when using any of these options, along with the option and rank.

REFERENCES

1. W. Uddin, R. F. Carmichael III, and W. R. Hudson. *Life-Cycle Analysis for Pavement Management Decision Making—Final Report.* Report FHWA-PA-85-028, Pennsylvania Department of Transportation, Harrisburg, March 1986.
2. W. Uddin, R. F. Carmichael III, and W. R. Hudson. A Microcomputer Program To Evaluate Cost-Effective Alternatives for Concrete Pavement Restoration. In *Transportation Research Record 1109*, TRB, National Research Council, Washington, D.C., 1987, pp. 60–68.

AUTHOR'S CLOSURE

The discussant raised a very important question about real and nominal discount rates that deserves further discussion.

The LCA program will not permit the mixing of real and nominal values. An amalgamation of the discount rates would present a totally erroneous analysis. Using either the nominal or real discount rate will yield the same results as long as they are used consistently. Problems occur when they are mixed. For example, if an interest rate is 8 percent and an inflation rate is 6 percent, a real discount rate of 2 percent should be used, or for a nominal discount analysis both the stated inflation and interest rates would be used directly. Mixing the discount rates by inflating a cost out to a future time using an inflation rate of 6 percent and then discounting back to PW using the real discount rate of 2 percent would effectively create a debtor's dream, as the following analysis demonstrates.

$$FV = PV/(1 + I/1 + i)^n$$

where

FV = future value,
PV = present value,
I = inflation rate,
i = interest, and
n = period or number of years.

Substituting I = 6 percent, i = 2 percent
Yields $FV = PV/(1.039)^n$

In this case, the larger the period, the smaller the future value of money. An investor under these conditions would be much better off to borrow all their funds today and simply pay them back at a future date at a cost less than the face value of the original loan. The opposite of this condition, of course, creates a money-generating machine. In either case, the analysis is a distortion of the actual conditions. If a nominal discount rate is used for the analysis, i and I equal 0.08 and 0.06, respectively. For a real discount rate analysis, the inflation rate is not included directly in the analysis and is equal to zero. The corresponding real discount rate, however, takes the inflation rate into consideration because it is the differential between interest and inflation, or 0.02. As long as the consistent factors are used in the analysis, either the nominal or real discount rate may be used. The program includes both methods to allow for maximum flexibility.

The salvage values in the program are based not on the actual salvage value of the material but on the residual service life the product provides for the facility. It is unrealistic to assume that there would be any net salvage value for a product material once the costs for removing and hauling it away are considered. The embankment and all the drainage structures within it must serve far longer than the roadway itself. Pavements may be replaced relatively easily compared with the disruption and cost associated with removing a pipe. Roadways are also seldom abandoned because of the high cost of right-of-way, and most are required to serve longer than their original project design life. Many states design their roadways with these considerations in mind. In their May 1987 durability study, the Missouri Highway and Transportation Department states that "roadbeds and highway corridors are selected and designed with no foreseeable intent to relocate." Even if a roadway is relocated, the old embankment remains intact and efficient movement of water through it must be maintained. It is, therefore, more reasonable to assume a residual value for a material based on the extended project design life of the facility and not on the salvage value of the product material.

There are a number of input options in the program that can yield the results listed in the discussant's comments. The only option that currently cannot be fulfilled within the actual computational routines of the program is the exclusion of salvage values. Salvage values or residual costs are calculated on the last material action that exceeds the project design life. A user, however, could obtain a design void of salvage value costs by adding the residual cost listed in the output to the total costs, but unfortunately this calculation must be done outside the program.

A computer program should be a dynamic entity, constantly evolving and improving. Enhancements such as ranking of alternatives have benefits in documenting the analysis and will be worthwhile additions to the program. Other enhancements and updates will surface as the program is being used. Those revisions that represent a benefit to designers and planners within the engineering community will be included in any future versions of the program.

REFERENCE

1. *Study of Use, Durability, and Cost of Corrugated Steel Pipe on the Missouri Highway and Transportation Department's Highway System.* Missouri Highway and Transportation Department, Jefferson City, May 1987.

Publication of this paper sponsored by Committee on Culverts and Hydraulic Structures.