A Microcomputer Program To Evaluate Cost-Effective Alternatives for Concrete Pavement Restoration

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A methodology for evaluating cost-effective alternatives for rehabilitation of pavements that was developed for microcomputer applications is described. The life-cycle cost–1 (LCC1) microcomputer program is designed for comprehensive economic evaluation of competing alternatives provided by users. The LCC1 program is unique for life-cycle cost analyses because of its flexibility and the options it offers users: it creates and saves multiple input files and provides default data, manipulates input data without going through an entire session, offers seven available optimization options for rank ordering the strategies, and considers multiple maintenance and rehabilitation treatments. The user inputs an array of design strategies (for initial construction or rehabilitation design). Several cycles of maintenance and rehabilitation actions can be included in a single strategy. Peripheral cost items like moving guide rails and adjusting drainage structures are also considered. The LCC1 methodology is capable of computing user operating costs and added user costs due to traffic delays during rehabilitation and reconstruction. The present worth or the annualized equivalent annuity method can be used to establish ranking of alternatives. Applications of the LCC1 program to the analysis of various alternative strategies for concrete rehabilitation are presented in this paper.

Several computer programs for life-cycle analysis of pavements are found in the literature for project-level application in surface or rehabilitation type selection *(1–5)*. Most of these programs, however, rely on predictive models for generating alternative design strategies. Moreover, these programs are generally not capable of considering multiple rehabilitation activities. A life-cycle cost analysis involves modeling for several years the performance of a particular structure exposed to a given set of conditions, including expected environment, forecast traffic loadings, selected maintenance treatments, and selected rehabilitation strategies. The analysis is used to evaluate several different rehabilitation or maintenance actions.

Life-cycle cost (LCC) analysis of pavements enables pavement management decision makers to optimize the expenditure of available funds by evaluating the cost-effectiveness of competing rehabilitation strategies. The development of a comprehensive procedure for comparing project-level designs of new or existing pavements based on an optimum life-cycle cost was the primary objective of this study for the Pennsylvania Department of Transportation (PennDOT). The following criteria, established by the sponsors at the outset of the study *(6, 7)*, were used in the development of the methodology: *(a)* The alternative strategies will be user inputs. Performance or distress prediction models will not be used to generate design strategies. *(b)* Multiple options for maintenance and rehabilitation treatments, compatible with standard methods used by PennDOT, will be considered. *(c)* Agency cost models will include peripheral cost items like guide rail relocation, drainage structures, and related shoulder work. *(d)* A model for added user costs due to traffic delays during rehabilitation work must be included in the life-cycle cost procedure. *(e)* Present worth analysis will be used for economic evaluation unless a better and more versatile method is identified.

In this paper the LCC1 microcomputer program that incorporates the developed methodology is described and example applications are presented.

METHODOLOGY

The LCC methodology developed in this study *(7–9)* considers alternatives for resurfacing existing pavements, concrete pavement restoration, maintenance, rehabilitation cycles, and peripheral activities. The thrust of this LCC methodology is a straightforward economic evaluation. The competing design alternatives are user inputs.

For a new pavement project, the main issues related to initial structural design are surface type and thickness design. The LCC methodology considers several types of pavements for new pavement design or reconstruction. The available options are *(a)* four surface types including asphaltic concrete pavement (ACP), plain jointed concrete pavement (JCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP); *(b)* eight types of base course materials including crushed aggregate, dense-graded crushed aggregate, bituminous aggregate, cement aggregate, lean concrete, aggregate lime pozzolan, bituminous concrete, and cement concrete; and *(c)* granular and stabilized subbase materials.

Some of the factors considered in selecting rehabilitation alternatives for a given pavement section are structural capacity; roughness; type, extent, and degree of pavement distress; skid resistance; type of facility; traffic characteristics; subgrade characteristics; and adjoining roads. Resurfacing is a major rehabilitation option. Determining resurfacing thickness requires an evaluation of the existing pavement and the material properties of new overlay or recycled materials.

Maintenance and Rehabilitation Alternatives

Several types of maintenance treatments and rehabilitation actions are considered in the LCC methodology. For life-cycle

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TABLE 1 MAINTENANCE TREATMENTS CONSIDERED IN THE LCC METHODOLOGY

Treatment	Applicable to
Cleaning and sealing joints	PCC
Spall repair	PCC
Subsealing	PCC
Slab jacking	PCC
Rigid patching	PCC
Crack sealing	BF/BR
Bituminous patching, manual	BF/BR
Bituminous patching, mechanized	BF/BR
Seal coat/surface treatment	BF/BR
Base repair	PCC/BF/BR

NOTE: PCC = portland cement concrete (rigid pavement), BF = bituminous surfacing over flexible base (flexible pavement), and BR = bituminous surfacing over rigid base (composite pavement).

costing, maintenance and rehabilitation scheduling is provided by users. The selection of these alternatives is primarily based on *(a)* type of existing pavement, *(b)* concrete pavement rehabilitation techniques recommended by PennDOT *(10)*, and *(c)* maintenance treatments considered in the Systematic Technique to Analyze and Manage Pennsylvania Pavements (STAMPP) system of PennDOT *(11)*. Selected maintenance treatments are given in Table 1. Table 2 gives various rehabilitation alternatives considered in the LCC methodology. These include overlays, concrete pavement restoration techniques, and reconstruction. The methodology is designed to handle a combination of rehabilitation techniques under a single strategy.

A survey of PennDOT experts working in various areas (maintenance, construction, design, and administration, for example) was performed in this study. Expected life data for various rehabilitation alternatives were collected for bituminous pavements, portland cement concrete pavements, and bituminous pavements with rigid bases. The results, summarized by Uddin et al. *(8)*, can be used for scheduling maintenance and rehabilitation activities in a design strategy.

TABLE 2 REHABILITATION ALTERNATIVES

Alternative	Applicable to
Milling	Bituminous pavements
Leveling course	Bituminous pavements
Recycling	Bituminous pavements
Scratch course	Bituminous or PCC pavements
Joint rehabilitation	PCC pavements
Spall repair	PCC pavements
Subsealing	PCC pavements
Slab jacking	PCC pavements
Slab replacement	PCC pavements
Diamond grinding	PCC pavements
Recycling	PCC pavements
"Do nothing"	All pavement types
Asphalt concrete overlay[a]	All pavement types
Continuously reinforced concrete overlay[a]	All pavement types
Plain jointed concrete overlay[a]	All pavement types
Jointed reinforced concrete overlay[a]	All pavement types
Reconstruction	All pavement types

[a]Overlays can be considered with or without bond breaker layers.

Peripheral Activities

The LCC methodology also considers a number of peripheral items:

- Construction, maintenance, and rehabilitation of unpaved, asphaltic concrete, surface treated, or portland cement concrete shoulders.
- Moving guide rails, shifting and repairing drainage structures, and three miscellaneous items specified by the user.

COST MODELS

The following cost models are included in the LCC methodology: construction costs, maintenance costs, rehabilitation costs (including overlay and reconstruction costs), peripheral costs (including maintenance and rehabilitation costs), cost of maintenance and protection of traffic, user costs due to traffic delays, user operating costs, salvage value, and value of extended life. All types of unit costs and fixed cost components are user inputs. However, default values for these cost components are provided in the computer program.

Construction Costs

The initial construction cost for a new pavement is the sum of the cost of right-of-way, the cost of engineering and surveying, the mobilization cost, the cost of subgrade preparation, the cost of subbase and base construction, the cost of surfacing, and peripheral costs. The cost for asphaltic concrete surfacing consists of the costs for prime coats, tack coats, and asphaltic concrete. The cost for a portland cement concrete pavement includes the placement cost, steel reinforcement cost, longitudinal joint cost, and cost of transverse joints (if jointed concrete pavement is specified).

Maintenance, Rehabilitation, and Peripheral Costs

The maintenance cost is a function of a fixed unit cost and a variable unit cost. The periodically updated computer printouts of costs, based on maintenance performance standards and annual maintenance expenditure summaries prepared by an agency, are excellent sources of unit costs for various maintenance activities. The methodology also considers annual routine maintenance cost as a function of surface type. Examples of this type of unit cost are $825 per lane-mile per year for rigid pavements and $1,825 per lane-mile per year for flexible pavements.

The cost model for rehabilitation activities (excluding overlays and reconstruction) is also a function of a fixed unit cost and a variable unit cost. The overlay cost model is a function of the type of overlay. It is a sum of the site establishment cost, the surface preparation cost, the overlay placement cost, the steel reinforcement cost, and the cost of joints. The cost of bond breaker construction is calculated if a bond breaker is required to retard reflective cracking of overlays on PCC pavements.

In the case of an asphaltic concrete overlay on an existing rigid pavement, the cost of locating the existing transverse joints, saw cutting into the new overlay, and sealing is also considered. This is a standard practice in Pennsylvania. If the user does not wish to include this item in his overlay alternatives, he can simply ignore it by specifying a zero value for the unit cost of this item.

Two components are used in the cost model for reconstruction: *(a)* demolition cost and *(b)* reconstruction cost using the initial construction cost model. The cost model for peripheral items is a function of a single unit cost and includes maintenance and rehabilitation costs.

Maintenance and Protection of Traffic

Maintenance and protection of traffic during resurfacing, rehabilitation, and reconstruction projects are treated as a lump sum cost item, expressed as a percentage of the total cost for overlay, reconstruction, and concrete pavement restoration (CPR) work. For maintenance treatments, the fixed cost of each item should reflect the traffic-handling cost.

Traffic Delay Cost

Overlay placement, reconstruction, or CPR has a definite impact on traffic. The excess user costs associated with this impact are estimated using a traffic delay cost model. The model used was originally developed by Scrivner et al. *(12)* for overlay construction. Five types of traffic detour models are used in the model, which has been updated and modified by other investigators *(13)*. The model used in the LCC1 program *(8, 9)* handles the following activities: bituminous concrete or PCC overlays, CPR work, other rehabilitation activities (milling, leveling course, surface treatment, recycling), and reconstruction.

The model first predicts the delay time incurred by each vehicle as it passes through the restricted zone of work. This is calculated using the production rate and quantity of work associated with a specified rehabilitation action. Daily distributions of traffic for rural and urban areas are user inputs. Incremental user delay costs per unit time are built into the model. These, along with the user-specified traffic volumes and periods during which the delays will occur, are used to determine the traffic delay cost.

User Operating Cost

The option of determining the user operating cost associated with the performance history of pavements is also provided in the LCC methodology. Basically, the user operating cost model calculates operating costs due to a decrease in the present serviceability index (PSI). The consumption rate tables developed by Zaniewski et al. *(14)* are used for vehicle operating cost computations.

In the LCC methodology, an initial running speed of 55 mph is assumed for a pavement in ideal condition. The procedure for assigning various speed adjustment parameters for speed change and stop cycles is based on the FHWA's HPMS program *(15)*. Performance history of the pavement during its entire analysis period is estimated by calculating a PSI for each year. A linear relationship is used for pavement deterioration from an initial PSI (P1) to a terminal PSI (PT). The PSI at a given time is readjusted for overlay, reconstruction, CPR work (diamond grinding, slab jacking and subsealing, slab replacement, and spall repair), and recycling. PSI-values for future years are recalculated using linear deterioration rates based on the new PSI (after rehabilitation) and the expected lives of rehabilitation activities. An example of built-in expected lives for rehabilitation of portland cement concrete pavements is given in Table 3.

Salvage Value and Value of Extended Life

Salvage value is the residual value of the pavement or its reusable materials, or both, at the end of service life. Consideration should also be given to the value of extended life

TABLE 3 BUILT-IN DATA USED BY THE LCC1 PROGRAM TO PREDICT THE PSI HISTORY OF A GIVEN STRATEGY (portland cement concrete)

Alternative	Code	Expected Life (yr)[a] Low Traffic (ADT < 30,000)	High Traffic (ADT ≥ 30,000)	PSI
Construction/	1–10			
reconstruction	11–20			
< 8 in.		20	15	P1 (construction)
≥ 8 in.		20	20	PCON (reconstruction)
Thin overlay (< 2 in.)	21–40	7	4	POV[b]
Thick overlay (≥ 2 in.)	21–40	12	9	POV
Spall repair	45	9	5	0.8 (POV)
Subsealing	47	9	5	0.8 (POV)
Slab jacking	48	9	5	0.8 (POV)
Slab replacement	49	20	15	0.8 (POV)
Diamond grinding	50	9	6	0.8 (POV)
Recycling	51	15	15	0.9 (POV)

[a]Based mostly on the survey of PennDOT's engineers.
[b]POV = serviceability value after overlay or other types of rehabilitation.

related to the unequal serviceability levels of various alternatives at the end of the analysis period. As is shown in Figure 1, the two strategies result in different values of extended life. In the proposed LCC methodology, both the value of extended life (YVEXL) and the salvage value (TSALV) are considered. These are either negative costs or zero values.

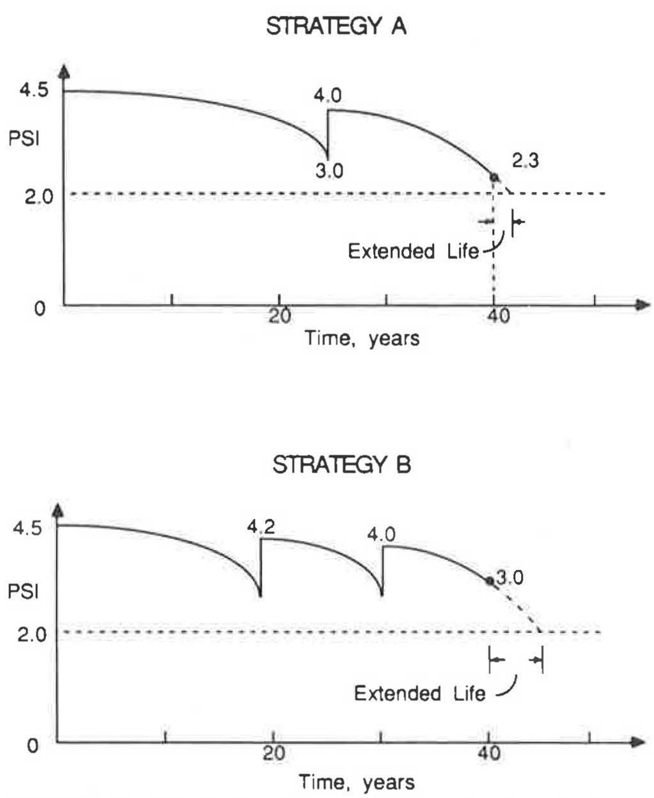

FIGURE 1 Illustration of expected lives for two strategies.

OPTIMIZATION

The LCC methodology uses a simple rank-ordering scheme to optimize the analyzed strategies. Several available options enable users to assess the impact of various economic considerations on rank ordering of the strategies. All options include future overlay costs. The program output will show the strategies ranked in order of ascending costs. These options are *(a)* total life-cycle costs, *(b)* initial construction costs (only for new pavements), *(c)* total life-cycle costs excluding maintenance costs, *(d)* total life-cycle costs excluding user costs, *(e)* total life-cycle costs excluding salvage value, *(f)* construction and rehabilitation costs, and *(g)* total of construction, maintenance, and rehabilitation costs.

PROCEDURES FOR ECONOMIC EVALUATION

Present worth (PW) analysis remains the best general method for LCC evaluations. The PW and equivalent uniform annual cost (EUAC) methods should not be regarded as separate or mutually exclusive options. Options for both methods are provided in the LCC methodology. The following discussion is largely drawn from Wilkes and Harrison *(16)*. Using the present worth method, the analysis period (also referred to as horizon length) should be the same for all alternative design strategies *(17)*. The present worth of costs for a given alternative can be calculated by discounting various cost streams (initial capital cost of construction, future rehabilitation and maintenance costs, user costs) by the chosen discount rate.

The EUAC method, known alternatively as the annual equivalent annuity (AE) method *(17)*, will give answers consistent with a benchmark PW when the decision-making environment is not complex. For example, EUAC can be used for a straight choice between alternatives in the absence of inflation and when anticipated inflation is uniform (meaning constant over time, across the alternative maintenance strategies, and for all sources of cost). EUAC is not precise under conditions of differential inflation (where the guaranteed consistency with PW is lost) but would be expected to give serviceable approximate results.

A discount rate, which is used to adjust future costs or benefits to present-day value, should not be confused with an interest rate, which is associated with the actual cost of borrowing money. In practice, the discount rate used will always contain judgmental elements. The validity of PW and AE is demonstrable when actual (nominal) cash flow and actual (nominal, not real) discount rates are used. Decisions based on real rates will be correct only if they are consistent with those obtained using nominal rates. If the real rate is defined appropriately, this consistency is guaranteed. For a given nominal rate of interest $100r\%$ the equivalent real rate is $100e\%$ given by

$$e = [(1 + r)/(1 + i)] - 1$$

where the appropriate rate of inflation is $100i\%$.

A real rate can be used only with cash flows expressed in base year prices (i.e., uninflated costs). Similarly, a nominal rate can only be used in conjunction with the actual cash flow expected.

The inflation rate to use is that which is relevant to the determination of actual cash flow (i.e., a rate that is drawn from changes in materials, equipment, labor, and other related costs and not a consumer price index). As with the discount rate, an element of judgment enters. An inflation rate using a published index could be worked out in the following manner. Highway maintenance and operation cost trends *(18)* indicate that

Year	*Index*
1982	160.04
1983	166.28

The current annual rate of inflation of these costs is

$$(166.28/160.04 - 1) * 100\% = 3.9\%$$

If present circumstances are thought likely to persist, the figure so obtained (rounded to 4 percent) can be used as the inflation figure. If federal policy is thought likely to reduce inflation significantly, judge a lower figure—say 3 percent. It should be noted that use of a lower figure in these circumstances would not represent financial imprudence. These figures are used to make a correct decision between alternatives. Use of an artificially high inflation figure may well lead to incorrect selection of maintenance strategy and consequently higher-than-necessary costs.

DEVELOPMENT OF THE MICROCOMPUTER PROGRAM

A microcomputer program, Life-Cycle Cost Analysis for Pavement Management, Version 1 (LCC1), was developed using the proposed LCC methodology for operation on an IBM-PC microcomputer using the MS-DOS operating system. The program requires a minimum of 200 k random-access memory (RAM). In addition, the following equipment is needed: at least one disk drive for double-sided, double-density floppy disks; monochrome video monitor; printer; and GWBASIC software. The execution of the LCC1 program, operating procedure, and input guide are treated in detail in the LCC1 user's manual *(9)*. Salient features of the LCC1 program are that it

- Generates an audio signal whenever the user makes an unacceptable entry.
- Features user-friendly data input sessions.
- Enables the user to update or modify data in a given category at any time during an input session.
- Has a built-in set of default input data.
- Checks the value of each input variable entered by the user against built-in maximum and minimum values.
- Allows the user to prepare an input data file in a given session by *(a)* creating an entirely new data file by entering all new data, *(b)* using the default data file with modifications to input default values in the desired categories, or *(c)* modifying any of the existing input files from the previous sessions without going through a complete input session.
- Allows the user to save changes made in the existing input data files for later use.
- Examines alternative strategies for new as well as existing pavements.
- Considers various types of pavements: *(a)* asphaltic concrete (bituminous) pavements, *(b)* continuously reinforced concrete pavements, *(c)* jointed reinforced concrete pavements, *(d)* jointed plain concrete pavements, and *(e)* bituminous pavements with rigid base.
- Considers multiple maintenance and rehabilitation activities.
- Calculates initial construction and future cost streams.
- Calculates user cost relative to traffic delays because of overlay construction.
- Includes user operating cost as an optional feature.
- Analyzes various economic scenarios using the PW or AE methods.
- Varies analysis periods.
- Performs full economic analysis at three different interest and inflation rates during a single session.
- Ranks up to a maximum of nine design strategies in order of ascending discounted life-cycle costs (PW or AE methods) using one of the seven available optimization options.

The LCC1 program consists of a series of program units and data files based on the capabilities of microcomputers. Figure 2 shows the job control system flow of the LCC1 program. The input data component is programmed in BASIC language. The analysis component has been programmed in FORTRAN 77. Communication between the BASIC and FORTRAN components is effected within the LCC1 program using user instructions in a friendly interactive mode.

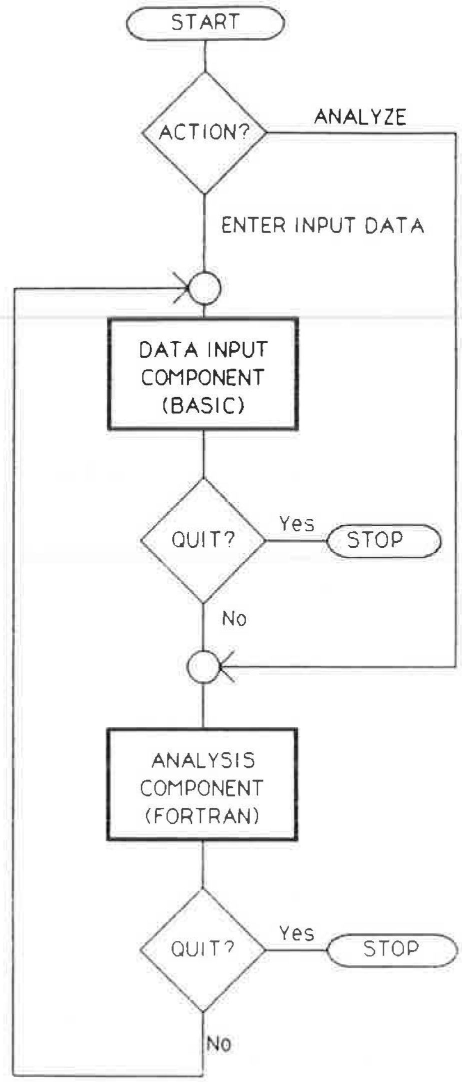

FIGURE 2 Job control system flow of the LCC1.

BASIC Component

The primary functions of the BASIC component are to generate the input data file, which is read and used by the FORTRAN component; to create an entirely new input data file or edit or modify an existing input data file; to load the default input data whenever the program finds that the specified file name does not exist; to edit and modify the default data file; to overwrite the modified values on the current input file (being edited) or create another file; to save the modified values or changes in the file specified by the user; to modify the value of a specific input variable in a current input file without going through the whole file; to create and modify several input data files in one session before starting the analysis part; and to check the input data in a current session for errors and unreasonable values wherever necessary.

The LCC1 program can store input data from every session in separate data files. The following menus are used for entering input data interactively.

Menu	*Description*
A	General design information,
B	Project data (including traffic data),
C	Roadway cost items,
D	Base and subbase placement costs,
E	Surface placement costs,
F	Maintenance unit costs,
G	Rehabilitation unit costs,
H	Peripheral maintenance and rehabilitation unit costs,
I	Traffic delay cost parameters,
J	User operating cost parameters,
K	Road structure information (associated with design strategies),
L	Overlay structure information (associated with design strategies),
M	Design strategies, and
N	Exit program.

The user is permitted to make changes in any of the menus described in the main menu without going through the entire session. Default data are provided for every variable in each of these menus. The default unit costs are based primarily on a review of tabulations of 1985 bids prepared by PennDOT.

To improve the efficiency of data entry for design strategies, it is recommended that the users enter up to 10 construction and reconstruction alternatives in Menu K (with information on layer types and thicknesses, shoulder type, width, thickness, etc. for each alternative). Similarly, up to 20 overlay alternatives can be entered in Menu L. Menu M is then used to enter up to 9 design strategies and associated analysis periods. The user can edit or review any of these design strategies before exiting from a given input data session.

FORTRAN Component

The FORTRAN component asks the user the name of the input data file for LCC analysis; reads the input data from the specified file; prints the input data; calculates life-cycle costs for every strategy; performs the economic analysis using the specified option (PW or AE methods, or both) and the first set of interest and inflation rates; ranks the strategies in order of ascending discounted life-cycle costs using one of the seven specified options; prints the results; calculates life-cycle costs; ranks and prints results for the second and third sets of interest and inflation rates; and analyzes additional input data files before exiting, if desired by the user. The FORTRAN component of the LCC1 program calls several different subprograms to perform the pertinent analyses, rank and print the input data, and produce the final output.

APPLICATION

The LCC1 program has been used for life-cycle analysis of rigid and flexible pavement designs. Examples of the LCC analysis of alternatives for the rehabilitation of existing rigid pavements are presented here. Table 4 gives several design

TABLE 4 STRATEGY FOR LIFE-CYCLE ANALYSIS OF CONCRETE PAVEMENT REHABILITATION

Time	Activity
Bituminous Overlay	
1 year	Bituminous overlay (minimum 3 1/2 in.) saw and seal joints
	Adjust guide rail and drainage structures
	Type-7 paved shoulders
	Maintenance and protection of traffic
	User delay
5 years	Seal coat shoulders
	Clean and seal 25% of joints
10 years	1% full-depth patching
	60-psy scratch course
	1 1/2-in. ID-2 overlay, saw and seal joints
	Type-7 paved shoulders
	Adjust guide rail and drainage structures, if necessary
	Maintenance and protection of traffic
	User delay
15 years	Seal coat shoulders
	Clean and seal 25% of joints
20 years	1 1/2-in. cold milling (recycling)
	3% full-depth patching
	45-psy scratch course
	1 1/2-in. ID-2 inlay
	Seal coat shoulders
	Maintenance and protection of traffic
	User delay
25 years	Seal coat shoulders
	Clean and seal 25% of joints
30 years	Same as 20 years, except patching same as 10 years
35 years	Seal coat shoulders
	Clean and seal 25% of joints

TABLE 4 *continued*

Time	Activity
Concrete Pavement Restoration	
1 year	CPR (using restoration techniques)
5 years	Seal coat shoulders
	Clean and seal 25% of joints
10 years	Concrete patching—25% of initial quantity
	Spall repair—25% of initial quantity
	Subsealing—25% of initial quantity
	Grinding—25% of initial quantity
	Clean and seal 25% of joints
	Seal coat shoulders, if Type 6 or 7
	Maintenance and protection of traffic
	User delay
15 years	Seal coat shoulders, if Type 6 or 7
	Clean and seal 25% of joints
20 years	1% full-depth patching
	Clean and seal 25% of joints
	60-psy scratch course
	3 1/2-in. ID-2 overlay, saw and seal joints
	Type-7 paved shoulders
	Adjust all guide rail and drainage structures
	Maintenance and protection of traffic
	User delay
25 years	Seal coat shoulders
	Clean and seal 25% of joints
30 years	3% full-depth patching
	60-psy scratch course
	1 1/2-in. ID-2 overlay, saw and seal joints
	Type-7 paved shoulders
	Adjust guide rail and drainage, if necessary
	Maintenance and protection of traffic
	User delay
35 years	Seal coat shoulders
	Clean and seal 25% of joints
Cement Concrete Overlay	
1 year	Plain cement concrete overlay (using the Corps of Engineers method for design)
	Patch existing pavement
	Spall repair and grinding
	Concrete shoulder
	Adjust guide rail and drainage structures
	Maintenance and protection of traffic
	User delay
5 years	Clean and seal 25% of longitudinal joints, including shoulders
	Reseal 5% of roadway transverse joints, 0% if neoprene seals are specified
10 years	Concrete patching—10% of quantity as determined in Year 0 (based on field measurement)
	Spall repair—10% of quantity as determined in Year 0 (based on field measurement)
	Diamond grinding—10% of quantity as determined in Year 0 (based on field measurement)
	Clean and reseal 25% of longitudinal joints, including shoulders
	Reseal 10% of roadway transverse joints, 0% if neoprene seals are specified
	Maintenance and protection of traffic
	User delay
15 years	Clean and seal 25% of longitudinal joints, including shoulders
	Reseal 10% of roadway transverse joints, 0% if neoprene seals are specified
20 years	CPR project, same as 10 years except double patching, grinding, and sealing quantities
	Reseal 5% of transverse joints if neoprene seals are specified
25 years	Clean and seal 25% of longitudinal joints, including shoulders
	Reseal 10% of roadway transverse joints, 5% if neoprene seals are specified
30 years	2% full-depth patching
	Clean and seal all joints
	60-psy scratch course
	3 1/2-in. ID-2 overlay, saw and seal joints
	Type-7 paved shoulders
	Adjust all guide rail and drainage structures
	Maintenance and protection of traffic
	User delay

TABLE 4 *continued*

Time	Activity
Cement Concrete Overlay	
35 years	Seal coat shoulders Clean and seal 25% of joints
Reconstruction	
1 year	Reconstruction after removal of existing concrete pavement Maintenance and protection of traffic User delay cost
5 years	Clean and seal 25% of longitudinal joints, including shoulders Reseal 10% of roadway transverse joints, 0% if neoprene seals are specified
10 years	Same as 5 years
15 years	Clean and seal 25% of longitudinal joints, including shoulders Reseal 10% of roadway transverse joints, 0% if neoprene seals are specified
20 years	Concrete patching—2% of area Spall repair—0.5% of area Subsealing—25% of the joints, minimum Diamond grinding—100% of roadway Clean and seal 25% of longitudinal joints, including shoulders Clean and reseal all transverse joints Reseal 5% of roadway transverse joints if neoprene seals are specified Maintenance and protection of traffic User delay
25 years	Clean and seal 25% of longitudinal joints, including shoulders Reseal 10% of roadway transverse joints, 5% if neoprene seals are specified
30 years	2% full-depth patching Clean and seal all joints 60-psy scratch course 3 ½-in. ID-2 overlay, saw and seal joints Type-7 paved shoulders Adjust all guide rail and drainage structures Maintenance and protection of traffic User delay
35 years	Seal coat shoulders Clean and seal 25% of joints

NOTE: For high-volume roadways, the resurfacing interval should be reduced to between 5 and 8 years.

strategies for a new highway facility. Some important design and economic variables used in this analysis follow. The present worth analysis (user operating cost not considered) optimization code is 1 (all costs).

Location = rural
Lanes = four
Project length = 1 mi
Design strategies = four
Discount rate = 10.0%
Inflation rate = 4.0%
Base year for costs = 1985
Base year for analysis = 1986
Initial ADT = 10,000
Initial ADT year = 1985
Design year ADT = 15,000
Design year = 2005
Percentage trucks = 5%

A summary of results is shown in Figure 3.

SUMMARY AND RECOMMENDATIONS

The LCC1 microcomputer program is designed for detailed economic evaluation of an array of feasible strategies for design and rehabilitation of pavements. The program consists of BASIC and FORTRAN components and provides a user-friendly and flexible input data entry and modification subsystem. The LCC1 program is designed for execution on an IBM-PC or any compatible microcomputer.

The LCC1 program offers the options of using the present worth or the annual equivalent annuity method for economic evaluation. The LCC1 analyses can be performed at three different sets of interest and inflation rates. The provision of a comprehensive default data file and the ability of the user to examine the default values of various input variables before entering new values are other features. The program can be used to examine the cost-effectiveness of restoration alternatives compared with resurfacing or reconstruction alternatives for concrete pavement rehabilitation.

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LIFE CYCLE ANALYSIS FOR PAVEMENT MANAGEMENT DECISION MAKING

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

LCCI
SUMMARY OF RESULTS
USING OPTIMIZATION CODE 1

TITLE: TEST FILE 1 (PCC P. REHAB)
LOCATION: PENNSYLVNIA(EXAMPLE)
USER: WAHEED UDDIN

DATE: 05/20/86
DISCOUNT RATE: 10.00
INFLATION RATE: 4.00

RANK	1	2	3	4
STRAGEGY #	1	2	4	3
ANALYSIS PERIOD (YR)	40	40	40	40
PRESENT WORTH COSTS ($ ×1000)				
CONSTRUCTION	6.	4.	2.	123.
MAINTENANCE	87.	367.	63.	242.
REHABILITATION	383.	1319.	2113.	2250.
PERIPHERAL MAINT.	28.	22.	6.	34.
PERIPHERAL REHAB.	0.	0.	0.	0.
USER VEH. OPERATING	0.	0.	0.	0.
TRAFFIC DELAY	17.	54.	143.	46.
SALVAGE DUE EXTENDED LIFE	0.	0.	0.	-7.
PAVING MATERIAL SALVAGE	0.	-4.	-3.	-5.
TOTAL PRESENT WORTH	521.	1762.	2325.	2683.
ANNUAL EQUIV. ANNUITY ($)	34.	114.	150.	173.
RANK COSTS ($ ×1000)	521.	1762.	2325.	2683.

FIGURE 3 Summary of results generated by the LCC1 program.

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