A SYSTEM FOR LIFE-CYCLE DESIGN OF PAVEMENT

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Facility design and maintenance based on life-cycle cost analyses has been justified from economic and serviceability standards. The Armed Services Procurement Regulations acknowledges this by stating: "It is the policy of the Department of Defense to procure supplies and services from responsible sources at fair and reasonable prices calculated to result in the lowest ultimate overall cost to the Government".[1] To efficiently accommodate this guidance in pavement management activities, the Construction Engineering Research Laboratory (CERL) has developed a computerized system for performing life-cycle pavement analyses.

The purpose of this paper is to describe this system and exemplify its use relative to the life-cycle design of portland cement concrete (PCC) pavements.

LIFE2

The computerized life-cycle model developed at CERL has been designated LIFE2. As shown in Figure 1, LIFE2 is an integral part of a pavement management system. Other components of the management system are in various stages of development and implementation (see references 2, 3, 4, 5).

LIFE2 is a second generation digital computer program designed to provide life-cycle costs for alternative pavement design schemes and maintenance and repair strategies. The first generation program, LIFE1, was devised solely for military airfield pavements. LIFE2 embodies procedures for designing airfields, roads, and other paved areas.

SCOPE OF THE PROGRAM

Several analytical procedures are incorporated in the LIFE2 program as shown in Figure 2. These procedures generally follow the accepted Corps of Engineers criteria as published in the Department of the Army *Technical Manual* series.

The program provides the user three general options: design analysis, maintenance analysis, and life-cycle analysis.

Design Analysis

The design analysis generates alternative pavement construction schemes and determines the required component thicknesses for both rigid and flexible pavement designs. The solutions are then ranked by lowest estimated construction cost.

The design calculations provide the user with several options. The earthwork, drainage, and frost analyses can be performed by the program, circumvented by the user specifying a cost or quantity, or excluded completely. In addition, the program can be restricted to either flexible or rigid designs; if it is not, it will generate both types of designs. When designing rigid pavements, the user may input pavement stresses or have the program perform these calculations. Tradeoff between base thickness and slab thickness is also optional in rigid designs. When designing flexible pavements, the user may specify the combinations of layers desired or have the program use the input materials to generate all combinations. In the design calculations, the computed thicknesses are assumed to provide a pavement that will remain serviceable for the entire design life.

Maintenance Analysis

The maintenance analysis considers the overlay requirements for an existing pavement, the maintenance and repair (M&R) activities and costs, and the associated user costs. The various maintenance strategies are then ranked by their total discounted costs (i.e., the costs are discounted to present worth in the first year of the strategy).

The principal options provided to the user with the maintenance calculations are the overlay restriction and the method of computing maintenance costs. The program can be restricted to design either flexible or rigid overlays; if it is not, it will select the optimal type for each time of overlay. Maintenance costs can be specified by cost curves for individual activities or by a cost curve for a single parameter which includes all M&R activies.

Life-Cycle Analysis

Life-cycle calculations combine the design and maintenance procedures. The design schemes for each overlay strategy have service lives equal to the number of years before placement of the first overlay. Rigid and flexible life-cycle designs are saved separately and ranked by total adjusted cost (i.e., construction cost plus the total of all discounted M&R costs).

FORMAT OF THE PROGRAM

LIFE2 is written in FORTRAN Extended for CDC 6000 series computers and is currently used in a remote batch mode. The program is available on computer cards or magnetic tape.

Input data is entered using free-format. A program included in LIFE2 (called SCAN [6])enables the computer to identify specific words or word strings. Thus, on the input cards, the user enters the appropriate name of an input variable followed by its value in any format. This free-form style makes data input as convenient and error-free as possible. The example given later in this paper illustrates the free-form input data.

To facilitate program modification, reduce required computer memory storage, and efficiently accommodate the diverse analytical procedures, LIFE2 utilizes a modular framework. This framework is illustrated in Figure 3. Each module is essentially a program in itself. Through user input, the main program (Module 0) selects and processes the necessary analytical procedures.

In addition to the input data and program software, the operation of LIFE2 requires the characteristics of the design vehicles. This information is derived through interaction with a vehicle data bank. This data bank is machine stored and contains information relating to a vehicle's gross load, weight per gear for airfields or axle load for roads, tire contact area, and other data required for either rigid or flexible pavement design.

Detailed information concerning input variables and program operation is in Reference 7. Inquiries regarding LIFE2 may be addressed to: The Military and Base Operations Branch, Facility Operations Division, U.S. Army Construction Engineering Research Laboratory, P.O. Box 4005, Champaign, Illinois 61820.

METHODOLOGY

This section summarizes the methodology employed in LIFE2 for performing life-cycle analyses of portland cement concrete pavements.

Design Procedures

Procedures for designing plain portland cement pavements for airfields and for roads are included in LIFE2. The procedures model accepted Corps of Engineers criteria with slight modifications necessitated by computerization or application to life-cycle analysis.

The procedure for designing airfield pavements is as follows:

1. A set of maximum tensile bending stresses are calculated for each aircraft. Each set consists of 10 stresses produced by analyzing an edge-loading condition for 10 thicknesses of slab. The analysis uses a computerized version of the Westergaard elastic-plate-on-a-liquid-subgrade theory [8]. The thicknesses are determined by dividing a range of thickness specified by the user into 10 equal parts.

2. The ratio of concrete flexural strength to the maximum edge stress is defined as the Design Factor (DF). Using the edge stresses calculated in step 1, DFs are determined for each aircraft at each of the 10 thickness levels. From the fatigue curve shown in Figure 4, the number of coverages of the aircraft being considered, which would produce initial failure in a plain concrete pavement, is determined for each slab thickness. This produces an array of coverages-to-failure vs. slab thickness for each aircraft.

3. Mixed traffic is accounted for by enforcing Miner's rule as follows:

$$\sum_{i=1}^{N} \frac{(\text{actual coverages})i}{(\text{coverages to failure})i} = 1$$

where: i designates a particular aircraft
N is the number of aircraft considered.

The actual coverages for each of the i = 1, N aircraft are derived from estimated traffic volumes. The traffic volumes are summed for the time being considered and converted to coverages by an empirically determined pass-to-coverage ratio. The mixed traffic coverages to failure are determined by interpolation of the thickness vs. individual coverages-to-failure relationship produced in step 2. This computation can be performed at user-specified times; otherwise, the program divides the design life of the pavement into six periods and performs the computation for each. The ultimate result is a thickness vs. time relationship for the total traffic being considered.

4. The slab thickness required to provide a serviceable pavement to the time of the planned first overlay can then be determined using the thickness vs. time relationship established in step 3.

5. A tradeoff between the slab and base course thicknesses is then performed. For various base thicknesses, an effective k (subgrade modulus of reaction) is determined. The required slab thickness for each base thickness and effective k is then calculated.

6. Thickness constraints resulting from minimum thickness and frost protection criteria are applied to each design scheme.

7. The resulting schemes are evaluated by cost, and one optimal design is retained.

8. The program returns to step 4 and analyzes each overlay strategy.

The procedure for designing roadway pavements is as follows:

1. A slab thickness for 5000 coverages is found by using information from Figure 5.

2. Design traffic is specified by a Design Index ranging from 1 to 10. The Design Index is converted to 18,000-lb equivalent single-axle loads (ESAL) and this quantity equated to coverages.

3. Using Figure 6 and the number of coverages determined in step 2, a percent of design thickness is found. The slab thickness required for the design traffic is produced by multiplying the thickness for 5000 coverages (step 1) by this percentage.

4. The remainder of the analysis uses steps 5, 6, 7, and 8 of the airfield analysis.

Overlay Design

The program considers partially bonded and unbonded PCC overlays as well as flexible overlays of existing PCC pavements. For partial bonding, the overlay thickness is determined by:

$$h_o = 1.4\sqrt[1.4]{h_d^{1.4} - Ch^{1.4}}$$

where: h_o = required overlay thickness in inches.

h_d = the required slab thickness for the predicated traffic during the overlay's service life. This thickness is calculated by the procedure used to design new pavements as discussed in the previous section.

C = a coefficient used to classify the condition of the existing PCC pavement.
- C = 1.00 for good condition (i.e., little or no structural cracking in slabs).
- C = 0.75 for initial failure (i. e., slabs show initial cracking due to loading, but little or not multiple cracking).
- C = 0.50 for shattered slabs (i.e., a larger number of slabs show multiple cracking, but the majority are intact or contain only single cracks).
- C = 0.35 for complete failure (i.e., the majority of slabs show multiple cracking).

h = the existing pavement slab thickness in inches.

For unbonded overlays, the formula used is :

$$h_o = \sqrt{h_d^2 - Ch^2}$$

Where h_o, h_d, C, and h are defined as above.

For a flexible overlay, the thickness is computed by:

$$t = 2.5\ (F\ h_d - Ch)$$

Where: t = flexible overlay thickness in inches
- F = a transformation factor based on the anticipated traffic and the modulus of subgrade reaction.
- C as defined previously except flexible overlays will not be used when slabs are considered in a complete failure condition and:
  - C = 1.00 for good condition and for initial failure,
  - C = 0.75 for shattered slabs.
- h_d and h are as defined previously.

The time of overlay placement is stipulated by the user. The service life traffic, that between succeeding overlays, is calculated in the manner described in the preceeding section. At each time of overlay, the least expensive overlay (partial bond, unbonded, or flexible) is used. The program can consider up to nine overlay strategies during each run. For example: strategy 1--might be no overlays; strategy 2--overlays at 7 and 14 years; strategy 3--overlays at 5, 10, and 15 years; and so on.

In the maintenance option, the program always begins by determining if an overlay is required in year one. If so, an overlay is included. The program then continues with the analysis of strategies input by the user.

Maintenance Costs

LIFE2 provides two alternative procedures for incorporating maintenance activities in the life-cycle analysis.

The first procedure employs user cost estimates for five maintenance activities: repairing scaling and popouts; sealing joints and cracks; replacement of slabs; cleaning and sweeping; and maintaining drains. Two additional categories, other maintenance and other repairs, are also included to provide the user with a capability of estimating activities not specifically mentioned. The individual methods used to estimate costs for these activities are described below. All of these methods were derived during a previous study of maintenance costs [9].

Repairing Scaling and Popouts. The cost for this activity is estimated using the following relationship:

$$\text{Cost} = A(1.0 + \frac{B-4}{22})C$$

Where: A = the present cost/sq. yd. for repairing scaling and popouts. This is input by the user.

B = the year during the service life which is being considered. B is reset to zero at each overlay

C = the pavement area in sq. yd.

Sealing Joints and Cracks. The user estimates the cost for this activity by specifying the cost/sq. yd. and the time period between applications. Time is reset to zero at each overlay.

Replacement of Slabs. The periodic cost of replacing slabs is calculated by the product of the pavement thickness, the total pavement area, a yearly factor, and a cost/sq. yd./in. input by the user. The yearly factors used are:

Year in ServiceLife	4	6	8	10	12	14	16	18	20	22	24
Factor	.04	.13	.28	.31	.51	.99	1.16	1.41	1.21	.88	.41

These factors essentially represent the percent of the total area which would require replacement during the year specified. Time is reset to zero at each overlay.

Cleaning and Sweeping. The cleaning and sweeping operations are estimated by the product of the year in the service life, the total pavement area, and the cost/sq. yd. input by the user. Thus, the cost of this activity is a linear progression during the service life. Time is reset to zero at each overlay.

Maintaining Drains. The cost for this activity is estimated the same as for sealing cracks and joints.

Other Maintenance. The cost of any other maintenance activities can be estimated using this variable. The estimating procedure follows that for sealing cracks and joints.

Other Repairs. This variable provides the user with the capability of accounting for repairs other than those specifically listed. The cost estimate is input by the year in which the cost is incurred followed by a lump sum dollar amount.

Since a cost estimate for total M&R is at times more accessible than an individual cost break down, the alternative procedure allows the user to specify a cost-time function for the total anticipated M&R of the section. A cost curve is stipulated for each type of construction ---PCC pavement, PCC overlay, and flexible overlay.

In addition to cost estimates for M&R activities, LIFE2 also considers delay costs incurred by the user due to closing of the facility during overlayment and vehicle maintenance costs caused by roughness, slipperiness, or structural failure.

All of the above mentioned maintenance costs are estimated for each year during the design life. The costs are then discounted back to present worth in the first year for each life-cycle strategy analyzed.

Other Options

The LIFE2 program also provides the capability of performing an earthwork analysis and subsurface drainage design for each pavement design scheme examined. The earthwork analysis results in cut and fill quantities, a mass diagram, and cost estimates which are directly dependent on the pavement thickness design. The subsurface drainage analysis determines when underdrains are necessary and provides quantity and cost estimates where applicable. This cost is considered in the life-cycle analysis since, by Corps criteria, some pavement thicknesses will require drainage while others will not for the same site.

Life-Cycle Analysis

At the user's perogative, any or all of the above procedures are combined in the life-cycle analysis. The result is a ranking of all acceptable combinations of design schemes and maintenance strategies by total discounted cost over the structure's design life. This life-cycle analysis is exemplified in the following section.

LIFE2 EXAMPLE

LIFE2 was used in the preliminary pavement design analysis for a tank hardstand. Due to the use of this facility, a plain PCC slab type of pavement was selected. Figure 7 is the program output for one design scheme and one maintenance strategy. Figure 8 summarizes the life cycle analyses for four alternatives. Note that case 2 provides a 3.6 percent ($71,078) savings over a design scheduled to last the entire design life.

LIFE2 IMPLEMENTATION

LIFE2 is an implementable tool which can aid the pavement engineer in:

1. Developing an economical pavement design based on construction costs;
2. Determining an economical maintenance and repair strategy based on costs incurred to keep a facility functional throughout its service life;
3. Developing an economical pavement design based on life-cycle costs which account for initial construction, maintenance, and repair costs throughout the facility's life.

LIFE2 Service Test

As a first step to full implementation of the computerized LIFE2 system, a service test was conducted at a U. S. Army Corps of Engineers, District Office. Three separate pavement projects were selected for analysis using LIFE2. The first project was used as a demonstration with CERL performing the analysis and the District reviewing the results. The second analysis was a joint effort of CERL and District personnel. The third project was designed by District personnel with CERL reviewing the results.

By proceeding in this manner, the District personnel were trained in the use, advantages, and limitations of the LIFE2 system. In addition, experience gained during the service test has served to validate program logic, or indicate where modifications were required. The test also served to demonstrate the capability of operating the program from a remote site via a telephone interface with a central computer.

Based on the results of the service test, and projected annual expenditures for paved areas, it has been estimated that an annual savings of approximately $2,000,000 could accrue by using life-cycle analysis rather than designing pavements

on least initial cost.

Future Work

During FY 77, CERL effort on the LIFE2 system will include:

1. Examine the possibility of incorporating in LIFE2 procedures for designing reinforced portland cement concrete pavements based on Corps of Engineers criteria;

2. Improve M&R cost estimating procedures based on data from military installations;

3. Revise program logic as changes in Corps criteria are approved (frost, drainage, and flexible pavement design procedures are presently under review);

4. Prepare training and operation manuals for implementation of LIFE2 at Corps of Engineer District Offices.

ACKNOWLEDGEMENT

The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the U. S. Army Construction Engineering Research Laboratory.

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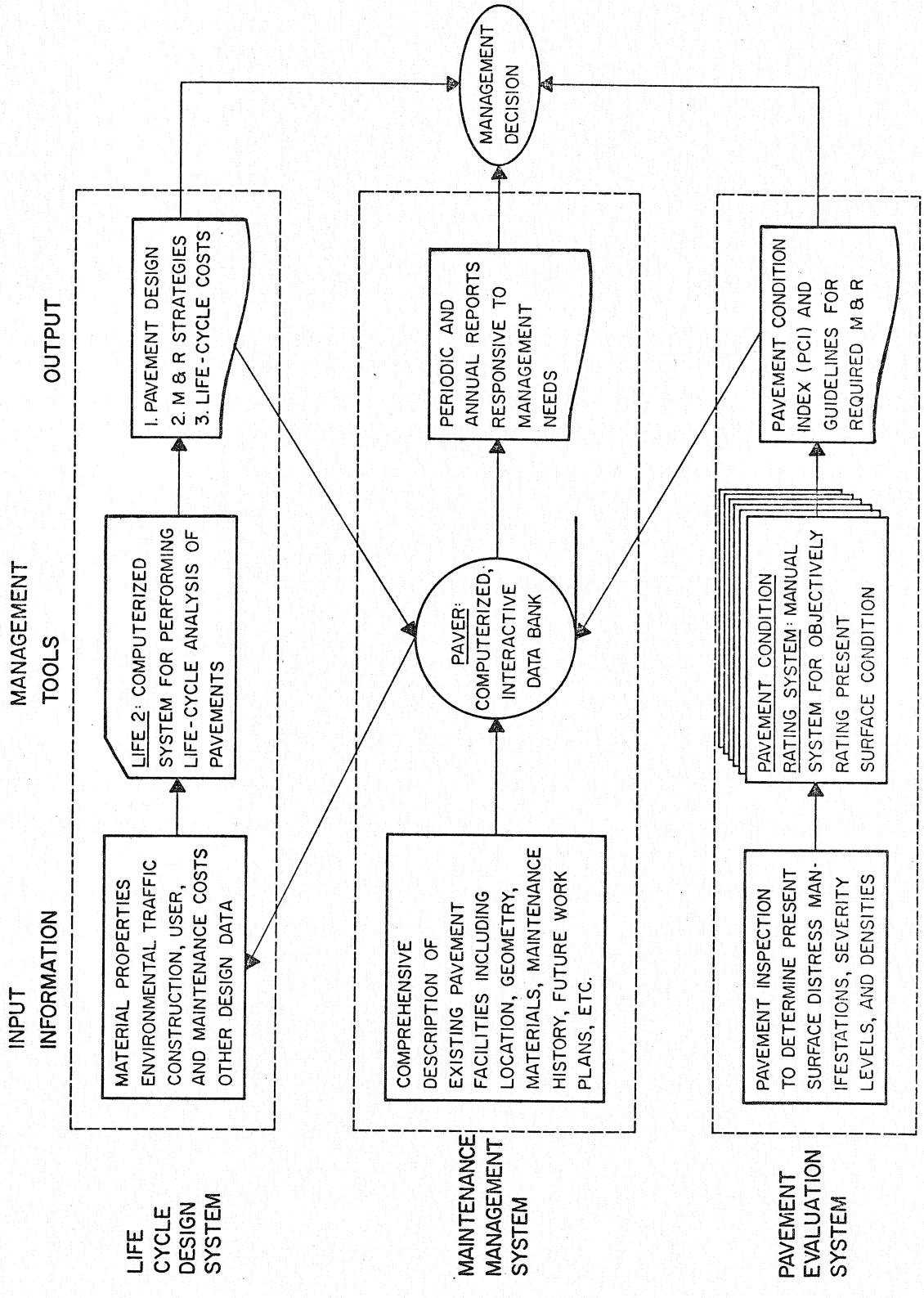


FIGURE 1. Pavement Management System Framework.

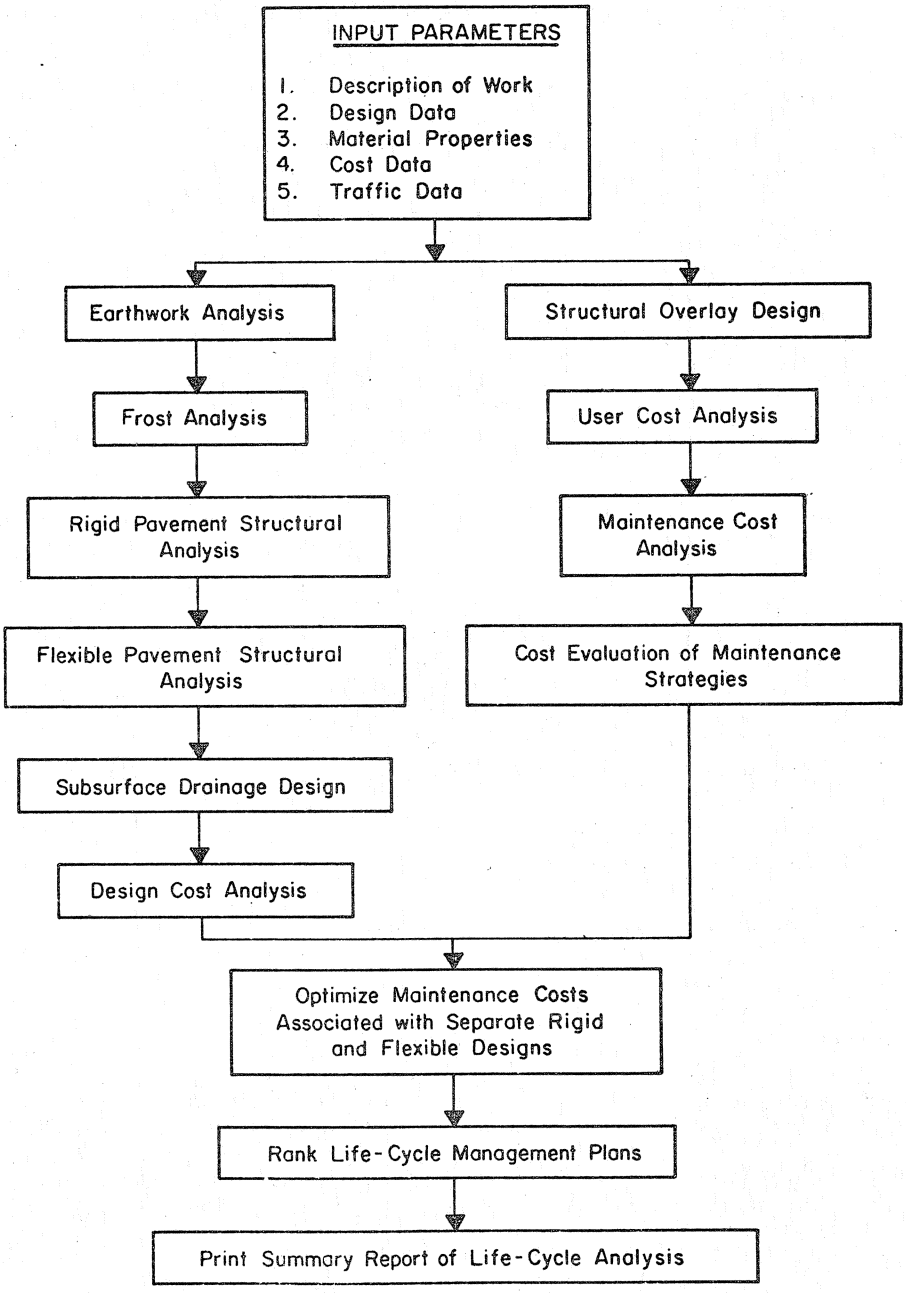


FIGURE 2. Summary of Analytical Procedures in LIFE2 (both Airfield and Roadway Pavements are Considered).

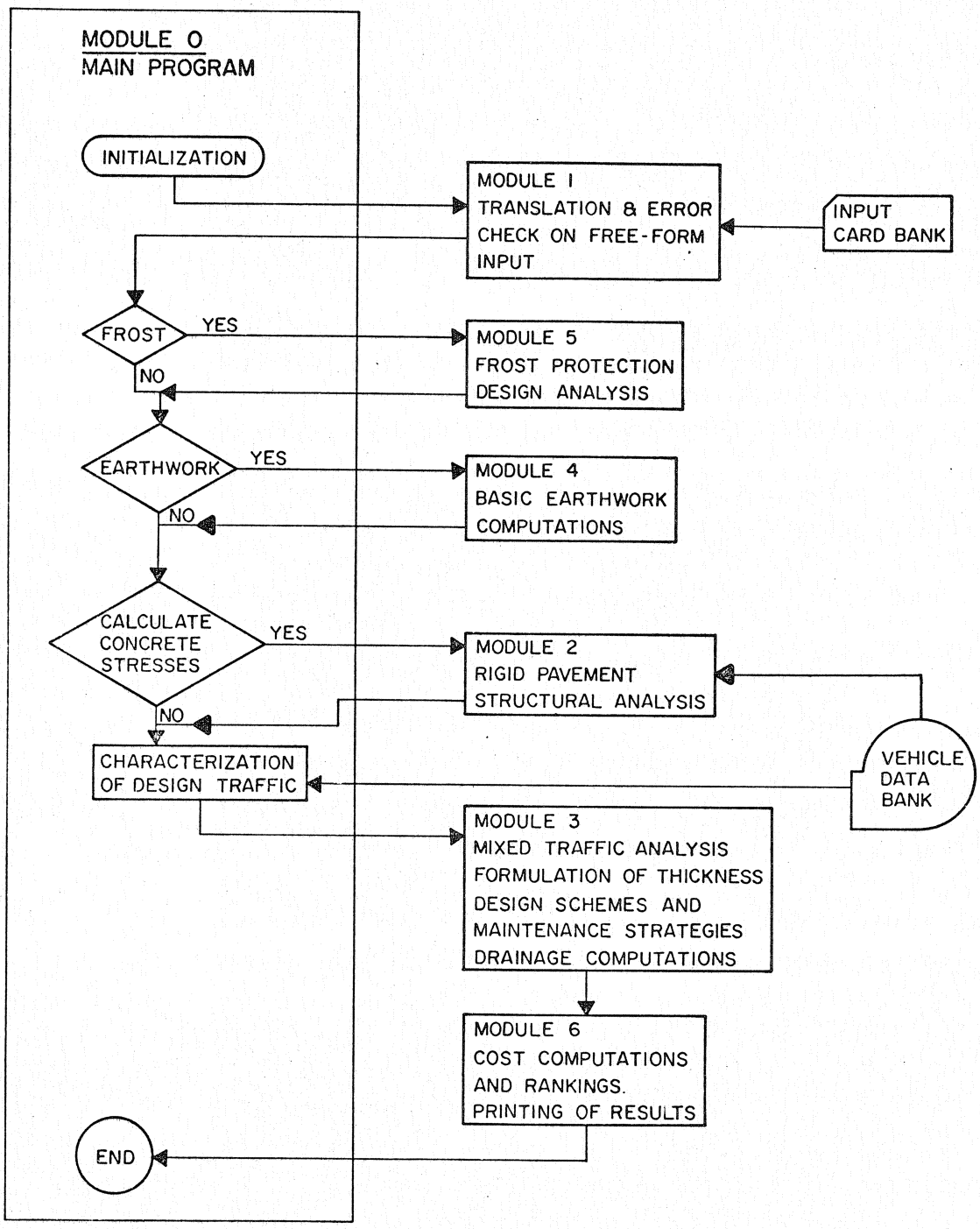


FIGURE 3. Framework of LIFE2 Modules.

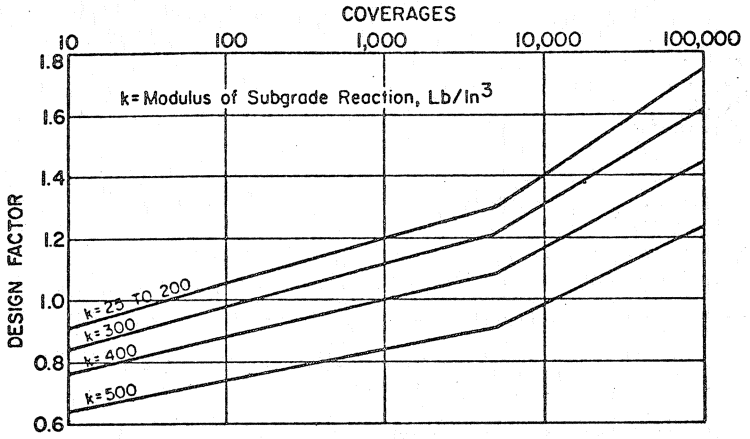


Figure 4. Coverages to Failure Curve for Rigid Pavement. [10]

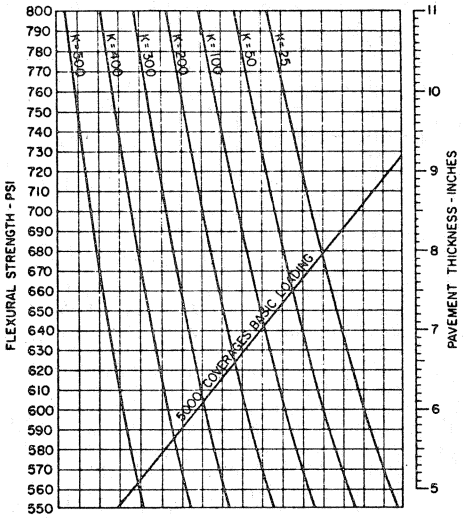


Figure 5. Design Curves for Rigid Pavements Based on 18,000 lb. Single Axle Loads (Dual Wheels - 13.5 "X 58.5" X 13.5"). [11]

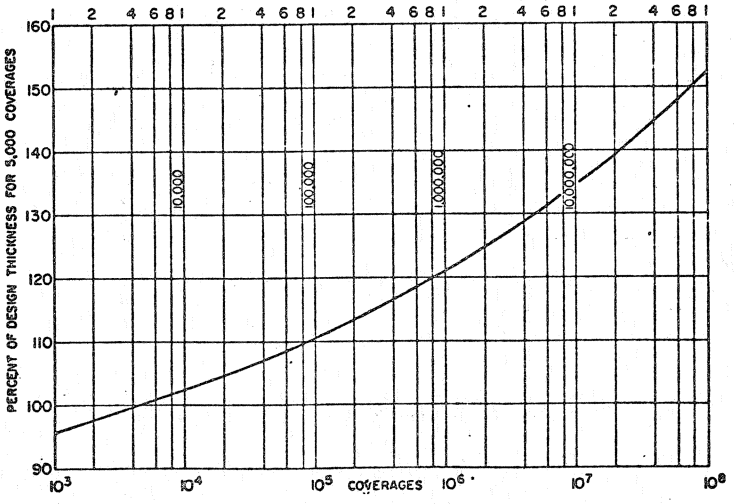


Figure 6. Coverages vs. Rigid Pavement Thickness. [11]

Input Data

```
NAME.OF.BASE "          "
LOCATION.OF.BASE "      "
GENERAL.DESCRIPTION "TANK HARDSTAND"
IDENTIFICATION.NUMBER "TRIAL 1"
CALCULATION.TYPE LIFE.CYCLE
DESIGN.LIFE 25
LENGTH.OF.SECTION 3000.
WIDTH.OF.SECTION 399.414
EARTHWORK 167750
RANGE.OF.THICKNESS 6 25
DESIGN.RESTRICTION RIGID
BASE.TRADEOFF TRADEOFF
GRANULAR.BASE.MATERIAL WGCM
CLIMATE NORMAL
BONDING BOTH
INITIAL.FAILURE YES
TIMES.OF.OVERLAYS
STRATEGY 1
STRATEGY 2 15
OVERLAY.RESTRICTION FLEXIBLE
MINIMUM.THICKNESS.RIGID.OVERLAY 4
MINIMUM.THICKNESS.FLEXIBLE.OVERLAY 1
FLEXIBLE.PAVEMENT.MATERIAL.PROPERTIES
BASE 1 80
SUBGRADE.MODULUS 300
SUBGRADE.CBR 5
SUBGRADE.DENSITY 90
SUBGRADE.COHESION.INDEX COHESIVE FS
CONCRETE.FLEXURAL.STRENGTH 650
DISCOUNT 0.10
ESCALATION.RATE 0.0625
GEOGRAPHIC.FACTOR 1.0
  FLEXIBLE.PAVEMENT.BASE  1  "CBR=80"  1  .23  20  4.58
FLEXIBLE.PAVEMENT  1  .36  10  3.62
RIGID.PAVEMENT.BASE  1  .23  20  4.58
RIGID.PAVEMENT  1  1.14  20  22.78
RIGID.OVERLAY.PARTIAL.BOND 1 1.20 10 12.00
RIGID.OVERLAY.UNBONDED 1 1.22 10 12.10
FLEXIBLE.OVERLAY 1 .85 10 8.50
ROUTINE.MAINTENANCE RIC 1 0 10 0
ROUTINE.MAINTENANCE FIC 1 0 10 0
ROUTINE.MAINTENANCE FOS 1 0 10 0
 MAINTENANCE.COST.ANALYSIS YES
SEAL.JOINTS.CRACKS.RIGIDPAVEMENT .24 10
CLEANING.SWEEPING.RIGIDPAVEMENT .01
CLEANING.SWEEPING.FLEXIBLE.PAVEMENT .01
SURFACE.TREATMENT.FLEXIBLE.PAVEMENT 0.20
VEHICLE.TYPE  ROAD-LOAD
DESIGN.INDEX 9
CLASS.OF.ROAD A
END OF INFORMATION
```

FIGURE 7. Example of LIFE2 Output.

REQUIRED THICKNESS OF PROTECTION VERSUS SERVICE LIFE RELATIONSHIP FOR FLEXIBLE PAVEMENT MATERIALS WITH CBR=5 USED IN THIS RUN

	SERVICE LIFE					
CBR	1.	5.	10.	15.	20.	25.
5.	24.8	27.2	28.2	28.8	29.2	29.5
80.	1.0	1.0	1.0	1.0	1.0	1.0
100.	1.0	1.0	1.0	1.0	1.0	1.0

TOTAL FLEXIBLE PAVEMENT THICKNESS VERSUS SERVICE LIFE RELATIONSHIP FOR THE SUBGRADE CBR USED IN THIS RUN

	SERVICE LIFE					
CBR	1.	5.	10.	15.	20.	25.
5.	24.8	27.2	28.2	28.8	29.2	29.5

RIGID PAVEMENT THICKNESS(PCC) VERSUS SERVICE LIFE RELATIONSHIP FOR THE SUBGRADE MODULUS(K) USED IN THIS RUN

	SERVICE LIFE					
SUBGRADE MODULUS	1.	5.	10.	15.	20.	25.
300.	7.3	7.9	8.2	8.4	8.6	8.7

RIGID CONSTRUCTION COST ANALYSIS FOR SCHEME 1 ASSOCIATED WITH OVERLAY STRATEGY 1

LAYER NO	DESCRIPTION	THICKNESS(IN)	COST/SY	TOTAL COST
1	RIGID PAVEMENT	8.0	9.11	1213237.54
2	RIGID PAVEMENT BASE	8.0	1.83	243992.90
TOTAL THIS SECTION		16.0	10.95	$ 1457230.45

TOTALS FOR ALL SECTIONS	AREA = 133138 SY	COSTS = $ 1457230.45
EARTHWORK COSTS		$ 167750.00
DRAINAGE COSTS		$ 0.00
TOTAL ALL CONSTRUCTION		$ 1624980.45

FIGURE 7. Continued.

SUBOPTIMIZED SOLUTION FOR OVERLAY STRATEGY 1

YR	MAINTENANCE COST	OVERLAY THICKNESS(IN)	OVERLAY COST	USER COSTS	TOTAL COST	ADJUSTED COST
1	1331.38		0.00	0.00	1331.38	1291.04
2	2662.76		0.00	0.00	2662.76	2503.83
3	3994.14		0.00	0.00	3994.14	3641.93
4	7508.98		0.00	0.00	7508.98	6639.35
5	8048.80		0.00	0.00	8048.80	6900.99
6	12209.96		0.00	0.00	12209.96	10151.51
7	10832.59		0.00	0.00	10832.59	8733.43
8	18189.07		0.00	0.00	18189.07	14219.98
9	13616.39		0.00	0.00	13616.39	10322.53
10	53565.05		0.00	0.00	53565.05	39376.93
11	16400.18		0.00	0.00	16400.18	11690.82
12	28656.14		0.00	0.00	28656.14	19808.43
13	19183.98		0.00	0.00	19183.98	12859.00
14	41664.93		0.00	0.00	41664.93	27081.66
15	21967.77		0.00	0.00	21967.77	13846.07
16	48070.08		0.00	0.00	48070.08	29379.98
17	24751.56		0.00	0.00	24751.56	14669.50
18	56179.39		0.00	0.00	56179.39	32286.86
19	27535.36		0.00	0.00	27535.36	15345.30
20	86655.89		0.00	0.00	86655.89	46829.43
21	30319.15		0.00	0.00	30319.15	15888.17
22	50456.88		0.00	0.00	50456.88	25639.72
23	33102.95		0.00	0.00	33102.95	16311.56
24	43228.70		0.00	0.00	43228.70	20655.57
25	1331.38		0.00	0.00	1331.38	616.88
TOTALS	$ 661463.47	0	$ 0.00	$ 0.00	$ 661463.47	$ 406690.44

THIS STRATEGY IS APPROPRIATE FOR USE WITH A RIGID DESIGN

F OR R REPRESENTS FLEXIBLE OR RIGID OVERLAYS

A NUMBER IN PARENTHESES FOLLOWING FLEXIBLE IS THE THICKNESS OF BASE MATERIAL IN THE OVERLAY SYSTEM

FOR RIGID, P IN PARENTHESES MEANS PARTIAL BOND AND U MEANS UNBONDED

MAINTENANCE COSTS STRATEGY 1

(PORTLAND CEMENT CONCRETE)

YR	REPAIR SCALING AND POPOUTS	SEALING JOINTS AND CRACKS	REPLACEMENT OF SLABS	CLEANING AND SWEEPING	MAINTAIN DRAINS	OTHER MAINTENANC	OTHER REPAIRS	TOTAL
1	0.	0.	0.	1331.	0.	0.	0.	1331.
2	0.	0.	0.	2663.	0.	0.	0.	2663.
3	0.	0.	0.	3994.	0.	0.	0.	3994.
4	1331.	0.	852.	5326.	0.	0.	0.	7509.
5	1392.	0.	0.	6657.	0.	0.	0.	8049.
6	1452.	0.	2769.	7988.	0.	0.	0.	12210.
7	1513.	0.	0.	9320.	0.	0.	0.	10833.
8	1573.	0.	5965.	10651.	0.	0.	0.	18189.
9	1634.	0.	0.	11982.	0.	0.	0.	13616.
10	1694.	31953.	6604.	13314.	0.	0.	0.	53565.
11	1755.	0.	0.	14645.	0.	0.	0.	16400.
12	1816.	0.	10864.	15977.	0.	0.	0.	28656.
13	1876.	0.	0.	17308.	0.	0.	0.	19184.
14	1937.	0.	21089.	18639.	0.	0.	0.	41665.
15	1997.	0.	0.	19971.	0.	0.	0.	21968.
16	2058.	0.	24710.	21302.	0.	0.	0.	48070.
17	2118.	0.	0.	22633.	0.	0.	0.	24752.
18	2179.	0.	30034.	23965.	0.	0.	0.	56179.
19	2239.	0.	0.	25296.	0.	0.	0.	27535.
20	2300.	31953.	25776.	26628.	0.	0.	0.	86656.
21	2360.	0.	0.	27959.	0.	0.	0.	30319.
22	2421.	0.	18746.	29290.	0.	0.	0.	50457.
23	2481.	0.	0.	30622.	0.	0.	0.	33103.
24	2542.	0.	8734.	31953.	0.	0.	0.	43229.
25	0.	0.	0.	1331.	0.	0.	0.	1331.

TOTAL MAINTENANCE COST OF THE STRATEGY 1 IS $ 661463.

TOTAL DISCOUNT MAINTENANCE COST OF THE SAME STRATEGY IS $ 406690.

FIGURE 7. Continued.

Figure 8 TANK HARDSTAND
LIFE CYCLE SUMMARY

CASE	CONSTRUCTION COST*	OVERLAY DESIGN AND COST+	DISCOUNTED MAINTENANCE COST	DISCOUNTED TOTAL COST	PERCENT DIFFERENCE
1. Rigid Pavement - 8 in. Base Course - 8 in. 16 in.	$1,624,980	No Overlay	$406,690	$2,031,671	3.6%
2. Rigid Pavement - 8 in. Base Course - 4 in. 12 in.	$1,503,054	Flexible Overlay: 15th Year - 3 in. - $339,502	$243,554	$1,960,592	----
3. Rigid Pavement - 8 in. Base Course - 4 in. 12 in.	$1,503,054	Rigid Overlay, Partial Bond: 15th Year - 4 in. - $645,276	$247,381	$2,157,146	10%
4. Rigid Pavement - 8 in. Base Course - 4 in. 12 in.	$1,503,054	Rigid Overlay, Partial Bond: 10th Year - 4 in. - $645,276	$221,161	$2,198,572	12%

*The thickness design in all four cases is predicated on construction over a 4% lime-stabilized subgrade (K = 300 psi). An earthwork cost of $167,750 is included in the construction cost to cover this layer.

+Overlay costs are included in discounted maintenance cost.