Lecture #6:

◎ Pavement Management Process
(Haas, Chapter 4-5)
- Pavement Management Levels and Functions
- Using PMS as a Research Planning and Technology Improvement Tool

◎ Pavement Management Levels & Functions

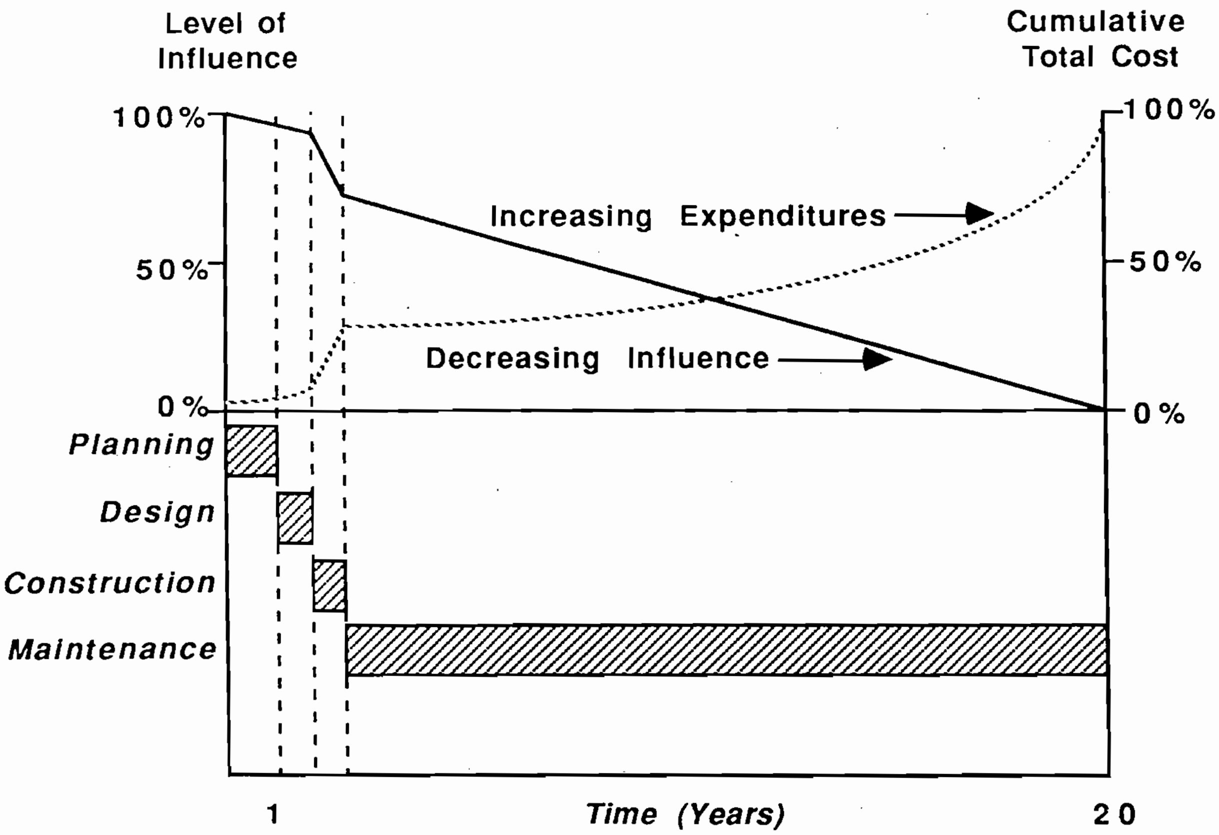
※Influence Levels of PMS Compenents
Network-level Needs: Selecting "Candidate" Projects, "Not Enough Funding" as Always

※Project Level, Project Selection Level, Program Level (Network): Detail of Information, Complexity of Models

※PMS Functions: Historical Data Base, Information Flows (i.e., Information, Analysis, Implementation Subsystems)

※Information Flows

1. Network Level: Information (Periodic Updates), Network Analysis (Program Decision Criteria & Budget Constraints), Implementation, Interface Between Network Level & Overall Transportation System Management



'igure 4.2 Influence level of PMS subsystems on the total costs.

maining level of influ...

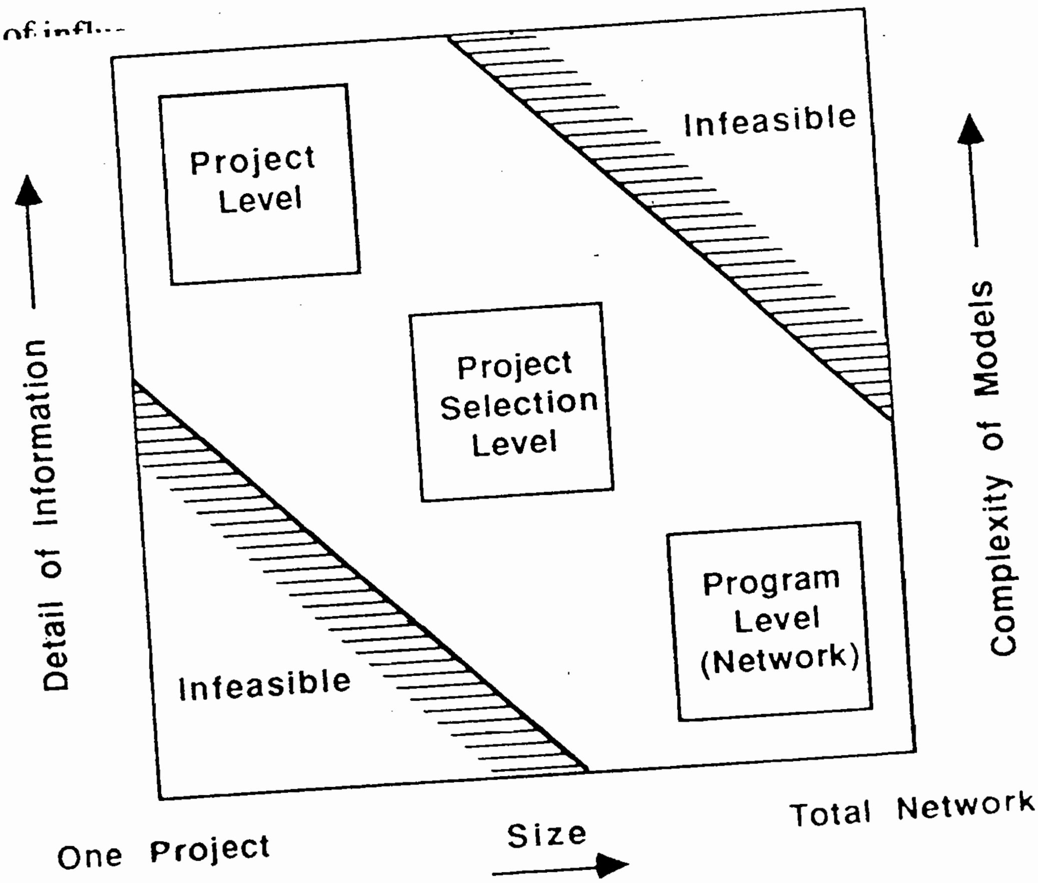


Figure 4.3 Information detail and complexity of models for a three level PMS.

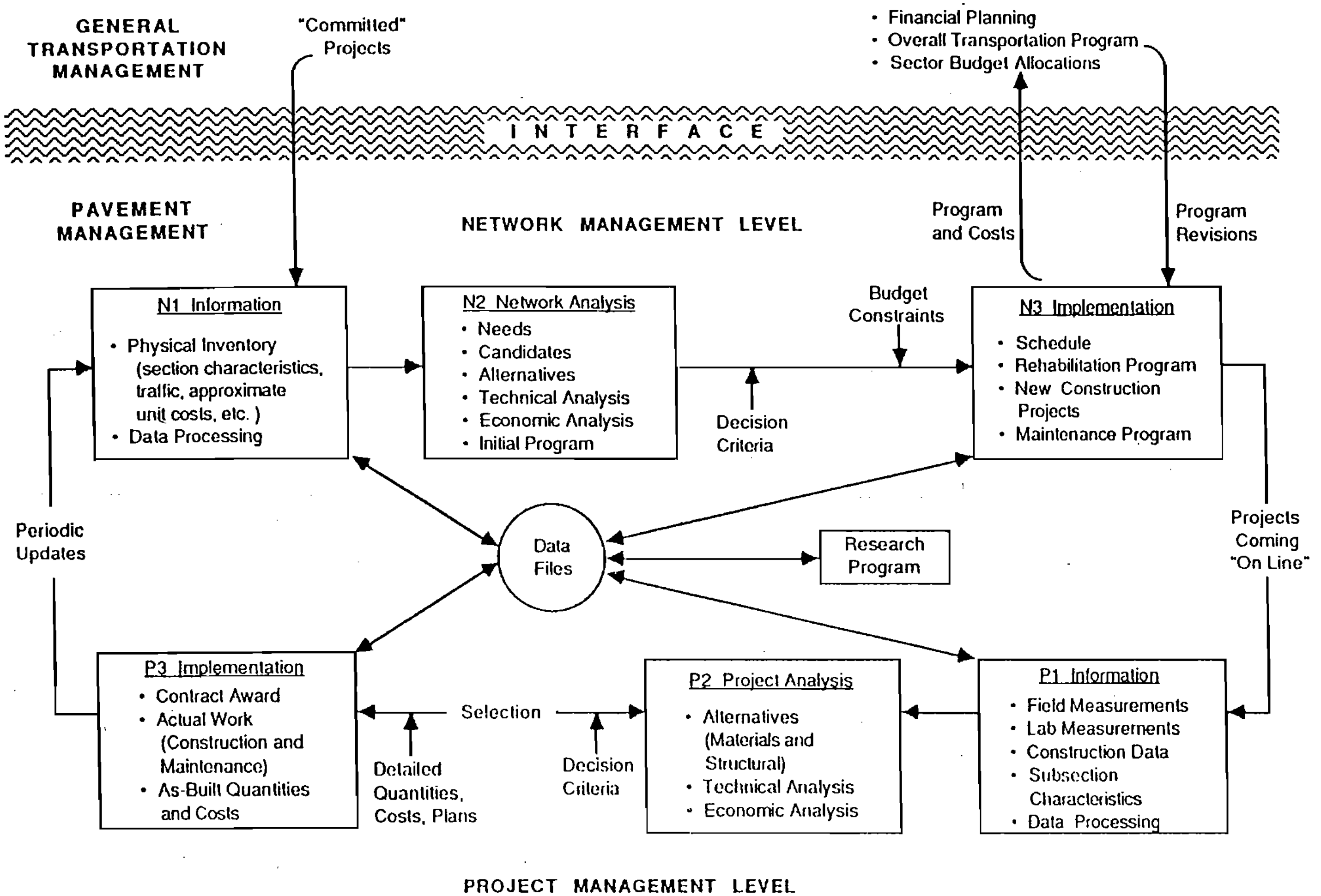


Figure 4.4 Information flows in a pavement management system. [Hudson 79].

2. Project Level: Porjects Coming On-Line from Network Implementation, Information, Analysis (Decision Criteria & Selection), Detailed Quantities & Costs & Plans, Implementation, Data Files & Research Programs

※Key Considerations in Application of a Total PMS Concept (Precise, Flexibility, People, Effective in Technical & Economic & Others, Interface, Maintenance Management)

※Function of Pavement Evaluation

Major Types of Outputs: Structural Adequacy, Performance, Surface Distress, Safety, (and Maintenance Cost & User Cost for Economic Analysis)

※Distress vs. Performance

Distress => Limiting Response or Damage

Performance => Serviceability History, Time-Related Accumulation of Data

※User-Related vs. Engineering Evaluation

1. Functional Behavior => e.g., PSR
2. Structural Behavior => e.g., PCI

※Pavement Evaluation w.r.t. User Costs

Table 4.1 Steps in the Highway Programming Process [TRB 78]

1. Project initiation
   (a) technical sources
   (b) nontechnical sources
2. Initial listing
   (a) headquarters
   (b) district
   (c) county
3. Preliminary analysis
   (a) available data and analyses
   (b) planning report
4. Combined listing, first draft
5. Advanced analysis and prioritizing
   (a) technical prioritizing
      (1) sufficiency ratings
      (2) priority ratings
      (3) option-evaluation techniques
      (4) input from other agencies
   (b) nontechnical prioritizing
      (1) political commitments
      (2) legislative mandate
      (3) emergency
      (4) special emphasis
      (5) commitments to other agencies
      (6) system continuity-connectivity
      (7) position in pipeline
   (c) feedback from project planning and development
      (1) development of alternatives/joint development
      (2) environmental analysis
      (3) community and technical interaction
      (4) input from other agencies
6. Combined listing, second draft
7. Financial analysis
   (a) categorical grants
   (b) geographical distribution
   (c) fiscal-year fund projections
   (d) manpower analysis
   (e) financial modifications
8. Preliminary program (projects vs. projected allocations)
9. Executive session
10. Short-range program, first draft
11. Executive and legislative review
12. Short-range program, final draft
13. Scheduling
14. Monitoring
15. Modifying

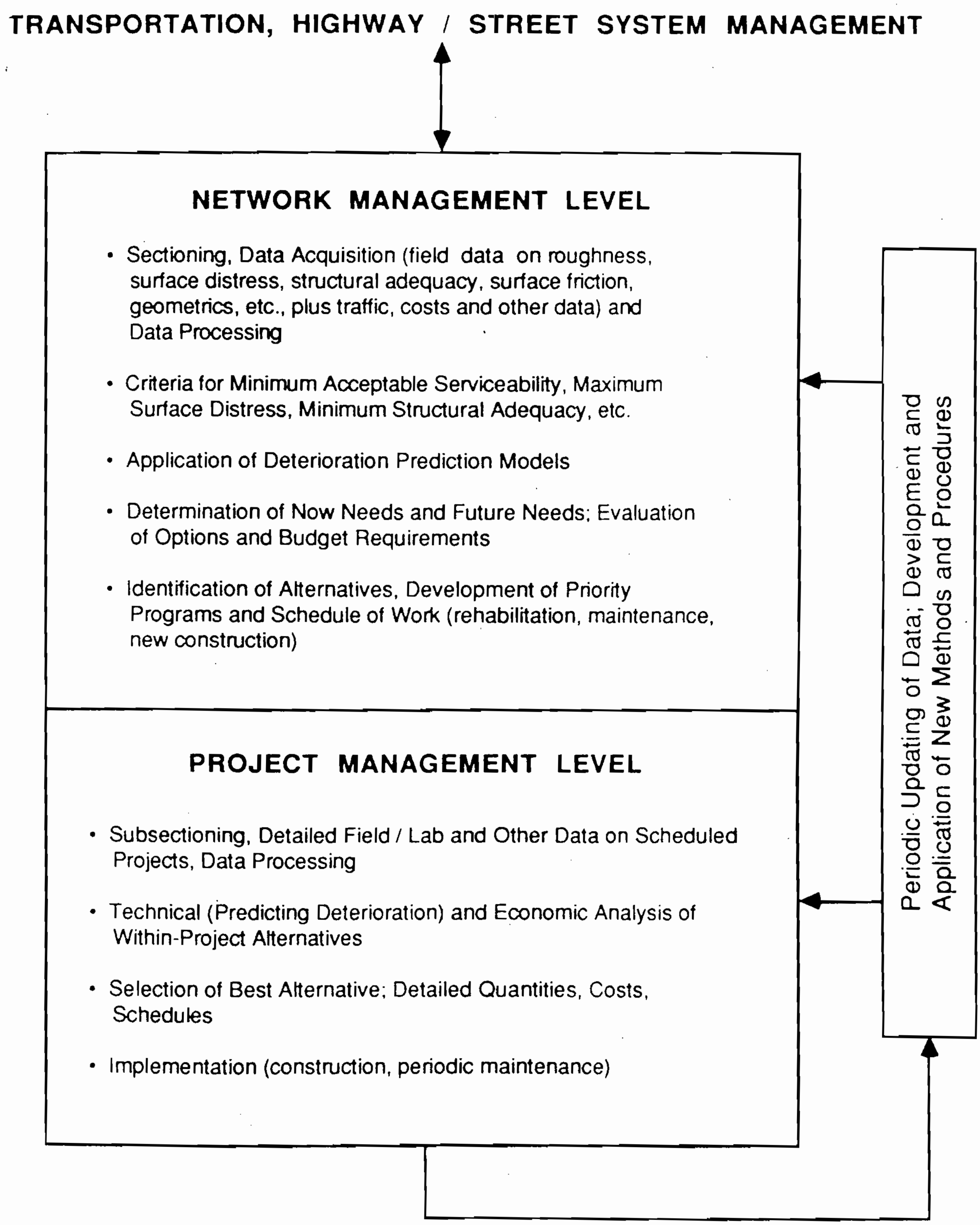


Figure 4.1 Basic operating levels of pavement management and major component activities.

build requires more decision making, but initially at a very broad level. For example, should it be a flexible pavement or a rigid pavement, and, if rigid, with joints or continuously reinforced? How thick should it be and with what kind of materials? Once decisions are firm and commitments are made, the further level of influence of

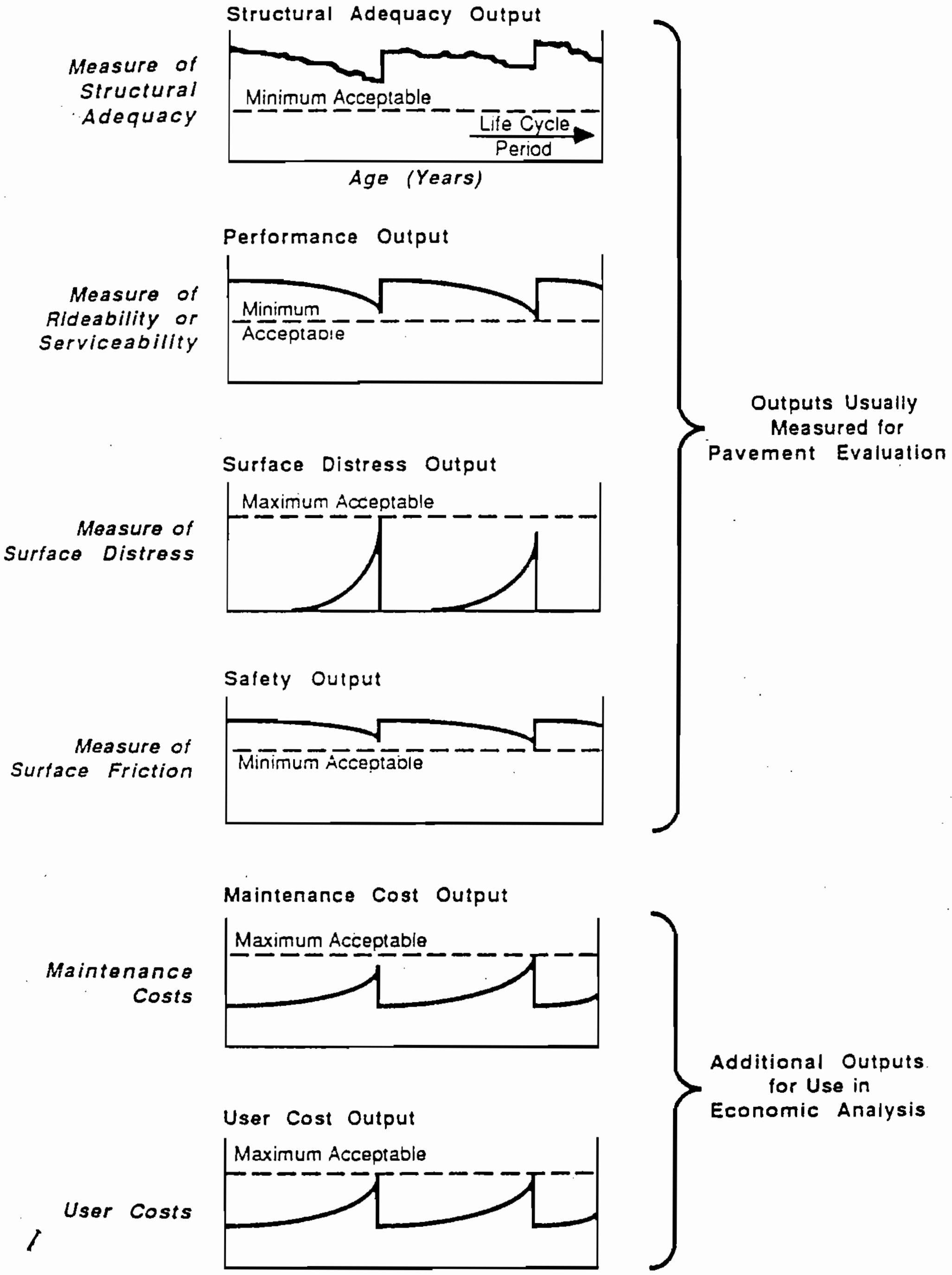


Figure 4.5 Major types of pavement outputs.

◎ Using PMS as a Research Planning and Technology Improvement Tool

※Identifying Research Needs

※System Parameters & State of the Art:
Model Used, Past Experience, Quality of Measuring Techniques and Available Data, Inherent Variability
(==> Cyclic Improvements)

※Future Advances In PMS:
Continuing Incremental Improvements, More Widespread Use, Use of New Equipments & Technologies
(SHRP/LTPP, 20-yr Study => FHWA)

※Establishing Priorities

※Implementing Research Results

◎ Linear Regression (PSI Eq.)
(Fitting a Straight Line by Least Squares)

Handouts:

1. Draper, N. R., and H. Smith, ***Applied Regression Analysis***, Second Edition, John Wiley & Sons, Inc., 1981, pp.8-23.
2. Two Pages of S-PLUS Example Outputs

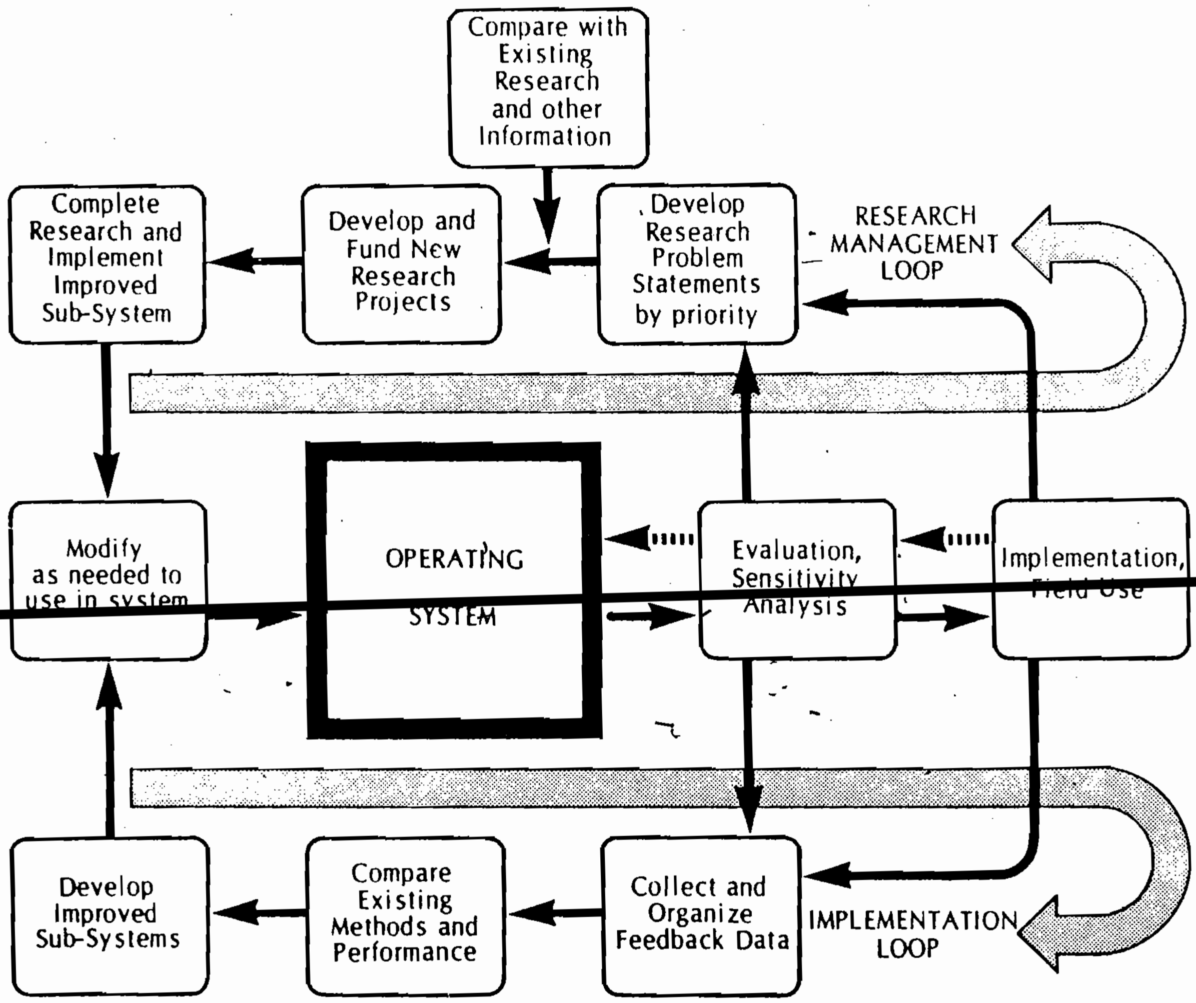


Figure 5.1 Cyclic improvements of pavement design and management systems.

increases, as portrayed in Fig. 5.2. Step 1 in this process involves considering methods currently being used. Also, the current state of the art should be used in the initial, perhaps crude, systems model. Then sensitivity analyses can be performed and work to improve the system can be done on a continuing, step-by-step basis (Fig. 5.2).

Thus, the way model building, selection of parameters, and the entire system development relate to each other begins to become apparent. In some components, such as traffic, it seems easy to define the significant parameters. However, there are questions as to the form in which the data are to be provided in the model and the way they should be summarized. For example, the AASHO Road Test models involved equivalent 18-kip single-axle loads; however, the original data also provide information on vehicle load, placement, and other factors such as tire pressure and tire width.

Environmental variables have historically been rainfall, temperature, and depth of frost penetration. In all cases, however, except for a few theories such as those for slab restraint, the models have involved crude correlations. The use of these correlations often causes problems in developing general pavement models because the experiment and the data used to develop the correlations were basically applicable only to a particular situation or locale.

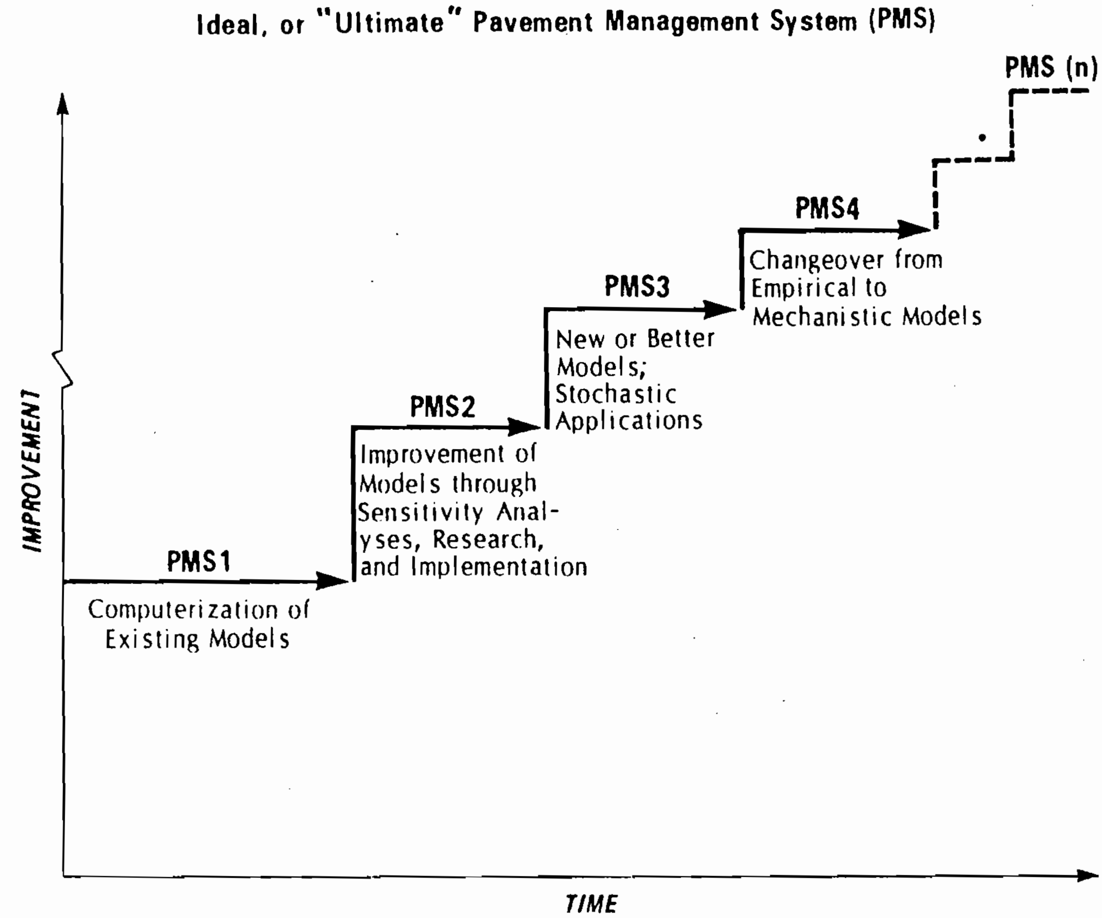


Figure 5.2 Step-by-step improvements in development of pavement management systems.

5.3 ESTABLISHING PRIORITIES

One of the important parts of research management is the task of establishing priorities for work to be done. Almost no research budget is adequate for attacking all perceived problems. Too often in the past the priorities have been set by the main interests or abilities of existing research staff rather than by the needs of the job. This can be overcome to a large degree with a well-developed pavement management system, including an initial operating system with which to work. Sensitivity analyses can be run with the working system to determine the areas or parameters in the model that seem most to affect the output of the system. These results can be compared with estimates of the accuracy with which these parameters, or models, as the case may be, are known or can be determined. By combining this information a priority list of important factors can be determined. This priority list can be compared to research costs and potential payoff or benefit to establish actual research program priorities.

5.4 IMPLEMENTING RESEARCH RESULTS

There is a greal deal of concern in the scientific community about implementing research results. This concern has carried into the transportation and specifically the

Assume a True Model: $Y = \beta_0 + \beta_1 X + \varepsilon$

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i \quad (\textit{for } i = 1,\ 2,\ \ldots,\ n)$$

$$\textit{Minimize}\ \ S = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} \left(Y_i - \beta_0 - \beta_1 X_i\right)^2$$

$$\frac{\partial S}{\partial \beta_0} = -2\sum_{i=1}^{n}\left(Y_i - \beta_0 - \beta_1 X_i\right) = 0$$

$$\frac{\partial S}{\partial \beta_1} = -2\sum_{i=1}^{n} X_i\left(Y_i - \beta_0 - \beta_1 X_i\right) = 0$$

Normal Equations:

$$\begin{cases} b_0 n + b_1 \sum_{i=1}^{n} X_i = \sum_{i=1}^{n} Y_i \\ b_0 \sum_{i=1}^{n} X_i + b_1 \sum_{i=1}^{n} X_i^2 = \sum_{i=1}^{n} X_i Y_i \end{cases}$$

$$b_1 = \frac{\sum\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sum\left(X_i - \overline{X}\right)^2} = \frac{SXY}{SXX}$$

$$b_0 = \overline{Y} - b_1 \overline{X}$$

$$SXX = \sum\left(X_i - \overline{X}\right)^2 = \sum X_i^2 - n\overline{X}^2$$

$$SYY = \sum\left(Y_i - \overline{Y}\right)^2 = \sum Y_i^2 - n\overline{Y}^2$$

$$SXY = \sum\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right) = \sum X_i Y_i - n\overline{X}\,\overline{Y}$$

$\sum X_i^2$ = *Uncorrected Sum of Squares of the x's*

$\sum Y_i^2$ = *Uncorrected Sum of Squares of the* y's

$\sum X_i Y_i$ = *Uncorrected Sum of* Pr*oducts of x and y*

SXX, *SYY*, *SXY* = *Corrected ... (Same as above)*

$$\left(Y_i - \overline{Y}\right) = \left(\hat{Y}_i - \overline{Y}\right) + \left(Y_i - \hat{Y}_i\right)$$

$$\sum\left(Y_i - \overline{Y}\right)^2 = \sum\left(\hat{Y}_i - \overline{Y}\right)^2 + \sum\left(Y_i - \hat{Y}_i\right)^2$$

SS about the mean = *SS due to regression* +
SS about regression

$$R^2 = \frac{SS\ due\ to\ regression}{SS\ about\ mean}$$

Figure 1.6 *Geometrical Meaning*

Table 1.3 *Analysis of Variance* (*ANOVA*) *Table*

※Linear Regression in Matrix Format

$$Y = X\beta + \varepsilon$$

$$\hat{\beta} = \left(X'X\right)^{-1} X'Y$$

$$\hat{Y} = X\left(X'X\right)^{-1} X'Y = HY$$

H is called "Hat Matrix"

◎ Use EXCEL Add-in and S-Plus Program

作業二：請利用EXCEL軟體之Add-in功能，建立柔性與剛性鋪面之PSI公式。

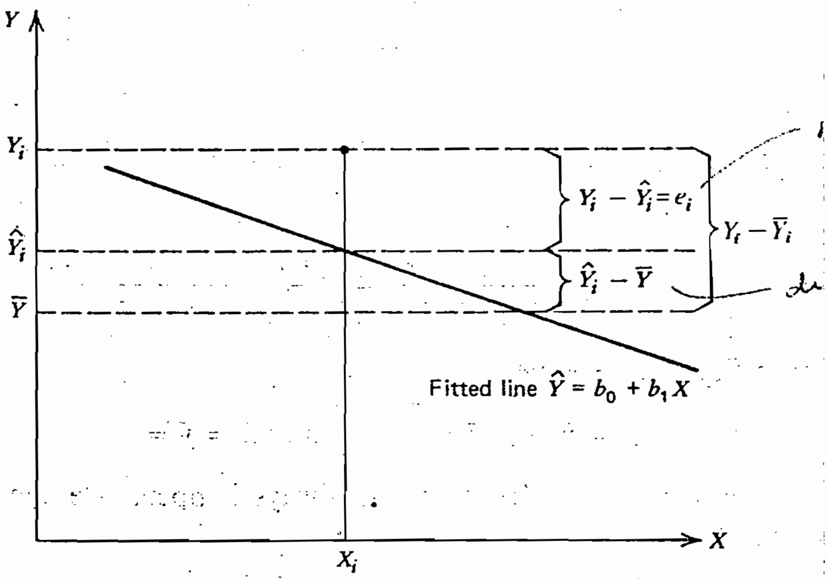


Figure 1.6 Geometrical meaning of the identity (1.3.1).

Table 1.3 Analysis of Variance (ANOVA) Table; the Basic Split

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)
Due to regression	1	$\sum_{i=1}^{n}(\hat{Y}_i - \bar{Y})^2$	MS_{Reg}
About regression (residual)	$n-2$	$\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$	$s^2 = \dfrac{SS}{(n-2)}$*
Total, corrected for mean $\bar{Y}$	$n-1$	$\sum_{i=1}^{n}(Y_i - \bar{Y})^2$	

* Some regression programs have documentation that labels the quantity $\sum (Y_i - \bar{Y})^2/(n-1) = S_{YY}/(n-1)$ as s^2. For us, this would be true *only* if the model fitted were $Y = \beta + \varepsilon$. In this case, the regression sum of squares due to b_0 would be (as it is in general—see, for example, Table 1.4) $n\bar{Y}^2 = (\sum Y_i)^2/n$ and S_{YY} would be the appropriate residual sum of squares for the corresponding fitted model $\hat{Y} = \bar{Y}$.

Statistical Analysis Software (SAS) 統計軟體程式使用說明 "Reg.SAS"

```
options ls=78 ps=500;
data example;
input y x1 x2;
cards;
 1  1  1
 5  2  4
 9  3  9
23  4 16
36  5 25
;

proc reg;
model y= x1 x2;
output out=res p=pred r=yhat;

proc print;
var pred yhat;

proc iml;
y={1, 5, 9, 23, 36};
x={1  1  1,
      1  2  4,
      1  3  9,
      1  4 16,
      1  5 25};

start regress;
 xpxi=inv(t(x)*x);
 beta=xpxi*t(x)*y;
 yhat=x*beta;
 resid=y-yhat;
 sse=ssq(resid);
 n=nrow(x);
 dfe=nrow(x)-ncol(x);
 mse=sse/dfe;
 cssy=ssq(y-sum(y)/n);
 rsquare=(cssy-sse)/cssy;
print 'Regression Results', sse dfe mse rsquare;
stdb=sqrt(vecdiag(xpxi)*mse);
t=beta/stdb;
prob=1-probf(t#t,1,dfe);
print , 'Parameter Estimates', beta stdb t prob;
print , y yhat resid;
finish regress;

run regress;
```

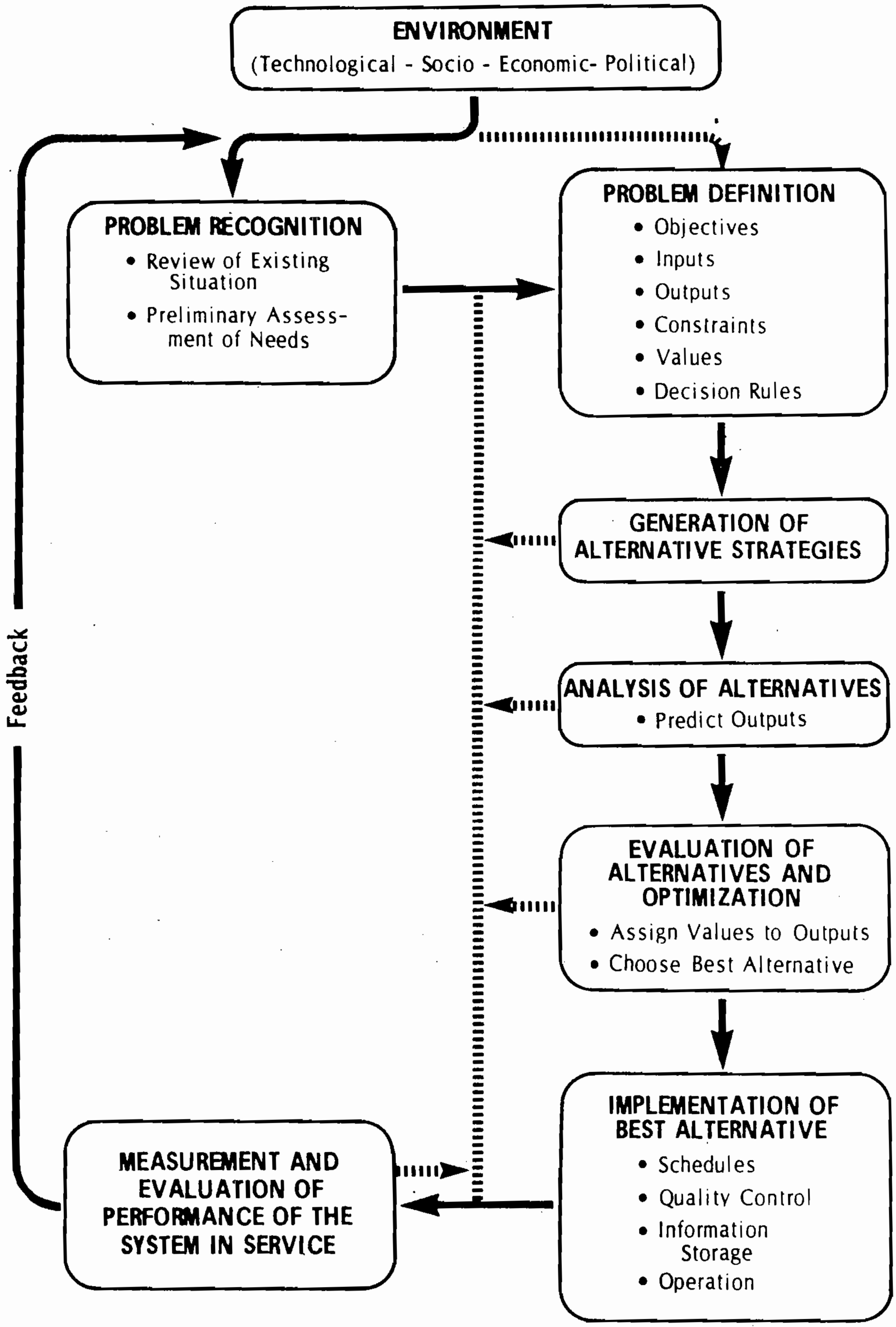


Figure 2.1 Major phases and components of the systems method.

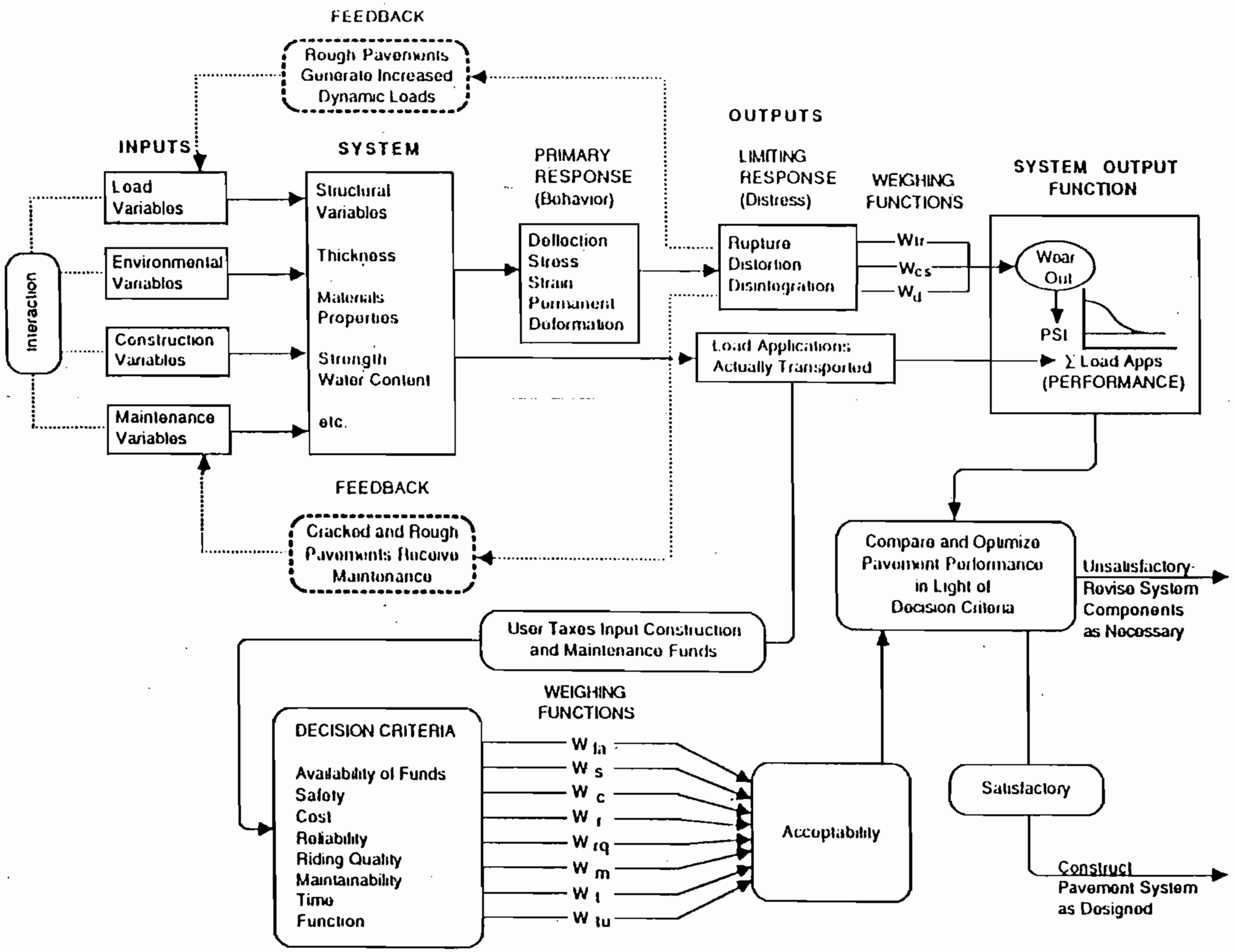


Figure 3.1 Early definition of a project-level pavement design system and its major components [Hudson 68].

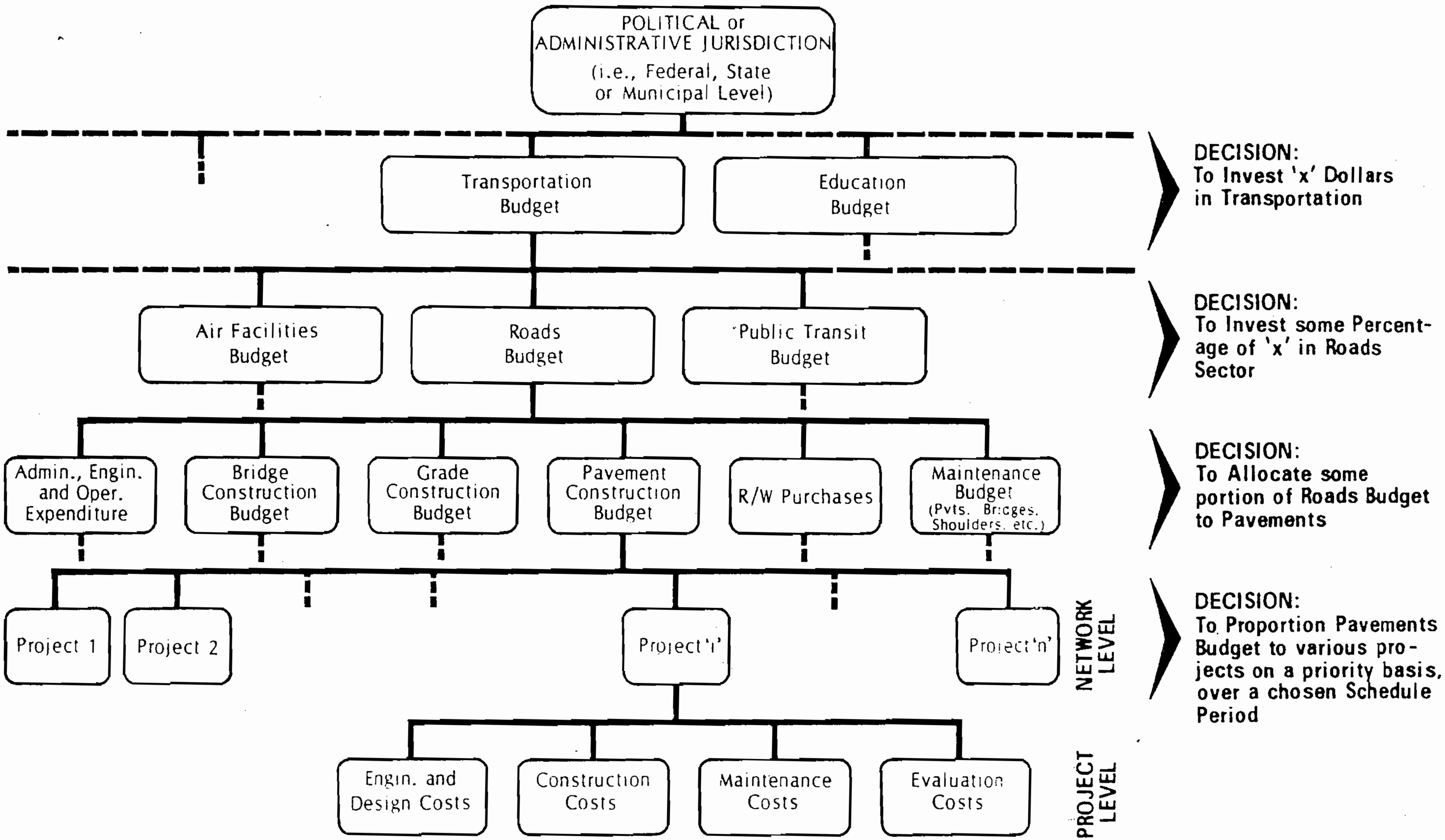


Figure 4.1 The role of pavement investment planning.

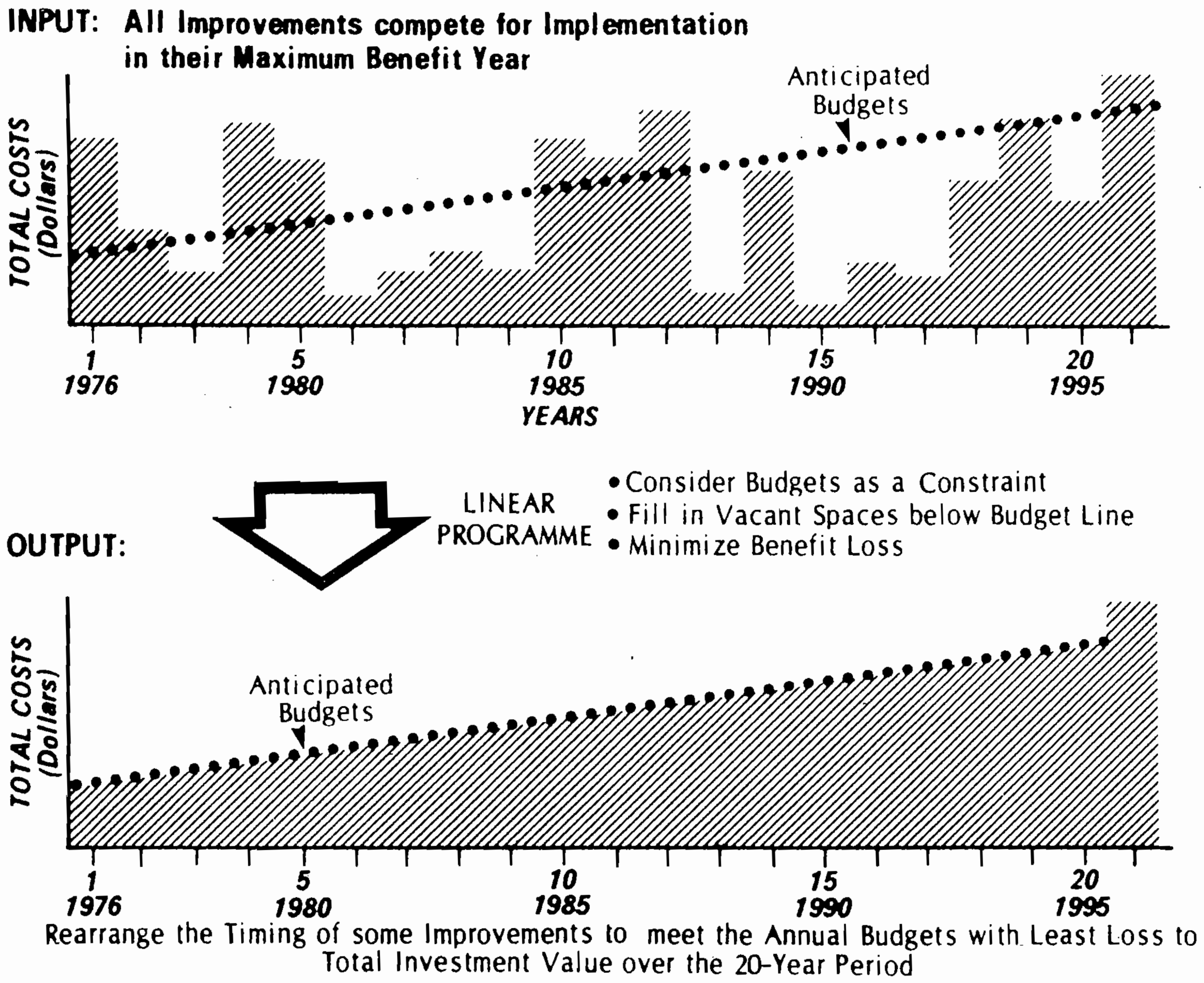


Figure 4.4 Schematic representation of linear programming method for rearranging optimum investment times for improvements so that total benefit loss is minimized and budget constraints are not exceeded.

minimizes the total benefit loss. Because the actual budget may vary from the anticipated budget, annual updating is required.

The benefit-maximization method as summarized in the foregoing paragraphs was developed basically for programming all types of highway improvements by the Ontario Ministry of Transportation and Communications [54, 55]. However, in using this method, constraints may have to be placed on such considerations as allocating minimum portions of the budget by district or region and allocating minimum portions of the budget to the various sectors of the highway (i.e., bridges, new grade construction, pavements, etc.); otherwise, the tendency would be to place major emphasis on capacity improvements for high-volume facilities.

4.4.3 Cost-Minimization Method

The cost-minimization method works basically the same as the benefit-maximization method, except that the benefits of the improvements are not considered. In other words, the optimum set of improvements is that which results in the least fiscal cost to the agency involved. Again, a linear programming model can be used, and the budget constraint is applicable.

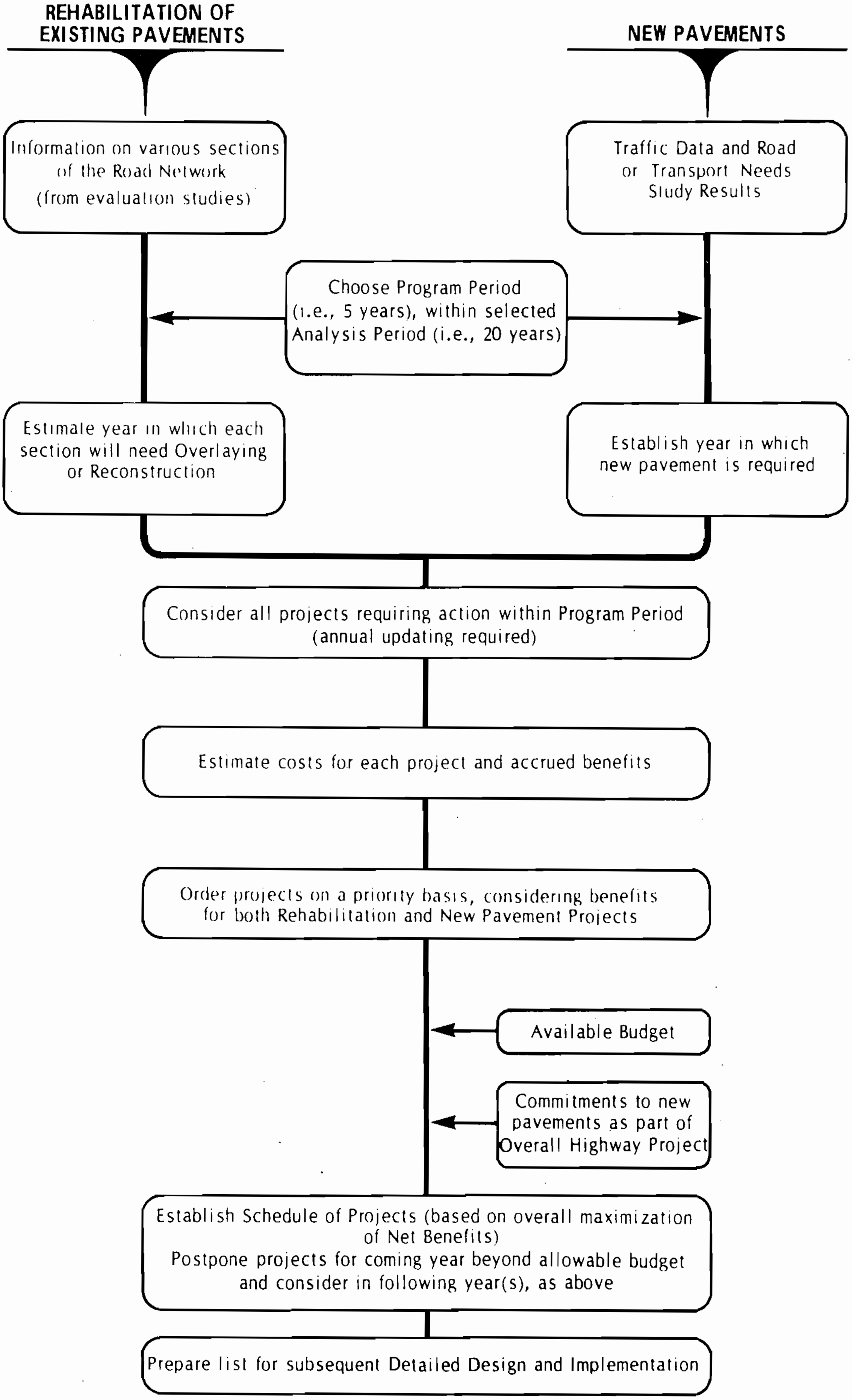


Figure 4.5 Steps in planning pavement investments over chosen program period.

Table 4.1 Example List of Pavement Improvement Projects

1976 First-priority projects

Project no.	Description	Functional class and no. of lanes	Length, miles	A.D.T. At time of construction	A.D.T. At end of service life	Expected PSI[a] before improvement
76-401-10	Hwy. 401; jct. Hwy. 25 to jct. Hwy. 6	Rural fwy., divided 4 lanes	8.8	10,000	20,000	2.6
76-13-1	Hwy. 13; jct. Hwy. 17 to McCay Rd.	Rural arter., 2 lanes	10.3	5,000	10,000	2.4
76-28-2	Hwy. 28; Rally city limits to 8.6 mi north	Rural arter., 2 lanes	8.6	–	8,500	–
76-97-3	Hwy. 97; jct. Flac Rd. to jct. Oly Rd.	Rural collector, 2 lanes	6.2	3,500	4,500	3.0

1976 Second-priority projects

76-33-10	Hwy. 33; jct. Hwy. 14 to 5.3 mi south	Rural collector, 2 lanes	5.3	3,000	5,000	2.0
76-22-1	Hwy. 22; jct. Blem Rd. to 8.1 mi north	Rural arter., 2 lanes	8.1	2,200	3,800	2.6

1977 First-priority projects

77-24-2	Hwy. 24; jct. Hwy. 5 to jct. Hwy. 94	Rural arter., 2 lanes	7.2	2,000	5,000	1.4
77-7-8	Hwy. 7; Branton city limits to 4.8 mi east	Rural arter., 2 lanes	4.8	5,500	8,000	2.2

1977 Second-priority projects

						etc.

[a]PSI, Present Serviceability Index, is a measure of the present serviceability of the road surface to the road user, primarily in terms of riding comfort, on a scale of 0 to 5 (see chap. 7 for details).

Proposed improvement	Expected initial service life, years	Expected PSI[a] after improvement	Total capital cost	Total maintenance cost	Annual cost per mile	Annual user savings per mile	Net annual savings per mile	Remarks
1976 First-priority projects								
3.5 in. overlay	12	3.1	1,030,000	70,000	10,400	85,890	75,490	
3 in. overlay	10	3.1	600,000	25,000	6,068	54,600	48,532	
New pvt.	12	4.0	1,650,000	—	—	—	—	Overall hwy. improvement determines priority
Seal coat	8	3.0	68,000	—	—	—	—	Safety improvement for skid res.
1976 Second-priority projects								
15 in. overlay	13	2.4	700,000	50,000	10,900	17,500	6,600	
S[illegible] coat	10	2.6	94,000	—	—	—	—	Existing surf. extensively cracked and patched
1977 First-priority projects								
Pave exist. gravel rd.	15	2.6	400,000	10,000	3,800	45,000	41,200	
Partial reconstr. of exist. pvt.	11	2.9	1,000,000	30,000	19,500	48,750	29,250	
1977 Second-priority projects								
etc.								

4.5.2 Basis for Net Benefit Calculations for Pavement Improvements

The basis for the user savings calculations of Table 4.1 is the relationship between vehicle operating costs and pavement serviceability, for various speeds, of Fig. 4.6, and the operating speed guidelines of Table 4.2. Figure 4.6 is a graphical representation of vehicle consumption rates translated into very approximate costs. These consumption rates and costs have been synthesized from Refs. [56–62] for North American conditions. They should be recognized as being very rough estimates only and applicable primarily to the network type of investment planning analysis shown in Table 4.1.

Table 4.2 also represents some very approximate estimates and again is applicable primarily to the Table 4.1 type of analysis. The basis for the Table 4.2 estimates is Refs. [62–64]. To use Table 4.2 in conjunction with Fig. 4.6, it is necessary first to select the operating speed corresponding to the PSI or RCI of the pavement surface from Table 4.2. This same PSI or RCI value is then located along the horizontal axis of Fig. 4.6, and the operating speed selected is located vertically from this point (interpolation may be necessary). Finally, the average user operating cost is determined by going horizontally to the vertical axis.

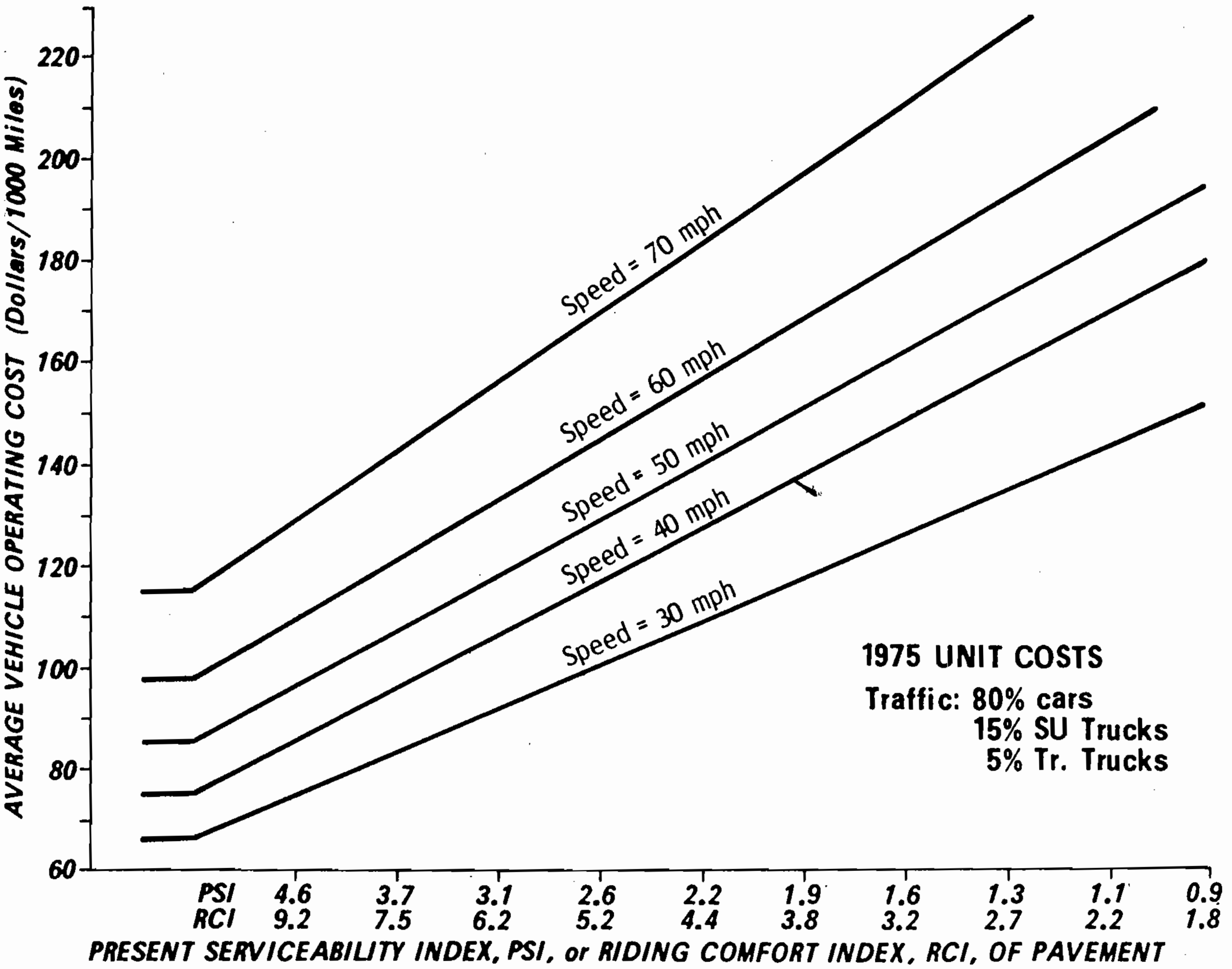


Figure 4.6 Approximate vehicle operating cost as a function of pavement serviceability and speed under rural, free-flow conditions.

Table 4.2 Guidelines for Selecting Approximate Average Highway Operating Speed, Under Free-Flow Conditions, for Various Levels of Serviceability

		Approximate average speed for roads with following speed limits[c]				
PSI[a] range	RCI[b] range	50 mph	55 mph	60 mph	65 mph	70 mph
0–0.5	0–1	30	30	30	30	30
0.5–1.0	1–2	42	42	42	42	42
1.0–1.5	2–3	46	48	50	50	50
1.5–2.0	3–4	48	53	55	57	58
2.0–2.5	4–5	50	55	58	62	65
2.5–3.0	5–6			60	65	68
3.0–3.5	6–7					70
3.5–4.0	7–8					
4.0–4.5	8–9					
4.5–5.0	9–10	50	55	60	65	70

[a]PSI, Present Serviceability Index, is a measure of the present serviceability to the road user, primarily in terms of riding comfort, of the pavement surface, as developed at the AASHO Road Test. It is measured on a scale of 0 to 5 (see chap. 7 for details).

[b]RCI, Riding Comfort Index, is the Canadian equivalent of PSI, but measured on a scale of 0 to 10 (see chap. 7).

[c]A maximum speed limit of 55 mph was instituted in the United States in 1975. Consequently, the last three columns are not applicable where this situation occurs.

For example, suppose that an existing pavement section with Present Serviceability Index (PSI) of 1.6 and AADT of 3,000 is to be a candidate project for an overlay. The overlay is expected to have a service life of 10 years (i.e., at the end of 10 years, the PSI of the pavement will be back down to 1.6). Immediately after construction, the PSI is expected to be 3.1. Consequently, the average PSI over the 10 years would be $1.6 + (3.1 - 1.6)/2 = 2.3$. These conditions will result in the following speeds and average vehicle operating costs:

PSI	Average operating speed (Table 4.2), mph		Average vehicle operating costs per 1,000 vehicle miles (Fig. 4.6)
1.6	53		$167
2.3	55		$144
		Savings	$ 23

If the AADT is expected to increase linearly to 4,000 at the end of 10 years, the average AADT over the 10 years is 3,500. So the average annual user savings due to the improvement are $23/1{,}000 \times 3{,}500 \times 365 \simeq \$29{,}000$ per mile. The net annual savings, or benefits, would then be calculated by subtracting the average annual cost of construction plus maintenance from these savings, as shown in Table