Lecture #10:

◎ Determine Present and Future Needs, and Priority Programming (Haas, Chap. 15-20)

※ Pavement Deterioration Prediction Models

- Performance <=> Deterioration or Damage
- Measurement of Deterioration (e.g., PSI, PCI, IRI), Pavement Age / Accumulated Axle Loads, Past and Prediction of Future Deterioration, Establishing Criteria, Remaining Life, Rehabilitation Alternatives (Fig. 16.1)
- Types of Prediction Models
  Deterministic vs. Probabilistic Models (i.e., Survivor Curves, Markov Transition Process Models) (Table 16.1)
- "A transition probability matrix defines the probability that a pavement in an initial condition state will be in some future condition state." (Table 16.3, 16.4)
- = F(Pavement Type, Thickness, Subgrade Type, Traffic, Environmental Effects)
- Advantages & Disadvantages
- Arizona DOT Use "Rate of Crack Change"

Prediction Models for Pavement Deterioration

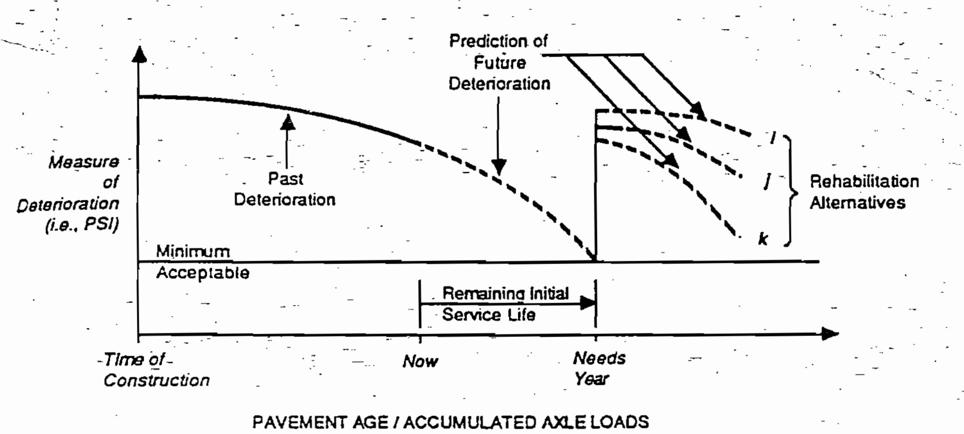


Figure 16.1 Illustration of how a deterioration model is used to predict future deterioration of an existing pavement, and rehabilitation alternatives constructed in the needs year.

Determining Needs

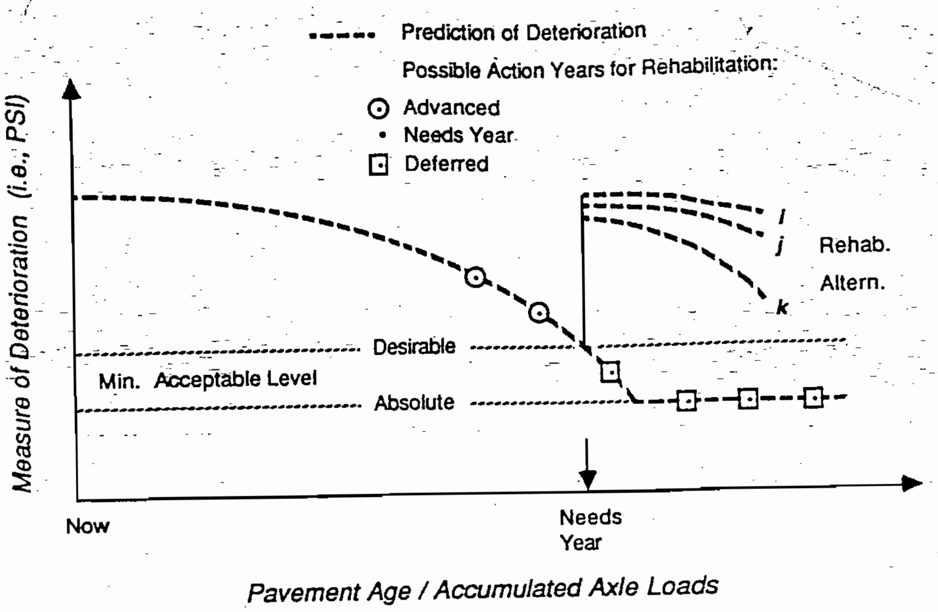


Figure 17.1 Needs year and possible action years for rehabilitation.

A Markov transition matrix expresses the probability that a group of pavements of similar age or level of traffic will transition from one state of distress or serviceability index to another within a specified time period. The use of a Markov transition matrix implies that the following assumptions are valid:

1. There are a finite number of states of distress or serviceability index in which the pavement can be found. A "state" is a range of distress or serviceability index such as between a PSI of 4.0 and 4.2.

2. The probability of making a transition from one state to another depends only upon the present state.

3. The transition process is stationary, that is that the probability of changing from one state to another is independent of time. This assumption is a critical one for it assumes that changes in weather conditions within a planning horizon will not affect the transition probabilities. This assumption is not true, in general, for most pavement conditions.

The Markov process describes a probable "before" and "after" condition of the pavement. The "before" condition is described by probabilities that the pavement will be found in each of the assumed finite number of states as is illustrated in Figure 2. The "after" condition is described in a similar manner as illustrated in the same figure. However, the probabilities are shifted downward to lower condition states which are described by ranges of serviceability index.

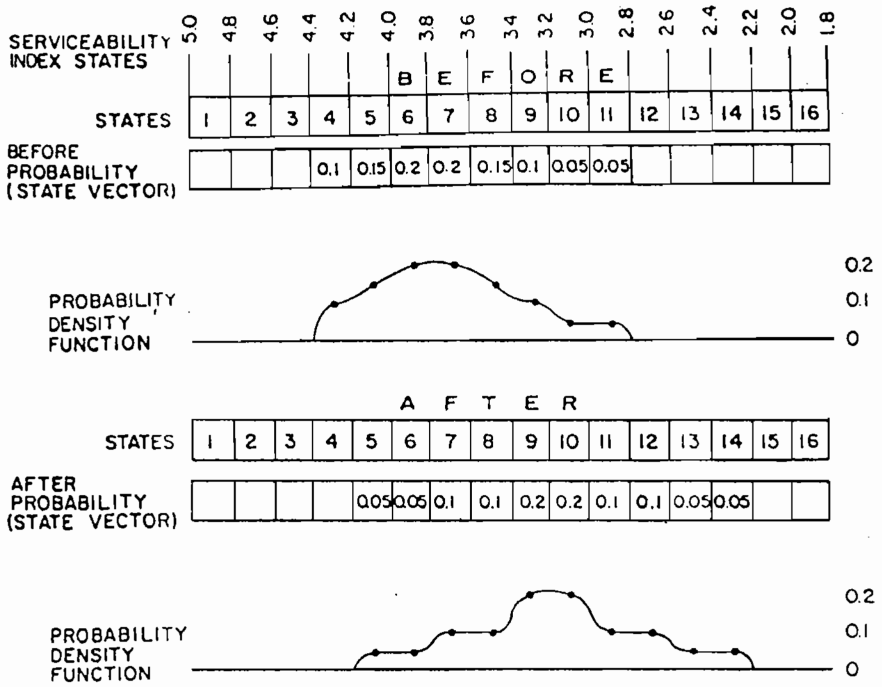


Figure 2. Before and After Serviceability Index State Vectors.

Markov transition matrices can be constructed for any process of pavement deterioration and, especially if the assumptions that are made for Markov processes are valid, they can be used reliably to simulate the overall performance of a network of pavements of similar types with similar weather and traffic patterns.

Semi-Markov Models of Pavement Deterioration Processes

From: Lytton, R.L, "Concepts of Pavement Performance Prediction and Modeling," Proceedings, Second North American Conference on Managing Pavements", Vol. 2, Toronto, 1987.

Survivor Curves

(* Next Page on Markov Models)

Survivor curves are used for planning maintenance and rehabilitation alternatives on pavement networks. The construction, maintenance, and rehabilitation histories that are recorded by the state agencies are valuable sources from which to develop survivor curves. A survivor curve is a graph of probability versus time. The probability drops off with time (or traffic) from a value of 1.0 down to zero and it expresses the percentage of pavements that remain in service after a number of years (or passes of a standard load) without requiring major maintenance or rehabilitation. A typical survivor curve is shown in Figure 1. The slope of the survivor curve is the probability density of survival and is also illustrated in that figure. The probability density curve for survival may be constructed from historical data by determining the percentage of pavements that must be maintained or rehabilitated each year after its most recent major repair or new construction.

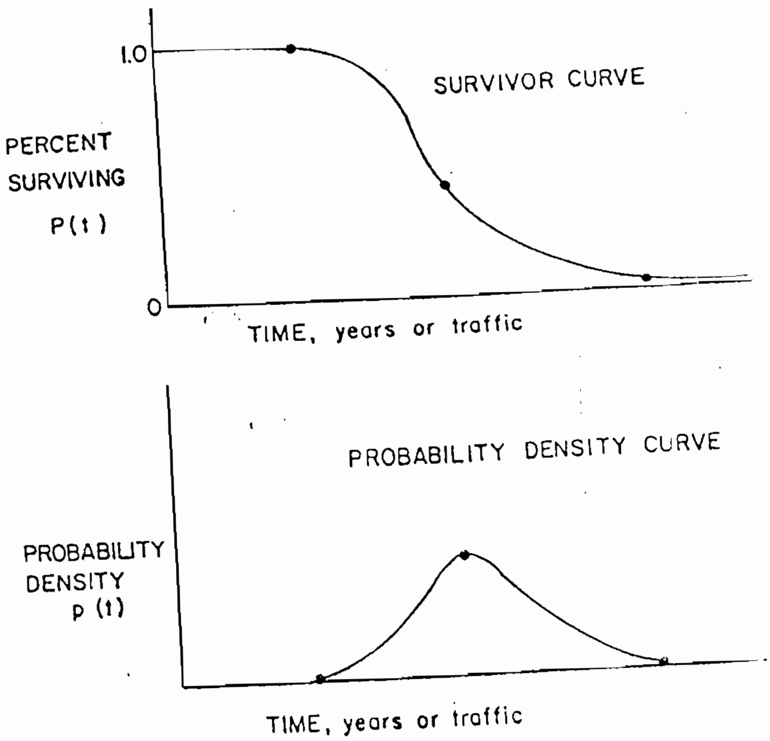


Figure 1. Survivor Curve and Probability Density Function for Survival.

- Development Process: Lee's Ph.D. Thesis
  Lee, Y. H. (1993), "Development of Pavement Prediction Models," Ph.D. Thesis, University of Illinois, Urbana.

※ Establishing Criteria and Determining Needs
- Examples of Measurements, Affecting Factors, Effects of Changing Criteria
- Needs Years and Action Years
- Effects of Prediction Model Errors
  "Deterioration Predictions Should be Periodically Updated."
- Need versus Type of Action Taken
- Graphical and Tabular Representation of Needs

※ Rehabilitation and Maintenance Strategies
- Identification of Alternatives: Rehabilitation, Routine Maintenance (Preventive), Major Maintenance (Corrective) (Fig. 18.1)
- Decision Processes & Expert Systems Approaches to Identifying Feasible Alternatives: Simple Judgment --> Decision Tree of Expert Systems Approach (can also be in Matrix Form) (Fig. 18.2, 18.3)

Rehabilitation and Maintenance Strategies

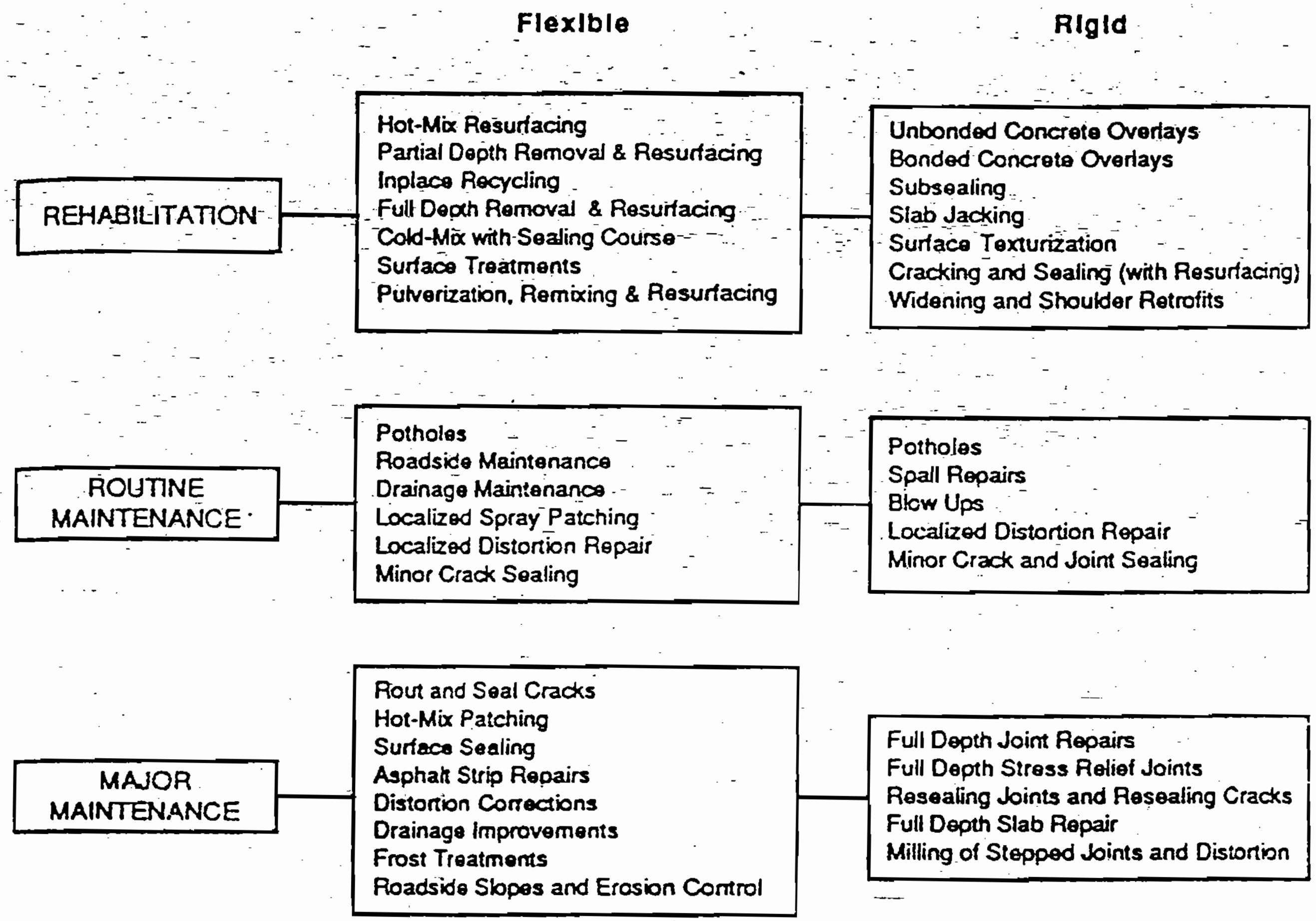


Figure 18.1 Rehabilitation and maintenance alternatives used in Ontario.

Table 16.1 Classification of Prediction Models [Mahoney 90]

	Types of Models						
	Deterministic				Probabilistic		
Levels of Pavement Management	Primary Response • Deflection • Stress • Strain • etc.	Structural • Distress • Pavement • Condition	Functional • PSI • Safety • etc.	Damage • Load Equiv.	Survivor Curves	Transition Process Models: Markov	Transition Process Models: Semi-Markov
National Network				•	•	•	•
State Network		•	•	•	•	•	•
District Network		•	•	•	•	•	•
Project	•	•	•	•			

Table 16.3 Example Condition State for a Markov Process Model

Pavement Roughness	Surface Distress, percent area cracked		
	0–3	3–7	>7
0–40	1	4	7
41–90	2	5	8
>90	3	6	9

Table 16.4 Example Transition Probability Matrix for a Markov Process Model

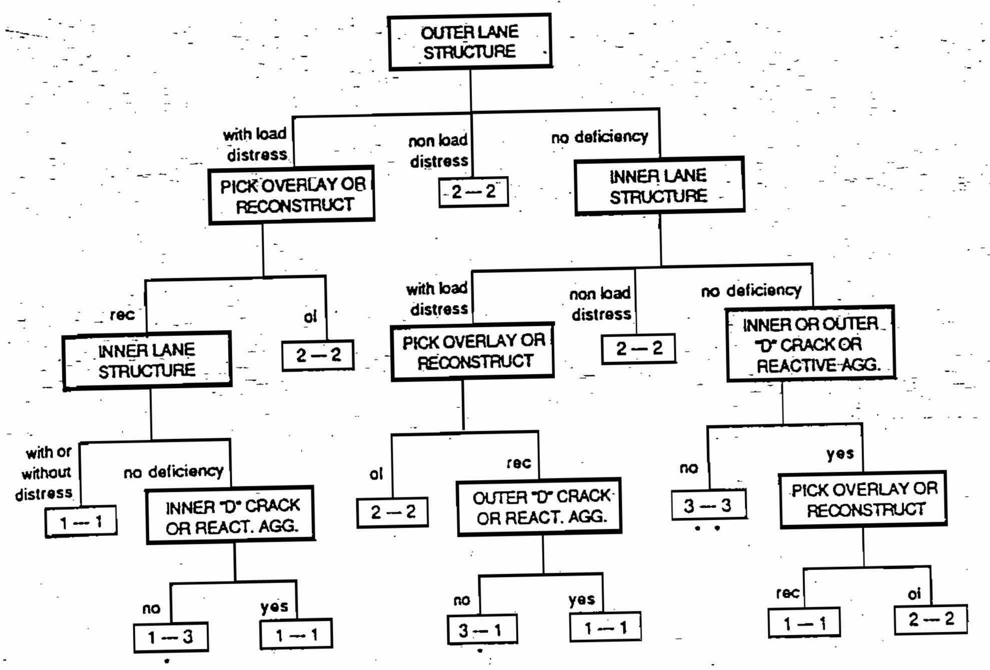
Initial Condition State	Future Condition State								
	1	2	3	4	5	6	7	8	9
1	0.90	0.04	0.02	0.03	0.01	0	0	0	0
2	0.01	0.90	0.03	0	0.05	0.01	0	0	0
3	0	0.01	0.92	0	0.01	0.03	0	0.01	0.02
4	0	0	0	0.92	0.05	0.02	0	0.01	0
5	0	0	0	0.01	0.94	0.03	0.01	0.01	0
6	0	0	0	0	0.01	0.94	0	0.01	0.04
7	0	0	0	0	0.02	0	0.95	0.02	0.01
8	0	0	0	0	0	0	0.01	0.96	0.03
9	0	0	0	0	0	0.01	0	0.01	0.98

DISTRESS PRESENCE	COMBINATIONS OF DISTRESS (READ VERTICALLY)																	
PSI < 4.0	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Cracking Major	NO	NO	NO	NO	YES	YES	YES	YES										
Rutting > 30%	YES	NO	NO	NO														
Ravelling > 30%		YES	NO	NO														
Bleeding > 30%			YES	NO														
Alligator Crack > 30%					NO	NO	NO	YES										
Edge Crack > 30%					NO	NO	YES											
Longitudinal Crack. > 30%					NO	YES												
Excess Crown Major									YES	NO	NO							
AADT > 5000										NO	YES	NO	YES	NO	YES		NO	YES
Alligator Crack Major												NO	NO	YES	YES			
Rutting Major																NO	YES	YES
FEASIBLE REHABILITATION ACTIONS	3 4 6 11	1 5 7 12	1 8 12	2 4 5	2 5 7	3 4 6 9 10	2 6 9 11	3 6 11	4 10	1 4 10	2 9 11	2 4 5 9 10	3 4 9 11	2 4 6 10	3 9 11	2 4 5 8	3 4 5 8 10	3 6 9 11

REHABILITATION REHABILITATION CODES

1. 1 in. Overlay
2. 2 in. Overlay
3. 3 in. Overlay
4. Mill 1 in. + Chipseal
5. Recycle 1 in. + 1 in. Overlay
6. Recycle 1 in. + 2 in. Overlay
7. Heater Plane 1 in. + 1 in. Overlay
8. Heater Plane 1 in. + 2 in. Overlay
9. Heater Plane 1 in. + 3 in. Overlay
10. Reconstruct 2 in. AC/ 4 in. ABC
11. Reconstruct 2 in. AC/ 6 in. ABC
12. Chipseal

Figure 18.2 Example decision tree (matrix form) for identifying feasible rehabilitation alternatives.



1 — 1 Reconstruct Both Lanes
1 — 3 Reconstruct Outer, Restore Inner
3 — 1 Restore Outer, Reconstruct Inner
3 — 3 Restore Both Lanes
2 — 2 Overlay Both Lanes

* Option to Go to 1 — 1 Provided
** Option to Go to 1 — 1, 1 — 3, or 2 — 2 Provided

Figure 18.3 Decision tree for selection of main rehabilitation approach [Hall 87].

- EXPEAR Program: "Expert Systems for Pavement Evaluation and Rehabilitation" to Be Discussed in Next Semester
- KBES (Knowledge Based Expert System): Development Tool or "Shell" 專家系統
- Deterioration Modeling of Rehabilitation & Maintenance Alternatives: Remaining Life Analysis
- Costs, Benefits, and Cost-Effectiveness:
  - (a) Costs: Actual Work, Vehicle Operating Costs, User Delays (e.g., Minnesota), Accident, Environmental Damage Costs
  - (b) Benefits: Effectiveness is the "Net Area under the Performance or Deterioration Curve" Multiplied by Section Length and Traffic (= AREA * Length * ADT)
  - (c) Cost-Effectiveness = Effectiveness / Cost Unit Cost, Average Annual Cost

※ Priority Programming of Rehabilitation and Maintenance

- Basic Approaches: (a) Strategic Approach for Certain Future Targets; (b) Defining a Set of "Approved" R&M Alternatives; (c) Policy-Oriented Approach by Specifying a Limited Number or Type of Alternatives

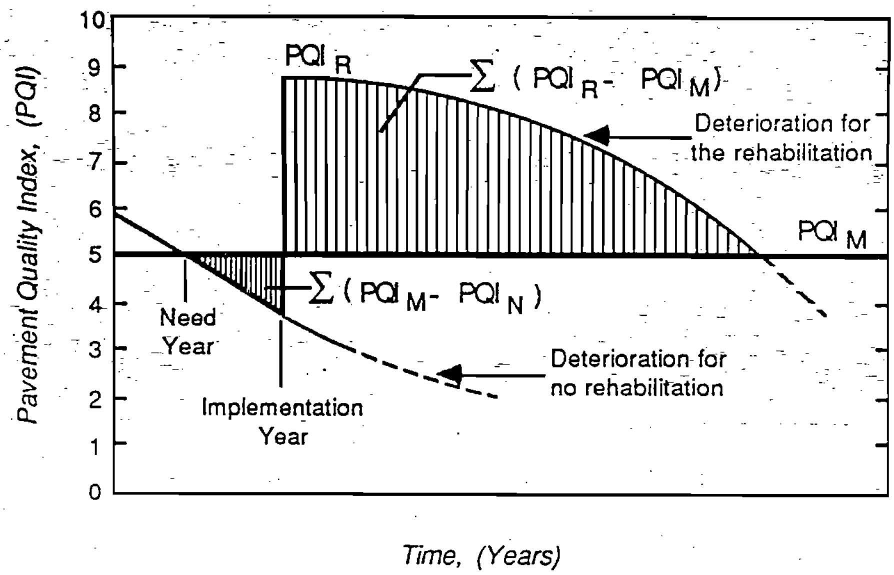


Figure 18.9 Schematic illustration of effectiveness for a rehabilitation alternative.

from its needs year is given in Figure 18.9. Effectiveness is the net area under the rehabilitation deterioration curve (the shaded area to the right of the rehabilitation implementation year minus the shaded area to the left) multiplied by length of section and volume of traffic; that is,

$$\text{Effectiveness} = \left[\sum_{\text{Rehab Year}}^{\text{PQI}_R \geq \text{PQI}_M} (\text{PQI}_R - \text{PQI}_M) - \left(\sum_{\text{PQI}_N \geq \text{PQI}_M}^{\text{Rehab Year}} (\text{PQI}_M - \text{PQI}_N) \right) \right] \cdot [\text{ADT}] \cdot \left[\begin{matrix} \text{Length of} \\ \text{Section} \end{matrix} \right] \qquad (18.2)$$

where

PQI_R = Pavement Quality Index (PQI) after rehabilitation (i.e., for the implementation year) and for each year until PQI_M is reached
PQI_M = minimum acceptable level of PQI
PQI_N = yearly PQI from the needs year to the implementation year

The calculation of cost-effectiveness, CE, would then be a simple ratio of effectiveness divided by cost. This ratio has no physical or economic meaning per se, but is valuable in the relative comparison of alternatives and in carrying out priority programming as described in the next chapter. It may be noted that while the ter-

※ 工程經濟分析

$$S = P(1+i)^n = P[spcaf(i,n)]$$

$$S = R\frac{(1+i)^n - 1}{i} = R[uscaf(i,n)]$$

$$P = R\frac{(1+i)^n - 1}{i(1+i)^n} = R[uspwf(i,n)]$$

P＝投資現額

S, F＝n期後之總額

R＝連續每期償付或收回之固定金額

i＝每期最低報酬率(Interest / Discount Rate)

n＝期數

spcaf＝ 一次償付複利因子(single-payment compound-amount factor)

sppwf＝ 一次償付現值因子(single-payment present-worth factor) = 1/spcaf

uscaf＝ 定額複利因子(uniform-series compound-amount factor)

sfdf＝ 基金儲存因子(sinking-fund deposit factor) = 1/uscaf

uspwf＝ 定額現值因子(uniform-series present-worth factor)

crf＝ 資金還原因子(capital recovery factor) = 1/uspwf

- Selecting Length of Program Period (5- or 10- Year Program): Single Year by Single Year Program, or Multiyear Program
- Basic Functions of Priority Programming: Major Steps: Information, Identification of Needs, Priority Analysis, Output Reports (Fig. 19.2)
- Priority Programming Methods: (Table 19.1)
  (a) Subjective Ranking
  (b) Parameter Based Ranking:
      Ex: Rational Factorial Rating Method (A Priority Index <= Expert Opinion)
  (c) Ranking Based on B/C
  (d) Near Optimization Using Marginal Cost-Effectiveness (邊際成本效益) (Incremental B/C)
  (e) Long-Term Optimization: Multiyear Program, Most Complex
- Mathematical Programming: (Page 92, Mohseni's Thesis)
- Examples and Comparisons
- Budget Level Evaluation
- Funding Level Requirements for Specified Standards, Final Program Selection

※ Developing Combined Programs of M & R

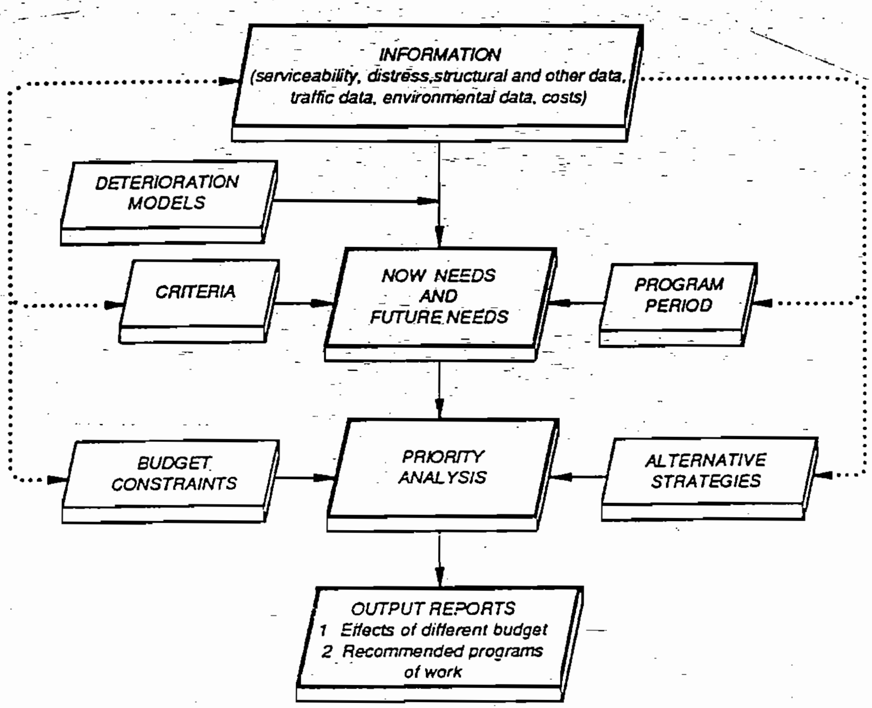


Figure 19.2 Major steps in priority programming.

Table 19.1 Different Classes of Priority Programming Methods [Haas 85a]

CLASS OF METHOD	ADVANTAGES AND DISADVANTAGES
Simple subjective ranking of projects based on judgment	Quick, simple; subject to bias and inconsistency; may be far from optimal
Ranking based on parameters, such as serviceability, deflection, etc.	Simple and easy to use; may be far from optimal
Ranking based on parameters with economic analysis	Reasonably simple; should be closer to optimal
Optimization by mathematical programming model for year-by-year basis	Less simple; may be close to optimal effects of timing not considered
Near optimization using heuristics and marginal cost-effectiveness	Reasonably simple; can be used in a microcomputer environment; close to optimal results
Comprehensive optimization by mathematical programming model taking into account the effects	Most complex; can give optimal program (max. of benefits)

rehabilitation program. In addition, the cost of rehabilitation for each section, the total rehabilitation cost for the network, and the measurable impact of the rehabilitation program on network performance or benefit should also be determined in a network analysis.

	Subjective →	Prioritization →	Optimization
Condition Rating	Subjective	Subjective or Condition Index	Condition Index
Condition Prediction	None	None or Judgement	Models
Project-Level Selection	Judgement	Judgement or L C C	Generate All Feasible Strategies
Network-Level Selection	Ad-Hoc	Ranking (Worst-First rule)	Max. Benefit or Min. Cost

Figure 2.2 - Alternative Network-Level Algorithms.

There are several ways that a rehabilitation program can be generated (see Figure 2.2). The simplest way to arrive at a rehabilitation program involves a subjective inspection of the pavement network (rating each pavement on some scale), identification of pavement sections in need of treatment including a time estimate of when it is needed, and treatment type recommendations. A rehabilitation program is then developed by considering the pavement rating and maintaining the pavement network at a certain standard (or condition level) is desired, the total pavement network rehabilitation cost is minimized for a network performance standard.

This research, however, only considers the rehabilitation programming formulation since this formulation is mainly considered for comparison with other ILLINET options. The formulation for rehabilitation programming with one multi-year (e.g. 10-year) budget limit is as follows:

MAXIMIZE:

$$\sum_{j=1}^{np} \sum_{i=1}^{ns_j} B_{ij} * P_{ij}$$

SUBJECT TO:

$$\sum_{j=1}^{np} \sum_{i=1}^{ns_j} C_{ij} * P_{ij} \le Total\ Budget$$

and

$$\sum_{j=1}^{ns_j} Pij = 1$$

Where:

P_{ij} is a decision variable identifying the jth strategy of ith section, binary (0 or 1)

B_{ij} the benefit of jth strategy in the ith section

C_{ij} the cost of jth strategy in the ith section