十五、 Selection of the Preferred 4R Alternatives

參考資料：

1. Darter, M. I. " Techniques for Pavement Rehabilitation," Training Course, FHWA, 1987. (Module 7A)

◎ Introduction

1. Costs for maintenance and rehabilitation at different points in time
2. Life Cycle Cost (LCC): (Figure 1)
   Present worth (PW)
   Equivalent Uniform Annual Cost (EUAC)
3. "Preferred Alternative" = the one that meet all of the engineering criteria (e.g., traffic control, initial funding) and is cost-effective

◎Development of Alternatives

※Major Design Alternatives:

1. Asphalt Overlay with extensive patching
2. Asphalt Overlay with little or no patching
3. Concrete Overlay with minor repairs
4. Recycle one or more layers plus overlay
5. Restore the existing pavement through extensive patching, grinding, etc. (without an overlay)

※ Recommended Approach: (Figure 2 Rehabilitation Alternative Design Process)

1. Obtain available project information
2. Establish existing condition of pavement
3. Determine the causes of distress
4. Develop feasible alternatives: (Figure 3, 4)
   a. Restoration b. Recycling
   c. Resurfacing d. Reconstruction
5. Conduct engineering and economic analysis
6. Select the preferred rehabilitation alternatives
7. Design the rehabilitation alternative
8. Make follow-up reviews of pavement performance

※ Value Engineering (VE)

1. Appointment of a design review committee: including planning, design, construction, traffic operations, standards, maintenance, and purchasing
2. Solicitation of intra-department or inter-department suggestions
3. Solicitations for ideas from contractors, material suppliers, etc.
4. Brainstorming by either individuals or committees
5. Review of previous studies and ideas from other highway agencies

※ Greatest Obstacle: "Habitual Thinking"

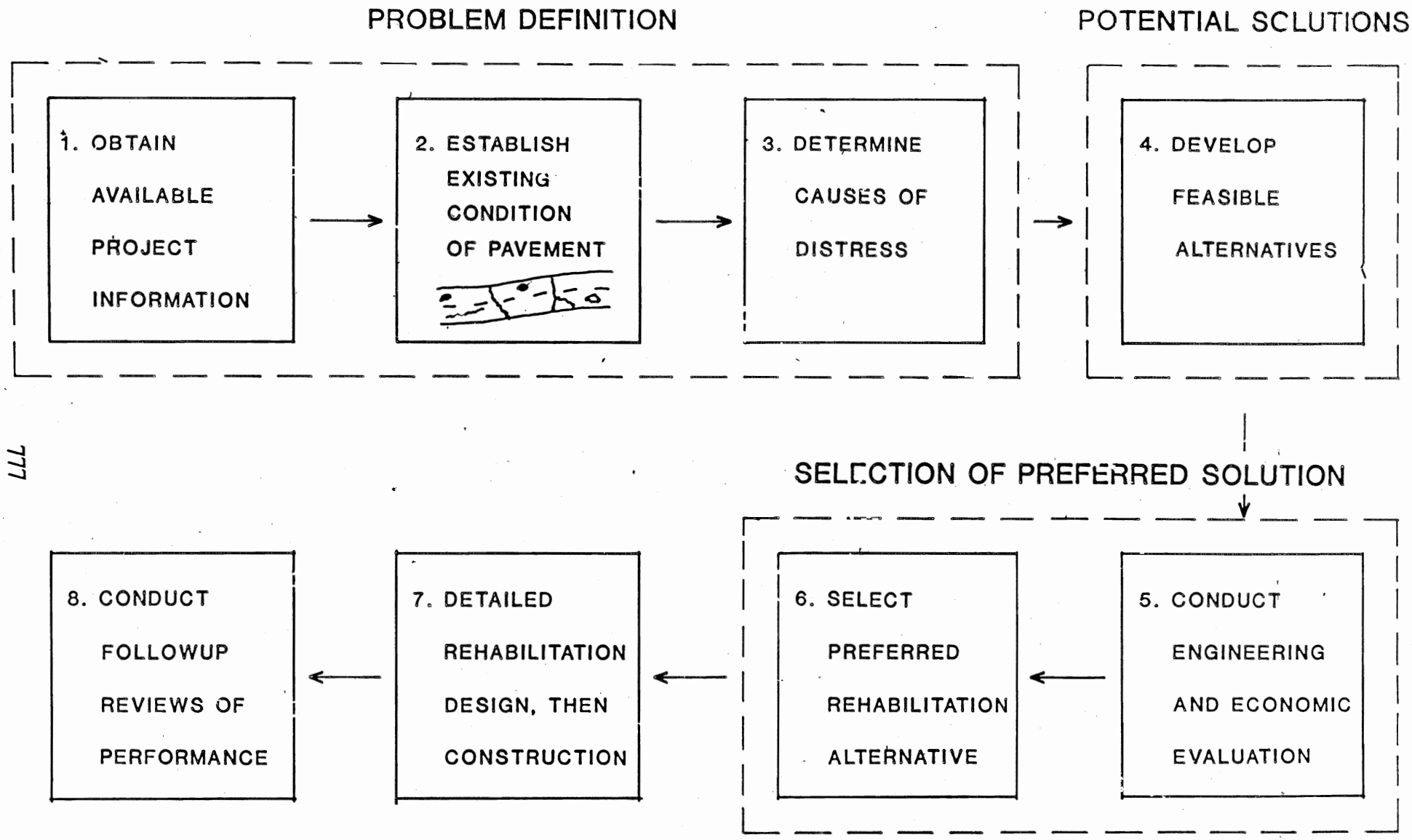

Figure 2. Rehabilitation Alternative Design Process.

Joint/Crack Distress	Repair Methods	Preventive Methods
Alligator Cracking	1. Full-Depth Repair	1. Crack Sealing (may slow down alligator cracking) 2. Structural AC OL
Bleeding	1. Apply Hot Sand	
Block Cracking	1. Seal Cracks	1. Rejuvenator
Depression	1. Level-up Overlay	
Polished Aggregate	1. Skid Resistant Surface Treatment 2. Slurry Seal	
Potholes	1. Full-Depth Repair	1. Crack Sealing 2. Seal Coat
Pumping	1. Full-Depth Repair	1. Crack Sealing 2. Seal Coat
Raveling and Weathering	1. Seal Coat	1. Rejuvenating Seal
Rutting	1. Level-up Overlay 2. Cold Milling With or Without Overlay	Depends on Cause
Swell	1. Removal and Replacement	1. Paved Shoulder Encapsulation

Figure 3. Candidate Repair and Preventive Methods for Flexible Pavement Distress.

Joint/Crack Distress	Repair Methods	Preventive Methods
Pumping	1. Subseal	1. Reseal Joints 2. Restore Load Transfer 3. Subdrainage 4. Edge Support (PCC Shoulder/Edgebeam)
Faulting	1. Grind 2. Structural Overlay	1. Subseal 2. Reseal Joints 3. Restore Load Transfer 4. Subdrainage 5. Edge Support (PCC Shoulder/Edgebeam)
Slab Cracking	1. Full-Depth Repair 2. Replace/Recycle Lane	1. Subseal Loss of Support 2. Restore Load Transfer 3. Structural Overlay
Joint or Crack Spalling	1. Full-Depth Repair 2. Partial-Depth Repair	1. Subseal Loss of Support 2. Restore Load Transfer 3. Structural Overlay
Blowup	1. Full-Depth Repair	1. Pressure Relief Joint 2. Resealing Joint/Cracks
Punchouts	1. Full-Depth Repair	1. Polymer or Epoxy Grouting 2. Subseal Loss of Support 3. Rigid Shoulders

Figure 4. Candidate Repair and Preventive Methods for Rigid Pavement Distress.

◎ Selection of the Preferred Alternative Design

※ Overriding Factors: traffic, soils, climatic, traffic control, lane closures, available materials and equipment, overall pavement management considerations

※ Life-Cycle Costs:

1. Costs to the highway agency
2. Costs to the highway user

Figure 6 - Various Cost Components for Example Design Strategy B

Figure 7 - Cost Components for Five Example Design Strategies

Figure 8 - Life-Cycle Cost Computation Example

$$PW = Cashflow \frac{1}{(1+i)^n}$$

$$EUAC = PW(CRF)$$

$$PW = EUAC\left(\frac{1}{CRF}\right) = EUAC\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)$$

$$= EUAC\left(\frac{1-(1+i)^{-n}}{i}\right)$$

※ LCC Computations:

1. Analysis Period
2. 4R Alternative Performance Period
3. Future Maintenance and Rehabilitation Costs
4. Salvage Values

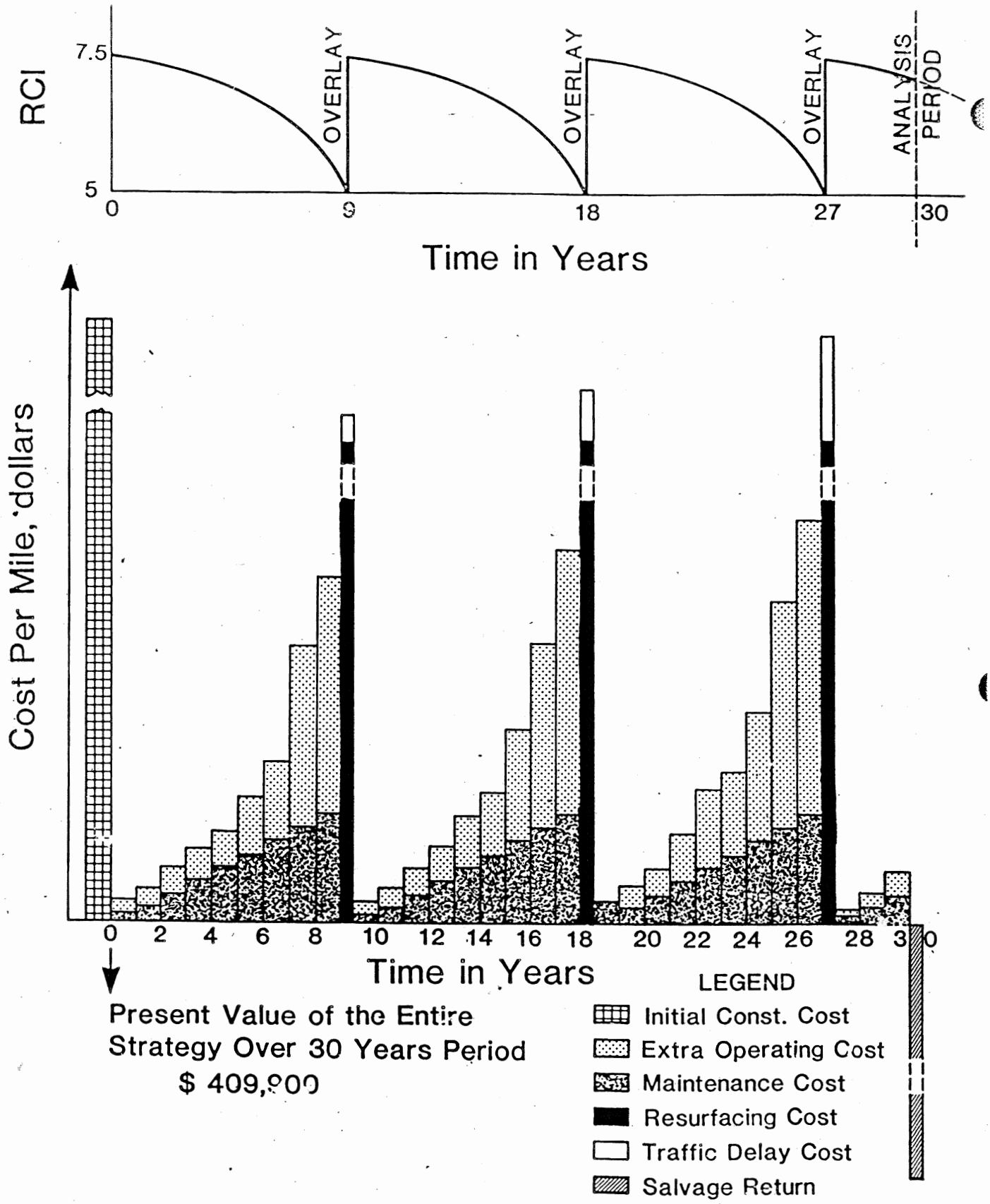

Figure 6. Various Cost Components for Example Design Strategy B (Ref. 17).

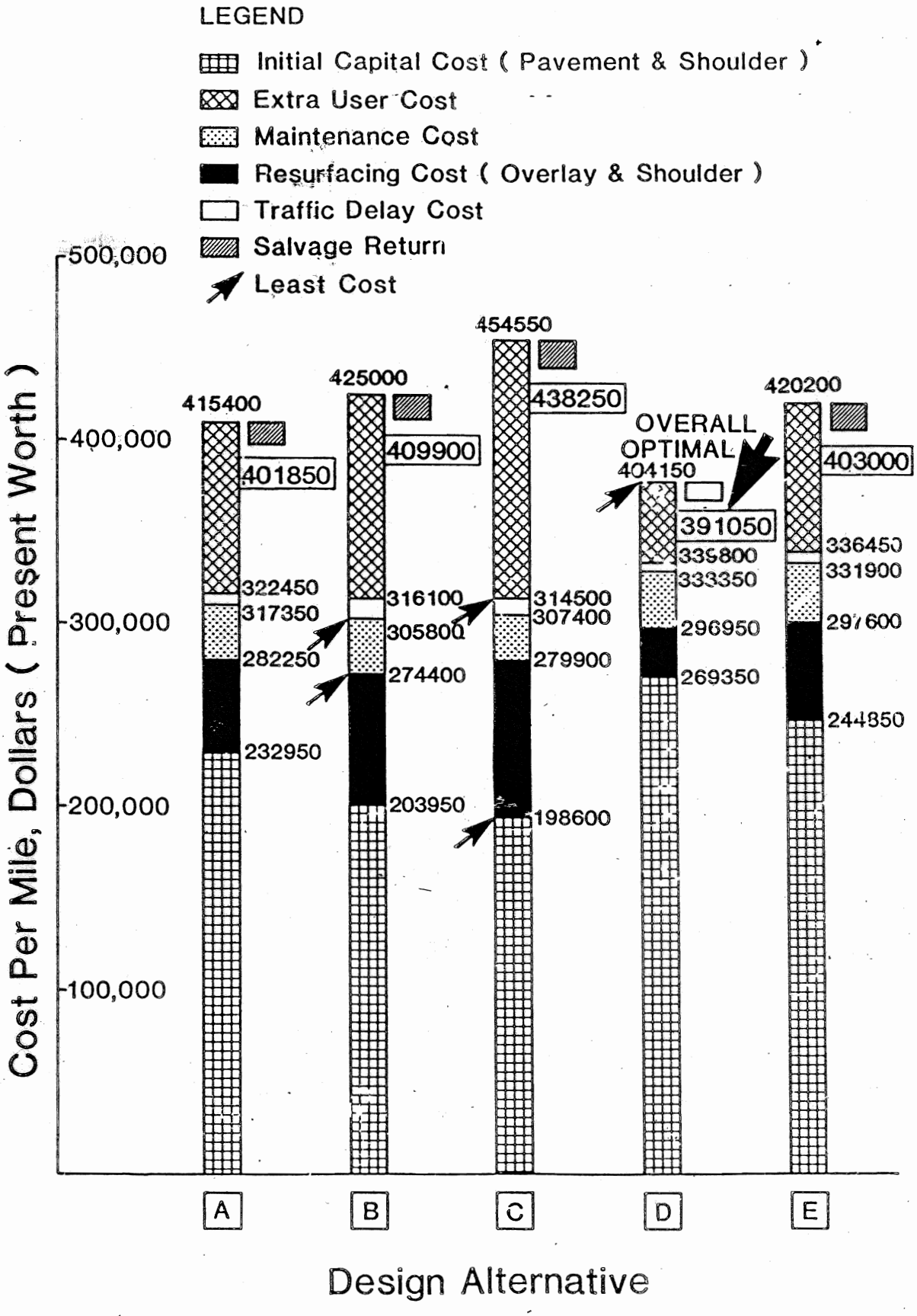

Figure 7. Diagramtic Representation of Cost Components for Five Example Design Strategies (Ref. 17).

5. Discount Rate
    a. Commonly called an interest rate in business investments
    b. Opportunity cost of capital
    c. NCHRP Syntheis:
        "There is general agreement that the discount rate or real discount rate should be the difference between the market interest rate and inflation using constant dollars."

[Figure 10 Preliminary Example LCC analysis]
[Table 3.4 Illustration of EUAC computation]

$$PW = C_i \frac{(1+\text{inf})^n}{(1+\text{int})^n} \approx C_i \frac{1}{(1+i)^n}$$

$$\textit{discount rate},\ i = \text{int} - \text{inf}$$

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

※ Evaluate Overall Important Decision Factors
※ Detailed Design for Selected Alternative

Table 3.4 Illustration of How to Compute the Equivalent Uniform Annual Cost (EUAC) of a Single Alternative

1. Interest Rate = 10 percent
   Inflation Rate = 4 percent

2. Analysis Period = 20 years

3. Maintenance Strategy:

Thin OL & Patch	Thin OL & Patch	Chip Seal Coat	End
(1984)	(1994)	(1999)	(2004)

4. Costs in 1984
   Thin OL & Patch = $4.05/sy
   Chip Seal Coat & Patch = $0.91/sy

5. Present Costs (1984)

$$\text{Present Value} = C_i\,[(1 + \text{inf})/(1 + \text{int})]^n$$

where C_i = cost at present year
inf = inflation rate
int = interest rate
n = number of years

Present Value of Thin OL & Patch: $= 4.05\,[(1 + 0.04)/(1 + 0.10)]^{10} = 2.31$

Present Value of Chip Seal & Patch: $= 0.91\,[(1 + 0.04)/(1 + 0.10)]^{15} = 0.39$

Maintenance	1984 Cost	Year Performed	Present Value
Thin OL & Patch	$4.05/sy	1984	$4.05/sy
Thin OL & Patch	&4.05/sy	1994	$2.31/sy
Chip Seal & Patch	$0.91/sy	1999	$0.39/sy
		Total Present Value =	$6.75/sy

Table 3.4 Illustration of How to Compute the Equivalent Uniform Annual Cost (EUAC) of a Single Alternative (Cont'd)

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6. Average Annual Cost Per Square Yard (EUAC)

The Present Value can be converted to an average annual cost over the analysis period by multiplying it by the Capital Recovery Factor (CRF):

$$CRF = [int(1 + int)^n]/[(1 + int)^n - 1]$$

where int = interest rate
n = number of years

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i = discount rate

$$EUAC = 6.75\ [0.10(1 + 0.10)^{20}]/[(1 + 0.10)^{20} - 1]$$
$$= \$0.79/sy$$

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7. Actual Costs

The actual agency costs of performing the maintenance work given a 4 percent interest rate is:

Year	Actual Cost
1984	$4.05/sy
1994	$4.05\ (1 + 0.04)^{10} = \$5.99/sy$
1999	$0.91\ (1 + 0.04)^{15} + \$1.64/sy$
	Total Actual Cost = $11.68/sy

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8. Summary

The total cost of performing this maintenance work over the next twenty years can be expressed in three ways:

Present Value = $6.75/sy
Annual Cost = $0.79/sy
Sum of Actual Inflated Costs = $11.68/sy

◎ 工程經濟分析(表二~7)

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

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

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

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， 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)

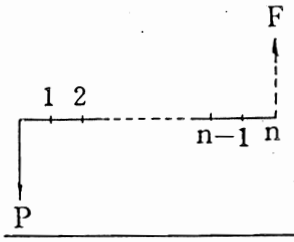
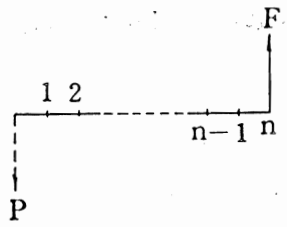
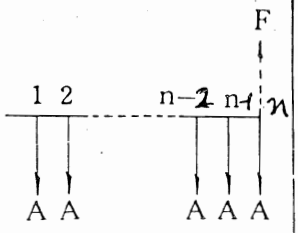
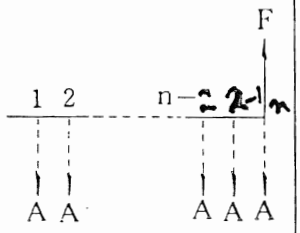
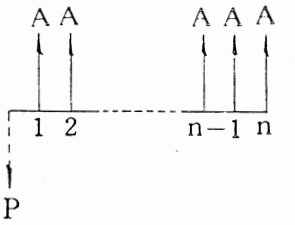
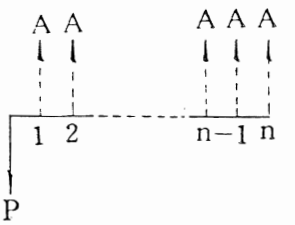
sfdf = 基金儲存因子(sinking-fund deposit factor) = 1/uscaf

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

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

[將分析期間所發生之任何成本(C)或利益(B)均換算成等額之年值或現值，再比較選擇經濟可行之方案]

表二～7　公路經濟分析之基本公式

圖例	公式及說明
	$F=P(CA)$；$CA=(1+i)^n$ ……（2−2） CA＝一次償付複利因素 一次存款P，在利率爲i，n期後一次獲利之本利和F。
	$P=F(PW)$；$PW=1/(1+i)^n$ ……（2−3） PW＝一次償付現值因素 在利率i，n期後一次獲得本利和爲F之相當於目前之現值。
	$F=A(SCA)$；$SCA=[(1+i)^n-1]/i$ …（2−4） SCA＝定額序列複利因素 每期定額存款A，在利率i，n期後一次獲得之本利和F。
	$A=F(SF)$；$SF=i/[(1+i)^n-1]$ ……（2−5） SF＝基金存儲因素 n期後欲一次獲得本利和F，則每期應定額存儲之款額A。
	$P=A(SPW)$；$SPW=[(1+i)^n-1]/i(1+i)^n$ ……（2−6） SPW＝定額序列現值因素 每期支出一定額款數A，在利率i，期數n的情況下，相當於現值P。
	$A=P(CR)$；$CR=i(1+i)^n/[(1+i)^n-1]$ ……（2−7） CR＝資金還原因素 目前一次貸款額爲P，則在利率i，期數n的情況，每期定額償付之款額A。

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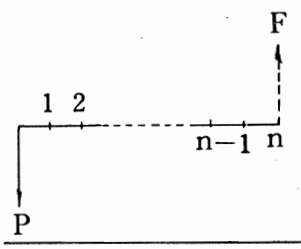
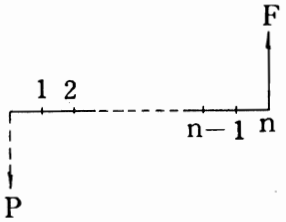
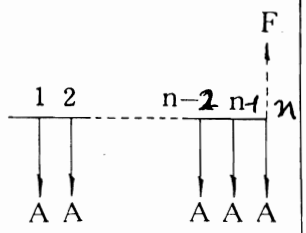
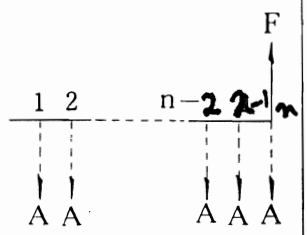
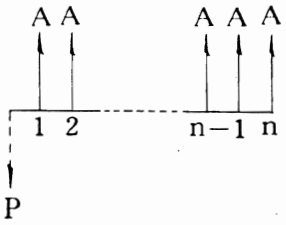
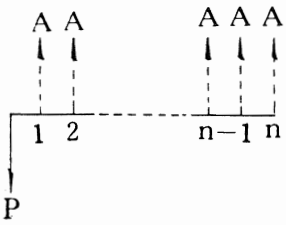
	$F=P(CA)$；$CA=(1+i)^n$ ……（2－2） CA＝一次償付複利因素 一次存款P，在利率爲i，n期後一次獲利之本利和F。
	$P=F(PW)$；$PW=1/(1+i)^n$ ……（2－3） PW＝一次償付現值因素 在利率i，n期後一次獲得本利和爲F之相當於目前之現值。
	$F=A(SCA)$；$SCA=[(1+i)^n-1]/i$ …（2－4） SCA＝定額序列複利因素 每期定額存款A，在利率i，n期後一次獲得之本利和F。
	$A=F(SF)$；$SF=i/[(1+i)^n-1]$ ……（2－5） SF＝基金存儲因素 n期後欲一次獲得本利和F，則每期應定額存儲之款額A。
	$P=A(SPW)$；$SPW=[(1+i)^n-1]/i(1+i)^n$ ……（2－6） SPW＝定額序列現值因素 每期支出一定額款數A，在利率i，期數n的情況下，相當於現值P。
	$A=P(CR)$；$CR=i(1+i)^n/[(1+i)^n-1]$ ……（2－7） CR＝資金還原因素 目前一次貸款額爲P，則在利率i，期數n的情況，每期定額償付之款額A。