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Toward a Generic Protocol for Infrastructure Life Cycle Cost

Final Report

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TOWARD A GENERIC PROTOCOL FOR INFRASTRUCTURE LIFE CYCLE COST

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EXECUTIVE SUMMARY

There are many life cycle cost models (and views) in place around the world today. Some are simplistic (i.e. if a pavement system has a life of about 50 years we should replace 2% of pavement section each year), while other models are considerably more complex. In essence, there are a number of key elements for minimizing infrastructure life costs. Special consideration should be given to the following:

- *Customer Service Standards*
- *Replacement/Rehabilitation Analysis*
- *Statistical Life Assessment*

These three elements are essential in any process that minimizes the life costs for infrastructure asset. Lack of any one of these elements can make the whole process unstable.

The content of the report is a systematic study that addresses various strategies and implementation issues associated with the process of life cycle cost of infrastructure assets. This research introduces the basic concepts of LCCA including the economic factors and parameters involved in the process. The research examines the main types of assets, categories of assets and a breakdown of highway assets that can be incorporated into LCCA. As well, it examines method of asset valuation i.e., establishing a value for infrastructure assets by investigating two models in use. The first model, Perpetual Inventory Method (PIM) follows a depreciation technique for valuing capital stock that can be applied to transportation infrastructure assets, where as the second model, Caltran's process to Valuing Infrastructure, is based on engineering measurements of the condition of bridges.

LCCA User Delay and Cost Effectiveness examples are presented in Chapter's 3 and 4 of the report. A simulation analysis using Real Cost software is also presented. The example examines two pavement sections using traffic data such as AADT, vehicle demand, roadway capacity, dissipation capacity, queue rate etc. Some of the values are based on average capacity and some are assumed or adjusted to reflect the facility type. Various individuals in the private sector were also interviewed based on their experience with LCCA. These results are summarized in Chapter 3.

Chapter 5 of the report defines a "Generic Protocol." An attempt is made to fit MTO business plan into a generic protocol for LCCA. A detailed step-by- step procedure for LCCA starting from the network/system wide level toward the project level is also presented. The intent of having this generic protocol is to have it entirely applicable to all areas of various infrastructures.

The report ends with a summary of LCCA and the benefits that may be attributed from a generic protocol for highway assets. A recommendation on improvements related to maintenance and renovation of MTO's infrastructure assets of facilities is presented in order to improve the Ministry of Transportation Ontario's Asset Management Programs.

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Agencies have historically used some form of Life Cycle Cost Analysis (LCCA) to assist in the evaluation of alternative pavement design strategies. For example, the 1986 AASHTO Guide for the Design of Pavement Structures encourages the use of LCCA. The guide also presents a process to evaluate the cost effectiveness of alternative designs [AASHTO 86]. The application of good practice was specified within the guide instead of specific LCCA procedures. In 1995, the National Highway System (NHS) Designation Act of stipulated the use of LCCA on NHS projects costing $25 million or more. However, only a few agencies routinely practice this plan [Walls 98].

The U.S. Federal Highway Administration's (FHWA) position on LCCA is defined in its Final Policy Statement published in the September 18, 1996, Federal Register [Walls 98]. FHWA policy indicates that LCCA is a decision support tool. As a result, FHWA encourages the use of LCCA in analyzing all investment decisions.

Although the Transportation Equity Act for the 21st Century (TEA-21) has removed the requirement for agencies to conduct LCCA on high cost projects, it is still the intent of FHWA to encourage the use of LCCA for NHS projects [FHWA 98]. For instance, FHWA has even developed training courses to encourage and promote the importance of LCCA and alternative design strategies to agencies.

1.2 SUMMARY OF RESEARCH APPROACH

The purpose of this report is to provide a synthesis of current state of the practice and state of the art LCCA practices by agencies such as Ministry of Transportation Ontario (MTO), FHWA, and various others. It also examines and analyzes some alternative approaches to LCCA in the generic asset management context with an attempt to minimize the Life Cycle Cost of highway infrastructure.

1.3 RESEARCH PROBLEM

The following includes a list of issues and questions that are included in this report:

1. Provide MTO with a consistent approach to LCCA:
    a. Roads and pavements
    b. Other assets such as: Signs, culverts, FTMS, changeable signs, electrical, bridge, etc.
2. Provide guidance on the service life of an asset including:
    a. What questions need to be asked?
    b. What are the factors that impact the service life of an asset?
3. Provide guidance on co-coordinating with MTO Asset Management System
4. Provide guidance on how to best handle User Delay
    a. How do you calculate these delays/costs?
    b. What should be included?

1.4 REARCH OBJECTIVES AND SCOPE

The previous sections have outlined the background of LCCA as well as, a short history of the subject. Since life cycle costing has been performed for many decades and for many different types of projects, there exists a plethora of research and application documentation regarding this topic. The ultimate objective of this research is discussed below.

1.4.1 Research Plan:

1. **Task 1**: Develop a "Primer" that describes the principles, major elements and applications of LCCA for a general audience within MTO and interested stakeholders.
2. **Task 2**: Develop a matrix that compares the various LCCA models in use operating level (e.g. network and/or project) economic basis, type of analysis (deterministic or probabilistic), available software packages, inclusion of user costs, features, advantages and disadvantages, etc.
3. **Task 3**: Develop a breakdown of highway assets that can be incorporated into LCCA. This would use categories of fixed assets (within the ROW), unfixed and fixed assets (outside the ROW) and other assets (non physical) where the breakdown must recognize the need for the practicality.
4. **Task 4**: Initiate the development of a generic protocol that incorporates the strategic, network and project levels for LCCA, which defines those circumstances and individual highway assets where a more simple analysis (e.g. spreadsheet formulation) is sufficient.
5. **Task 5**: Prepare a draft primer (Task 1), a report on Tasks 2 to 4 that includes recommendations for an implementation plan. Prepare a summary presentation/seminar for MTO staff.

1.4.2 Scope

The report's scope is limited in that its major contribution is toward a generic protocol for LCCA of highway infrastructure assets. The primary concern is how this project fits into the larger MTO picture. In other words, the project's goal is to ensure that LCCA fits into the implementation of the New MTO Asset Management System.

1.5 RESEARCH PROJECT SCOPE

In order to accomplish the objectives outlined above, a thorough review of the literature has been completed first to identify the parameters associated with highway infrastructure assets and LCCA that are most significantly related. In addition to these parameters, those aspects of highway infrastructure assets that impact other agency costs and user cost have also been researched.

1.6 ORGANIZATION OF THE REPORT

This report is organized into six chapters as follows:

Chapter 1: This chapter introduces the subject and provides a brief history on the topic. It also outlines the report objectives and scope, which are divided into five tasks as previously presented.

Chapter 2: A comprehensive literature review of the basic concepts and approaches related to Life Cycle Cost Analysis is presented in this chapter. It also includes useful discussion of the pros and cons of several budgeting systems, cost components and the process of a LCCA.

Chapter 3: A survey of existing LCCA models and application is presented. It also describes how these existing models are currently deployed in private industry and state departments of transportation. The chapter discusses models that use mainframe programs, those that are designed for personal computers such as spreadsheet application and other LCCA models.

Chapter 4: A discussion on highway assets and LCCA is presented in this chapter. Methods of asset valuation are discussed and two examples of establishing a value for infrastructure assets are also introduced. Examples of LCCA are also presented in this chapter.

Chapter 5: A generic protocol for infrastructure life cycle cost is drafted. This includes a classification of stakeholders involved.

Chapter 6: This chapter summarizes and concludes the report with final recommendations from the results of the research.

CHAPTER 2. LITERATURE REVIEW

2.1 INTRODUCTION TO BASIC CONCEPTS of LCCA

This chapter reviews the basic concepts and approaches related to LCCA. It also describes the process currently being used by the FHWA and The Ministry of Transportation Ontario (MTO). Useful discussion of the advantages and disadvantages of several budgeting systems (line-item, functional, and program budgeting) in terms of facilitating the calculation of unit costs are also discussed.

The chapter emphasizes that cost allocation is time-consuming and requires careful choices about methodology. It concludes that despite the difficulties of setting up such a budgeting system, it is worth the time and effort for programs to be able to accurately determine true unit costs and program costs. Although the advantages are primarily discussed in terms of practical benefits for program managers, the ability to accurately allocate costs and value of services is also a prerequisite for cost-benefit analysis as a long-term evaluation strategy. A summary of information related to this area is presented.

2.2 DEFINITION OF LIFE CYCLE COST ANALYSIS

LCCA is a method of calculating or analyzing the cost of a system or a product over its entire life span. Section 707 of Executive Order 13123 defines life-cycle costs as "...the sum of present values of investment costs, capital costs, installation costs, energy costs, operating costs, maintenance costs, and disposal costs over the life-time of the project, product, or measure." [GLCCA 03].

In other words, it is an analysis technique for economically evaluating the complete lifetime costs of competing project alternatives. It considers not only initial construction costs, but also ongoing maintenance costs over the lifetime of the project and other user costs such as lost productivity due to traffic delays. Projects are then chosen not just on lowest initial costs, but also on their ability to minimize user costs over the entire project lifetime [LTRC 02].

2.2.1 Stakeholders/Clients for LCCA

The potential stake holders/clients for LCCA are shown in Figure 2.1 below:

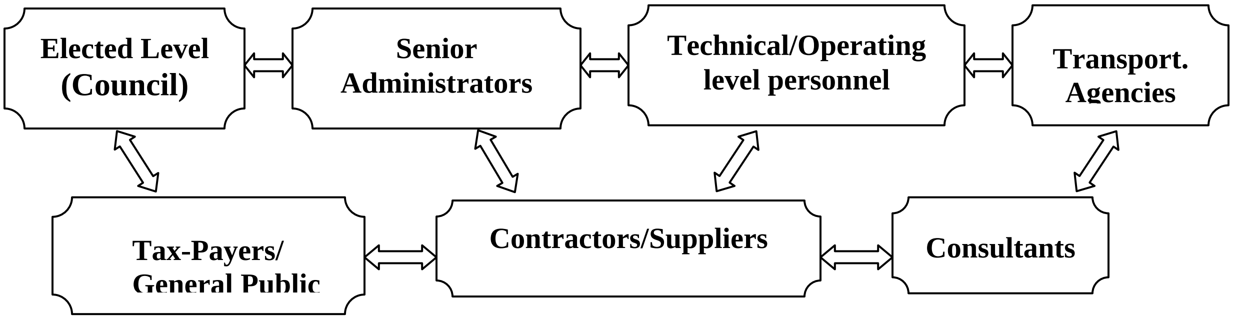


Figure 2.1 Stakeholders/clients for LCCA

The results of LCCA may vary and that depends on how these stakeholders view and use those results. For example, interest groups could view an LCCA as only one factor toward making a decision. Other factors might include consideration of equity, potential impact, social impact etc., which may also be relevant to them [Haas 01a].

2.3 IMPROVEMENT OF LIFE CYCLE COST ANALYSIS

Pavement design and analysis has improved significantly over the past few decades. Consequently, the ability to predict and calculate a wide range of costs associated with highways has also greatly improved. When performing a cost analysis on an infrastructure system, usual considerations include the total initial or installed cost of the system and the annual operating costs. Various costs are included in these two cost divisions. Unfortunately, other important costs have often been omitted due to the difficulty involved in predicting such costs [Cheresource 02].

However, with today's advanced testing methods and the availability of a significant engineering history to learn from, these "new" costs can be estimated with a higher degree of confidence than in the past. So what are those costs? The analysis of a typical infrastructure or system could include such costs factors as:

- System Planning and Concept Design
- Preliminary System Design Cost
- Design and Development Costs
- Product Costs
- Maintenance Costs (Maintenance cost to alter design)
- User delay costs
- Labor cost involved with maintenance
- Disposal Costs (Salvage value)

This type of analysis often uses values calculated from other reliability analyses like:

- Failure rate
- Cost of extras or standbys
- Repair times
- Component costs

The preceding list of parameters is important in developing a life cycle cost analysis. Those cost components are further broken down into two major categories:

Agency Cost

- Initial construction cost, maintenance cost, rehabilitation cost, replacement cost

Direct and External Societal Costs

- Travel Time Delay
- Vehicle Operating Cost
- Emissions
- Accidents
- Discount Rate
- Reliability
- Environmental costs

2.4 THE MERIT OF LCCA

In conducting a life cycle cost analysis, relationships from testing or calculations may begin to resemble that of Figure 2.2. Rather than considering initial costs only and assuming that the equipment or material will perform well throughout the infrastructure's life, transportation agencies are beginning to consistently look at the "overall" big picture.

As can be seen in Figure 2.2, Material 1 is less expensive than Material 2, but at a future time it must be replaced with Material 1 or a comparable material. Therefore, the cost of using Material 1 is actually the cost of Material 1 + cost of replacement Material. In addition, there are significant user costs associated with this work. Overall, these are the sort of scenarios that life cycle cost analysis is designed to prevent because the cost associated with changing design specifications is often significant.

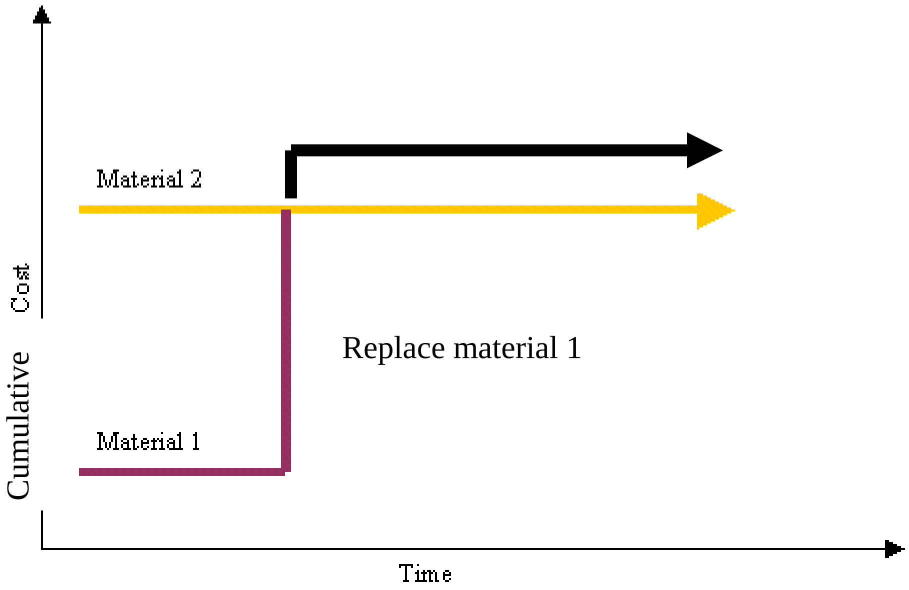


Figure 2. 2 Material Choices may Impact the Future

An agency could use a life cycle cost analysis to determine warranty costs. This type of analysis could be based on anticipated failures, repair times, and costs of repairs. Many agencies are finding that a life cycle cost analysis is a valuable tool during the design phase of a project in order to determine the most cost effective solution before substantial costs are incurred.

2.4.1 What Life-Cycle Cost Analysis Can Do

LCCA enables one to define the elements included in the lifespan of a system or product, and assign equations to each element. Examples of equations used in cost analysis includes, Net Present Value (NPV), Cost Effectiveness and Cost/Benefit ratio. These equations represent the calculation of the cost of that particular element or asset. Equations such as Net Present Value and Cost Effectiveness will be discussed later in this chapter.

2.5 OBJECTIVES of LIFE-CYCLE COST ANALYSIS

The objective of performing a LCCA should include the following:

- To choose the most cost effective approach for using available resources over the entire lifespan of the product or system.
- The LCCA provides a systematic process for evaluating and quantifying the cost impacts of alternate courses of action.
- It can be used to support tradeoff analysis between several design configurations, or as a measure of sensitivity of a specific design to changes in selected performance parameters (such as reliability, maintainability, and testability).

End result or as-built quality can affect the distribution of costs between upfront program and construction costs, field operation and repair costs.

2.6 HOW LIFE-CYCLE COST ANALYSIS WORKS

The idea of life cycle costing can be used to understand various transportation issues. For example, the financial affliction of transit that causes under investment in infrastructure and vehicles and under maintenance of vehicles and infrastructure can benefit from LCCA [Sussman 00]. Figure 2.3 presents a basic philosophy associated with LCCA.

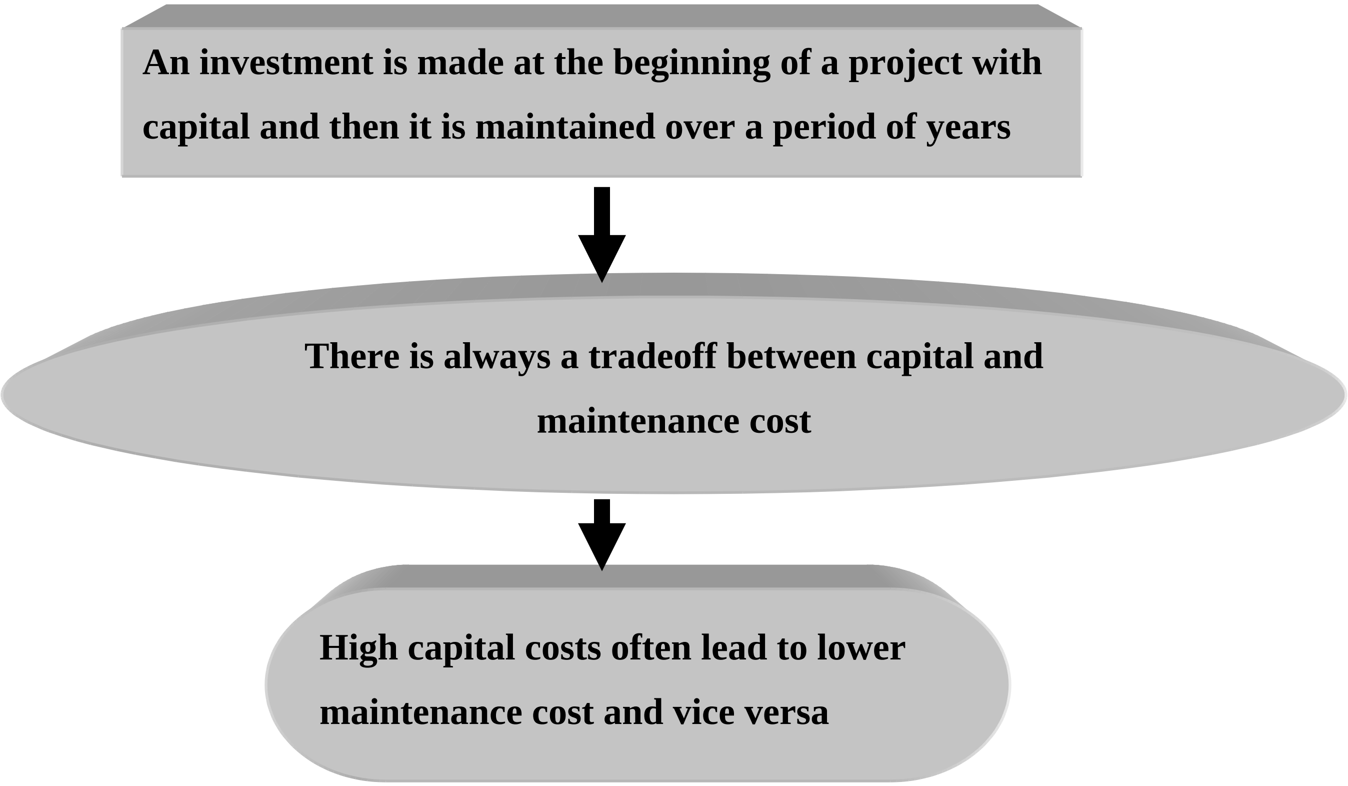


Figure 2. 3 The Philosophy of Life-Cycle Costing

Figure 2.4 shows a flow of cost, both capital and maintenance over time for an infrastructure facility.

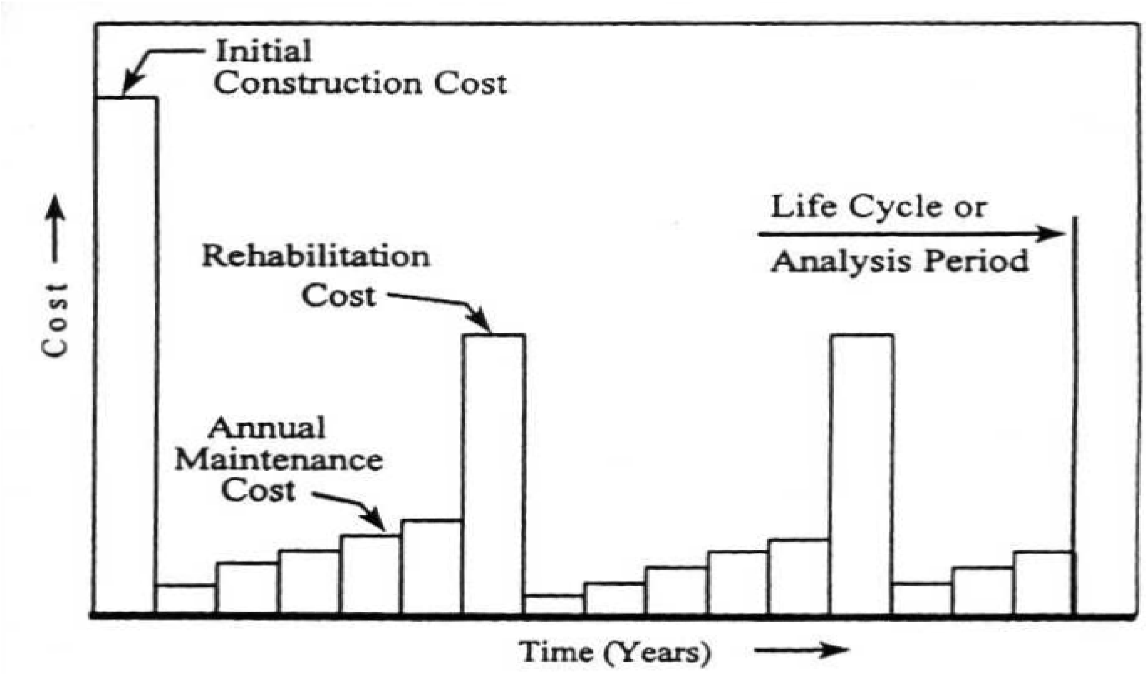


Figure 2. 4 Life cycle cost streams for infrastructure analysis [Hudson et al, 1997]

2.7 THE PROCESS OF A LCCA

LCCA should be conducted as early in the project development cycle as possible. The level of detail in the analysis should be consistent with the level of investment. [Hicks 99]. LCCA basically involves the following steps:

Step 1. Develop rehabilitation and maintenance strategies for the analysis period.

Step 2. Establish the timing (or expected life) of various rehabilitation and maintenance strategies.

Step 3. Estimate the agency costs for construction, rehabilitation, and maintenance.

Step 4. Estimate user and non-user costs.

Step 5. Develop expenditure streams.

Step 6. Compute the present value.

Step 7. Analyze the results using either a deterministic or probabilistic approach.

Step 8. Reevaluate strategies and develop new ones as needed.

The applications of the above steps to pavement infrastructure are described below.

Step 1. Establish Alternative Design Strategies

The primary purpose of a LCCA is to quantify the long-term economic implications of initial infrastructure decisions. Various rehabilitation and maintenance strategies can be employed over the analysis period as seen in Figure 2.5. This first step is to identify alternate strategies over the analysis period, typically 40 years. For example, a pavement structure may receive different maintenance (or rehabilitation) treatments depending on its initial structure/budgets, etc., until the life reaches the analysis period of 40 years (see Figure 2.6).

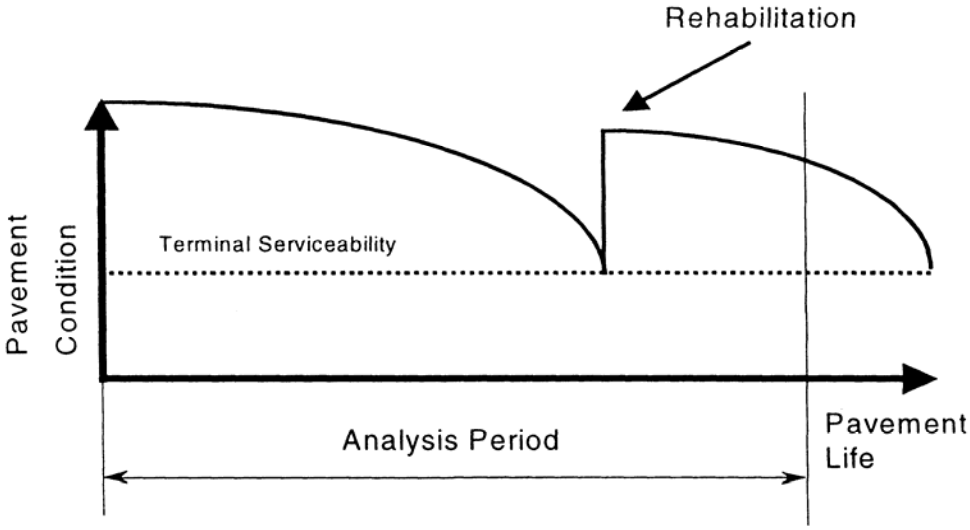


Figure 2. 5 Analysis period for a pavement design alternative

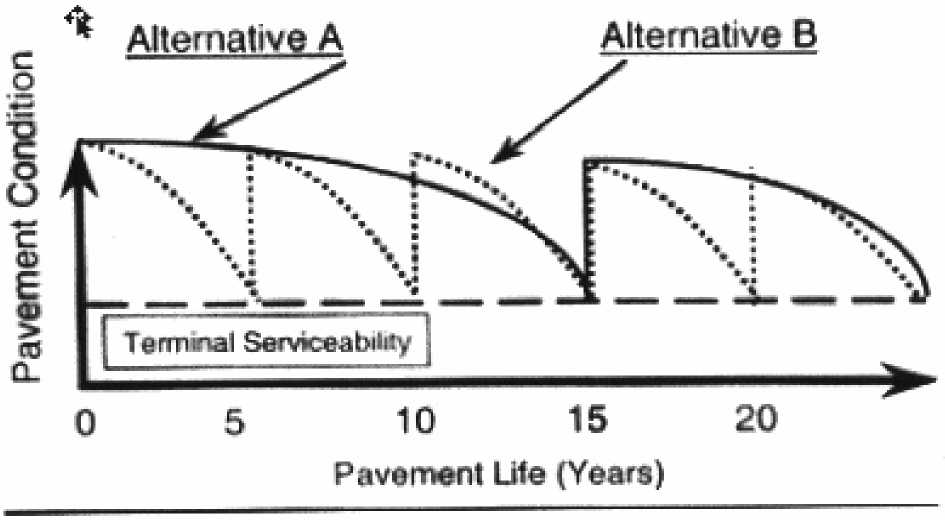


Figure 2. 6 Performance curves for two rehabilitation or maintenance strategies [Hicks 99]

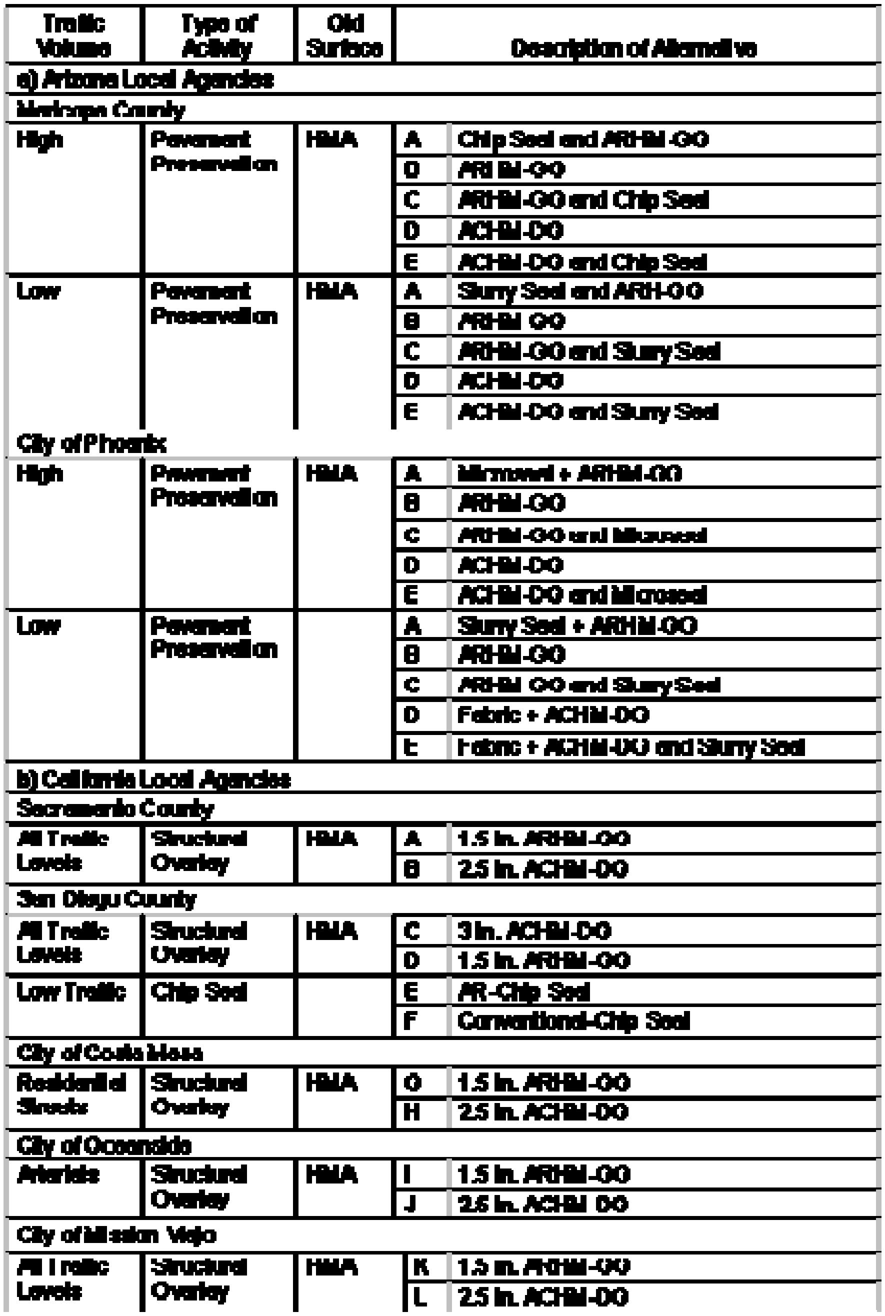
Example of Alternative Design Strategies

An example of alternative design strategies from for asphalt pavement is presented below. It is based on a study done in Arizona and California. However, the technique can be applied in a similar measure to the Ontario conditions. Typical strategies used in these states are summarized in Table 2.1. A logical comparison between conventional mixtures and mixtures containing asphalt rubber for each of the scenarios is presented.

Step 2. Determine Expected Life of Rehabilitation and Maintenance Strategies

The next step was to obtain estimates of expected lives for the various rehabilitation and maintenance strategies. For this example, these estimates were also determined based on interviews with state and local agencies in each state. Estimates for pavement life for each of the scenarios considered by the local agencies are given in Tables 2.1 and 2.2. Similar data was collected for the state highway agencies surveyed in Arizona and California. The table includes an average life and the lowest and highest expected life for a given strategy. In this example, the low and high values represent the 10 and 90 percentile values for expected life. According to Hicks, it should be emphasized that the estimated lives are best estimates only and in many cases the alternatives have not yet reached the 90% value [Hicks 99].

Table 2. 1 Typical Design Strategies Use [Hicks 99]



Traffic Volume	Type of Activity	Old Surface	Description of Alternative	
a) Arizona Local Agencies				
Maricopa County				
High	Pavement Preservation	HMA	A	Chip Seal and ARHM-GG
			B	ARHM-GG
			C	ARHM-GG and Chip Seal
			D	ACHM-DG
			E	ACHM-DG and Chip Seal
Low	Pavement Preservation	HMA	A	Slurry Seal and ARH-GG
			B	ARHM GG
			C	ARHM-GG and Slurry Seal
			D	ACHM-DG
			E	ACHM-DG and Slurry Seal
City of Phoenix				
High	Pavement Preservation	HMA	A	Microseal + ARHM-GG
			B	ARHM-GG
			C	ARHM-GG and Microseal
			D	ACHM-DG
			E	ACHM-DG and Microseal
Low	Pavement Preservation		A	Slurry Seal + ARHM-GG
			B	ARHM-GG
			C	ARHM GG and Slurry Seal
			D	Fabric + ACHM-DG
			E	Fabric + ACHM-DG and Slurry Seal
b) California Local Agencies				
Sacramento County				
All Traffic Levels	Structural Overlay	HMA	A	1.5 in. ARHM-GG
			B	2.5 in. ACHM-DG
San Diego County				
All Traffic Levels	Structural Overlay	HMA	C	3 in. ACHM-DG
			D	1.5 in. ARHM-GG
Low Traffic	Chip Seal		E	AR-Chip Seal
			F	Conventional-Chip Seal
City of Costa Mesa				
Residential Streets	Structural Overlay	HMA	G	1.5 in. ARHM-GG
			H	2.5 in. ACHM-DG
City of Oceanside				
Arterials	Structural Overlay	HMA	I	1.5 in. ARHM-GG
			J	2.5 in. ACHM DG
City of Mission Viejo				
All Traffic Levels	Structural Overlay	HMA	K	1.5 in. ARHM-GG
			L	2.5 in. ACHM-DG

Notes: ARHM –GG –Asphalt-Rubber Hot Mix (Gap Graded)
ACHM-DG – Asphalt Concrete Hot Mix (Dense Graded)
Fabric- The basic interlayer installation involves placing a paving fabric between an older asphalt pavement and a new overlay placed on top of the fabric

Table 2. 2 Summary of Various Maintenance and Rehabilitation Life Expectancy and Costs, Arizona Local Agencies [Hicks 99]

Class of Roadway	Rehabilitation alternatives	Expected Life Years			Rehabilitation Cost		
		Average	Low	High	Average	Low	High
Maricopa County							
High Traffic Volume (Collector and above)	CS	6	1.5	7	0.06/sm		
	ACHM –DG (50mm)	6	5	10	0.04/m3	0.03/m3	0.05/m3
	ARHM-GG (38-50mm)	12.5	10	15	0.059/m3	0.047/m3	0.00/m3
	AR-CS	6	5	15	1.5sm		
Lower Traffic Volume (Residential)	SS	5	2	7	0.42/sm		
	PM-SS	7	0	10	0.49/sm		
	ARHM-GG (38mm)	12.5	10	15	0.05/sm	0.05/m3	0.00/m3
	ACHM –DG (50mm)	6	5	10	0.04/m3	0.03/m3	0.05/m3
	CS				0.72/sm		
Other Treatments	Fog Seal				0.133/sm		
					170 ton		
	Crack Seal- (Asphalt Rubber)				0.17/sm	0.15/sm	0.2/sm
	Scrub Seal				0.0.42/sm		
City of Phoenix							
High Traffic Volume	PM-SS	10	5	15	1.17/sm		
	ACHM –DG (32mm)	7	12	10	0.06/m3	0.05/m3	0.05/m3
	ARHM-GG (32mm)	8	4	22	0.001/m3		
	ARHM-GG (25mm)	20	10	25	0.001/m3		
	SS	10	5	15	0.45/sm		
Other Treatments	Fog Seal -Emulsion				0.15/sm		
	Fog Seal -Polymer				0.17/sm		
	Crack Seal-Residential				0.10/sm		
	Crack Seal- Collector/Arterial				0.033/sm	0.02/sm	0.05/sm
	Fabric Interlayers				0.75/sm	0.66/sm	.836/sm

Step 3. Estimate Agency Costs

Agency costs include all costs incurred directly by the agency over the life of the project. These costs typically include expenditures for preliminary engineering, contract administration, construction, including construction supervision, and all future maintenance (routine and preventive), resurfacing and rehabilitation. Estimates for these costs were obtained from Arizona and California and these are also summarized in Tables 2.3 and 2.4 [Hicks 99]. The low and high values represent the 10th and 90th percentile values for expected costs.

Salvage Value

Salvage value represents the value of an investment alternative at the end of the analysis period. The method used to account for salvage value in Hicks example was prorated based on the cost of final rehabilitation activity, expected life of rehabilitation, and time since last rehabilitation activity as shown below:

$$SV = 1 – (L_A/L_E) \text{ x } C \qquad (1)$$

Where:

L_E = the expected life of the rehabilitation alternative

L_A = portion of the expected life consumed

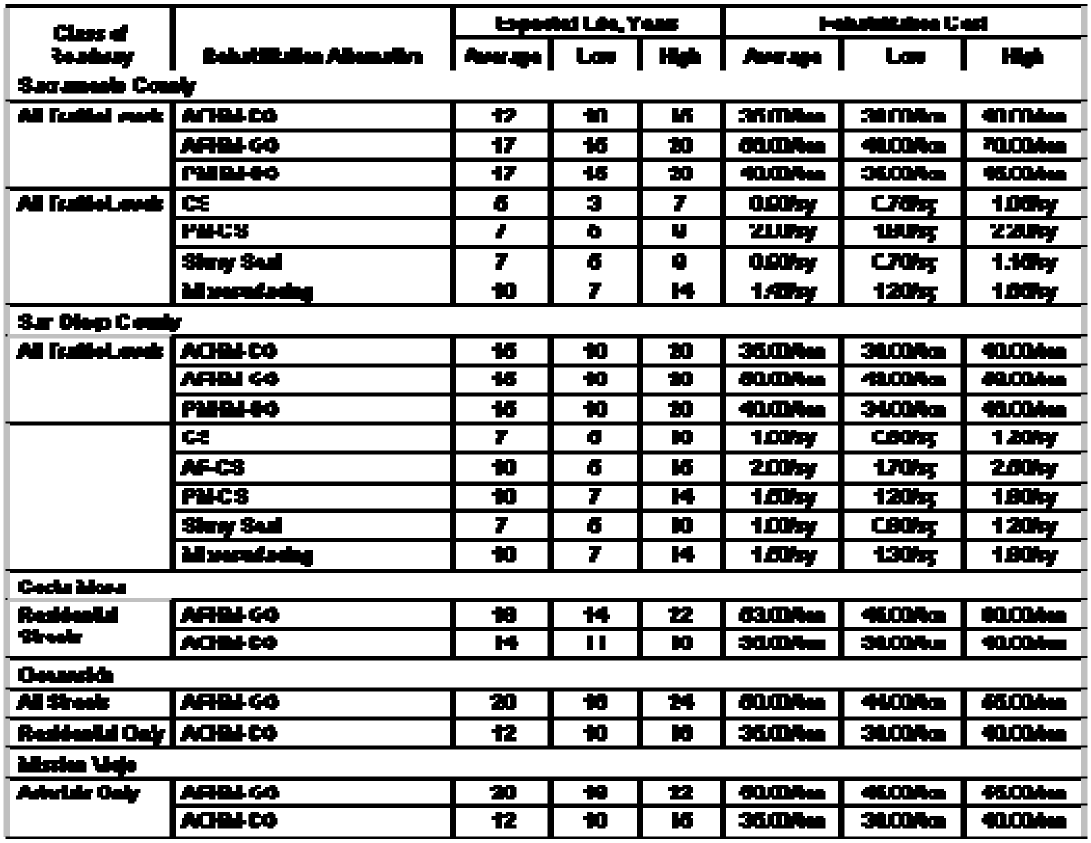
C= Cost of rehabilitation

Step 4. Estimate User and Non-User Costs

In simple terms, user costs are those incurred by the highway user over the life of the project. They include:

- Vehicle operating costs (VOC),
- User delay costs, and
- Accident costs.

Table 2. 3 Summary of Various Maintenance and Rehabilitation Life Expectancy and Costs, California Local Agencies [Hicks 99]



Class of Roadway	Rehabilitation Alternative	Expected Life, Years			Rehabilitation Cost		
		Average	Low	High	Average	Low	High
Sacramento County							
All Traffic Levels	ACHM-CO	12	10	15	35.00/ton	30.00/ton	40.00/ton
	ARHM-GG	17	15	20	60.00/ton	40.00/ton	70.00/ton
	PMHM-GG	17	15	20	40.00/ton	35.00/ton	45.00/ton
All Traffic Levels	CS	5	3	7	0.90/sy	0.70/sy	1.00/sy
	PM-CS	7	6	9	2.00/sy	1.80/sy	2.20/sy
	Slurry Seal	7	6	9	0.90/sy	0.70/sy	1.10/sy
	Microsurfacing	10	7	14	1.40/sy	1.20/sy	1.60/sy
San Diego County							
All Traffic Levels	ACHM-CO	15	10	20	35.00/ton	30.00/ton	40.00/ton
	ARHM-GG	15	10	20	50.00/ton	40.00/ton	60.00/ton
	PMHM-GG	15	10	20	40.00/ton	34.00/ton	48.00/ton
	CS	7	6	10	1.00/sy	0.80/sy	1.20/sy
	AR-CS	10	6	15	2.00/sy	1.70/sy	2.60/sy
	PM-CS	10	7	14	1.50/sy	1.20/sy	1.80/sy
	Slurry Seal	7	6	10	1.00/sy	0.80/sy	1.20/sy
	Microsurfacing	10	7	14	1.50/sy	1.30/sy	1.80/sy
Costa Mesa							
Residential Streets	ARHM-GG	18	14	22	63.00/ton	45.00/ton	80.00/ton
	ACHM-CO	14	11	16	33.00/ton	30.00/ton	40.00/ton
Oceanside							
All Streets	ARHM-GG	20	18	24	50.00/ton	44.00/ton	55.00/ton
Residential Only	ACHM-CO	12	10	16	35.00/ton	30.00/ton	40.00/ton
Mission Viejo							
Arterials Only	ARHM-GG	20	18	22	50.00/ton	45.00/ton	55.00/ton
	ACHM-CO	12	10	15	35.00/ton	30.00/ton	40.00/ton

Note: 1 sy = 0.836 sm
$1.00 U.S. = $1.3119 CA (Jan. 23, 2004)

For most pavements on the National Highway System (NHS), the VOC are considered to be similar for the different alternatives. However, slight differences in VOC rates caused by differences in roughness could result in huge differences in VOC over the life of the pavement. Hicks assumes VOC rates to be equal in his example.

Delay cost rates have been derived for both passenger cars and trucks for the example. These can range from $10-$13 ($13-$16 CA)/veh-hr for passenger cars and $17-$24 ($20-$27 CA)/veh-hr for trucks [Hicks 99]. These cost figures are similar to those found in a report written by Walls [Walls 98]. Because these costs require project specific information for inclusion in LCCA and also because the value of delay costs is often questioned, Hicks opted to use a simpler approach using lane rental fees (Table 2.4). Typical values for lane rental fees might vary with traffic volume as follows:

Table 2. 4 Lane Rental Fee [Hicks 99]

Type of Facility	AADT	Ca$/Lane-Km/Day
Low volume	5000	1,250
Moderate volume	15000	6,250
High volume	75000	12,500

These values are estimates only, but allow the effect of delays to be accounted for indirectly.

According to Hicks, accident and non-user costs may also vary with type of rehabilitation and maintenance strategy. For purposes of this example, the effects of pavement strategy on these costs were ignored.

Step 5. Develop Expenditure Streams

Expenditure streams are graphical or tabular representations of expenditures over time. They are generally developed for each pavement design strategy to visualize the extent and timing of expenditures. Figure 2.7 is an example of an expenditure stream. Normally, costs are depicted as upward arrows and benefits are reported as negative cost (or downward arrows). The only benefits, or negative cost, included herein are the costs associated with the salvage value.

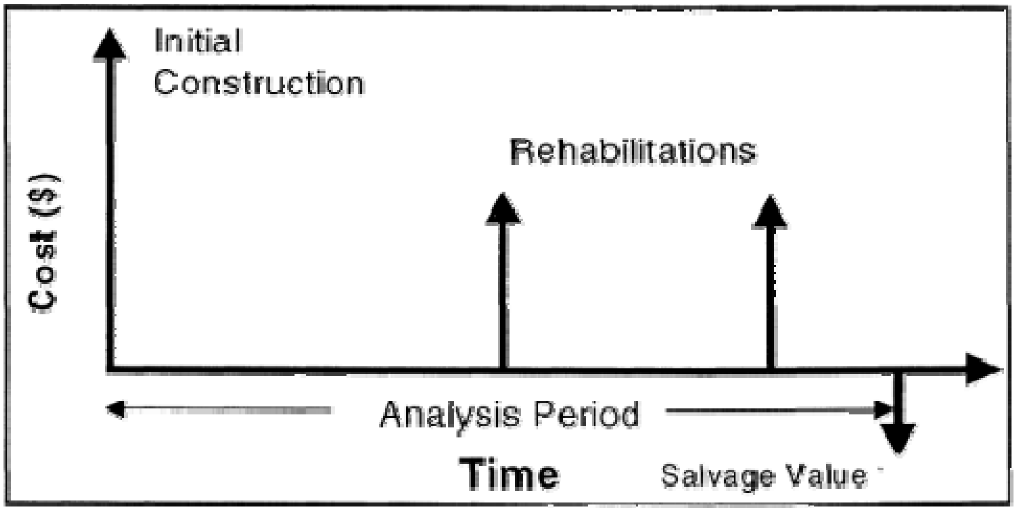


Figure 2. 7 Typical expenditure stream diagram for a pavement design alternative

Step 6. Compute Net Present Value (NPV)

LCCA is a form of economic analysis used to evaluate the cost efficiency of various investment options. Once all costs and their timing have been established, the future costs must be discounted to the base year and added to the initial cost to determine net present value (NPV). NPV is calculated as follows:

Net Present Value

$$NPV = \text{Initial Cost} + \sum_{k=1}^{N} \text{Oper'l Cost}_{\text{k}} \left[1/(1+i)^{n}\right] \qquad (2)$$

Where

i =discount rate typically 3% to 5%
n = year of expenditure
k =maintenance or rehabilitation strategy or user cost

Both agency and user cost are incorporated into the analysis. The results can be presented using a deterministic or probabilistic approach as will be discussed in the examples to follow.

Step 7. Analyze Results

Once completed, all LCCA results should be subjected to a sensitivity analysis to determine the influence of major input variables. Many times the sensitivity analysis will focus on inputs with the highest degree of uncertainty (i.e., life) in an attempt to bracket outcomes. For example, if a conventional project lasts 10 years, how long must an asphalt rubber design last for it to be cost effective? An example of a sensitivity analysis will be discussed later in this report.

Step 8. Reevaluate design strategy

Once the NPV has been computed for each alternative, the analyst needs to reevaluate competing design strategies. Questions to be considered include:

1. Are the design lives and maintenance and rehabilitation costs appropriate?
2. Have all the costs been considered (e.g., shoulder and guard- rail)?
3. Has uncertainty been adequately treated?
4. Are there other alternates which should be considered?

Many assumptions, estimates, and projections feed the LCCA process. The variability associated with these inputs can have a major influence on the results.

2.8 ECONOMIC FACTORS AND PARAMETERS IN LIFE-CYCLE ANALYSIS

This section deals with the economic factors and parameters associated with LCCA. An MTO approach is examined for most part of this section. Generally, LCCA involves the modeling from several years of the performance of a particular road exposed to a given set of condition. It also involves:

- Economic factors
- Traffic loading
- Selected rehabilitation and maintenance treatments, etc.

Future costs are discounted at a series of desired interest rates and the results expressed as a percent worth of cost and cost-effectiveness ratio. The best strategies, which would minimize the total cost or maximize the total benefits may then selected by the user [MTO 90].

The following section is a review of some of the decisions necessary in order to determine the main input parameters in the Present Worth of cost method of life cycle costing. It also covers some of the ways each component can be assessed economically. Some of the factors are as follows:

2.8.1 Analysis Period

This is the length of time (usually in years) that is selected for consideration of life cycle cost. The choice of an analysis period should not be biased in favor of any particular rehabilitation alternative nor extend beyond the period of reliable forecast [MTO 90]. Periods of 20 and 40 years have been chosen by most transportation studies as a considerable reasonable range. An analysis of 30 years is more reasonable because of all the uncertainties that are associated with forecasting performance of rehabilitation treatments. The main reason for choosing this 30-year period is that discounted costs beyond this period do not generally contribute significantly to the total present worth of the system. MTO uses 20 to 30 years, 20 years for rehabilitation and 30 years for new construction [MTO 90].

2.8.2 Discount and Interest Rate

A discount rate is a means for comparing alternative use of funds by reducing the expected costs and benefits to present day terms. Interest rate is different in that it is associated with the current rate of borrowing money and the two should not be confused [MTO 90].

The choice of a discount rate may make the difference between acceptance and rejection of a rehabilitation alternative but this is rarely in practice. For example, if a low discount rate is used, alternatives with large initial capital expenditure will be favored over those that involve more modest initial investments. The selection of a proper discount rate, therefore, is essential in lifecycle cost analysis. The rate used in an agency's cash flow calculation is a policy decision. It might vary with the factor being analyzed and the purpose of the analysis. However, most agencies do, in fact, use a single rate.

The value of the discount rate is sometimes chosen to coincide with the agency's rate of borrowing money. Using a discount rate which represent the real cost of capital (i.e., real rate of return) in constant dollar is the generally accepted procedure into the engineering profession [MTO 90]. The actual rate used by various agencies may vary from four to six percent; the most common is six percent. Frequently LCCA are conducted using several discount rates to allow an assessment of how sensitive the analysis are to variations in the real rate of return.

2.8.3 Rehabilitation Costs

In most agencies, detailed cost analysis is necessary for in-depth project evaluation. On the other hand, average benchmark cost information may be used if desired. Detailed calculations are included as an option. The cost of resurfacing a road, for example, is calculated as follows:

$$\text{COST} = \text{LW} * \text{T} * \text{D} * \text{UC} * 10^{-3} * \text{N} * \text{PL} + \text{Additional Construction Costs} \qquad (3)$$

Where:

COST = Rehabilitation Cost ($)
LW = Lane width (m)
T = Thickness (mm)
D = Density of compacted material (kg m^{-3})
UC = Unit cost of surfacing material ($/tonne)
N = Total number of lanes
PL = Project length

For any improvement action that is undertaken, it is usually necessary to repair road shoulders so there is not an unsafe drop-off along the edge of the maintained lane. The normal method is to resurface the shoulder to keep it at the same grade as the adjoining riding surface. The shoulder repair costs are given as:

$$SCOST = SW * T * D * UC * 10^{-3} * PL + \text{Additional Construction Costs} \qquad (4)$$

Where:
SCOST = Shoulder repair cost
SW = Total width of shoulder
T = Thickness surfacing material (mm)
D = Density of compacted surfacing material (kg m^{-3})
UC = Unit cost of surfacing material ($/tone)
N = Total number of lanes
PL = Project length

The total rehabilitation cost is the sum of the riding surface rehabilitation costs and the shoulder repair costs [MTO 90].

2.8.4 Periodic and Annual Routine Maintenance Costs

Periodic Maintenance Cost

Periodic maintenance costs are those associated with activities, which are performed on a less frequent basis to prolong the life of a road section at a serviceable level. This may range from machine patching to rout and sealing of cracks. The cost involve can be included as one of the rehabilitation treatments for a particular alternative [MTO 90].

Routine Maintenance Costs

Routine maintenance costs, on the other hand, are those associated with activities, which are performed on a more frequent basis to maintain the health of a road section. This may range from clearing of side drains to pothole filling. These costs can be represented as a uniform annual or annual linear increasing cost [MTO 90].

2.8.5 User Delay Costs

This section briefly describes the process of User Delay Costs. This topic will be discussed later in Chapter 3 of this report. It is undeniable that a rehabilitation activity has a definite impact on traffic. The delay or inconvenience to traffic results in a cost to motorist. Most agencies, however, do not account for user delay costs in their lifecycle costing analysis. The delay costs that are suffered by the road users are sometimes considered to be indirect (not agency) cost. However, user delay cost may be significant enough in some cases particularly on heavily traveled roads, to justify their inclusion in the economic evaluation [MTO 90]. The factors that may affect delay costs include:

- Expected duration of paving
- Expected delay per vehicle during rehabilitation
- Work period (paving at night usually affects less traffic)

The following example represents a very simple approach to calculating user delay cost based on MTO process [MTO 90]:

Initial Traffic Volume (AADT) = 50,000 Vehicles

15% Trucks = 7,500 trucks/day

85% Autos = 42,500 autos/day

Average Truck delay cost = $30 per hour

Average auto delay cost = $ 30 per hour

Avg. Traffic delay due to rehabilitation = 3 minutes

Traffic affected during rehabilitation = 50 percent

Duration traffic is affected due to rehab = 2 days

Total user delay cost due to rehabilitation:

Trucks = $30 * (3/60) * (7,500 * 50/100) * 2 = $ 11,280
Autos = $10 * (3/60) * (42,500 * 50/100) * 2 = $ 21,260
Total $ 32, 540

It can be seen that even relatively short delays in travel time can amount to appreciable amounts of delay costs during maintenance or rehabilitation activities.

For future rehabilitation treatment occurring in year t, the effect of traffic growth should be taken into consideration as shown below [MTO 90]:

$$\text{Traffic (AADT) in year } t = (1+\text{growth rate})^t \qquad (5)$$

Where t = Number of years

2.8.6 Salvage/Terminal Value

Salvage value involves the residual value of the pavement materials at the end of the analysis period. Terminal value is the value of the extended life related to the unequal serviceability levels of various rehabilitation alternatives at the end of the analysis period [MTO 90].

2.8.7 Effectiveness (or Benefits)

The scheduling of rehabilitation strategies depends on the effectiveness of the expected service life. The effectiveness of various rehabilitation alternatives must also be included in the life cycle analysis in order to choose the best alternative. Benefits which are defined as savings in road user cost (i.e., vehicle operating cost and travel time) are more desirable. This information can be difficult to collect or quantify. The effectiveness approach seems to be a more simple approach. The effectiveness in this case is a non-monetary term. It is simply the performance area or the area under the PCI-time curve as shown in Figure 2.8. A large performance area is more desirable as it simplifies that the overall condition is remaining good over a period of time thereby providing the user with a more desirable surface to ride on [MTO 90].

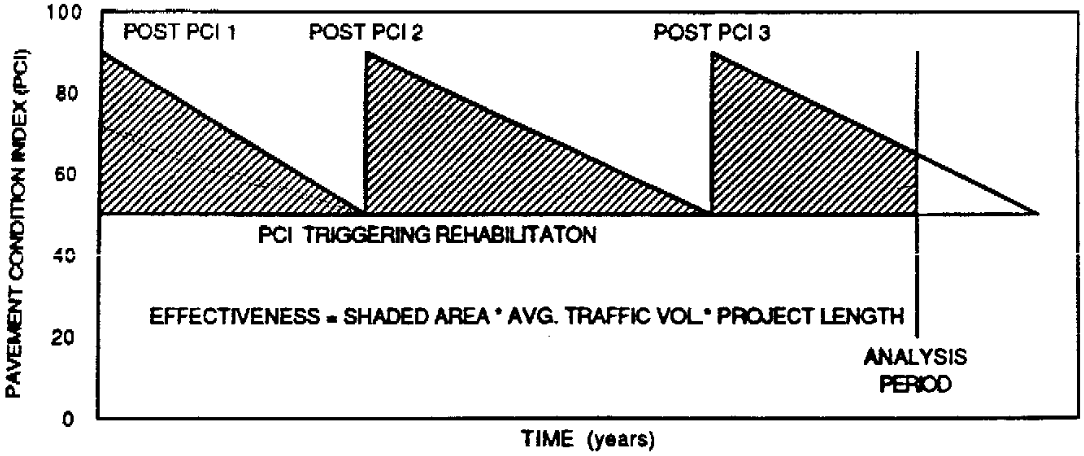


Figure 2. 8 Calculation of Effectiveness for a Typical Rehabilitation Alternative

This approach is considered adequate for comparing and selecting the most economical alternative. The following is the key information required in the calculation of effectiveness.

- Pavement Condition Index (PCI) triggering rehabilitation
- Expected PCI after rehabilitation
- Estimated service life of a rehabilitation treatment

Figure 2.8 above shows how effectiveness of a rehabilitation alternative can be obtained. The total effectiveness is then multiplied by traffic weighed by project length. This is important for comparing different projects under limited funding situations [MTO 90].

$$E = \text{SHADED AREA} * \text{AADT}\ (1+GR)^{T/2} * L \qquad (6)$$

SHADED AREA = f(POST PCI, MIN PCI, LIFE)

Where:

E = Effectiveness
POST PCI = PCI after rehabilitation (e.g., 90)
MIN PCI = PCI triggering rehabilitation (e.g., 50)
LIFE = Estimated service life of each strategy
AADT = Traffic Volume
GR = Average Traffic growth rate (decimal)
T = Analysis period (years)
L = Length of road section (km)

2.9 METHODS & PROCEDURES OF ECONOMIC EVALUATION

According to several sources, there are many rehabilitation options available to the designer. This includes a staged rehabilitation approach in which the structural strength of the pavement is increased from time to time according to growth in traffic loadings. Alternatively, the designer can also plan for a high initial cost rehabilitation strategy, which, it is assumed, will require little maintenance for a lengthy period [MTO 90].

While such choices may be structurally equivalent over a specified analysis period, the choices are unlikely to be equivalent from an economic standpoint. Because the costs of rehabilitation and maintenance occur at different times over the analysis period, the cost streams in these different years must be adjusted to the same base before the economic implication (i.e., cost and benefits) can be assessed [MTO 90]. The economic models that can be used to incorporate costs, or costs and benefits, include the following [Haas 01]:

2.9.1 Present Worth Method

The Present Worth Method remains the best general method of taking into account, separately or in combination, the factors and parameters discussed in the previous section for life cycle cost analysis. This method can be used for costs, or benefits, or benefits minus costs (i.e. the Net Present Worth, Present Worth of Cost “PWC” or Net Present Value “NPV” method). NPV is computed by assigning monetary values to benefits and costs, discounting future benefits ($PV_{benefits}$) and costs (PV_{costs}) using an appropriate discount rate and subtracting the sum total of discounted costs from the sum total of discounted benefits [Haas 01].

$$PV = PV_{benefits} - PV_{costs} \qquad (6)$$

The general equation for Present Worth of Costs (PWC) is represented mathematically as follows:

$$PWC = C_0 + U_0 + (\Sigma_{t=1} F_i , t\ [C_t + M_t + U_t]) – F_{i\ ,\ n} * TV \qquad (7)$$

Where:

PWC = Present Worth of Cost
C_0 = Rehab cost at year 10
U_0 = User Delay cost at year 0
F_i , t = Discount factor for discount rate I, in year t = $(1+I)^{-t}$
C_t = Rehab cost in year t
M_t = Routine Maintenance cost in year t
U_t = User Delay cost in year t
$_n$ = Analysis period in years
TV = Terminal value of extended life

In general, the above equation in not difficult to apply though the values of some of the input parameters are open to debate as mentioned in previous sections [MTO 90]. If the NPV method is selected, the designer will have a choice on whether to use constant dollars or nominal dollars. Constant dollars are also called real dollars as they reflect a "constant" purchasing power over time. For example, it is presumed that to purchase hot mix today at \$20/tonne will remain at \$20/tonne in the future. Alternatively, nominal dollars reflect fluctuations in purchasing power as a function of time. Thus, hot mix at \$20/tonne today, may be \$22/tonne in the future. Regardless of the choice, the two types of dollars should not be mixed and should be consistent throughout an analysis [Haas 01].

2.9.2 Cost-Effectiveness Method

The cost-effectiveness method can be used to compare alternatives if significant, appropriate measures of effectiveness can be established. It has become particularly useful in the pavement field where effectiveness of an alternative is the area under the performance curve multiplied by traffic and is then weighted by the section length [Haas et al 94]. In order to include benefits in the analysis, the cost effectiveness (C-E) of a rehabilitation alternative is calculated as follows:

$$\mathbf{CE} = \frac{\left[\sum_{\mathrm{Re}\,hab\_Year}^{PQI_R \geq PQI_M} \left(PQI_R - PQI_M\right) - \left(\sum_{PQI_N \geq PQI_M}^{\mathrm{Re}\,hab\_Year} \left(PQI_M - PQI_N\right)\right)\right] * \left[AADT\right] * \left[Length\_of\_Section\right]}{Present\ Worth\ of\ Cost} \qquad (9)$$

Or in simplified terms:

$$\mathrm{CE} = \frac{\underline{[\Sigma(\text{Area above } PQI_M) - \Sigma\,(\text{Area below } PQI_M\,)] * [\text{AADT}] * [\text{Length of Section}]}}{Present\ Worth\ of\ Cost} \qquad (10)$$

Where: PQI_R = Pavement Quality Index (PQI) after rehabilitation

PQI_M = Minimum acceptable level of PQI

PQI_N = yearly PQI from the needs year to the implementation year

The objective is to choose the alternative with the least ratio, a reverse notion of the benefit –cost ratio method.

2.9.3 Benefit/Cost Ratio Method:

One important tool of cost-benefit analysis is the **benefit-to-costs ratio**, which is the total monetary cost of the benefits or outcomes divided by the total monetary costs of obtaining them. In essence, it represents the net discounted benefits of an alternative divided by net discounted cost or the ratio of the equivalent uniform annual benefits to the equivalent uniform annual costs. B/C ratios greater than 1.0 indicate that benefits exceed cost. This method has been widely used in the infrastructure area, particularly for large projects such as dams and causeways. The benefits are established by a comparison of alternatives [Haas et al 94].

$$\textbf{Benefit-to-costs ratio} = \frac{\textbf{the total monetary cost of the benefits}}{\textbf{Total monetary costs}} \quad (11)$$

The B/C ratio approach is not recommended for several infrastructure types, however, including pavements, because of the difficulty in quantifying benefits. Another disadvantage is the possible confusion over whether maintenance cost reductions should be in the numerator or the denominator, and whether cost reductions are “benefits” or “negative costs” [Haas 01].

2.9.4 Internal Rate of Return:

This is primarily used in private industry. Internal rate of return is also used extensively by the World Bank, where it is desired to see directly the rate of return on the investments they make in various (largely developing) countries. It involves a determination of the discount rate at which the costs and benefits for a project are equal or it can be in terms of the rate at which the equivalent uniform annual cost is exactly equal to the equivalent uniform annual benefits. This method has a major advantage in that the results are well understood by most people. However, it must be remembered that the discount rate is not a real interest rate in financial terms.

2.9.5 Equivalent Uniform Annual Costs (EUAC):

This method combines all initial capital costs and all recurring future expenses into equal annual payments over the analysis period. The basic advantage of this method is its simplicity and ease of understanding for public officials. However, it does not include benefits in the evaluation of the alternatives and the comparison among these alternatives must be on the basis of costs alone assuming that they have equal benefits (e.g. bridge). The U.S. FHWA [FHWA 98] defines the EUAC as the Net Present Value (NPV) of all discounted costs and benefits of an alternative as if they were to occur uniformly throughout the analysis period. EUAC is a particularly useful indicator when budgets are established on an annual basis. The EUAC indicator is recommended as long as the cost is derived from the NPV [Haas et al 94].

2.10 USING COST ANALYSIS IN EVALUATION

This section explains the concept of using cost analysis in evaluating infrastructure assets. Different authors use different terms when describing cost analysis. However, they all represent the same definition. A few of these terms are as follows:

- Economic evaluation
- Cost allocation

- Efficiency assessment
- Cost-benefit analysis
- Cost-effectiveness analysis

2.10.1 What is Cost Analysis?

Cost analysis is currently a somewhat controversial set of methods in program evaluation. One reason for the controversy is that these terms cover a wide range of methods, but are often used interchangeably [Sewell 03].

At the most basic level, **cost allocation** is simply part of good program budgeting and accounting practices, which allow managers to determine the true cost of providing a given unit of service [Kettner 90]. At the most ambitious level, well-publicized **cost-benefit** studies of early intervention programs have claimed to show substantial long-term social gains for participants and cost savings for the public [Berreuta-Clement, 84].

Although these studies have been widely cited and credited by several authors, advocates are making more use of cost-benefits analysis in evaluating alternatives. For example, the cost-benefit or cost-effectiveness studies were noted as being complex, requiring very sophisticated technical skills and training in methodology and in principles of economics, and should not be undertaken lightly [White 88]. It is a good idea for program evaluators to have some understanding of the concepts involved in cost benefit, because the cost and effort involved in producing change is a major concern that most impact evaluation of alternative strategies.

2.11 THREE TYPES OF COST ANALYSIS IN EVALUATION:

The following section discusses three types of cost analysis that can be used in evaluation of alternative strategies in LCCA:

- **Cost allocation**
- **Cost-effectiveness analysis**
- **Cost-benefit analysis**

The above represent a continuum of types of cost analysis, which can have a place in program evaluation. They range from fairly simple program-level methods to highly technical and specialized methods. However, they all have specialized and technical aspects [Sewell 03].

2.11.1 Cost Allocation:

Cost allocation is a simpler concept than either cost-benefit analysis or cost-effectiveness analysis. At the program or agency level, it basically means setting up budgeting and accounting systems in a way that allows program managers to determine a **unit cost** or **cost per unit of service**. This information is primarily a management tool. However, if the units measured are also outcomes of interest to evaluators, cost allocation provides some of the basic information needed to conduct more ambitious cost analyses such as cost-benefit analysis or cost-effectiveness analysis. [Sewell 03].

Besides budget information, being able to determine unit costs means that you need to be collecting the right kind of information about clients and outcomes. In many agencies, the information recorded in service records is based on reporting requirements, which are not always in a form that is useful for evaluation. For an evaluation, however, it is best to be able to break down that number in different ways. Deciding how to collect enough reliable or good quality data to give useful information, without overburdening staff with unnecessary paperwork requirements, requires a lot of planning. Larger agencies often hire experts to design data systems, which are called MIS or management-and-information-systems [Sewell 03].

Agencies should be able to separate unit costs for services or outcomes. This may depend on the systems that are already in place for budgeting, accounting, and collecting service data [Kettner 90].

2.11.2 Cost-Effectiveness and Cost-Benefit Studies

Most often, cost-effectiveness and cost-benefit studies are conducted at a level that involves more than just a local program. Sometimes they also involve following up over a long period of time, to examine the long-term impact of interventions. They are often used by policy analysts and legislators to make broad policy decisions, so they might look at a large federal program, or compare several smaller pilot programs that take different approaches to solving the same social problem. People often use the terms interchangeably, but there are important differences between them [Sewell 03].

2.11.3 Cost-Effectiveness Analysis:

Cost-effectiveness analysis assumes that a certain benefit or outcome is desired, and that there are several alternative ways to achieve it. The basic question asked is, **"Which of these alternatives is the cheapest or most efficient way to get this benefit?"** By definition, cost-effectiveness analysis is comparative, while cost-benefit analysis usually considers only one program at a time. Another important difference is that while cost-benefit analysis always compares the monetary costs and benefits of a program, cost-effectiveness studies often compare programs on the basis of some other common scale for measuring outcomes (e.g., IRI, PQI, RCI etc.). They address whether the **unit** is greater for one program or approach than another, which is often much easier to do, and more informative, than assigning a dollar value to the outcome [White 88]. Cost-Benefit Analysis:

Two basic questions that maybe asked in a cost-benefit analysis are,

1. **Do the economic benefits of providing this service outweigh the economic costs** and
2. **Is it worth doing at all?**

The two most common tools for comparison in cost-benefit analysis is the **benefit-to-costs ratio**, which is the total monetary cost of the benefits or outcomes divided by the total monetary costs of obtaining them and the **net rate of return**, which is basically total costs minus the total value of benefits.

$$\textbf{Net rate of return} = \textbf{Total costs} - \textbf{Total value of benefits} \qquad (12)$$

The idea behind cost-benefit analysis is simple: if all inputs and outcomes of a proposed alternative can be reduced to a common unit of impact (namely dollars), they can be aggregated and compared. If people would be willing to pay dollars to have something, then presumably it is a benefit; if they would pay to avoid it, it is a cost. In practice, however, assigning monetary values to inputs and outcomes in LCCA of infrastructure assets is rarely so simple, and it is not always appropriate to do so. This is the ultimate goal of this report.

2.12 WHAT COST ANALYSES CAN TELL YOU:

- **Cost analyses can provide estimates of what a program's costs and benefits are likely to be, before it is implemented.** "Ex-ante" or "before the fact" cost analyses may have to be based on very rough estimates of costs and expected benefits. However, if a program is likely to be very expensive to implement, very difficult to "un-do" once it is in place, or very difficult to evaluate, even a rough estimate of efficiency may be quite valuable in the planning stages [Rossi 93].
- **Cost analyses may improve understanding of program operation, and indicate what levels of intervention are most cost-effective.** A careful cost analysis within a program might indicate, for example, that it does not so much matter whether an agency currently has a 10 year program or a 20 year program for pavement, but that the time to performance ratio does matter (that is, pavement benefit more from low ratios than they do from longer days). This information might influence decisions about how soon or what type of pavement rehabilitation strategies may be required so that the pavement can serve effectively.
- **Cost analyses may reveal unexpected costs.** A cost analysis program might unexpectedly find that it costs more to use corrective measures such as hot-and cold-mix patching rather than to use preventative measures such as chip seals or slurry seals as rehabilitation alternatives, because the hot-and cold-mix patching requires more training, supervision, or takes more time. Or, working on weekends on a section of pavement as opposed to working during the weekdays, which will avoid traffic congestion and reduce user delay cost. Working during

the weekdays might have the unplanned result of higher user delay cost, long-traffic congestion, and maybe worker frustration.

2.13 WHAT COST ANALYSES CANNOT TELL YOU:

- **Whether or not the program is having a significant net effect on the desired outcomes.** Cost analysis may be considered an extension of an impact or outcome evaluation, but it cannot take the place of one. Unless one knows for sure that the program is producing a benefit, it doesn't make sense to talk about the cost of producing that benefit [Rossi 93].
- **Whether the least expensive alternative is always the best alternative**. Often political or social values other than cost need to determine program and policy choices. When there are competing values or goals involved, cost analysis is often just one factor to be considered, and usually there are other ways of deciding which factors should take priority.

2.14 USING COST ANALYSES AS AN EVALUATION GUIDE:

This following section outlines five approaches to program evaluation using cost analysis. Cost analyses maybe used at the levels referred below in Figure 2.9:

Tier 1 - Program Definition

At this stage, cost studies may be used based on previous experience in similar programs, since cost data are unlikely to be available at that point. This means that the estimates used will only be approximations, and may not accurately reflect the future cost. However, "ex-ante" cost analyses done in the planning stages before implementing a

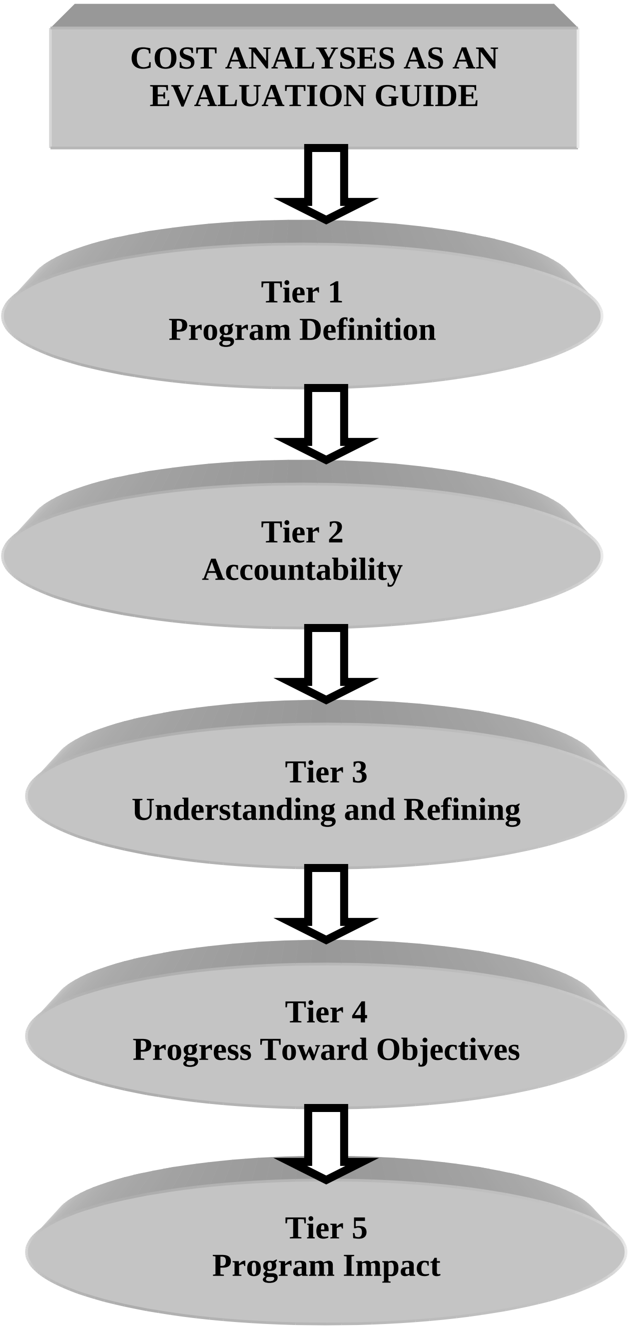


Figure 2. 9 Cost Analyses and Evaluation Guide

program, can potentially prevent some very costly mistakes. If there is access to cost-effectiveness studies of programs similar to the one being considered, especially if it is possible to compare the relative costs and benefits of several alternative strategies, before any substantial investments of time or money is made, some program design decisions may be easier.

Tier 2 - Accountability

Clearly, fiscal accountability is one of the primary reasons for using any kind of cost analysis as part of evaluation. Any responsible program should keep service statistics and financial records that are accurate and up-to-date enough to be able to determine some very basic information about unit costs, and funders usually require this. However, the minimal information routinely collected by programs for fiscal and reporting purposes is not always in a form that lends itself to evaluation uses. Often, unless advance planning has taken place, this data is too aggregated to reflect outcomes of interest to researchers and evaluators. At this stage (or earlier), careful consideration should be given to the kinds of client and cost data that will be needed later, so that it can be built into the accounting and record-keeping systems of the program [Kettner 90].

Tier 3 - Understanding and Refining

Similar to any other type of information gathered for evaluation purposes, the cost information collected in Tier 2 for accountability purposes provides programs with a basis for mid-course adjustments and program refinements, either at the end of a funding cycle, or in the course of implementation.

Tier 4 - Progress Toward Objectives

Using cost information in Tier 4 is closely tied to the program design issues of Tier 1, and the accountability issues of Tier 2. If appropriate program outcomes and indicators have been identified in Tier 1, and the appropriate unit cost information is included in the routine data that is collected as part of Tier 2, then the job of identifying progress toward objectives in Tier 4 becomes much easier.

Tier 5 - Program Impact

When it has been possible to conduct a full-scale cost-benefit analysis over a long period of time, and it shows significant long-term gains and cost savings in a particular population or problem area, the policy implications may be significant. It is widely believed that one reason why many projects are so influential is the fact that they included a cost-benefit analysis. While monetary cost is not the only basis for policy decisions, it is usually a very salient one for voters and politicians [Kettner 90].

2.15 ADVANTAGES AND DISADVANTAGES OF USING COST ANALYSES:

There are both advantages and disadvantages in using Cost analysis for evaluation. Table 2.5 and the subsequent section explain the benefits and shortcomings of using cost analysis for evaluation purposes. As can be seen, there are more disadvantages than advantages of using cost analysis in evaluation**.**

2.15.1 Advantages of Using Cost Analysis

- **Promotes fiscal accountability in programs.**

Too often, program managers cannot easily determine the cost of providing particular services or achieving certain outcomes, because they are not systematically collecting the necessary data, either about clients or about costs. At the least, programs should be able provide funders (or potential funders) with information on services and their respective cost for a given time period [Jacobs 88].

- **Helps set priorities when resources are limited.**

Program managers can use cost information in designing programs, and in budgeting and allocating funds to get the most out of their resources.

Table 2. 5 Advantages and Disadvantages of Cost Analyses

ADVANTAGES	DISADVANTAGES
▪ Promotes fiscal accountability in programs	▪ Requires a great deal of technical skill and knowledge
▪ Helps set priorities when resources are limited	▪ **Critics feel that** many cost analyses are overly simplistic**, and** suffer from serious conceptual and methodological inadequacies.
▪ Can be extremely powerful and persuasive to legislators, policy makers, and other funders	▪ There are no standard ways to assign dollar values to some qualitative goals
▪ Provides assistance with budgeting projects	▪ Market costs (what people actually pay for something) don't always reflect "real" social costs
▪ Provides technical people with an evaluation of raw cost effective figures.	▪ Sometimes there are multiple competing goals, so we need to weight them or prioritize them in some way
	▪ Sometimes costs and monetary values are considered less important than other, more intangible values or program outcomes
	▪ The best-known cost-benefit studies have looked at long-term outcomes, but most program evaluations do not have the time or resources to conduct long-term follow-up studies.

- **Can be extremely powerful and persuasive to legislators, policy makers, and other funders.**

The analysis may help convince administrators to invest in particular kinds of programs. Some argue that this advantage of cost-benefit analysis may hold true even when it is not possible to assign monetary values to all program costs and outcomes; if the effect is strong enough, even a relatively incomplete cost-benefit analysis may be persuasive [Barnett 93].

2.15.2 Disadvantages of Using Cost Analysis:

- **Requires a great deal of technical skill and knowledge.**

A true cost-benefit analysis requires a solid grounding in economic theory and techniques, which is beyond the training of many evaluators. It may be necessary to hire a consultant if this type of analysis is desired.

- **Critics feel that many cost analyses are overly simplistic**, **and suffer from serious conceptual and methodological inadequacies.**

There is a danger that an overly-simplistic cost-benefit analysis may set up an intervention to fail, by promoting expectations that are unrealistically high, and cannot really be achieved. This may result in political backlash which actually hurts future funding prospects instead of helping.

- **There are no standard ways to assign dollar values to some qualitative goals**, especially with regards to social costs. For example, how do we value things such as **user delay time during construction**, **human lives saved**, or **quality of life?**
- **Market costs (what people actually pay for something) do not always reflect "real" social costs.**

For example, sometimes one person's cost is another person's benefit. Also, market costs do not necessarily reflect what economists call the "opportunity costs" of choosing to do one thing instead of another.

- **Sometimes there are multiple competing goals, so we need to weight them or prioritize them in some way**.

For example**,** if a program leads to improvement in one area, but results in problems in another area, is it still worth doing?

- **Sometimes costs and monetary values are considered less important than other, more intangible values or program outcomes.**
- **The best-known cost-benefit studies have looked at long-term outcomes, but most program evaluations do not have the time or resources to conduct long-term follow-up studies.**

2.16 HOW TO BUDGET & ALLOCATE COSTS FOR COST EFFECTIVENESS STUDIES:

The type of budgeting and accounting system a program or agency uses may well determine how much useful cost data is available for evaluating the program, or comparing it to others. Three major types of budgeting formats commonly used in social service programs will provide different types and amounts of information [Kettner 90]. The following is an outline of the three major types of budgeting formats:

1) Line-Item Budget Format-

The most common format is the **Line-Item Budget** format, which simply looks at revenues (money coming in from various sources, including grants, user fees or United Way funds) and expenditures (costs broken down into broad categories like salaries, rent, utilities, and postage), and tries to ensure that they balance. The main purpose of a line-item budget is financial control, and the categories are usually too broad to give much information about the cost of providing a particular service or obtaining a particular result.

2) The Functional Budget Format

This format starts with a line-item budget, and takes it a step further. It focuses on process, or the cost of providing a service. For example, with a Functional Budget, it can determine that it cost a highway agency $45,000 to construct 100 km of highway.

3) The Program Budget

This format also starts with a line-item budget, examines at the same information from the point of view of outcomes or the cost of achieving a result. For example, if the 100 km of highway construction resulted in actually placing 50 tons of hot-mix asphalt resurfacing, the Program Budget would indicate that it cost the agency $45,000 to place 50 tons of hot-mix asphalt, which is an outcome.

Another way to look at this is that functional budgets measure productivity and program budgets measure the cost of achieving goals and objectives.

2.17 COMMON STEPS IN DEVELOPING PROGRAM & FUNCTIONAL BUDGETS:

The following flow chart, Figure 2.10 outlines the common steps necessary in developing program and functional budgets [Kettner 90]:

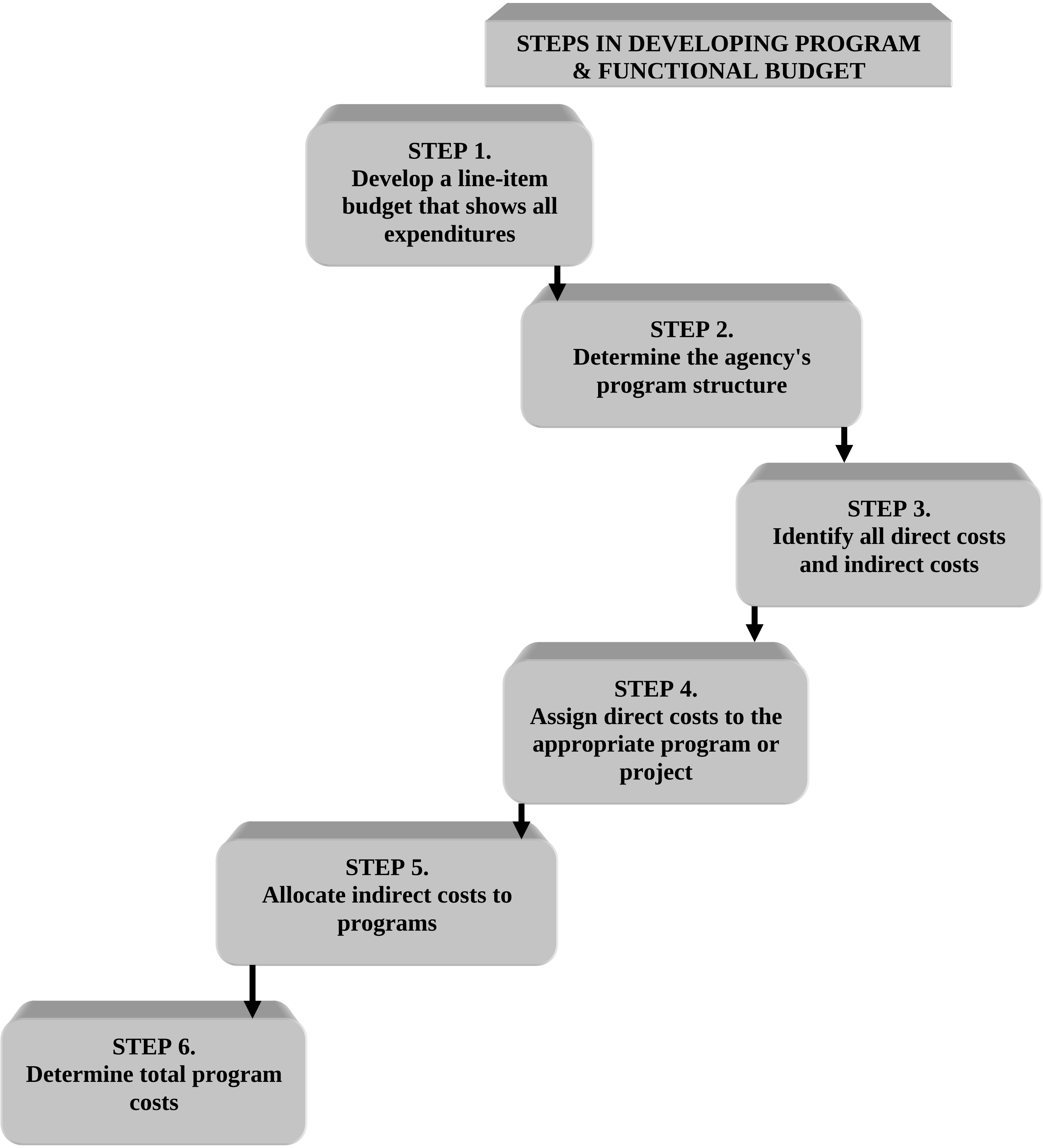


Figure 2. 10 Steps in Developing & Functional Program

1. **Develop a line-item budget that shows all expenditures.**

This is the minimal level of budgeting and accounting that is required by many funders, such as the World Bank or United Way. Some funders require a specific format, so that the categories used are standard across the programs that they fund.

2. **Determine the agency's program structure**

A distinct program is a set of activities or services designed to accomplish a specific set of agency goals and objectives. Many agencies have several different programs.

3. **Identify all direct costs and indirect costs**.

Direct costs are those that benefit only one program (for example, salaries of staff who work only for one program, or supplies and equipment used only for that program). Indirect costs or "overhead" costs are those that benefit or are shared by more than one program (for example, several programs in an agency might share the same building, and be served by the same bookkeeping and secretarial staff, utilities, or janitorial services).

4. **Assign direct costs to the appropriate program or project.**

This process is usually fairly straightforward. If one county agent has full-time responsibility for operating a State highway project, for example, then 100% of his or her salary and benefits would be assigned as an expense to that project in the budget. If a staff member spends 50% of their time on the State highway project and 50% on another assignment, then half of that person's salary and benefits would be assigned to the State highway project as a direct cost.

5. Allocate indirect costs to programs.

Deciding how to divide up the indirect (shared) cost pool among several programs in an agency can be much more complicated and technical. The actual practice of allocating or dividing up the indirect costs is usually best left to an accountant. There are several methods for doing this, each with particular advantages and disadvantages [Kettner 90]. Although cost allocation of indirect costs can be a time-consuming step, it is considered well worth doing because of the increased information it provides about the real costs of providing services.

6. Determine total program costs.

The total cost of a particular program (such as a State highway project) is the sum of the direct costs, and the portion of indirect costs that is allocated to that program. Once this information about total program costs is obtained, then the unit cost can be calculated. For a **Functional Budget**, this involves defining the units of service for each program (e.g., hours of day, miles of highway covered or studied etc.), and calculating the **cost per unit of service**. In the highway agency example above, the unit cost of conducting a pavement study would be $450 (total program cost divided by number of units of service or miles provided or covered). For a **Program Budget**, the final steps are determining the total cost of achieving the outcome objectives for the year, and calculating the **cost per outcome**. Using the highway example again, one can say that the highway agency described above successfully placed hot-mix asphalt at a **unit cost** of $900/mile (total program costs divided by the number of successful outcomes).

2.18 COST-EFFICIENCY & COST-EFFECTIVENESS STUDIES:

From the point of view of program evaluation, both the Program and Functional Budgeting systems are more useful than a Line-Item Budget. Unit cost information allows for useful comparisons of the costs of delivering services and getting results. With this information, the unit cost of one highway agency compared to another can be examined, to see whether one operates more efficiently. The unit cost (per alternative) of hot-mix placement to the unit cost (per alternative) of partial depth removal and resurfacing or minor crack sealing or treatment can be compared. This is basically what happens in a **cost-effectiveness study**.

In general, a cost-effectiveness study is more appropriate than a cost-benefit analysis when goals or outcomes cannot easily be quantified or monetized, or when there are multiple competing goals. As with budgeting and cost allocation, there are a variety of approaches to cost-effectiveness studies. The approach that is best will depend on a number of factors [Kettner 90].

2.19 HOW TO CONDUCT A COST-BENEFIT ANALYSIS:

Cost-benefit analysis is by far the most complex and controversial of the three methods of costs analysis that have been discussed. Barnett warns that it should not be attempted by those who lack technical expertise in that area. However, it is also one of the most powerful methods. Barnett [Barnett 93] outlines a nine-step process for conducting a cost benefit analysis as shown in Figure 2.11.

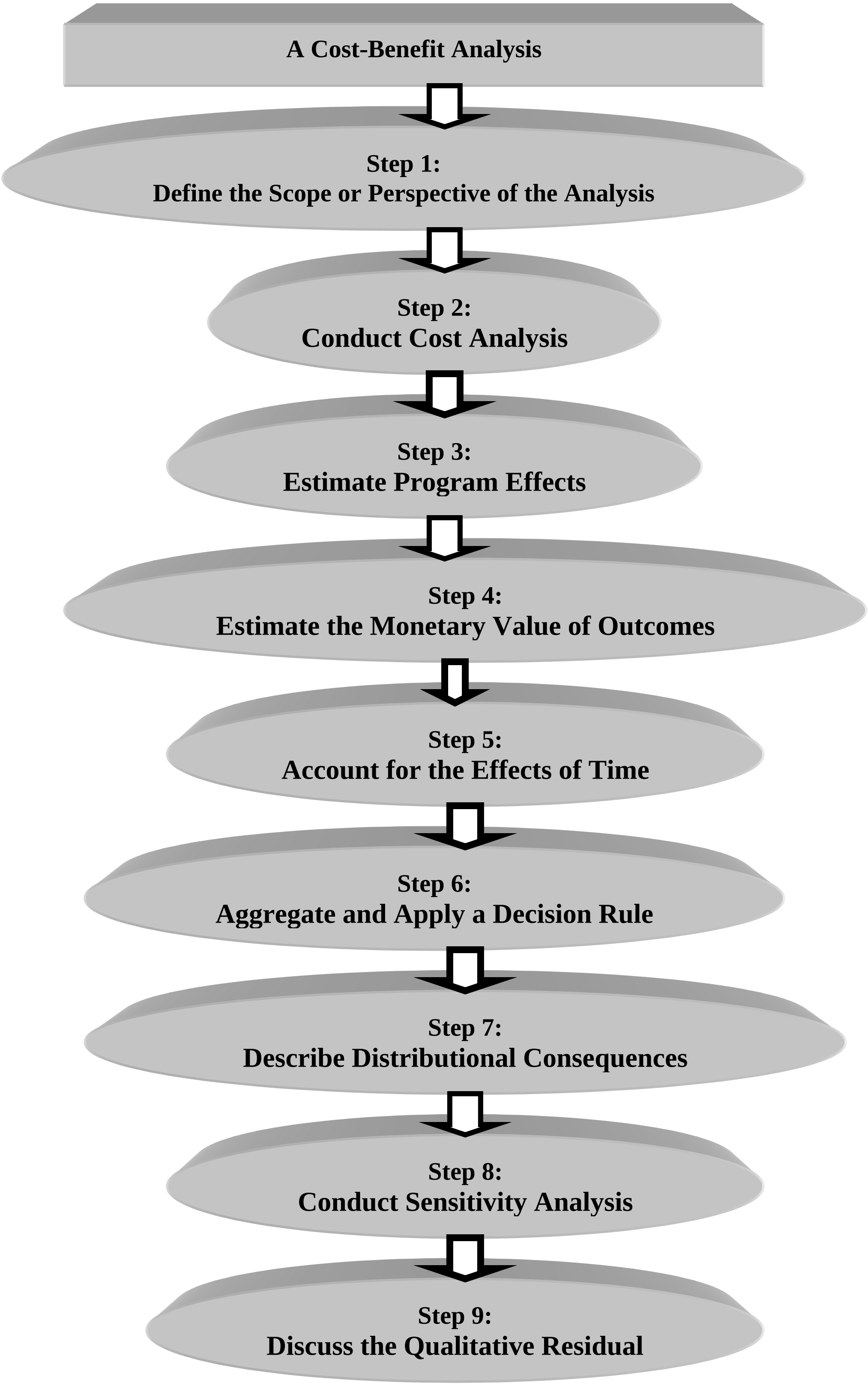


Figure 2. 11 Nine Steps to Conduct a Cost-Benefit Analysis

Step 1: Define the Scope or Perspective of the Analysis: –

The first step is to describe the alternative(s) to be evaluated, and determine whose perspective will guide the evaluation. A narrow cost analysis might look only at the monetary costs and benefits to the individual participant or target of services, or to a particular funder or agency. A broader perspective might attempt to look at a wide range of costs and consequences (intended and unintended, direct and indirect) for society as a whole. A program that is not cost-effective from the perspective of a particular agency within its limited mission and budget may well be cost-effective from the perspective of society, because it saves expenses or prevents problems in other areas. Rossi and Freeman [Rossi 93] note that because different stakeholders may have different values and priorities, mixing different viewpoints are likely to result in "confused specifications and overlapping or double counting." Whether it is acceptable or not, the perspective chosen for cost evaluation may have political implications. Therefore, while there are limitations to any one perspective, it is important for the evaluator to clearly state his or her position.

Step 2: Conduct Cost Analysis:-

The next step is to identify and estimate the monetary value of all resources used in the intervention, not just the budgetary costs. Some costs, such as salaries of direct service staff, rental of office space, or program supplies, are obvious and simple to determine. Indirect costs of supervision and administration need to be included as well. Other resources and costs may go well beyond the items that are usually included in an agency budget. Sometimes "overhead" (like office space or supervision) is provided as an in-kind service by an existing agency, but since there are probably some additional demands made on the time of the agency staff, this should be figured into the "real" cost of the intervention (what would you have to pay if the time or space had not been donated)?

Step 3: Estimate Program Effects: –

This is where more traditional impact or outcome evaluation methods come in. As noted earlier, if it is unknown whether there is a significant beneficial effect of the proposed program, then there is little point in asking how much it costs to get the effect, or whether it is more cost-effective than another kind of program. Often it is not possible to use a true experimental design in evaluating community-based programs, but there are a number of quasi-experimental designs available [Cook 79]. This is a standard reference on quasi-experimental research designs, which are commonly used for evaluation of community-based programs.

Also, it is important to note that it is often possible to use existing data to estimate program effects, as well. If an ongoing program is being considered, or one that is based on a national model, a search should be carried out to determine if formal evaluations have already been done elsewhere. It may also be possible to acquire useful information from the program's service statistics, or from local, state, or federal census data [Barnett 93].

Step 4: Estimate the Monetary Value of Outcomes: –

This is one of the most difficult and controversial aspects of conducting a cost-benefit analysis and it may require the input from several stakeholders. Some cost-savings are easier to estimate than others. For example, we may have data that the average cost of placing a hot-mix patch is $20,000 a year, so if we are able to prevent that major maintenance and instead, rehabilitate the pavement section using surface treatments every six months, the estimated savings is 0.5 X $20,000. However, other important outcomes may be much less obvious, and much harder to estimate.

Step 5: Account for the Effects of Time: –

One of the trickiest and most technical aspects of cost-benefit analysis, especially for longitudinal studies that follow clients or outcomes over a period of years, is **discounting** of costs and calculating **rates of return** for alternative uses of the money (such as investing it). This includes taking into account the effects of inflation on the value of the dollar over time, or figuring the depreciation in the value of things like buildings and other capital equipment. Similar issues apply in estimating the value of benefits over a period of time. For example, if one examines the projected life-time of an asset which is preserved or protected from the elements compared to an asset that is not, then it is critical to make projections which incorporate the environment impacts. Another consideration for government agencies is to examine the recovery of its investment in the construction of toll roads and highways through the taxes or toll fees the user will pay. Other considerations include examining the projections of increase rates in the future. These projections all require assumptions and skilled expertise for such a program.

Step 6: Aggregate and Apply a Decision Rule:–

If attempts are made to assess the costs and benefits on several outcomes (which is often the case), then one must examine how priorities will be established. If a program for rehabilitating pavements results in high life expectancy (and lower construction costs), but not in fewer repeat minor repair or maintenance, which outcome is more important? According to Haas, alternatives must be analyzed for their technical and economic impact so that priority programs at the network level or the best alternative at the project level can be identified and implemented [Haas 94].

Step 7: Describe Distributional Consequences: –

This is related to choosing a perspective of analysis. It involves specifying who gains and who loses under different conditions (because in some cases, one party's benefit is another party's loss). This may be a highly controversial and political step in the process.

Step 8: Conduct Sensitivity Analysis: –

This step involves identifying the assumptions behind the cost estimates, and considering how critical they are to the calculations. If one of the assumptions turns out not to be accurate, or if conditions change during the time of the study (for example, the minimum wage goes up, affecting salary costs), then this will change the overall result. Thus, it is important to conduct a sensitivity analysis to identify those variables that have the largest impact on the analysis.

Step 9: Discuss the Qualitative Residual: –

Since there are almost always some things that cannot be quantified or assigned monetary values, it is important that a report include some discussion of these issues. A realistic description of some of these qualitative issues in a report can provide a rationale for the provided conclusions, and reduce the chances of a study being used inappropriately.

CHAPTER 3. SURVEY OF LCCA INVESTMENT MODELS IN USE

3.1 REVIEW of LCCA PRACTICES and APPLICATIONS

This section explores existing LCCA models in use. It also describes how these existing models are currently deployed in private industry and state departments of transportation. Some of the models are designed to compare alternative highway investment strategies by comparing user benefits with life-cycle capital, operating, and maintenance costs under different strategies. Others are commonly used to assess tradeoffs between system expansion and system preservation, as well as to evaluate the benefits of different overall levels of investment [Haas 01]. The different types range from non-computerized methods to mainframe and personal computer programs.

While the basic life cycle cost methodology remains the same among different models, the types of cost that they consider and the way in which they calculate those costs and the expected life of assets (e.g., pavements) differ considerably [Wilde 99]. The following section will describe the major computer programs and other life cycle cost models that are available from the research study. A survey was conducted to determine how the private sector views LCCA. The results are indicated at the end of the chapter.

3.2 MAINFRAME PROGRAMS

The early versions of the Flexible Pavement System (FPS) and the Rigid Pavement System (RPS) were written for mainframe applications before the 1980s [Wilde 99].

During this era, computers required punch cards to run and manage their programs and inputs because these programs were written for execution on large mainframes.

Flexible Pavement System and Rigid Pavement System –TxDOT

The Flexible Pavement System and the Rigid Pavement System are the programs that were developed in the late 1960s by the Texas Transportation Institute and by the Center for Highway Research. The Rigid Pavement Rehabilitation Design System (RPRDS) is a modification of the RPS-3 program [Seeds 92]. The FPS program has been updated many times. The variance and all its important and sensitive variables are calculated and the variability of the overall life cycle cost is determined from these calculations. In addition, both of these programs use performance models to determine the level of distress in the pavement [Wilde 99].

Highway Performance Monitoring System (HPMS) - FHWA

The Highway Performance Monitoring System (HPMS) records and updates information on the current condition of U.S. highways as a way of assessing future highway needs, as required by U.S. Code, Title 23, Section 307A [HPMS 86]. The program was developed by the Federal Highway Administration (FHWA) to meet the requirements of this code.

HPMS was developed to provide an overall estimate of conditions and future needs of the highway system. It was not specifically designed for a project-level analysis, although many of its elements are similar to those found in other programs. It uses engineering criteria and a logic structure to determine improvement needs and to estimate the cost of those improvements. To determine motorist impacts, the program calculates an adjusted traveling speed and uses that speed to calculate fuel consumption and operating costs. The accidents are calculated as a function of the overall AADT and highway type.

The output related to motorist user costs consists of average overall travel speed: operating cost per 1000 vehicle km: fuel consumption per 1000 vehicle km: carbon-monoxide, nitrous oxide, and hydrocarbon emissions per 1000 vehicle km; and fatal, injury and “property damage only” accidents per 100 million vehicle km. Because overall user costs or benefits are not calculated, there are no summary calculations, such a benefit-cost ratio of net present value [Wilde 99].

3.3 LIFE CYCLE COST PROGRAMS FOR PERSONAL COMPUTERS

The majority of life cycle cost analysis programs has been written for the personal computer by far, most of which were developed at the beginning of the 1980s. The following describes examples of these programs.

LCCOST –Asphalt Institute

The Asphalt Institute developed the LCCOST program in 1991 [Wilde 99]. This program considers the initial cost of construction, multiple rehabilitation actions throughout the design life, and user delay at work zones during initial construction and subsequent rehabilitation activities.

In addition to these considerations, the program considers routine maintenance, if desired by the user that will be applied each year between rehabilitation activities. Routine maintenance is not, however, normally included in life cycle cost methodologies, since many departments of transportation do not account for the routine maintenance of individual highway segments. The magnitude of routine maintenance costs can be very large, and any disruptions to traffic may cause user cost to increase. The program does not include neither performance modeling nor a structural pavement model. The models also consider salvage value of the pavement and of the individual materials that make up the layers.

DARWin – AASHTO

The DARWin Pavement Design System is a program that automates the AASHTO design equations and simplifies the management of materials, layers, and construction activities. The life cycle cost module of DARWin accounts for project dimensions, initial construction, up to five preprogrammed rehabilitation strategies, and the salvage value of the pavement. It then discounts all the construction costs and salvage value to the present and reports the net present value of the project.

This program was not intended to provide a full life cycle cost analysis, but simply the agency costs associated with specific projects. The program performs very well as a database for managing materials, material properties, costs, and other aspects of pavement design and construction.

LCCP/LCCPR –Maryland

The University of Maryland developed a set of life cycle cost analysis programs that analyze flexible and rigid pavements [Rada 87] & [Witczak 97]. These programs incorporate user-operating costs associated with pavement roughness and other measures of user costs. These two computer programs are intended for project level analysis, and are better suited for use in pavement management systems. They are not as applicable to the comparison of alternate highway pavement designs [Wilde 99].

EXPEAR –FHWA

The computer program EXPEAR was developed in 1989 by the University of Illinois under the FHWA Project [Hall 89]. The program performs project level evaluation and requires data from a visual condition survey. The program recommends rehabilitation techniques that include reconstruction and resurfacing, among others. The program does not, however, consider user costs or other indirect impacts of the recommended rehabilitation techniques [Wilde 99].

Highway Design and Maintenance Standards Model –World Bank

The Highway Design and Maintenance Standards Model (HDM-III) computer program was developed by the World Bank for evaluating highway projects, standards, and programs in developing countries [Harral 79]. HDM-III is designed to make comparative costs estimates and economic evaluations of different construction and maintenance options, including different time staging strategies, either for a given road section or for an entire road network.

The HDM-III model is mainly designed for evaluation geometric and road surface improvements of rural roads. It considers construction costs, maintenance costs, and user costs. The vehicle operating costs calculations used in HDM-III is based on extensive operating cost studies. Special emphasis is placed on estimating vehicle-operating costs as related to roadway surface type and condition (e.g., dirt surface, gravel, surface, and paved surface of varying degrees of roughness).

The HDM program assumes that construction costs, maintenance costs, and vehicle operating costs are a function of vertical alignment, horizontal alignment, and road surface condition. Different Types of costs are calculated by estimating quantities and using unit costs to estimate total costs.

MicroBENCOST

The computer program MicroBENCOST was developed by Texas Transportation Institute in 1993 under NCHRP Project 7-12 [McFarland 93]. This program analyzes many types of projects including pavement rehabilitation, added lane capacity, bridge projects, and bypass projects. The program takes a large number of inputs and compares a benefit/cost analysis that considers with or without specific projects alternatives. While the program can be used to compare different alternatives, its main function is to evaluate the benefits and costs of constructing a particular project [Wilde 99].

3.3.1 Life Cycle Cost Programs for Spreadsheets

Several programs are meant to be used in conjunction with spreadsheet programs to analyze life cycle cost of assets or construction projects. This type of analysis requires the use of an existing, commercially available, spreadsheet program. The user can provide inputs in the cells of the spreadsheet, and perform calculations using preprogrammed macros that execute calculations similar to those executed by standard life cycle cost analysis computer program. Two examples of such programs are as follows:

American Concrete Paving Association

The American Paving Association (ACPA) has developed a spreadsheet-type analysis program that is used with Microsoft Excel to analyze both rigid and flexible pavements. The spreadsheet requires that the user input preprogrammed rehabilitation activities, from which simple user-cost analysis is performed, with all costs discounted to the present [Wilde 99].

Crystal Ball Version 4.0

Crystal Ball Version 4.0 is a user-friendly, graphically oriented forecasting and risk analysis program. It uses Monte Carlo simulation and is designed to takes the uncertainty out of decision-making [CB 96]. It is an effective tool especially for decision makers. It requires the user to input not only the expected values of most variables, but also a “plus or minus” value representing a 90% confident level. Thus the spreadsheet uses risk analysis to determine the 90% confident level in the total discounted costs expected over expected over the life of an asset such as pavements.

The Crystal Ball model has gone through many updates and currently, the latest version of this model, Crystal Ball 2000 is more compatible to the latest version of Windows and Microsoft Excel with minor modification compared to the old version. The Crystal Ball model is one of the tools that will be used in this report to help determine risk analysis and life cycle cost of infrastructure assets with inventory cost data as inputs.

3.4 OTHER LIFE CYCLE COST ANALYSIS METHODS

The Highway Economic Requirements System (HERS)

This model is a benefit-cost analysis system developed by the FHWA. It is used to compare improvements to highway segments including resurfacing, reconstruction, widening, etc. While it has primarily been applied at a national level, the states of Oregon and Indiana have adopted it to analyze statewide investment strategies. These features have been adopted into a new state-level version of the software known as HERS/ST [US DOT 02].

Federal Highway Administration (FHWA)

FHWA Interim Technical Bulletin [FHWA 98A], describes LCCA as a project level evaluation of alternative pavement design strategies for an analysis period recommended to be at least 35 years. It incorporates agency costs as well as user costs and advocates the use of a probabilistic approach to LCCA that incorporates the uncertainty in the input parameter to characterize the risk associated with future outcomes [Haas 03].

Pavement Design and Management Guide

Pavement Design and Management Guide by (TAC) [TAC 97] describes how LCCA may be performed on network level as well as project level of pavement management. It incorporates agency costs as well as user costs which include VOC and user delay costs. The LCCA period is a matter of choice but a range of 20 to 30 years is suggested [Haas 03].

Ontario Pavement Analysis of Costs (OPAC 2000)

OPAC 2000 is a comprehensive design package which incorporates engineering and LCCA procedures for new and rehabilitated pavements. The costs included are agency costs and user costs of VOC and user delay costs. OPAC 2000 provides a tool for the estimation of uncertainty based on standard engineering reliability principles. The LCCA period is a designer input [Haas 03].

Infrastructure Management Book

This text [Hudson et al, 97], describes how economic analysis can be applied to infrastructure projects at two basic levels. First determine the overall economic viability and timing of a project. Second, achieve maximum economy for a project once it has been selected. The LCCA includes the agency costs and user costs which, for roads represent VOC and user delay costs. The analysis period suggested varies with infrastructure type [Haas 03].

Highway Development and Management-4 (HDM-4) System

This model was developed by the World Bank. It estimates road user benefits, infrastructure costs, and externalities including accidents, energy, and emissions for alternative investment strategies. It can be applied at either the project or program level. Previous versions of the model have commonly been used internationally to evaluate tradeoffs between highway expansion and preservation [Haas 03].

HDM-4 is a very comprehensive software tool to appraise the technical and economic aspects of road investment projects. It introduces three application levels commonly used in decision making within the road sub-sector, are as follows:

- Strategic planning for estimating medium and long-term budget requirements for the development and preservation of a road network under various budgetary and economic scenarios.
- Program analysis for preparing single or multi-year work programs under budget constraints.
- Project analysis for estimating the economic or engineering viability of different road investment projects and associated environmental effects. Typical projects include the maintenance and rehabilitation of existing roads, widening or geometric improvement schemes, pavement upgrading and new road construction [Haas 03].

The Municipal Pavement Management Application, MPMA

The Alberta based MPMA performs network level rehabilitation analysis to determine the optimum, multi-year rehabilitation program.

MPMA uses the Present Worth basis and cost-effectiveness calculations for comparing competing alternatives at the network level over short, long or very long term horizons. The analysis defines [Haas 01]:

- Costs of feasible rehabilitation alternatives
- Discount rate to be used for calculating the present worth of rehabilitation alternatives
- Analysis period which can be set for short (5 to 10 years) or long horizons (20 years). This is primarily because of the errors of predicting performance beyond the period. However, a broad long term economic analysis can also be applied up to 99 years.

Principles of Cost-Benefit Analysis in a Canadian Context

This is a book that emphasizes the importance of having a finite economic life or LCCA for typical public sector projects such as dams, bridges, and hydroelectric facilities. All economic methods are included in addition to presenting practical methods for accounting for risk and uncertainty in cost-benefit analysis. Three cases of projects throughout Canada are presented and their economic evaluation is discussed. These projects are the Northumberland Strait Fixed Crossing Project, the Trans Labrador Highway Project, and the Rafferty-Alameda Dams Project [Haas 03].

Decision Trees, MPMA

Sections that are triggered at any time during the analysis period, as well as sections that are triggered because of their high maintenance cost, are identified as candidate sections for rehabilitation. Analysis is performed on the candidate sections to determine their future rehabilitation needs and the appropriate pavement rehabilitation treatments are determined through the use of a set of decision trees. The decision trees are free-form user defined structures that are meant to simulate the current practice of selecting feasible pavement rehabilitation treatments. The decision nodes can be defined using any field in single or complex SQL. The MPMA can have more than one set of trees and comparisons can be made between the results of each tree set [Haas 01].

Maintenance Cost Models, MPMA

The Maintenance Cost Model is a function of the pavement's age and condition, in terms of a Visual Condition Index (VCI) and is used to estimate the increasing maintenance cost of a pavement as it deteriorates and nears the rehabilitation trigger [Haas 01].

Project Level Models, MPMA

The MPMA has the option to carry out project level analysis; however, this has only been used to a limited degree by municipalities [Haas 01].

3.5 SUMMARY of LCCA METHODS

The life cycle cost analysis programs, spreadsheets, and other supporting routines and program that have been described in this chapter all contribute towards the development a generic protocol for infrastructure Life cycle cost. Each of these models has concepts and procedures that are important in the development of a comprehensive life cycle cost analysis methodology. The remaining sections and chapters of this report will describe the components required and will provide an analysis of infrastructure assets using computer software's such as Real Cost and Crystal Ball to determine the expected life cycle cost of particular assets. Table 3.1 below illustrate an overall summary of the preceding LCCA methods in use today. A summary comparison of the key features of the LCCA methods as well as their advantages and disadvantages is also presented in Table 3.2.

Table 3. 1 Summary of LCCA Methods [Haas 03]

						INCLUSION OF COST	
MODEL	**OPERATING LEVEL**	**ECONOMIC BASIS**	**TYPE OF ANALYSIS**	**AVAILABILITY OF SOFTWARE**	**VOCs**	**USER DELAY COSTS**	**ACCIDENTS**
FWHA	Project	Present Worth	Probabilistic	@ Risk Crystal Ball	Yes	Yes	Yes
TAC Pavement Design Guide	Project	Present Worth	Deterministic	No software (Use Excel Spreadsheet)	No	No	No
	Network (Priority Programming)	Present Worth	Deterministic		No	No	No
Ontario Pavement Analysis of Costs (OPAC 2000)	Project	Present Worth	Probabilistic	OPAC 2000	Yes	Yes	No
Infrastructure Management Book	Project	Present Worth	Deterministic	No software (Use Excel Spreadsheet)	Yes	Yes	No
	Network (Priority Programming)	Present Worth	Deterministic	No software (Use Excel Spreadsheet)	Yes	Yes	No
Highway Development and Management HDM4	Strategic	Present Worth Internal Rate Return	Deterministic	HDM 4	Yes	Yes	Yes
	Network	Present Worth Internal Rate Return	Deterministic	HDM 4	Yes	Yes	Yes
	Project	Present Worth Internal Rate Return	Deterministic	HDM 4	Yes	Yes	Yes
MPMA	Network	Present Worth	Deterministic	MPMA	Yes	Yes	No
	Project	Present Worth	Deterministic	MPMA	Yes	Yes	No
Cost-Benefit Anal. Canadian Context	Project	Present Worth	Deterministic	No software (Use Excel Spreadsheet)	NA	NA	NA

Table 3. 2 Comparisons of LCCA Models [Haas 03]

MODEL	FEATURES	ADVANTAGES	DISADVANTAGES
FHWA	-Excellent overview of generic procedures -Provides up to date recommendations	-Incorporates uncertainty; probabilistic -Incorporates various user costs	-No direct software -Need to buy a standard software package
TAC Pavement Design Guide	-Puts into Canadian context, provides Canadian best practice -Both project and network level	-Example is easy to understand -Can be used as a template for other infrastructure	-No software available but can be set up easily in Excel
OPAC 2000	-Includes user delays -Incorporates new engineering models -Based on Ontario best practice	-Could potentially pull out user delay formulas and use for other infrastructure -Models are well developed	-LCCA is specific to pavements -Project Level only
Infrastructure Management Book	-Both levels -Generic procedures	-More generic protocol -Examples easy to understand	-No software available -Could use deterministic approach
HDM4	-Operates at all three levels -International program	-Includes a number of costs -Allows for extensive sensitivity analysis on infrastructure -Incorporates numerous cost components	-Deterministic approach -Needs to be calibrated for Canadian practice
MPMA	-Developed for Alberta -Network level	-System in operation and good data is available -Uses maintenance cost models -Incorporates cost effectiveness	-Deterministic
Cost Benefit Analysis Canadian Context	-Good generic explanation of principles	-Good use of examples	-No software available

3.6 PERFORMANCE MODELLING

Performance modelling is an important concept in infrastructure management. Since construction quality changes throughout the service life of an infrastructure, the concept of performance measure is used as a variable, which changes with time. Hudson defines it as the degree to which a facility serves its users and fulfills the purpose for which it was built or acquired, as measured by the accumulated quality and length of service that it provides to its users [Hudson 97]. Figure 3.1 illustrates a graphical model of performance where performance is represented by plotting a time series verses a quality measurement such as condition index (CI) on a scale of 0 to 100.

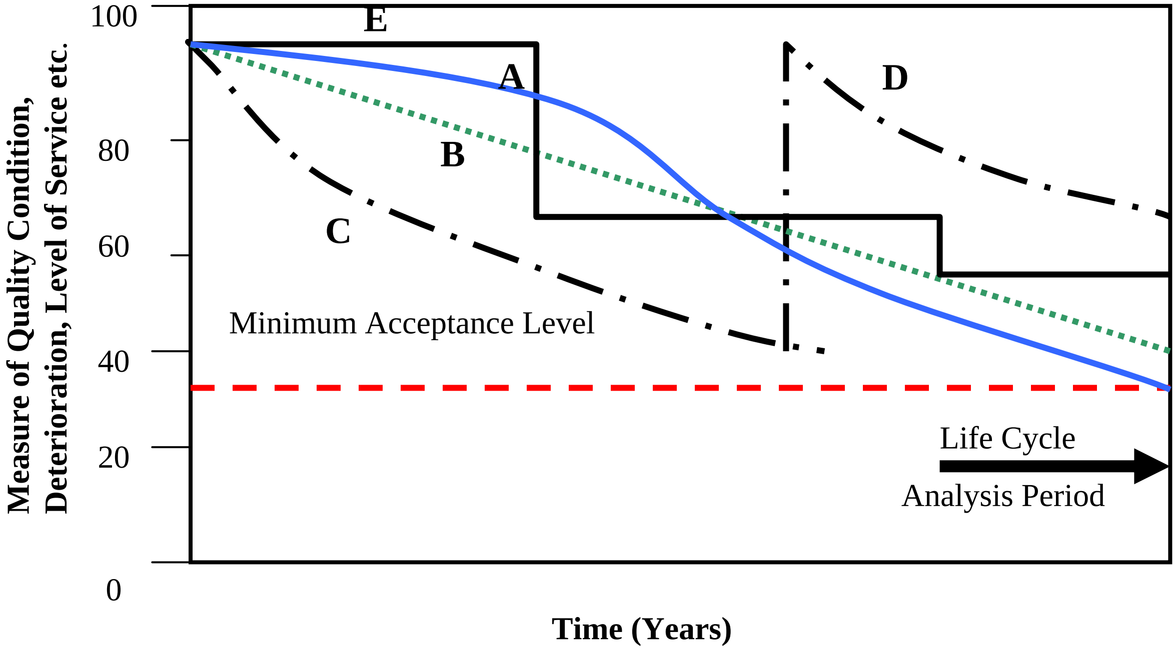


Figure 3. 1 Conceptual illustration of several forms of performance curves [Hudson 97]

- **Curve A (Curvilinear Form): -** Shows a good performance level provided by a facility with high level of service. Facility should be able to remain in relatively good and acceptable condition for most of the service life.

- **Curve B (Linear Form): -** Shows a good performance level provided by a facility with high level of service. Facility should be able to remain in relatively good and acceptable condition for most of the service life.

- **Curve C: -** Shows a poorer performing facility due to a relatively higher deterioration rate in the initial years

- **Curve D: -** A major restoration and rehabilitation intervention can extend the service life of the facility at this point.

- **Curve E (Discontinuous Form):-** Shows a good performance level provided by a facility with high level of service. Facility should be able to remain in relatively good and acceptable condition for most of the service life.

3.7 USER DELAY EXAMPLE

User costs are the costs borne by cars and trucks using the roadway. For maintenance, construction, and rehabilitation projects, user costs are primarily due to capacity reductions in the form of lane reductions, such as two lanes on an interstate having to merge into to one lane. From a driver's point of view, the impact of congestion is longer travel times with associated lost productivity, higher fuel costs, increased pollution, increased accident rates, and less easily quantified costs such as user dissatisfaction and frustration.

Speed changes are manifested as additional costs that are measured in a variety of ways. These costs, categorized under the general label, *user cost*, comprise four elements for the purpose of work zone evaluation. The first group is related to delay, or travel time costs. Reduced speeds and speed cycle changes lengthen the trip time, which means that the time is lost in making the journey (compared with that time expended on the same route without work zone). Such time elements are typically aggregated and then converted to monetary values by dollar rates for work and social values.

The second group of user costs relate to *vehicle operating costs*. These costs relate to elements of vehicle operation that result in costs incurred by the vehicle owner. These costs comprise fuel consumption, oil consumption, tire-wear, vehicle maintenance, vehicle depreciation, and spare parts. Again, speed changes and queuing alter the consumption of these items, particularly those related to fuel.

The third group of costs relate to speed change cycling, which again, work their way through certain operating costs and through emissions and other tailpipe pollutants. The final group of user costs are those associated with accidents, which are generally higher at the work zones for reasons given in previous section. Again, these are costs that would not ordinarily be generated by a regular trip, but are a result of imposing a work zone on traffic and should be included in the total user costs evaluated in a full-cost approach to work zone impacts. Figure 3.2 presents the main components of the user costs that are created by a work zone [Wilde 99].

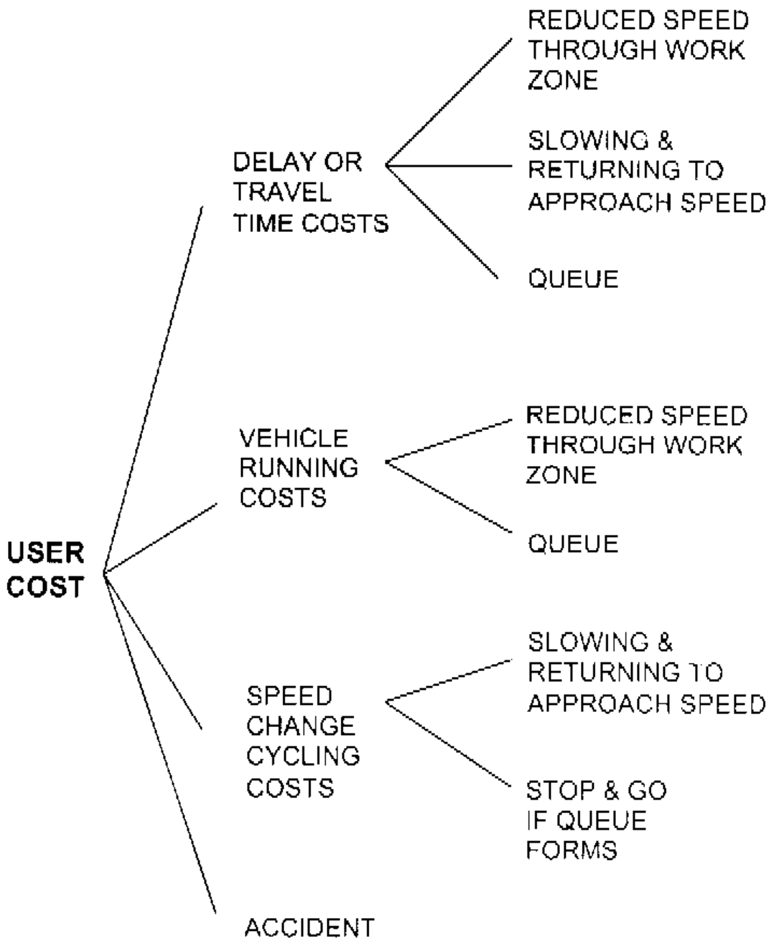


Figure 3. 2 Work Zone User Cost Components

The following tables represent user delay costs calculations for two highway situations obtained from the Ohio Department of Transportation [ODOT 03]. Table 3.3 illustrates detour cost calculations and Table 3.4 denotes No- lane closure cost. The total cost for both passenger cars and trucks is calculated and an average daily cost determined.

Table 3. 3 Detour Cost Calculation Procedure

Work Zone User cost calculations

9/18/2003

Project Number:
CRS:

Detour cost calculation procedure

	Passenger Car	**B/C Truck**
Cost per hour:	**$17.00**	**$31.50**
Length of work zone in km:	**6.75**	**6.75**
Length of Detour in km:	**19.7**	**19.7**
Free flow speed (normal 85% speed) in kmph:	**115**	**115**
Detour zone speed (85%) in kmph:	**83**	**83**
Average AADT of full section:	**500**	**20**
Duration of Closure in days	**20**	**20**
Calculated values:		
Travel time in free flow (secs):	210	210
Travel Time in detour (secs):	852	852
Delay (secs):	642	642
Delay (hours):	0.178	0.178
Cost per Vehicle:	$3.03	$5.61
Cost per day per closure:	$1,514.74	$112.27
Total Cost for closure duration:	$30,294.87	$2,245.38
Total Cost for all vehicles:	**$32,540.26**	
Average cost per day	**$1,627.01**	

The Average cost per day is the MAXIMUM that may be used as liquidated damages / disincentive

Table 3. 4 No lane closure cost calculation procedure

Work Zone User cost calculations 2/12/2004 Project Number: CRS:		
No lane closure cost calculation procedure		
	Passenger Car	**B/C Truck**
Cost per hour:	**$17.00**	**$31.50**
Length of Work zone in km:	**6.75**	**6.75**
Free flow speed (normal 85% speed) in kmph:	**115**	**115**
Work zone speed (85%) in kmph:	**100**	**100**
Average AADT of full section:	**45000**	**15000**
Duration of Closure in days	**300**	**300**
Calculated values:		
Travel time in free flow (secs):	211	211
Travel Time in work zone (secs):	243	243
Delay (secs):	32	32
Delay (hours):	0.0088	0.0088
Cost per Vehicle:	$0.150	$0.277
Cost per day per closure:	$6,735.33	$4,160.05
Total Cost for closure duration:	$2,020,597.83	$1,248,016.30
Total Cost for all vehicles:	**$3,268,614.13**	
Average cost per day	**$10,895.38**	

The Average cost per day is the MAXIMUM that may be used as liquidated damages / disincentive

3.8 FEEDBACK FROM THE PRIVATE SECTOR ON LCCA

Three private companies were contacted on their views relating to LCCA (Table 3.5). Interviews were conducted via telephone and site visit. Ten questions were prepared for the interviews. The following is a summary of the company input on the subject of LCCA.

Table 3. 5 Companies Interviewed

Company	**Company Representative**
1. Miller Paving Limited	Jean-Martin Croteau, P. Eng
2. Stantec Consulting Ltd.	Dr. Khaled Helali, P. Eng
3. Applied Research Association, Inc-ERES Consultants Division	David Hein, P. Eng

1. Feedback from Miller Paving Limited on LCCA [Croteau 03]

Questions:

1. How much does it cost to maintain a one km section of road?
    a. *Answer: Using a preventive maintenance treatment like micro-surfacing approximately $ 30,000.00 up to $ 100,000.00 if a more extensive treatment is use like Cold In-place Recycling with a Hot Mix overlay.*
2. What are the challenges involved in maintaining a section of roadway? (safety, environmental, financial or other considerations?)
    a. *Answer: It depends on the objective that is pursued by the agency. There are three categories of treatment that an agency may select: preventive maintenance 4 to 8 years, pavement rehabilitation 12 to 16 years and pavement reconstruction 15 to 20 years. The challenge for the agencies is certainly to establish long-term objectives for the road network. Many agencies are always dealing with the short-term "worst-first" scenario and the needs are always greater that the resources.*
3. What are the important factors considered in planning for maintenance? How does the season affect these factors?
    a. *Answer: The selection of the right treatment for the right road at the right time in the life of the pavement. As far as the construction season it is generally process specific.*

4. What is the most cost effective method of maintaining facility components?
    a. Do you have preventive maintenance program?
        i. *Answer: Strong preventive maintenance program are not often in place. In order to be effective preventive maintenance treatment must be performed when the pavement is still in relatively good condition. Agencies are struggling with this concept because the benefits are obtained in the long-term planning.*
5. Life Cycle Costing:
    a. Do you have or use LCCA Models/techniques? If so which methods do you use?
        i. *Answer: As a contractor the concepts associated with LCCA are not used very often because they are associated with the design work, which is something we do not get involved with.*
    b. Identify components for which these cost techniques are applicable.
        i. *Answer: The LCCA is the first step for the agency to start the long-term planning and to select the right treatment for the objectives that the agencies have established for themselves.*
6. What are the benefits attributed from LCCA? (Quantifiable or Non-quantifiable)
    a. How do you determine discount rates?
        i. *Answer: Designers are in a better position to provide an answer.*
    b. Should user costs be included in the cost calculations? If these costs are considered how do you determine what they are?
        i. *Answer: The user cost is very important after all the roads are built for them.*
    c. What are the user-cost impacts of alternative preservation strategies?
        i. *Answer: Preservation work provides an opportunity to lengthen the time between rehabilitation operations.*
    d. Which design alternative results in the lowest total cost to the agency over the life of the project?
        i. *Answer: Alternatives that will provide safety and comfort with preventive maintenance treatment over the structural life of the pavement. Very often rehabilitation work is required before the end of the structural life of the pavement. For example, for many agencies extensive thermal cracking will result into a poor ride and rehabilitation work will be required before the pavement becomes unsound structurally.*

        e. To what level of detail have the alternatives been investigated?
            i. *Answer: There is still a significant amount of subjectivity in LCCA. LCCA will provide trends not necessarily exact costing or irrefutable answers.*

7. How could LCCA be used to relate quality of performance and value?
    a. How do you report deficiencies or needs? Do you use a pavement management system?
        i. *Answer: Pavement management systems should be use by all agencies. It should also be associated with an asset management system. Unfortunately, these are not simple tools to implement and at this time only larger agencies that are moving away from the worst-first strategy have invested in those tools. The agencies that are still focused on the worst-first will likely not gain from using PMS.*
    b. Do you interface with other departments or agencies for information or solving problems (e.g. maintenance)
        i. *Answer: No comments*
    c. Do you review other practices, software, and technologies or compare to industry benchmarks?
        i. *Answer: No comments*
8. How to best explain (translate) the results of LCCA to engineers and policy makers?
    a. *Answer: Outreach and education*
9. Is there a difference between traditional projects and technology oriented projects such as Intelligent Transportation Systems (ITS) projects in terms of LCCA?
    a. *Answer: No comments*
10. What methods of prioritization do you use in terms of dealing with budget allocations?
    a. How do you identify maintenance tasks and priorities for scheduling?
        i. *Answer: No comments (see attached paper)*

2. **Feedback from Stantec on LCCA** [Helali 03]

Questions:

1. How much does it cost to maintain a one km section of road?

    Answer: Rehabilitation may cost $15 – $30 per square yard and reconstruction approximately $1,000,000.00 per mile on freeway.
2. What are the challenges involved in maintaining a section of roadway? (safety, environmental, financial or other considerations?)

    a. *Answer: Financial challenges-*
        i. *How to get new ways of funding*
        ii. *Lack of funding/budget (not enough money)*
        iii. *In the past maintenance cost was not included in the budget*
    b. *Safety-*
        i. *Safety is the second challenge. In case of an emergency, the company will rectify the problem immediately.*
    c. *Many agencies are always dealing with the short-term "worst-first" scenario and the needs are always greater than that the resources.*
3. What are the important factors considered in planning for maintenance? How does the season affect these factors?
    a. *Answer: Budget- The term "Political engineering" is used to describe the politics in selecting where budget is allocated.*
    b. *Seasonal variation- All construction starts in the summer and all planning is done in the winter.*
    c. *Conflict between infrastructure- Integration of different assets may be delayed for five years if they have to.*
    d. *Traffic- Most maintenance work is done at night to avoid traffic delays*
4. What is the most cost effective method of maintaining facility components?
    a. Do you have preventive maintenance program?
        i. *Answer: Yes. A combination of preventative maintenance, corrective maintenance and rehabilitation exists. All three is integrated for LCCA.*
5. Life Cycle Costing:
    a. Do you have or use LCCA Models/techniques? If so which methods do you use?
        i. *Answer: Yes. The company use LCCA models for all their infrastructure assets such as Pavement Management Systems (PMS) and Bridge Management Systems (BMS) using a deterministic approach. The company's software was developed in 1978.*
        ii. *30%-40% of their clients use the LCCA models.*
6. What are the benefits attributed from LCCA? (Quantifiable or Non-quantifiable)
    Answer: The LCCA is most cost effective in the long term.
        i. *Better performance of network level*
        ii. *Overall cost over the years would be less.*
    a. How do you determine discount rates?

    Answer: This is a policy decision.

  b. Should user costs be included in the cost calculations? If these costs are considered how do you determine what they are?
      i. *Answer: Only at the project level not at the network*
  c. What are the user-cost impacts of alternative preservation strategies?
      i. *Answer: Delayed time of people and vehicle.*
      ii. *Delayed Cost- stop time and delayed time*
  d. Which design alternative results in the lowest total cost to the agency over the life of the project?
      i. *Answer: Combination of preventative and rehabilitation in one program.*
  e. To what level of detail have the alternatives been investigated?
      i. *Answer: At the Network Level. How to establish the cost or itemize cost is the challenge.*

7. How could LCCA be used to relate quality of performance and value?
    a. How do you report deficiencies or needs? Do you use a pavement management system?
        i. *Answer: Yes the company uses a Pavement Management System (PMS).*
        ii. *Yes the company reports deficiencies. Percent deficiency is more efficient than reporting in average because the general public understands % deficiency better than average.*
    b. Do you interface with other departments or agencies for information or solving problems (e.g. maintenance)
        i. *Answer: Yes. The company deals with "Data warehouse." They integrate with maintenance and traffic construction because most agencies do not have a maintenance history in their database.*
    c. Do you review other practices, software, and technologies or compare to industry benchmarks?
        i. *Answer: Yes. The company does because this is party of competition. As a matter of fact, they review more than most universities.*
8. How to best explain (translate) the results of LCCA to engineers and policy makers?
    a. *Answer: The company uses Network Performance Graph which shows results of different funding and also the impact of different budget.*
9. Is there a difference between traditional projects and technology oriented projects such as Intelligent Transportation Systems (ITS) projects in terms of LCCA?

    a. *Answer: Yes. Technology in data collection*

10. What methods of prioritization do you use in terms of dealing with budget allocations?
    a. How do you identify maintenance tasks and priorities for scheduling?
        i. *Answer: Modeling cost effectiveness to prioritize budget allocation.*

3. Feedback from Applied Research Association, Inc-ERES Consultants Division on LCCA [Hein 03]

Questions:

1. How much does it cost to maintain a one km section of road?

    Answer: Winter maintenance may cost up to $10 to $11mil.

2. What are the challenges involved in maintaining a section of roadway? (safety, environmental, financial or other considerations?)
    a. Answer: Cost
    b. Safety- Speed control during construction.
    c. Equipment to protect workers.
3. What are the important factors considered in planning for maintenance? How does the season affect these factors?
    a. Answer: Safety- There is huge cost involved in not working safe.
    b. Productivity
    c. Quality
4. What is the most cost effective method of maintaining facility components?
    a. Do you have preventive maintenance program?
        i. *Answer: Asphalt -Ohmpa*
5. Life Cycle Costing:
    a. Do you have or use LCCA Models/techniques? If so which methods do you use?
        i. *Answer: No. The company does not apply LCCA. The city or region implement the LCCA.*
        ii. *30%-40% of their clients use the LCCA models.*
6. What are the benefits attributed from LCCA? (Quantifiable or Non-quantifiable)
        i. *Answer: Not Applicable.*
    a. How do you determine discount rates?

        Answer: Not Applicable.

   b. Should user costs be included in the cost calculations? If these costs are considered how do you determine what they are?
      i. *Answer: Not Applicable.*
   c. What are the user-cost impacts of alternative preservation strategies?
      i. *Answer: Not Applicable..*
   d. Which design alternative results in the lowest total cost to the agency over the life of the project?
      i. *Answer: Not Applicable.*
   e. To what level of detail have the alternatives been investigated?
      i. *Answer: Not Applicable.*
7. How could LCCA be used to relate quality of performance and value?
   a. How do you report deficiencies or needs? Do you use a pavement management system?
      i. *Answer: Not Applicable.*
   b. Do you interface with other departments or agencies for information or solving problems (e.g. maintenance)
      i. *Answer: Not Applicable.*
   c. Do you review other practices, software, and technologies or compare to industry benchmarks?
      i. *Answer: No comment*
8. How to best explain (translate) the results of LCCA to engineers and policy makers?
   a. *Answer: Not Applicable.*
9. Is there a difference between traditional projects and technology oriented projects such as Intelligent Transportation Systems (ITS) projects in terms of LCCA?
   a. *Answer: Not a lot of changes. Some equipment are more fuel efficient.*
   b. *Examples of changes are as follows:*
      i. *Lasers in pipes and ultrasonic methods used for slopes and gradient.*
      ii. *Computers replaced a few old electronic methods.*
   c. *Principle of surveying remains the same.*
10. What methods of prioritization do you use in terms of dealing with budget allocations?
   a. How do you identify maintenance tasks and priorities for scheduling?
      Answer: Based on safety issues. The company does not do prioritization.

CHAPTER 4. HIGHWAY ASSETS AND LCCA EXAMPLES

4.1 HIGHWAY ASSETS THAT CAN BE INCORPORATED INTO LCCA

This chapter deals with highway assets that can be incorporated into LCCA. It also uses and example from GASB 34 report [Maze 00], to clarify two methods for capitalizing infrastructure assets. The Perpetual inventory method (PIM) and an example taken from the California Department of Transportation (CalTrans) are described below.

4.1.1 Types of Assets

According to GASB 34, there are two main types of assets.

1) ***Capital Assets***:-

These are both tangible and intangible assets that are used in governmental operations and have initial useful lives extending beyond a single reporting period. Capital assets include: land, land improvements, buildings, building improvement, construction in progress, machinery and equipment, vehicles, infrastructure, easements, and works of art and historical treasures. Capital assets can be broken down into two basic classifications of fixed assets:

- Real property
- Personal Property

2) ***Infrastructure Assets***:-

These are long-lived capital assets that normally are stationary in nature and can be preserved for a significantly number of years than capital assets. Infrastructure assets do not include buildings, drives, parking lots, or any other example that are given in table 4.1 that are incidental to property or access to the property. Example of capital assets and infrastructure assets are illustrated in Table 4.1 below.

Table 4. 1 Examples of Capital & Infrastructure Assets

CAPITAL ASSETS	INFRASTRUCTURE ASSETS
Land/Easement	Roads
Land Improvements	Bridges
Building/Building Improvements	Tunnels
Vehicles	Drainage Systems
Telecommunication Equipment	Underground Utilities
Moveable Equipment	Dams
Historical Treasures	Streets/Highway Lighting Systems
	Sidewalks, Curbs & Signage
	Water/Sewer Distribution
	Collection Systems

State and local governments in the U.S. invest approximately $140-$150 billion annually in the construction, improvement and rehabilitation of capital assets, including infrastructure assets like bridges, highways and sewers [GASB 99]. These expenditures are significant, representing more than one out of every ten dollars spent by those governments. The majority of infrastructure investment is financed by borrowing or selling municipal bonds and using the proceeds to pay for construction.

4.1.2 Categories of Infrastructure Assets

Based on their primary functions and services, physical facilities and related services can be categorized in seven groups [Hudson 97]. Table 4.2 below illustrates those categories.

Table 4. 2 Categories of Infrastructure Assets

CATEGORY	INFRASTRUCTURE ASSET	SUBGROUP OF INFRASTRUCTURE ASSETS	EXAMPLES
1	Transportation	▪ Ground Transportation	Roads, Bridges, Tunnels, Railroads
		▪ Air Transportation	Airports, Heliports, Ground Facilities, Air Traffic Control
		▪ Waterways & Ports	Shipping channels, Main Terminals, Dry docks, Ports.
		▪ Intermodal Facilities	Rail/airport Terminals, Truck/Rail/Port Terminal.
		▪ Mass Transit	Subway, Bus Transit, Light Rail, Monorails, Platforms/stations.
2	Water & Waste Water	▪ Water Supply	Pumping Stations, Treatment plants, Main Water lines, Wells, Mechanical/electrical equipment.
		▪ Structural	Dams, Diversion, Structures, Tunnels, Aqueducts
		▪ Agricultural Water Distribution	Canals, Rivers, Weir, Gates, Dikes
		▪ Sewer	Main Sewer Lines, Septic Tanks, Treatment Plants, Storm water Drains.
3	Waste Management	▪ Solid Waste ▪ Hazardous Waste ▪ Nuclear Waste	
4	Energy Production and Distribution	▪ Electric Power Production	Hydro-electric power stations; gas-,oil-, and coal-fuel power generation
		▪ Electric Power Distribution	High-Voltage power transmission lines, Substations, Distribution systems,
		▪ Gas Pipeline	Gas production, pipeline, storage tanks
		▪ Petroleum/oil Production	Pimping stations, oil/gas separation plants, roads
		▪ Nuclear Power Station	Nuclear reactors, power-generation stations, Nuclear waste disposal facilities
5	Buildings	▪ Tall Buildings-Residential/commercial	Structures, Utilities, Swimming Pools, Parking, Security, Ground access
		▪ Public Buildings	Schools, Hospitals, Government offices, police stations, fire stations, postal Offices, Parking Structures.
		▪ Multipurpose Complexes	Convention Centers, Coliseums, amphitheaters, religious congregation buildings
		▪ Sports Complexes	Indoors, stadiums, golf courses
		▪ Movie Theaters	Indoor, Drive-ins
		▪ Housing Facilities	Public, Private

6	Recreation Facilities	▪ Parks and Playgrounds	Roads, Parking Areas, Recreational Facilities, Office Buildings, Rest rooms, Ornamental Fountains, Swimming Pools
		▪ Lake & Water Sports	Roads, Parking Areas, Picnic Areas, Marinas.
		▪ Theme Parks/Casinos	Access Roads, Buildings, Restaurant, Security Facilities, Structures.
7	Communication	▪ Telecommunication Network	Telephone-exchange stations, Cable Distribution
		▪ Television/Cable Network	Production Stations, Transmission Facilities, Cable Distribution
		▪ Wireless/Satellite Network	Satellite, Ground-control centers, Communication Systems
		▪ Information Highway Network	Computer Network, Cable Distribution, Data-processing hardware/software, Buildings, backup and recording Mediums.

4.1.3 Typical Highway Assets

Any highway system integrates both capital and infrastructure assets. Table 4.3 illustrates a few examples of highway assets that can be incorporated into life cycle cost analysis.

4.2 ASSET VALUATION

In the past, public sector accounting used an expense or expenditure statement to report revenues (government allocation) and expenditure (cost incurred to maintain the assets). Since there were no means of reporting the value of the assets on the revenue/expenditure report, a balance sheet was developed for public accountability where asserts were included. There are two distinct accounting basses for asset valuation:

Table 4. 3 Typical Highway Assets

Infrastructure Assets	Sub-category
Tunnels	
Bridges	
Pavements	
Culverts	
Hardware	Guard Rails
	▪ Lighting
	Barriers
	Impact Attenuators
	Signs ▪ Changeable message signs ▪ Lane control signs ▪ Close-Circuit Television System (CCTV) ▪ Electronic Surveillance & Monitoring Equipment ▪ Operating Facilities

Other Assets	Sub-category
Construction & Maintenance Equipment	
Vehicles	
Real estate	Buildings
	Property
	Roadside
	Right-of-way (ROW)
Materials	
Human Resources	
Corporate data & information	
Ground & Water transportation facilities & equipment	

1. Financial accounting, where historical cost (as built or purchase) is the preferred starting basis and current or book value is established by depreciating or amortizing the historical cost.
2. Management accounting where current value is normally established on written down replacement cost (WDRC) basis.

The overall context for asset valuation and performance measures should be the mission and vision statements of highway agencies. Accordingly, the performance measures selected as asset management systems and the measuring and reporting of assets should be linked, because they reflect the public expectations of what the highway systems should deliver [Cowe 01].

4.2.1 Methods for Asset Valuation

There should be a clear recognition of the features plus, pros and cons of the various asset valuation methods before any calculation of asset values. Table 4.4 summarizes five methods commonly used in addition to their pros and cons. The two most commonly used ones are (historical cost based) book value and written down replacement cost (WDRC).

4.2.2 Recommended Framework for Asset Valuation

Figure 4.1 illustrates a recommended framework for asset management. The structure of this framework is generic in nature and also flexible. It allows for the accommodation of individual agency needs, resources and policies. Classes or types of asset, their locations and amount or extent must first be identified and their current status or condition established. Qualitative or quantitative measures may be required for this operation. The current condition and the current estimated value of the individual asset will reveal the criteria as to which one is currently under-performing or potential future under-performers. Asset valuation methods are used to estimate or predict such scenarios as illustrated in Table 4.4.

Table 4. 4 Asset Valuation Methods: Features, Pros and Cons [Cowe 01]

Method	Features	Pros	Cons
Book Value (BV) Current value based upon Historical Cost	▪ Commonly used for financial accounting purposes ▪ Used historical records of procurement (first cost plus any subsequent cost), depreciated to present worth ▪ Provides direct comparisons in time series progressions	▪ Data is generally available ▪ Relatively simple	▪ Does not account for changes in prices ▪ Neglects technology and service standards changes ▪ Results can be misleading for older assets such as bridges, land etc.
Written Down Replacement Cost (WDRC) Current Values based on replacement cost depreciated to current conditions	▪ Commonly used for management accounting purposes ▪ Uses current market prices to rebuild or replace ▪ Current conditions used to establish write down values	▪ Reflects current prices and technology ▪ Easily understandable ▪ Can compare assets ▪ Basics for budgeting	▪ Conjectural on replacement cost (subject to external market forces) ▪ Question of how to handle an upgrade and improve replacement
Equivalent Present Worth In Place (EPWP) Historic cost adjusted for inflation and wear	▪ Accounts for changes in prices and usage ▪ Represents worth "as is" ▪ Applicable to comparing with other investments ▪ Based on historic costs adjustment for inflation, depreciation, depletion and wear	▪ Uses generally available data ▪ Accounts for changes in prices and usage ▪ Useful for comparing rates of return with other investments ▪ Basis for budgeting, especially maintenance, within life cycle analysis	▪ Neglects changes in technology and service standards ▪ Requires a number of conjectural assumptions
Productivity Realized Value (PRV) Net present value of benefit stream of remaining life	▪ Represents value in use (what is it worth not to loose it) ▪ Reflects relative importance of the assets	▪ Realistic reflection of importance of the assets ▪ Basis for budgeting	▪ Requires various assumptions and non-market estimates ▪ Subject to market forces particularly supply and demand if parallel services exists
Market Value (MV)	▪ Price buyer is willing to pay	▪ Simple concept ▪ Applicable to public agency disposal or sell off of assets	▪ Conjectural until offer is actually received ▪ Limited applicability (e.g., few highway agencies sell assets) ▪ Volatile as is subject to market forces

Table 4. 5 Appropriate Asset Valuation Method(s) and Suggested Deterioration Functions for Tangible Assets [Falls 01]

Type	Asset Item	Valuation Method	Suggested Deterioration Function
Fixed Assets (within the Right of Way)	Pavement	BV, WRDC	Concave up or down, straight line, or sigmoidal.
	Bridges	BV, WRDC	Function varies with component element (e.g., material, structural element, etc.).
	Drainage Structures (e.g. Storm Sewers)	BV, WRDC	Function depends on whether material and /or structural deterioration is involved and can be step (e.g. pipe collapse), or straight line or concave up or down
	ROW (land, vegetation, etc)		Straight line could apply to trees, grass, shrubs, etc. being constantly kept in trimmed condition; concave down would apply if maintenance ceases
	Grade (cut/fill)	BV, WRDC	Step function would apply when slope failure occurs; concave function would apply to progressive erosion
	Signs	BV, WRDC	Step function applies to sudden breakage or disappearance of sign kept in good condition. Curve function concave down applies to lack of maintenance (fading, peeling, etc.)
	Signals & loop detectors	BV, WRDC	Step function would apply to breakdown, otherwise, (flat) straight line would apply to properly maintained items
	FTMS Cameras	BV, WRDC	Same as for signals and loop detectors
	Guide rails & barrier walls	BV, WRDC	Concave down, generally, a deterioration accelerates; step function if sudden damages occurs
	Fences & noise barrier	BV, WRDC	Straight Line (basically flat) with periodic maintenance; step function if sudden damage occurs
	Culverts	BV, WRDC	Concave Down, Generally, with material and structural deterioration plus silting; step function for blockage.
	Pavement markings	BV, WRDC	Straight line or concave Down
	Lighting	BV, WRDC	Same as for Signals and Loop Detectors
	Sidewalks & bike paths	BV, WRDC	Same as for Pavements
	Curbs & Gutters	BV, WRDC	Same as for Culverts
	Utilities (Cable, gas, hydro, phone, water)	BV, WRDC PRV, MV	Deterioration can be progressive (e.g. concave down, or straight line) or step if breakdown occurs.
	Weigh scales & WIMS	BV, WRDC PRV, MV	Same As for signals and Loop detectors

Table 4. 6 Appropriate Asset Valuation Method(s) and Suggested Deterioration Functions for Tangible Assets [Cowe 01]

Type	Asset Item	Valuation Method	Suggested Deterioration Function
Unfixed Assets (Outside the Right of Way)	Quarries & Pits, Material Stockpiles	BV, WRDC PRV, MV	Straight Line
	Yard (building, salt sheds, fuel tanks, etc.)	BV, WRDC MV	Straight Line for most Items
	Mobile Offices, Laboratories	BV, WRDC MV	Straight Line
	Building (Regional of District	BV, WRDC MV	Straight Line
	Communication Equipment	BV, WRDC MV	Straight Line
	Computer Hardware/Software	BV, WRDC PRV	Straight Line
	Vehicles, Equipment & Parts Inventory	BV, WRDC MV	Straight Line

Figure 4.2 illustrates a recommended framework for asset valuation which is similar to the asset management framework in Figure 4.1. This framework may be applicable to any method of asset valuation. In order to establish current asset value, three fundamental questions need to be addressed [Cowe 01]:

- What assets are available?
- What are their current condition?
- What valuation method should be used and what is their value?
- Are all the assets criteria consistent for calculation? (need a consistent approach for all assets)

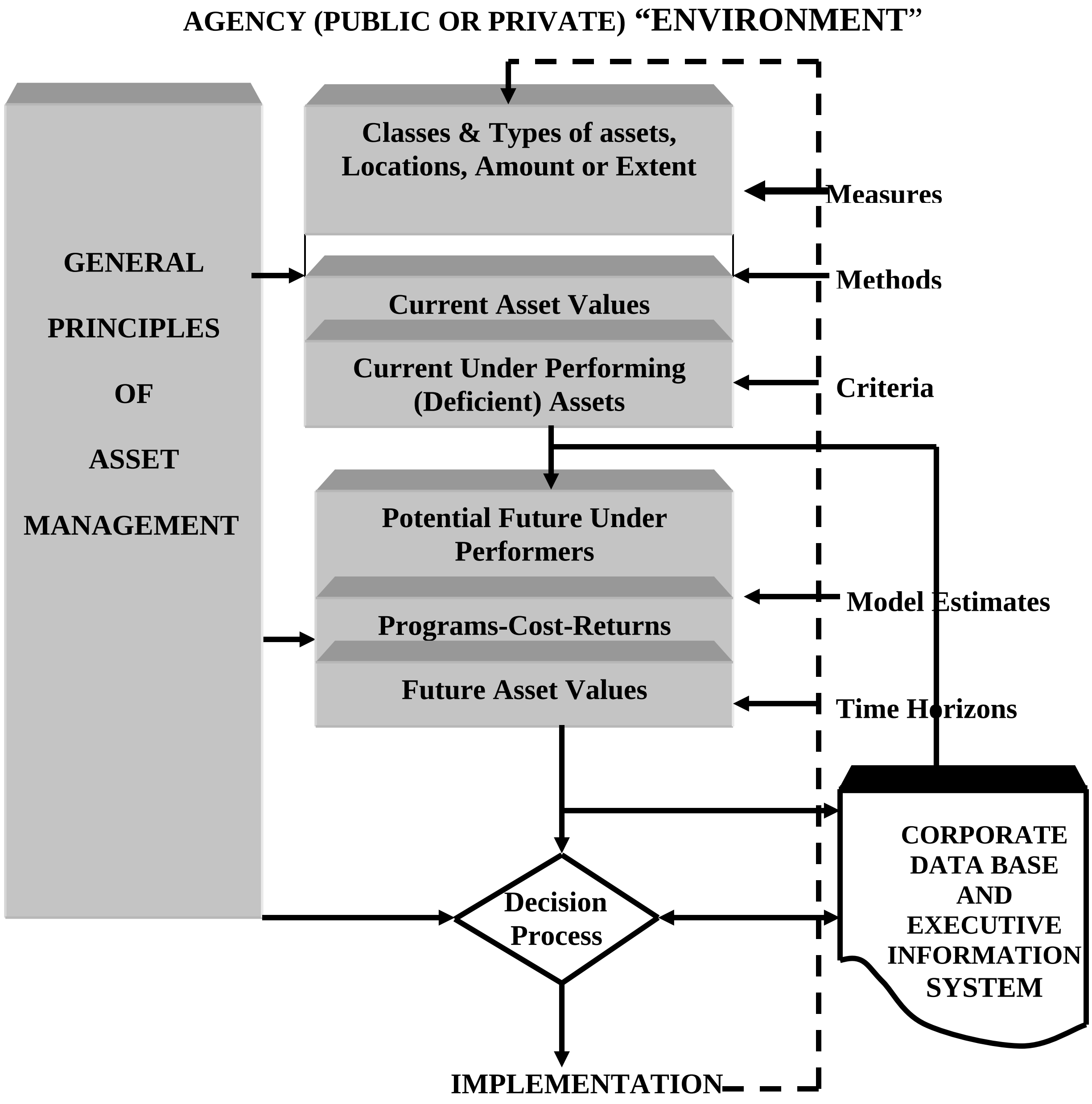


Figure 4. 1 Overall Framework for Asset Management [Haas 01]

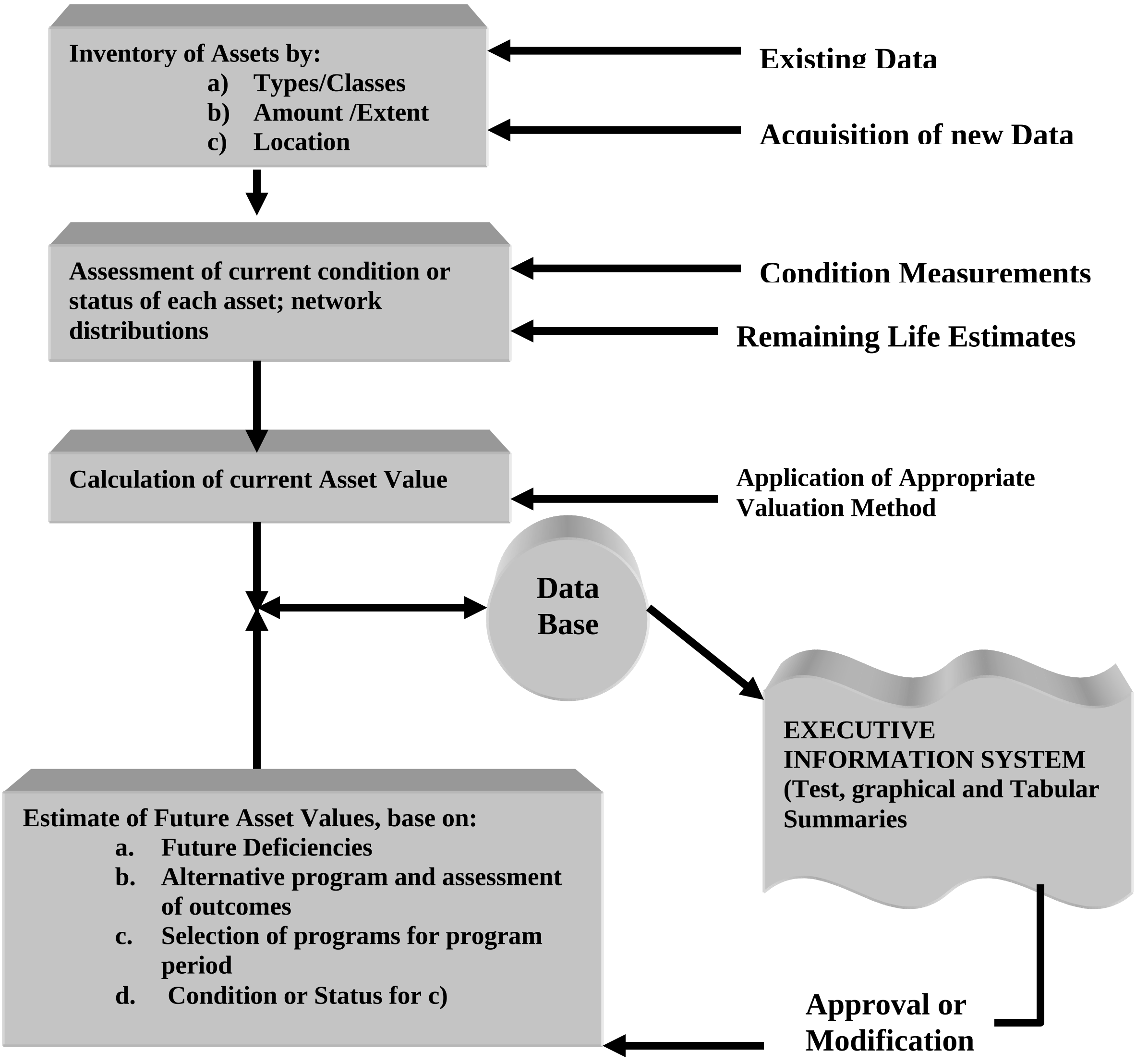


Figure 4. 2 Framework for highway asset valuation [Cowe 01]

4.2.3 A Generic Asset Management System

In an infrastructure asset management system, question and issues need to be addressed. Figure 4.3 below represents a generic asset management system with the major components and the relationship among them. The components indicated would typically be included in any asset management approach although some specifics may be different for various agencies within a highway department.

SYSTEM COMPONENTS

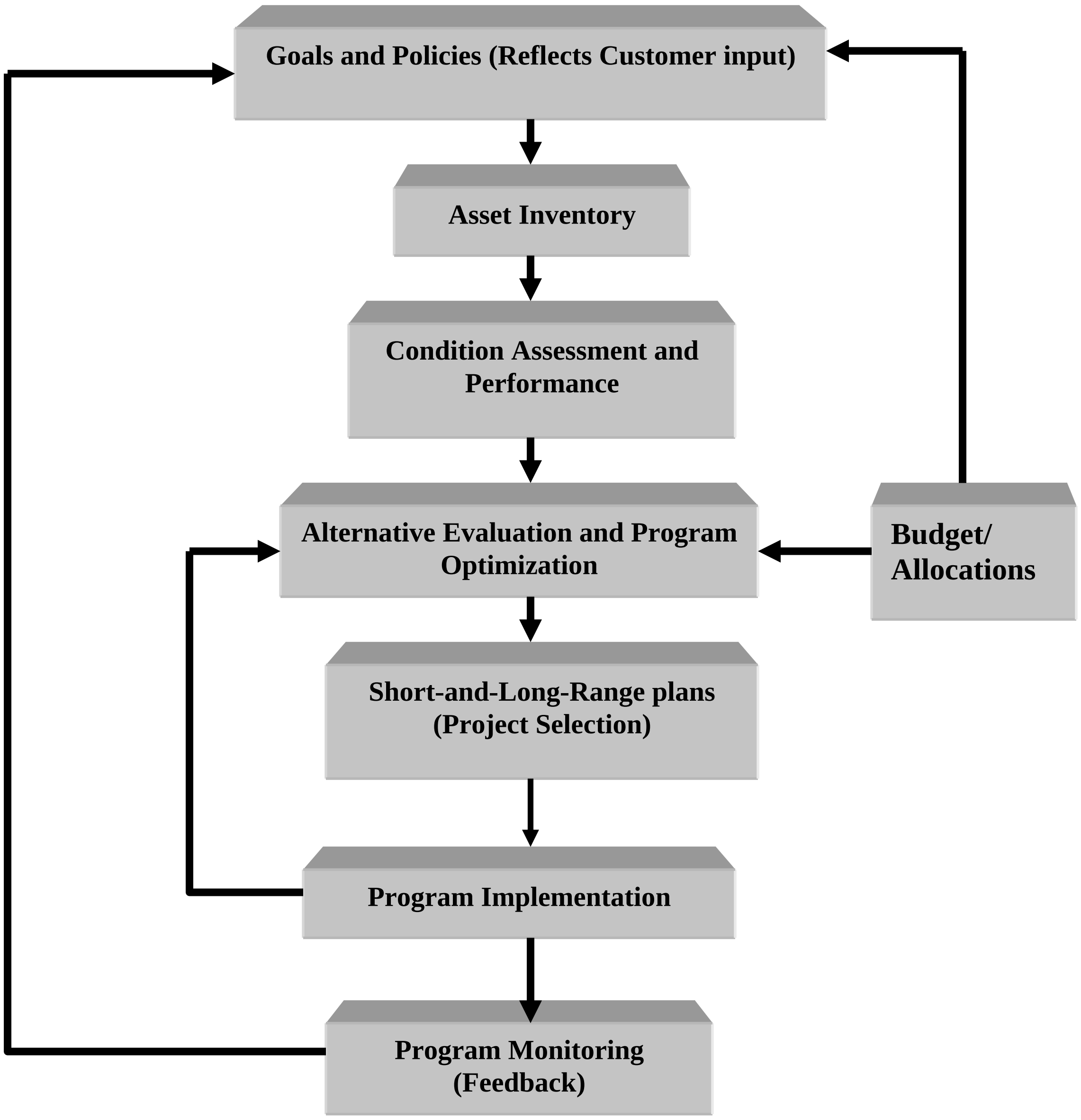


Figure 4. 3 Generic Asset Management System Components [U.S DOT 99]

Key Questions

- What is the agency’s mission? What are their goals and policies?
- What is included in their inventory of assets?
- What is the value of their assets? What are their functions? What services do they provide?
- What was the past condition and performance of the agency’s assets?
    - What is the current and predicted future condition and performance of their assets?
- How can they preserve, maintain, or improve their assets to ensure the maximum useful life and provide acceptable service to the public?
- What resources are available?
    - What is the budget level?
    - What is the projected level of future funding?
- What investment options may be identified within and among asset components classes?
    - What are their associated cost and benefits?
- Which option, or combination of options, is “optimal?”
- What are the consequences of an agency not maintaining their assets?
    - How can communicating the impact of the condition and performance of assets on the system and end user be recommended?
- How can the impact of decisions be monitored?
    - How can decision-making framework when indicated be adjusted?
- How can assets be best managed in order to least inconvenience the monitoring public when facilities are repaired or replaced?

4.3 ESTABLISHING A VALUE FOR INFRASTRUCTURE ASSETS

Estimating monetary values for infrastructure assets (i.e. capitalizing assets) is very important whether an agency chooses to report assets by:

a) Depreciating their value based on historical cost or

b) Using the modified approach outlined in GASB 34.

The value of its infrastructure cost must be included in its comprehensive financial report [Maze 00].

Little research has been conducted to develop standardized methods for capitalizing infrastructure assets. Most agencies and also according to a number of references, capitalize assets separately for example, bridge management system (BMS) and pavement management Systems (PMS) etc. Maze provides two example approaches in his report to help value infrastructure assets. The first one deals with the Perpetual Inventory Method (PIM), which is applied to depreciate the value of highway infrastructure asset through time. His second example, which requires a bridge management system, was obtained from the California Department of Transportation (CalTrans) and is based on engineering measurements of the condition of bridges. In this report an attempt is made to integrate most of the highway infrastructure assets into a consistent model by using either one of Maze's approaches. First and foremost, the two methods will be discussed to clarify the process involved in achieving such objective.

4.3.1 Perpetual Inventory Method

This method is a depreciation technique for valuing capital stock that can be applied to transportation infrastructure assets. PIM accounts for annual capital expenditures and assumes that existing capital assets depreciate in value at a standard rate every year [Maze 00].

The following equation estimates the total value of infrastructure assets on a year-by-year basis:

$$\textbf{Infrastructure Assets}_{\textbf{Year}} = \textbf{Capital Investment}_{\textbf{Year}} + \textbf{(1-r)Infrastructure Assets}_{\textbf{(Year-1)}} \quad (13)$$

Where:

Infrastructure Assets $_{\text{Year}}$ = the value of infrastructure assets in the current year
Capital Investment $_{\text{Year}}$ = the amount of capital investment in infrastructure assets in the current year
r = the annual depreciation rate of infrastructure assets
Infrastructure Assets $_{\text{(Year-1)}}$ = the value of the infrastructure assets in the year immediately prior to the current year

All capital investments should be expressed in constant dollars when using this formula. This is done so that meaningful comparisons can be made across time. The constant dollars exclude inflation and express dollars in terms of a base year [Maze 00].

An appropriate annual depreciation rate is required for the application of this formula to transportation. Taken from a study conducted by Fraumeni for the Bureau of Economic Analysis (BEA), the value of existing highway infrastructure assets depreciate by 0.0202 per year [Fraumeni 99]. This national average takes into account all types of highway infrastructure including bridges, pavements, rights-of –way, etc., and may be adjusted for local differences [Maze 00].

In the method mentioned above, a beginning year (a base year) should be selected as well as a value for the existing infrastructure assets for that year. This is done because each year’s estimate is derived from the prior year’s estimate of the depreciated value of infrastructure asset [Maze 00].

Example of Perpetual Inventory

Assumption

Maze used a base year in his example from a report by Andrew C. Lemer. Lemer claimed that municipalities typically have between $15,000-35,000 in infrastructure investment (using replacement cost) per resident [Lemer 00].

- City Total infrastructure per resident = $30,000
- Investment in roadway assets (streets and highways) = $20,000 (i.e. 65% of Total public investment)
- City population = 50,000
- Therefore, in base year 1980, investment in highways and streets = $100,000,000

Table 4. 7 Perpetual Inventory Method Example

Fiscal Year	Capital Investment during Current Year ($)	(1-0.0202)x Infrastructure Asset at the End of Prior Year ($)	Estimated Current Infrastructure Assets ($)
1980	$1,200,000	$100,000,000	$101,200,000
1981	$2,500,000	$97,980,000	$100,480,000
1982	$3,000,000	$96,000,804	$99,000,804
1983	$1,000,000	$94,061,588	$95,061,588
1984	$500,000	$92,161,544	$92,661,544
1985	$800,000	$90,299,881	$91,099,881
1986	$750,000	$88,475,823	$89,225,823
1987	$850,000	$86,688,611	$87,538,611
1988	$700,000	$84,937,501	$85,637,501
1989	$900,000	$83,221,764	$84,121,764
1990	$2,500,000	$81,540,684	$84,040,684
1991	$2,700,000	$79,893,562	$82,593,562
1992	$2,500,000	$78,279,712	$80,779,712
1993	$2,400,000	$76,698,462	$79,098,462
1994	$2,900,000	$75,149,153	$78,049,153
1995	$2,400,000	$73,631,140	$76,031,140
1996	$2,200,000	$72,143,791	$74,343,791
1997	$2,800,000	$70,686,487	$73,486,487
1998	$2,550,000	$69,258,620	$71,808,620
Total	$35,150,000		

4.3.2 Method # 2: Caltran's process to Valuing Infrastructure

Most asset management systems such as bridges and pavements are managed based on the effect of investment of assets by factors such as condition or performance. This may be done by the following approaches:

- Maintaining infrastructure inventory
- Regularly assessing and rating the condition of infrastructure
- Estimating cost to maintain the condition of infrastructure at the different levels.

The above approaches are not usually in the form of dollar value, and therefore, agencies using these management strategies need to convert performance or condition ratings to dollar value. This is important in order to capitalize infrastructure assets. CalTrans used that approach in the following example with its bridge management system.

CalTrans bridge management operates by using a system called Pointis. This program functions in the following way:

- Pointis is a bridge management system distributed by the American Association of State Highway and Transportation Officials.
- The condition of various elements in each bridge is regularly inspected and rated.
- Bridge inspectors are required to visually evaluate the severity and extent of deterioration to 108 commonly recognize bridge elements. Bridge elements may includes features such as:
    - Bridge decks
    - Girders
    - Columns
- A formula for converting the condition ratings was developed.
- All the elements in the bridge are then converted into an overall current dollar value.

- Three to five condition states may be assigned to each core element in conjunction with an extent of percent condition. Five condition states by Maze are follows [Maze 00]:
    1. **Protected**:- The element's protective materials or systems (e.g., paint or cathodic protection) are sound and functioning as intended to prevent deterioration of the element.
    2. **Exposed**:- The element's protective materials or system have partially or completely failed (e.g., pealing paint or spalled concrete), leaving the element vulnerable to deterioration.
    3. **Attack**:- The element is experiencing active attack by physical or chemical processes (e.g., corrosion, wood rot, traffic wear-and-tear) but is not yet damage.
    4. **Damage**:- The element has lost important amounts of materials (e.g., steel sections loss)
    5. **Failed**:- The element no longer serves its intended function (e.g., the bridge must be load posted).

Assumptions for example on the bridge girder

- Bridge has 150 metres of girders
- 15 metres of paint is peeling off
- Remainder of paint is in tact
- Girder condition:
    - 10% expose
    - 90% protected

Step 1: Weigh the severity of the condition state

The following table represents CalTrans severity weighting factors. This is how the table works: If a core element has three condition states, any proportion of the section rated condition state 3 (the most severe) receives a weighing factor of zero; any proportion rated condition state 2 receives a weighing factor of 50%.

Table 4. 8 Severity Weighting Factors (WF)

Number of Possible Condition States	State 1 WF	State 2 WF	State 3 WF	State 4 WF	State 5 WF
3 condition states	1.00	0.50	0.00		
4 condition states	1.00	0.67	0.33	0.00	
5 condition states	1.00	0.75	0.50	0.25	0.00

Step 2: Determine the current value of the bridge

- Calculate a dollar value for each element based on the weighted condition states
- Add the element values together.
- CalTrans uses the equation below:

$$\boxed{\textbf{Current element value} = \textbf{(quantity in condition state * WF*FC)}} \tag{14}$$

Where:

WF = Weighting factor for the severity of the deterioration as determined by Table 4.8

FC = Failure cost of the element (Cost of rehabilitation or replace an element if it fails).

Table 4.9 below is an example of a given database, which quantifies each element in each condition state for one bridge. The following describes the layout of the table and explains conditions of elements for the bridge example:

- Unit Failure cost- the right-most column
- 300 square meters of Concrete Deck
  - Five condition states
  - Deck is in state three (Attacked)

- 24 metres of joint seal,
    - Three condition states,
    - Joint seals are in condition state three (Failed)

Table 4. 9 Example Bridge CoRe Element Condition and Extent Data

Element	**Total Quantity**	**Units**	**State 1**	**State 2**	**State 3**	**State 4**	**State 5**	**Unit Failure Cost (FC)**
Concrete Deck	300	Sq metres			300			$600
Steel Girder		Metres	61	34	5			$3,500
Reinf. Conc. Abutment		Metres	24					$7,700
Reinf. Conc. Column		Each	4					$9,000
Joint Seal	24	Metres			24			$556

The values from Table 4.9 above are used to calculate a value for each element. This is demonstrated in Table 4.10 below. Values of all elements are summed to calculate an estimate value for the entire bridge

Table 4. 10 Bridge Valuation Calculations

Element	**Calculation**	**Current Element Value**
Concrete Deck	300 x 0.5 x 600	$90,000
Steel Girder	((61 x 1.0) + (34 x 0.75) + (5 x 0.5)) x 3,500	$311,500
RC Abutment	24 x 1.0 * 7,700	$184,800
RC Column	4 x 1.0 * 9,000	$36,000
Joint Seal	24 x 0.0 * 556	$0.00
	Total Current Value of Bridge:	$6,223,000

Step 3: Determine the Network-level estimate value of the bridges

To obtain a network-level estimate of the value of its bridges, all the values of bridges in the entire network are added together. This value is called the health Index. It may be used as a summary for an entire network or circulated by districts to demonstrate whether the system is improving or deteriorating over time [Maze 00].

In summary, either method may be used to for tracking the value of infrastructure assets. The perpetual Inventory method is very simple and requires good inventory and financial information. The CalTrans method is a little more complex however, it is clear and more useful to decision makers because of its structured approach. It requires sound engineering judgment and experienced inspectors to assign values of condition state to assets and convert this information to a dollar value to estimate an agency's transportation infrastructure network [Maze 00].

4.4 EXAMPLE OF LIFE CYCLE COST ANALYSIS

The following example using data from the Long Term Pavement Performance (LTPP) Program, demonstrates the application of LCCA on two pavement sections. The state of Texas (*48-1048-1)* and the province of Ontario (*87-1680-1*) were selected for this example. Using section (*48-1048-1),* the example further exhibits the implementation of a sensitivity analysis to evaluate the influence of several discount rates on LCCA results which may be used by decision makers for deciding the best value within a project network.

4.4.1 (LCCA) Procedures: Case Study

This task will identify the procedural steps involved in conducting a life cycle cost analysis (LCCA) based upon recommended distress improvement strategies. The procedures include:

- Establish alternative pavement design strategies for the analysis period
- Determine performance periods and activity timing
- Estimate user cost
- Compute net present value
- Analyze results

Table 4.11 illustrates an example of maintenance and rehabilitation strategies and calculation of Cost-In-Service for sections *48-1048-1* and *87-1680-1*. An example Calculation of User Delay Cost, for Texas (***48-1048-1),*** is shown in Table 4.12. The costs are summarized in Canadian dollars.

To calculate Present Worth (PW) @ 15 Years

$$PW = \text{Rehab Cost (F)} \times (1+i)^n \tag{15}$$

Discount Factor (i) = 5%

$(1+5\%)^{15}$ @ 5% for 15 years = 0.4810

PW = (\$147,380.78) x (0.4810)

= <u>\$70,890.15</u>

To calculate Present Worth (PW) @ 30 Years

$PW = \text{Rehab Cost (F)} \times (1+5\%)^{30}$

Discount Factor (i) = 5%

$(1+i)^n$ @ 5% for 30 years = 0.2314

PW = (367,752.00) x (0.2314)

= <u>\$85,097.81</u>

Table 4. 11 Maintenance and Rehabilitation Strategies and Cost-In-Service Pavements

Functional Category (1)	Scheduled Rehab. Year (2)	Rehabilitation And Maintenance Treatment (3)	Quantity Per km (4)	Item Price (5)	Cost Per km (6) = (4) x (5)	Total Cost for Section Length = 1.6 km (7) = (6) x (1.6 km)
Texas (***48-1048-1***) Provincial Urban Freeway	15	Mill 80 mm Asphalt Pavement	1434 t	$10.00	$14,340.00	
		Resurface with HDBC - 40 mm	717 t	$41.93	$30,063.81	
		Resurface with OFC - 40 mm	717 t	$66.549	$47,709.18	
					$92,112.99	**$147,380.78**
	30	Full Depth Removal	4208 t	$10.00	$42,080.00	
		Replace New Asphalt –200 mm	349 t	$47.00	$164,077.00	
		Replace Granular A –150 mm	2520 t	$9.40	$23,688.00	
					$229,845.00	**$367,752.00**
Ontario (***87-1680-1***) Provincial Rural Collector	15	Full Depth Removal	1544 t	$10.00	$15,440.00	
		Replace New Asphalt –90 mm	1544 t	$41.52	$64,106.88	
		Replace Granular A –150 mm	2520 t	$9.10	$22,932.00	
					$102,478.88	**$163,966.21**
	30	Mill 40 mm Asphalt Pavement	686 t	$10.00	$6,860.00	
		Resurface with HL –4-40 mm	686 t	$41.52	$28,482.72	
					$35,342.72	**$56,548.35**
					Total Cost =	**$735,647.34**

Table 4. 12 Example Calculation of User Delay Cost, Functional Category Texas (*48-1048-1)*, In-Service Pavements

Functional Category (1)	**Scheduled Rehab. Year (2)**	**Treatment Type (3)**	**Rehabilitation And Maintenance (4)**	**Maint. & Rehab. Costs**		**Construction Time (Hours)[1] (7)**	**User Delay Cost[2]**	
				Actual (5)	**Present Worth (6)**		**Actual (8) =(7) x $39.38**	**Present Worth (9)= (8) x $(1+i)^n$**
Texas (48-1048-1) Provincial Urban Freeway	15	Rehabilitation	Mill 80 mm Asphalt Pavement Resurface with HDBC - 40 mm Resurface with OFC - 40 mm	$147,380.78	$70,890.15	50	$1,969.00	$947.08
	30	Reconstruction	Full Depth Removal Replace New Asphalt –200 mm Replace Granular A –150 mm	$367,752.00	$85,097.81	100	$3,938.00	$911.25
Total					**$155,987.96**			**$1,858.34**

Notes: [1] Expected Construction time per one Km of section per hour

[2] Based on hourly cost of traffic delay of $39.38 [Jerry 96]

4.4.2 Example of Economic Analysis for Pavement Design Alternatives

This section deals with the economic analysis needed if the best value within the project is to be achieved. LCCA is a form of economic analysis used to evaluate the long- term economic efficiency between alternative investment options. Economic analysis focuses on the relationship between cost, cost timing, and discount rates employed. Once all cost and their timing have been develop, future costs must be discounted to the base year and added to the initial cost to determine the net present value (NPV) for the LCCA alternative (LCCA in Pavement Design, 1998). The example below is based on a 35-year analysis period for section *48-1048-1 (Texas).* Two methods for calculating the NPV are shown below. The bottom line of Table 4.11 shows the NPV of the aggregated individual PVs**.**

Initial Cost =$500,000.00

Rehab # 1 = $147,381.00

Work Zone User Cost: Rehab. # 1 = $1,969.00

Rehab # 2 = $ 367,752.00

Work Zone User Cost: Rehab. # 2 = $3,938.00

Salvage Value = -$50439.59 {10/15 of (147,381.00 +367,752.00)/2}

Using LCC to calculate net present value (NPV)

<u>*Method 1*</u>

$$NPV = \text{Initial Cost} + \sum_{k=1}^{N} \text{RehabCost}_{\text{k}} \left[1/(1+i)^{n}\right] \tag{2}$$

Where i =discount rate

n = year of expenditure

Using i = 5%

n= 15 & 30

Initial Pavement design cost (P) = $500,000.00

Total Rehab Cost ($\sum$ F) = \$147,380.78 + \$367,752.00 (**Table 4.12**)

To calculate Net Present Value (NPV):

$(1+i)^n$ @ 5% at 15 years = 0.4810 x 147,380.78 = 70,890.15
$(1+i)^n$ @ 5% at 30 years = 0.2314 x 367,752.00 = 85,097.81

NPV = 500,000.00 + [\$70,890.15 + \$85,097.81]
=<u>\$655,987.81</u>

<u>Method 2</u>

Table 4. 13 NPV calculation using 5% discount rate factors

Cost Component Activity	Years	Costs	Discount Factor @ 5%	Discounted Cost (\$1,000)
Initial Construction	0	500,000	1.0000	500,000
Initial Work Zone User Cost	0	1,000	1.0000	1,000
Rehab # 1	15	147,381	0.48	70,742
Rehab # 1 Work Zone User Cost	15	1,969	0.48	945
Rehab # 2	30	367,752	0.2314	85,097
Rehab # 2 Work Zone User Cost	30	3,938	0.2314	911
Salvage Value	35	-50,439	0.1813	-9,144
Total NPV				**\$649,552**

Sensitivity Analysis for LCCA

Once completed, all LCCA should, at minimum, be subjected to a sensitivity analysis. Sensitivity analysis is a technique used to determine the influence on major LCCA input assumptions, projections, and estimates on LCCA results. The sensitivity analysis evaluate the influence of the discount rate used on LCCA results and will focus on best case worst scenarios in an attempt to bracket outcomes [US DOT 98] .

Table 4.14 and Table 4.15 present the results of a spreadsheet analysis of the sensitivity of NPV of two examples of the pavement design for section *48-1048-1 (Texas)*. The discount rate ranges from 2 to 6 percent for a 35-year analysis period. Total NPV at discount rates are shown at the bottom of columns (e) to (i).

Table 4. 14 Sensitivity Analysis – Alternative #1

Activity (a)	**Year** (b)	**Cost** ©	**NPV**				
			2.0% (e)	**3.0%** (f)	**4.0%** (g)	**5.0%** (h)	**6.0%** (I)
Construction	0	500,000	500,000	500,000	500,000	500,000	500,000
User Cost	0	1,000	1,000	1,000	1,000	1,000	1,000
Rehab # 1	15	147,381	109,504	94,604	81,841	70,890	61,502
User Cost # 1	15	1,969	1,463	1,264	1,093	947	822
Rehab # 2	30	367,752	203,036	151,514	113,378	85,245	64,026
User Cost # 2	30	3,938	2,174	1,622	1,214	913	686
Salvage Value	35	-50,440	-25,220	-17,926	-12,781	-9,145	-6,562
Total NPV			**791,957**	**732,078**	**685,745**	**649,850**	**621,473**

Table 4. 15 Sensitivity Analysis – Alternative #2

Activity (a)	**Year** (b)	**Cost** ©	**NPV**				
			2.0% (e)	**3.0%** (f)	**4.0%** (g)	**5.0%** (h)	**6.0%** (I)
Construction	0	400,000	400,000	400,000	400,000	400,000	400,000
User Cost	0	25,000	25,000	25,000	25,000	25,000	25,000
Rehab # 1	10	125,000	102,538	93,013	84,450	76,738	69,800
User Cost # 1	10	10,000	8,203	7,441	6,756	6,139	5,584
Rehab # 2	15	150,000	111,450	96,285	83,295	72,150	62,595
User Cost # 2	15	50,000	37,150	32,095	27,765	24,050	20,865
Rehab #3	30	250,000	138,025	103,000	77,075	57,950	43,525
User Cost # 3	30	30,000	16,563	12,360	9,249	6,954	5,223
Salvage Value	35	-101,667	-50,833	-36,132	-25,762	-18,432	-13,227
Total NPV			**788,095**	**733,061**	**687,828**	**650,548**	**619,365**

Alternative #1 has a higher agency cost and a longer construction period than Alternative #2. This results to a lower user cost than alternative #2. However, alternative #2 requires 3 design rehabilitation years compared to two design rehabilitation for Alternative #1.

User Cost for Alternative #1 increase over time due to traffic levels, where as user cost for Alternative #2 first decrease due to a shorter work zone period and then increase as a result of increased traffic levels over time.

Both alternatives have a remaining service life of five years at year 35. The salvage value, as a prorated share of the last rehabilitation, is 13.7 percent of its last rehabilitation cost for

Alternative #1 (13.7% of $367,752.00). The salvage value for Alternative #2, on the other hand is 40.6 percent of its last rehabilitation cost (40.6 % of 250,000).

Table 4.16 shows a direct comparison of the NPV of both alternatives at several discount rates. The table reveals the following:

- Both alternatives decrease as the discount rates increases.
- This results from the reduced present value of future cost at higher discount rates.
- Alternative # 1 is more expensive at 2%, and at 6% discount rate only, where as Alternative #2 is more expensive at 3%, 4% and 5% discount rate.
- Figure 4.4 also shows these results graphically.

Table 4. 16 Comparison of alternatives NPVs to discount rate

Activity	Discount Rate (%)				
	2.0%	**3.0%**	**4.0%**	**5.0%**	**6.0%**
Total NPV Alternative # 1	791,957	732,078	685,745	649,850	621,473
Total NPV Alternative # 2	788,095	733,061	687,828	650,548	619,365
Cost Advantage Alt #2 vs. #1	3,862	-983	-2,083	-698	2,108

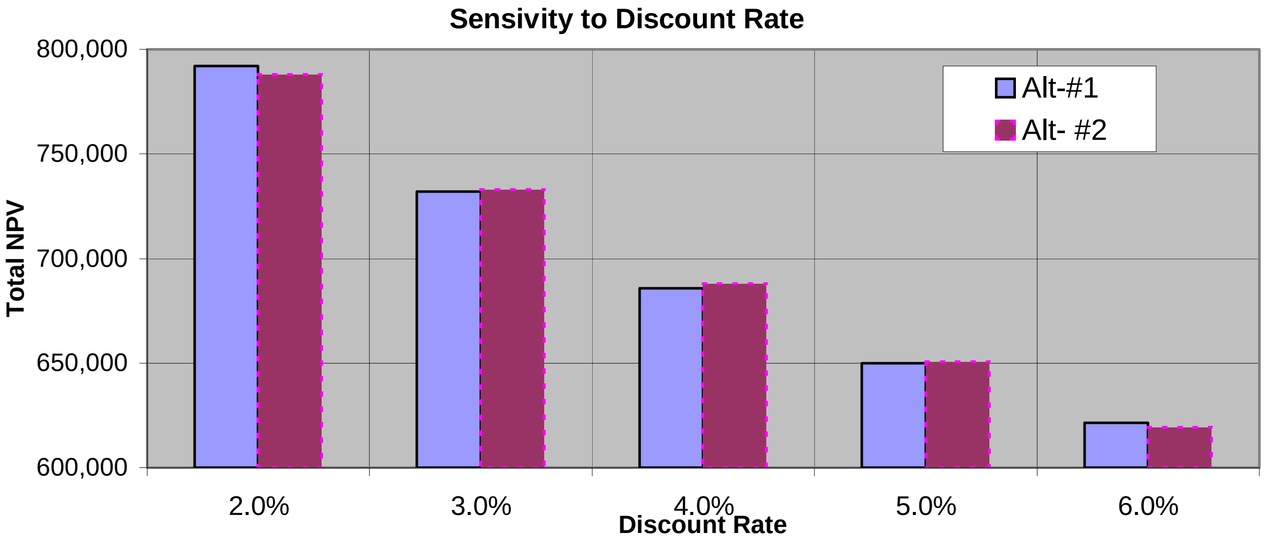


Figure 4. 4 Sensitivity of NPV to discount rate

4.5 COST EFFECTIVE EXAMPLE

This example analyses five sections of pavement in a network that have reached their minimum acceptable Riding Comfort Index (RCI) of 5.5. Characteristics of each section and the cost of the alternative rehabilitation treatment proposed for it are provided in Table 4.17 below. The Cost Effective (CE) method will help determine which sections should have the highest or lowest priority by ranking each section accordingly.

Table 4. 17 ***Section Data***

Sect. (A)	Cost of Rehab $ per km (B)	RCI after rehab (C)	Rate Deterioration (RCI Loss units per yr.) (D)	Sect. Lth (km) (E)	AADT (F)	Present Worth (G) = (B) x (E)	PQI(*R*) - *PQI(M)* (H) = (C) - 5.5	Life Term (Years) (I) = (H)/(D)
1	120,000	9.5	0.20	8	20,000	960000	4.0	20.0
2	95,000	9.0	0.25	9	30,000	855000	3.5	14.0
3	85,000	8.5	0.33	7	15,000	595000	3.0	9.1
4	62,000	8.3	0.40	8	9,000	496000	2.8	6.9
5	35,000	8.0	0.50	10	15,000	350000	2.5	5.0

For this data, the “Cost effectiveness” (CE) equation will be used to prioritize the sections from highest to lowest. This CE equation can be used as a guide for both qualitative and quantitative purposes such as comparing alternatives and for priority analysis (Pavement Design and Management Guide, 1997).

$$CE=\frac{\left[\sum_{Rehab\_Year}^{PQI_R \geq PQI_M}\left(PQI_R-PQI_M\right)-\left(\sum_{PQI_N \geq PQI_M}^{Rehab\_Year}\left(PQI_M-PQI_N\right)\right)\right]*\left[AADT\right]*\left[Length\_of\_Section\right]}{Present\ Worth\ of\ Cost} \tag{9}$$

Or in simplified terms:

$$CE=\frac{\left[\Sigma(\text{Area above } PQI_M)-\Sigma\ (\text{Area below } PQI_M)\right]*\left[AADT\right]*\left[\text{Length of Section}\right]}{Present\ Worth\ of\ Cost} \tag{10}$$

Where: PQI_R = Pavement Quality Index (PQI) after rehabilitation

PQI_M = Minimum acceptable level of PQI

PQI_N = yearly PQI from the needs year to the implementation year

Table 4. 18 ***Ranking based on Cost-Effectiveness of Each Section***

Section	Net Area Above 5.5 (J)=.5x(I)x(H)	CE K=(J)/(G)	Ranking
2	24.5	7.7	1
1	40.0	6.7	2
5	6.3	2.7	3
3	13.6	2.4	4
4	9.5	1.4	5

Conclusion: According to Table 4.18 Section 2 has the highest priority (CE = 7.7) and section 4 with the lowest priority (CE=1.4). This method of ranking may be used to select project in a network system or assist decision makers to allocate funds appropriately during budgeting.

4.6 REAL COST EXAMPLE

The real cost software calculates the life cycle cost of pavement design alternatives. It identifies the cost differences between design alternatives, accounting for both initial and future agency and user costs. The same level of service and performance is used for both alternatives. Traffic data inputs such as Annual Average Daily Traffic (AADT), capacity, hourly traffic distribution etc., are used for the analysis as illustrated in Table 4.19. Finally, the estimated cost of initial construction and future rehabilitation for the asset and the period of serviceability are entered (Table 4.20). The program then automates present value of agency and user cost for both alternatives (Table 4.21 and Figure 4.5).

Although, Alternative 1 and 2 begins with the same amount of initial construction costs of $231,064.00, the result from the analysis shows Alternative 2 with the lowest present value (PV) for both agency and user cost (Table 4.21 and Figure 4.5). For the agency cost, the higher PV of Alternative 1 may be the result of the initial construction service life of 15 years compared to 19 years for Alternative 2. Two factors that may have contributed to the higher user cost of Alternative 1 are as follows: 1) lower activity Service life for Alternative 1 (15 years) and 2), lower work zone speed limit of 30 mph (48 kmph) for Alternative 1.

The two pavement rehabilitation schedules used for this example (Alternative 1 and Alternative 2) those are illustrated in Appendix D. User cost data for passenger car ($17.00 per hour) and B/C trucks (-$ 31.50 per hour) were obtained from reference [ODOT 03]. The initial and rehabilitation cost data for Alternative 1 and 2 were obtained from [Hejek 96]. Rehabilitation treatments and activity service life were obtained from [TAC 97]. AADT data for urban minor arterial was assimilated from [Penn DOT 98]. All other traffic data used in this example were either assumed or calculated for the analysis.

Table 4. 19 Input Data Table 1

Input Data	Alternative 1	Alternative 2
User Cost Data		
Passenger Cars	$ 17.00 per hour	$ 17.00 per hour
B/C Trucks	$ 31.50 per hour	$ 31.50 per hour
Length of Work Zone	4.2 miles (6.79 km)	4.2 miles (6.79 km)
Work Zone Days	165	165
Analysis Options		
Traffic Direction	Both	Both
Analysis Period (years)	40	40
Beginning of analysis Period	2003	2003
Discount rate (%)	4.5	4.5
Traffic Data		
AADT Construction Year	2,100	2,100
Cars as % of AADT (%)	78	78
Single Unit Trucks as % of AADT (%)	7	7
Combination Trucks as % of AADT (%)	15	15
Annual Growth Rate (%)	3.2	3.2
Normal Speed Limit	70 mph (112 kmph)	70 mph (112 kmph)
No. of lanes in each direction	3	3
Free flow capacity	1982	1982
Rural/Urban Hourly Traffic Distribution	Urban	Urban
Queue Dissipation Capacity (vphpl)	1685	1685
Max AADT (Total for both directions)	7,197	7,197
Max Queue Length	0.3 miles (0.48 km)	0.3 miles (0.48 km)

Table 4. 20 Input Data Table 2

Input Data	Alternative 1	Alternative 2
Initial Construction		
Agency Construction Cost	$231,064.00	$231,063.81
User Work Zone Cost	$200.00	$300.00
No. Of Lanes Open	2	2
Activity Service Life (yrs)	15	19
Maint Frequency (Years)	2.5	2.5
Work Zone Speed Limit	30 miles (48 kmph)	40 miles (65 kmph)
Work Zone Capacity (vphpl)	1500	1500
Rehabilitation # 1	Mill 80mm Asphalt Pavement	Mill 80mm Asphalt Pavement
Agency Maintenance Cost	$20,721.00	$20,721.00
User Work Zone Cost	$20.00	$50.00
Activity Service Life (Years)	7	7
Rehabilitation # 2	Resurface with HL 1-80mm	Resurface with HL 1-80mm
Agency Maintenance Cost	$103,577.82	$103,578.00
User Work Zone Cost	$30.00	$300.00
Activity Service Life (yrs)	10	9
Rehabilitation # 3	Mill 40mm Asphalt Pavement	Mill 40mm Asphalt Pavement
Agency Maintenance Cost	$10,360.65	$10,361.00
User Work Zone Cost	$20.00	$50.00
Activity Service Life (Years)	6	6
Rehabilitation # 4	Resurface with HL 1-40mm	Resurface with HL 1-40mm
Agency Maintenance Cost	$51,788.91	$51,789.00
User Work Zone Cost	$30.00	$300.00
Activity Service Life (yrs)	6	6
Rehabilitation # 5	Resurface with HL 1-40mm	Cold In Place Recycle
Agency Maintenance Cost	$51,788.91	$41,125.00
User Work Zone Cost	$20.00	$50.00
Activity Service Life (Years)	6	7
Rehabilitation # 6	Resurface with HL 1-80mm	Resurface with HL 1-40mm
Agency Maintenance Cost	$103,577.82	$51,789.00
User Work Zone Cost	$30.00	$300.00
Activity Service Life (Years)	10	6

Table 4. 21 Summary of Results

Total Cost				
	Alternative 1:		**Alternative 2:**	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$728,260.44*	*$1,070.52*	*$728,260.81*	*$749.45*
Present Value	**$389,362.63**	**$443.04**	**$363,974.56**	**$302.42**
EUAC	$21,159.19	$24.08	$19,779.52	$16.43
Lowest Present Value Agency Cost		**Alternative 2:**		
Lowest Present Value User Cost		**Alternative 2:**		

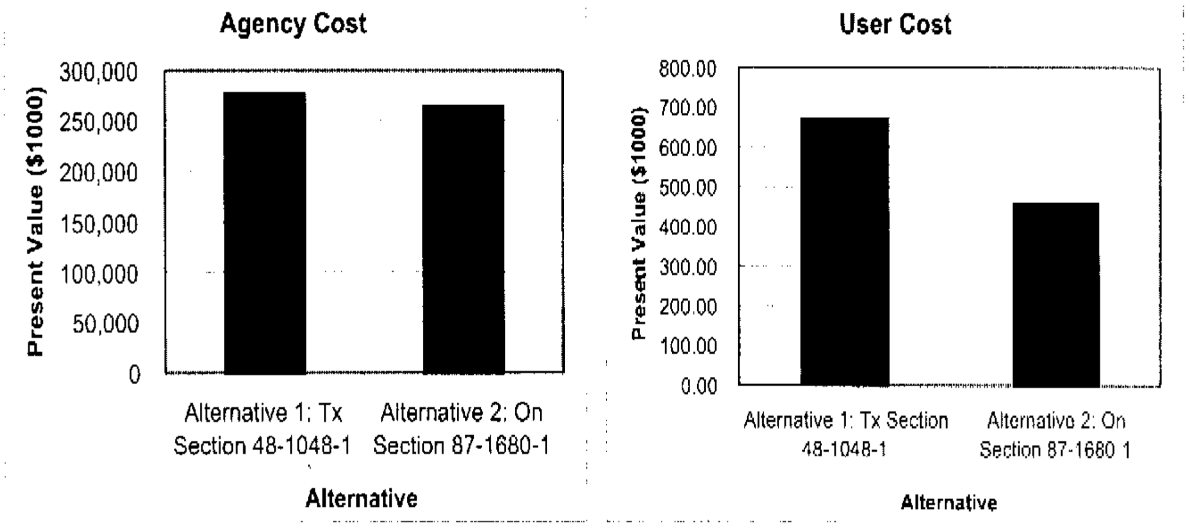


Figure 4. 5 Summary of Results for Alternative 1 and 2

CHAPTER 5. TOWARD A GENERIC PROTOCAL FOR LCCA

INTRODUCTION

In this section an attempt is made to fit the MTO business plan into a generic protocol for LCCA. From previous work carried out by Haas, Tighe and Cowe [Haas 01a], it can be seen that the overall framework for LCCA both at the network and project level can be applicable to most transportation agency business plans. The intent of having a generic protocol is to have it entirely applicable to all areas of various infrastructures. This course of action is not always simple and can sometimes be challenging. Customization of the framework may then become necessary for different infrastructure application because of differing condition, use, behavior etc. A few examples may include roads vs. buildings vs. recreational facilities vs. ……. other infrastructure elements [Haas 01]. In the following sections, a detailed step-by-step procedure toward a generic protocol for LCCA is generated starting from the network/system wide level towards the project or site- specific level.

5.1.1 Definition of Generic Protocol

Webster’s World Encyclopedia defines protocol as the rules, formality, etc. of any procedure, group etc [WWE 01]. Haas clearly defines the term as a set of rules or codes or procedures governing a process (originally related to diplomatic etiquette but now widely used in various fields) [Haas 01]. Since this course of action deals with the process of LCCA, the characteristics of MTO business plan will involve procedures and a set of rules that follows a general, consistent approach of the proposed plan.

5.1.2 Why or When Should LCCA be Carried Out?

Capital investments for infrastructure should be considered based on priorities reflected from the society, maintenance standards and the age of existing infrastructure. Identifying current/future needs or deficiencies and the budgets necessary to meet those needs are the key requirements in preserving and operating a safe infrastructure at the desired level of service. According to Haas, an "infrastructure gap" will most likely transpire whenever there is insufficient fund in the available budget [Haas 01a]. This results because it is not always easy to assume the precise need for infrastructure capital in the future. Hence, it can probably be assumed that, over the longer term, infrastructure has to be increased at least in proportion to growth in traffic, taking into account safety measures and regional development in addition to increase in capacity. For instance, as Ontario's economy and population grows, transportation infrastructure should expand proportionally to maintain the business economy of the province and also the quality of life for its residents.

As discussed in previous chapters, LCCA is a tool used to assist decision makers. This is a fundamental tool particularly for investors and decision makers. It is used to predict beforehand the return of an investment, to make necessary adjustments and also to avoid or minimized major investment mistakes. Accordingly, LCCA does not solve any infrastructure gap, as such, but it can be used to achieve the best value for available funds and/or to maximize the cost-effectiveness of those funds [Haas 01]. For instance, budgeted funds may have to be reallocated or adjusted according to LCCA results. Computation of LCCA may be used differently in the private and public industry. When employed in the public sector, best value or maximization of cost effectiveness is preferred, conversely, when used in the private sector, a desired rate of return is favored, clearly defining and considering liabilities such as environmental cleanups, outstanding debts, etc.

LCCA may not be needed for the reasons or situation that follows:

(a) The project or work to be carried out is of such size that a straightforward cost estimate is all that is warranted. For example, LCCA is not necessary when agencies set threshold levels of amount of work or value below LCCA.

(b) Only one feasible treatment or alternative is available and it is applied on a regularly scheduled basis. This is straight forward particularly where costs and procedures are consistent and on a regularly basis.

(c) A multi-year spreadsheet of scheduled expenses for repair/renovation/operation is an alternative. For example, schedules of expenses can be in the form of a spreadsheet and major repair expenditures can be managed from reserved funds. As damages occur and repairs become necessary, these funds are used to alleviate the problems.

5.1.3 Difference Between LCCA and Financial Planning

Basically, the main difference between LCCA and Financial Planning is that financial planning is fundamentally concerned with estimating revenues over some forecasting period and programming cost outlays through that period, whereas LCCA is used to compare the alternative uses of funds or expenditures. From a corporate or individual's perspective, Financial Planning may also include borrowing with expectations of profit on interest rates. [Haas 01a].

In reality, Financial Planning is an activity that any organization, private or public, practices by establishing a plan to achieve specified financial goals. Some of these goals may relate to staying out of debt, retirement, investment allocation, real estate purchases etc., and can either be short or long-term in nature. Life Cycle Cost Analysis then can assist in making decisions as to the best use of the available funds or budgets, usually by comparing alternatives within a defined need. LCCA can also be used as feedback to update financial plans and targets over time [Haas 01a].

5.1.4 What LCCA Can and Cannot Do

Life Cycle Cost Analysis can identify alternatives representing the lowest cost, most cost-effective, highest benefit to cost ratio or highest internal rate of return. For this purpose, it is an important tool in supporting decisions. Particularly in the case of Present Worth (PW) analysis, it compares alternatives in present day dollars.

LCCA cannot, however, answer questions of equity involving social, political and other considerations. One of its objectives is to achieve a fair allocation of funds or budgets among competing infrastructure elements. This is not always simple and may sometime require tradeoffs, lobbying, give-and-take between the stakeholders or a multi-dimensional set of criteria or factors. Many of these criteria's or factors however, are either not readily quantifiable and/or involve different measures for different infrastructure elements. In any case, even if a set of criteria or factors is agreed upon, they still require prioritization or consideration on the degree of importance.   Again, this is where LCCA becomes an applicable assistant tool.

The abovementioned may not be applicable to all infrastructures however. However, infrastructures operating as utilities such as water, power, natural gas and telephone would be exceptions in that they generate their own revenue streams and accordingly are able to develop their own budgets [Haas 01a].

5.2 STAKEHOLDERS FOR LCCA

Basically, the MTO stakeholders concerned with its infrastructure strategy would also be stakeholders in any LCCA. However, they may vary in various degrees, expectations, perceptions and requirements. Stakeholders are conveniently classified as follows [Haas 01a]:

A. City

1. Public at large
2. Elected level (Council)
3. Senior administration
4. Technical/operating level

B. Directly and Indirectly Concerned

1. Province (Ministry of Transportation, Ministry of Municipal Affairs, Provincial Treasurer)
2. Associations/Organizations, (Architects, Road Builders, Planners, Consulting Engineers, Federation of Community Leagues, Economic Development, etc.)
3. Academic (Dept. of Civil and Environmental Engineering)

A list of some of the expectations/perceptions/requirements applicable to each class of stakeholders is presented in Table 3.1. In this section, Table 5.1 focuses on LCCA with the stakeholders' expectations/perceptions/requirements extending well beyond LCCA itself and can range from the strategic to localized detail.

Stakeholders may sometimes have false impressions or hypo report on actual function and purpose of LCCA. Haas, Tighe and Cowe meticulously outline some of the misconceptions about LCCA that may be embraced by Stakeholders and they are as follows [Haas 01a]:

1. LCCA can resolve equity among competing infrastructure elements. As discussed in the previous section, this is not correct.

2. LCCA can result in distortions of budgets from one exercise to the next. In fact, LCCA is generally used under a scenario of planned budgets and of course these budgets are a function of revenues and needs. This is not to say, however, that a role of LCCA is to explore “what if” scenarios of different budget levels.
3. LCCA is a guessing game because of large uncertainties in forecasts of costs, predictions of condition or performance, expected budgets, etc. While these uncertainties exist, they are not reasons for not carrying out LCCA as good business practice (e.g., due diligence as previously noted). Moreover, even with uncertainties, there is a better chance of identifying and implementing the most cost-effective strategies than simply using judgement.
4. LCCA is a substitute for the responsibility of making decisions. In fact, however, the role of LCCA is to support or enhance decision-making.

5. LCCA may be able to identify the most cost-effective strategies but politics will prevail. While politicians have the ultimate responsibility of answering to the electorate, many politicians actually welcome LCCA as they can say the selected strategies are based on a fair (objective) competition for limited available funds. This does not, of course, remove the need to consider non- quantifiable factors in making a decision.

Table 5. 1 Some Expectations/Perceptions from LCCA Applicable To Various Stakeholders [Haas 01a]

Stakeholders	Expectations/Perceptions/Requirements
A. City	
1. Public at large	• Overall expectation that allocated budgets are being used as cost-effectively as possible • Periodic reports on condition and spending on various infrastructure elements
2. Elected level	• Justification that most cost-effective strategies are being implemented for various infrastructure elements • Reports on condition of infrastructure (past and current) vs. budgets • Future effects on condition of infrastructure for different budget levels (under scenario of LCCA being able to identify most cost-effective strategies) • Provides real or perceived accountability
3. Senior administration	• Clear role of LCCA in management of the City's infrastructure assets • Same justification as to most cost-effective strategies in A2. above • Same reports on condition vs. budgets (A2. above) plus amount of infrastructure below minimum acceptable level of service • Same reports on future condition of infrastructure (A2. Above) for different budget levels. • Assist in monitoring policy effectiveness
4. Technical/Operating level	• Data base for use in LCCA • Protocol for LCCA and validation/quality assurance procedures • Definitions of level of service for each infrastructure element, and minimum acceptable levels for various functional classes or components • Models for predicting future condition or performance • Procedures for communicating LCCA results to above levels • Diagnostic tool • Overall improvement in management • Provides guidance on short and long term goals
B. Directly and Indirectly Concerned	
1. Province	• Same as public at large and elected level but with more detailed reports
2. Associations/Organizations	• Generally, same as public at large but with more frequent access to and input for strategic planning as a whole, and LCCA's role
3. Academic	• Varying requirements covering all foregoing elements but dependent largely on individuals or groups involved and their interests

5.3 LCCA WITHIN THE CORPORATE BUSINESS PLAN

According to the MTO "Message from the Minister," thousands of businesses rely on the province's roads and highway to move more than $1.2 trillion worth of goods to domestic and international markets annually [MTO 03]. To keep goods moving safely and efficiently throughout the region, the Ministry of Transportation through their corporate vision, mission and goals has prepared a 2002-2003 Business Plan. The business plan outlines a summary of the ministry's scope of activities and directions for the future including the challenge to incorporate safe, efficient and seamless integrated transportation system throughout the province. Accordingly, since millions of people rely on the provinces' transit system, the ministry's fundamental goal is to continue promoting the province quality of life by investing in its transportation infrastructure. Through SuperBuild, $10 Billion will be invested over 10 years for highways and $3.25 Billion allocated for transit.

The MTO overseas the maintenance and operation of 16,500 kilometers of highways; 2,500 bridges/structures; 29 remote airports and eight ferry services [MTO 03]. MTO is also responsible for developing highway engineering, construction and maintenance policies, standards and infrastructure management systems. A generic protocol for LCCA for the aforementioned infrastructures is very much appropriate and applicable in terms of prioritizing projects and allocation of budget funds.

Figure 5.1 below outlines a framework of MTO's Business Plan and incorporates input from financial forecasts, public and private sectors, funding targets etc. Those inputs are used to develop the major strategies towards the protocol and must also fit within the overall budget of the agency. A summary of the operating and capital budget is shown in Figure 5.2.

The new LCCA protocol must fit within the existing process in order to be supported and sustained by the current practice and also for the long- term process. Consequently, this fit should include considerations of acceptability, usefulness, practicality and understandability according to Haas [Haas 01a].

5.4 LCCA GENERIC PROTOCOL: Network/System Wide Level

Figure 5.1 illustrates the strategic framework of MTO’s Corporate Business Plan and provides the context for an LCCA generic protocol at the network or system wide level. Figure 5.3 on the other hand, demonstrates that context at the strategic level (top portion of the Figure) following the identification of the major steps involved in the LCCA generic protocol. In accordance with previous work, the context of this summarized framework can work well with any infrastructure element or part of any comprehensive infrastructure management system.

The top portion of the framework, the strategic level, represents the budget planning process where all public input, ongoing monitoring of infrastructure assets, forecasting etc. takes place. Other issues such as preparation of department needs, cost estimates, budget requests and priorities may also be considered at that level.   All together, this level of planning prepares the entire network for the LCCA, which is necessary before the LCCA protocol can be implemented.

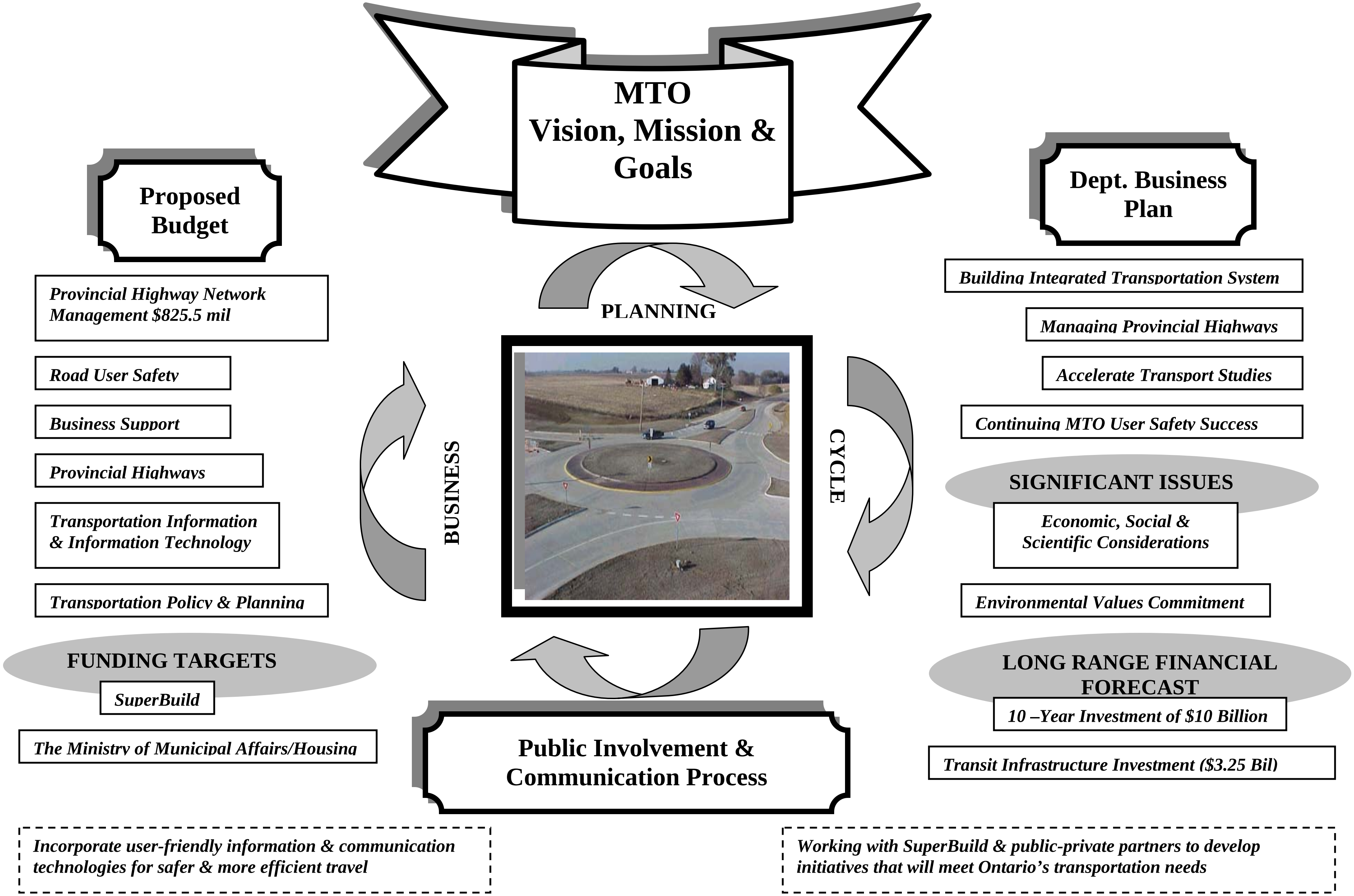


Figure 5. 1 Strategic Framework for Ministry of Transportation (MTO) Business Plan

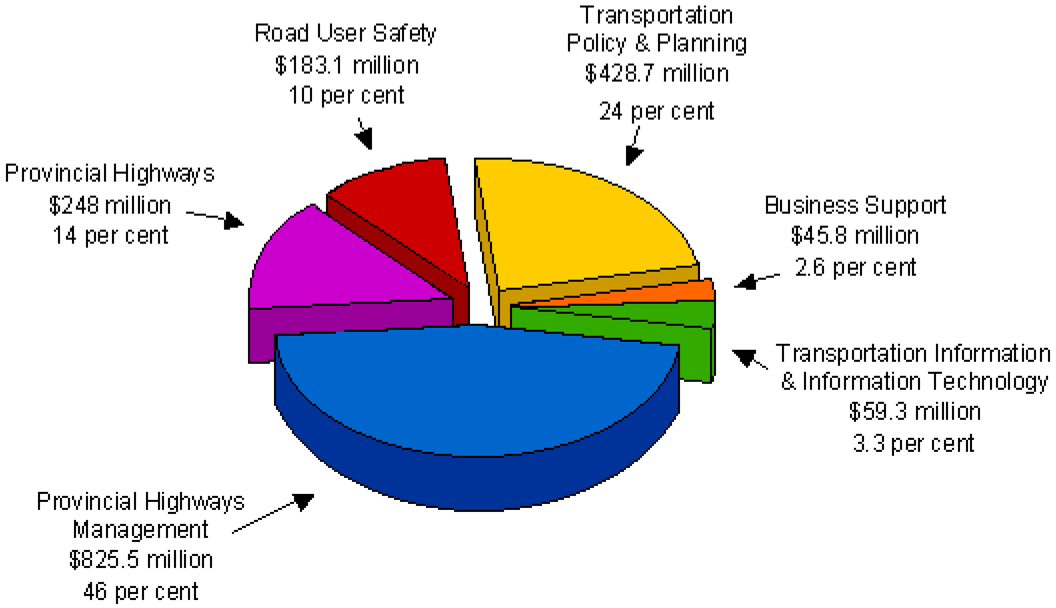


Figure 5. 2 Overall Summary of Operating & Capital Budget [MTO 03]

After this stage, it is important to “fine-tune” the LCCA of specific portions of projects, section, or area to determine the overall most cost-effective set of alternatives from the network/system wide application of LCCA.

Since Figure 5.3 is applicable to any infrastructure as previously stated, the generic protocol is therefore considered “infrastructure blind” [Haas 01a], nevertheless, the characteristics in the steps of Figure 5.3 may vary with infrastructure element. Such factors may include details, availability of models or estimates, uncertainties, methods of determining needs, measures of conditions, level of service (LOS), effectiveness, utilization etc. Ultimately, regardless of the framework application to each infrastructure element, the LCCA results should provide the best value for the available funds and LCCA benefits for any agency.

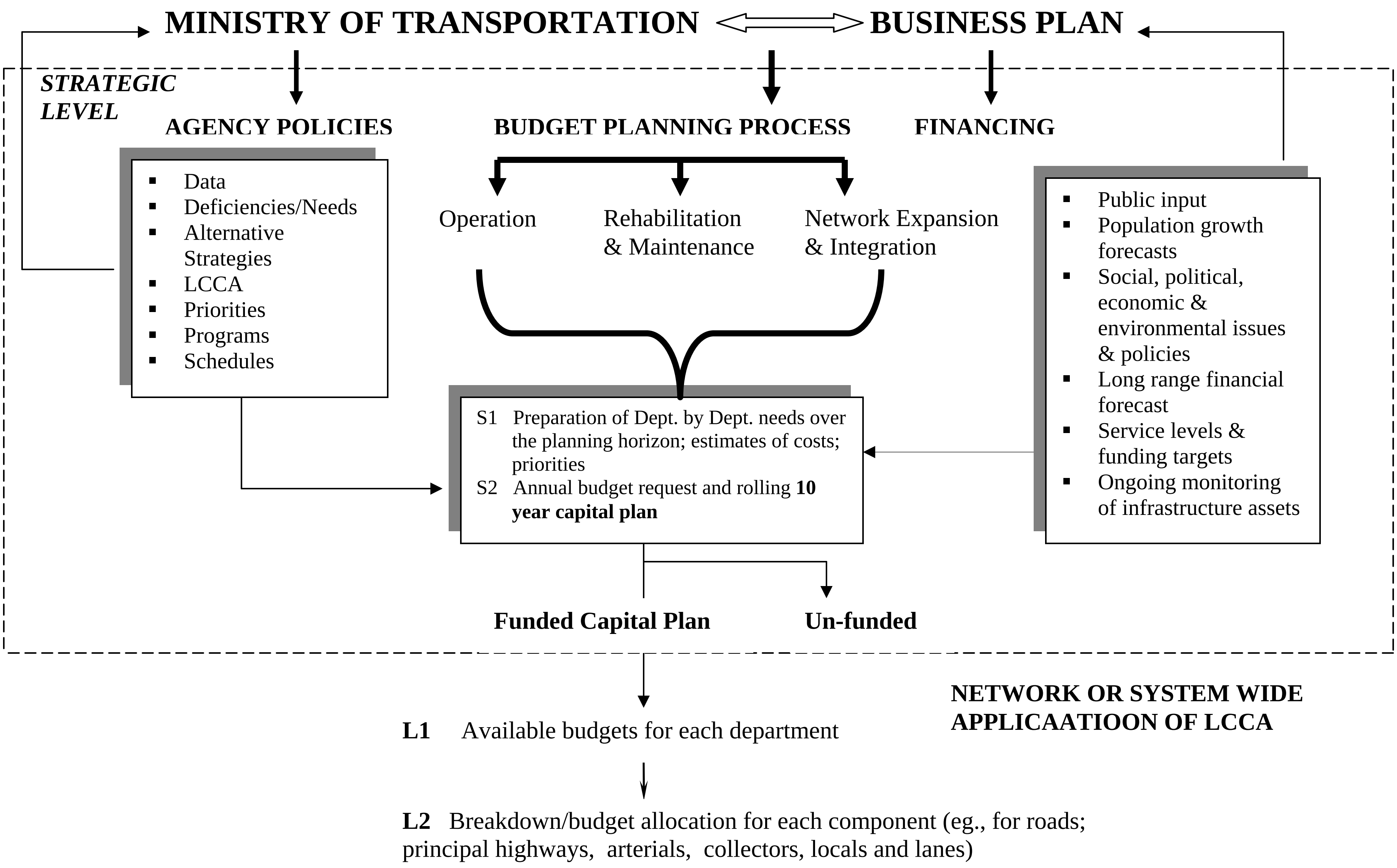
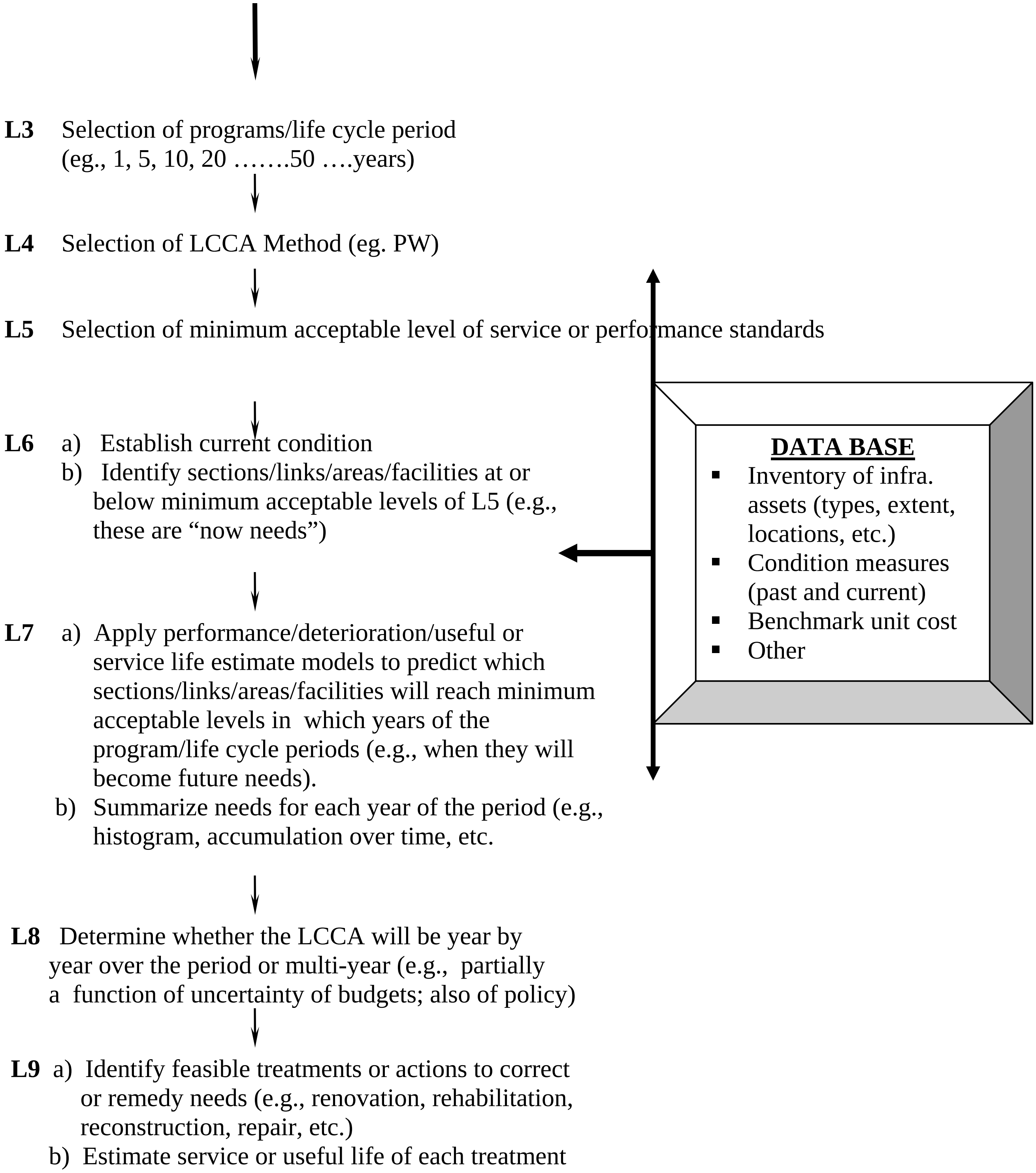


Figure 5. 3 Major Steps in LCCA Generic Protocol at the Network or System Wide Level



L3 Selection of programs/life cycle period (eg., 1, 5, 10, 20 …….50 ….years)

L4 Selection of LCCA Method (eg. PW)

L5 Selection of minimum acceptable level of service or performance standards

L6 a) Establish current condition
b) Identify sections/links/areas/facilities at or below minimum acceptable levels of L5 (e.g., these are "now needs")

L7 a) Apply performance/deterioration/useful or service life estimate models to predict which sections/links/areas/facilities will reach minimum acceptable levels in which years of the program/life cycle periods (e.g., when they will become future needs).
b) Summarize needs for each year of the period (e.g., histogram, accumulation over time, etc.

L8 Determine whether the LCCA will be year by year over the period or multi-year (e.g., partially a function of uncertainty of budgets; also of policy)

L9 a) Identify feasible treatments or actions to correct or remedy needs (e.g., renovation, rehabilitation, reconstruction, repair, etc.)
b) Estimate service or useful life of each treatment

DATA BASE

- Inventory of infra. assets (types, extent, locations, etc.)
- Condition measures (past and current)
- Benchmark unit cost
- Other

Figure 5.3 Continued

L10 Establish measures of effectiveness or utilization of the infrastructure asset (e.g., area under condition vs. age curve x number of users; number of users of facility per day, month, year; volume of throughput per day, month, year; number of calls or responses per day, month, year ------ these are functions of the infrastructure component involved)

L11 a) Select discount rate (this may be a function of policy)
  b) Calculate costs and reduce to PW of each combination of treatment ↔ section / link / area / facility ↔ needs year; including operating or maintenance costs if applicable and reduce to PW
  c) Calculate the effectiveness or utilization of each combination in b) and divide by the PW of costs (this provides a C/E ratio)
  d) Rank each of c) from highest to lowest C/E ratio

L12 a) If budget is year by year, start in Year 1 and assign that year’s cost to each combination, in rank order, which is a “now need”
  b) When the budget is used up, remaining combinations will have to be deferred to Year 2 (e.g., they are added to the backlog of needs, or the gap)

L13 Repeat L12 for Year 2’s budget, considering the deferred needs from Year 1. Again, remaining combinations, including possibly some from Year 1, will have to be deferred to Year 3, and so on

Figure 5.3 Continued

L12; L13 Alternate: If a multi-year analysis is desired (see L8), then each combination of L11 b) is also analyzed for effectiveness or utilization before its needs year (1 or more years before) and after its needs year (up to the end of the program period). This adds another dimension to the combinations (e.g, treatment ↔ section / link / area / facility ↔ action years) and requires an optimization procedure to determine the overall most cost-effective program

L14 Prepare a recommended year by year by infrastructure component program of work (renovations / rehabilitations, reconstruction, repairs which are applicable to the component)

Program approvals and / or modifications (where modifications can be due to considerations other that LCCA; eg., political or administrative overrides, fitting with other planned or ongoing infrastructure projects, such as sewer reconstruction, etc.)

Transfer to Design and Construction for project or section or site specific detailed design and LCCA*****, calling of tenders, actual construction / installation / building, QC / QA, final delivery and identification of any budget surplus or cost overrun.

*****See Figure. 5.4

Figure 5.3 Continued

The following illustrates an amplification of the steps in Figure 5.3 in accordance to MTO's business plan.

L1 **Available budgets for each Department**.

As shown in Figure 5.2, the overall budget is divided among six sectors within the ministry's core business. According to MTO's business plan, and investment of $10 billion in highway capital is considered over a 10-year period, $3.25 billion of which to renew, expand and integrate Ontario's municipal and inter-regional transit infrastructure including GO transit. The actual budget approval is annual, with a 10-year capital-funding plan. The ministry is also seeking matching municipal and federal contribution for their mission.

According to LCCA recommendations, any year one (1) program maybe under budgeted when the actual implementation occurs or it may be over budget. Consequently, projects initially falling below the budget cut-off line may be added for an under budget situation whereas the lowest ranked projects would be deferred to following years for an over budget situation. It is also important to note that the LCCA will always be carried out with a defined budget limit. In addition, LCCA may also be implemented to determine the budget required (in what is termed a "cost minimization mode") to meet certain levels of service or performance targets but this alternative is not covered in the steps for this protocol. According to Haas, this option has the advantage of directly seeing directly the budget implications of varying levels of service or performance targets [Haas 01a].

L2 **Breakdown/budget allocation for each component**:

This step represents a within-Department exercise that may be influenced by both internal priorities and external factors. As seen in Figure 5.2, Provincial Highway Management department has the highest portion of funds with $825.5 million representing 46% of the overall operating and capital cost. On the other hand, Business Support Department represents the least with only $45.8 million, a 26%

of the overall. Within the Ministry's core business, Provincial Highway Management encompasses the highest percentage of capital because it is viewed as top priority within the agency. Within that department alone, a supplementary breakdown of infrastructure assets may exist and at least some threshold allocation of budget must be made to infrastructures such as collectors, local roads, noise barriers, road signs etc. LCCA can be applied to these sub-networks individually rather than the entire network as a whole. Other infrastructure elements, such as parkland infrastructure, recreational facilities, drainage, etc. can also be broken down into sub-systems of infrastructure elements and LCCA applied as previously mentioned. In this step, budget priorities and allocation of funds can easily be seen with the application of LCCA for each component.

L3 Selection of program/life cycle period:

Since each infrastructure element is different, the selection of programs and life cycle period may vary widely. The life cycle period of technological equipment for example, may be shorter than the life cycle period of an infrastructure asset such as a noise barrier or a pavement section. Program period and life cycle period may be different for programs such as pavement rehabilitation where the program period may be as short as 5 to 10 years and the life cycle period for the analysis say 20 to 50 years. The program period in that case refers to the years in which designated projects/sections/areas/facilities are to undergo rehabilitation (e.g., a year by year list), but the life cycle period refers to the total years over which costs are estimated and then discounted back to present worth.

Appendix B and Appendix C of this report illustrates typical useful lives of infrastructure assets, which can be used as a guide in performing the life cycle costing of infrastructure elements. Other sources that can be useful include guidelines from the American Society of Testing Materials (ASTM), Illuminating Engineering Society of North America etc [Fickes 02, GASB 01, S of W 97].

L4 Selection of LCCA method

As discussed earlier in Chapter 2, the Present Worth Method (PW) remains the best general method of analysis for infrastructure assets taking into account, separately or in combination, the factors and parameters discussed in the previous section for life cycle cost analysis. This method can be used for costs, or benefits, or benefits minus costs (i.e. the Net Present Worth, Present Worth of Cost "PWC" or Net Present Value "NPV" method). The PW method should therefore be applicable for most of MTO's infrastructure elements.

Life cycle cost analysis should always be sufficiently long enough to reflect long-term cost differences associated with reasonable design strategies. The Federal Highway Administration (FHWA) recommends an analysis period of at least 35 years [Walls 98]. MTO uses 20 to 30 years, 20 years for rehabilitation and 30 years for new construction [MTO 90]. Generally, the life of concrete pavement is more than 20 years, while the life of asphalt pavement is around 10 years.

For infrastructure elements having longer life cycle periods, the LCCA should be applicable for the first 30 or 40 years. In such cases, a schedule of repair/renovation/rehabilitation etc. should be established for the life span of the infrastructure but the LCCA applied only for the first 30 or 40 years. Example of such infrastructures may include buildings, drainage, parklands and recreational facilities.

Although periods of 20 and 40 years has been chosen by most transportation studies as a considerable reasonable range, a 30 or 35 year analysis is more reasonable because of all the uncertainties associated with forecasting performance of rehabilitation treatments. Equally important, discounted rate beyond the period of 30 or 40 years generally does not contribute significantly to the total present worth of the system unless very low discount rate is used. In contrast, if a high discount rate is selected, say about 10%, the above 30 to 40 years reduces to about 20 years [Haas 01a]. The selection of an appropriate discount rate is therefore essential in LCCA.

In LCCA, the discount rate determines the relative importance of future costs and benefits associated with an investment alternative versus its initial cost. A high discount rate for instance, places emphasis on the initial cost while a low discount rate places emphasis on future costs and benefits. Ideally, the discount rate used will provide a reasonable balance between initial and future costs. Many sources agree that the criteria for selecting an appropriate discount rate should be based on the long term real return on money. Although a discount rate of 4% is commonly used in LCCA, discount rates can also be a policy decision by authorities within an agency or department.

Furthermore, a sensitivity analysis of the effect of different discount rates on the LCCA is often necessary and reasonable (e.g., plus or minus some percentages from the selected rate). Small percentage changes sometimes indicate that an originally lowest cost alternative now is replaced by another alternative (a good example is the competition between asphalt and concrete pavement on high volume facilities). Sensitivity analysis may also be necessary for other factors in the LCCA; e.g., the effect of varying the minimum level of service [Haas 01a].

L5 Selection of minimum acceptable levels of service or performance standards: Selection of a minimum acceptable level of service and performance standards should be appropriately established or identified at the network level. This is important especially for the development and improvement of performance prediction models from ongoing, in-service monitoring and historical data of the infrastructure. Measures of levels of service can be either discrete or continuous. Example of a discrete measure may be A to E where A represents excellent condition and E representing very poor condition. A continuous measure can be the International Roughness Index (IRI), which is used extensively on pavement evaluations. The selection of a minimum acceptable level is then a function of the component involved (e.g., a local street would have a higher IRI than a collector), the judgment of staff and/or stakeholder input, and economics (e.g., lower budgets might mean lower minimum acceptable levels). The Highway Design and Maintenance Standards Model (HDM-4) developed by the World Bank also classifies ride quality according to classes or roads and can be used as a guide for IRI ratings on pavements.

L6 (a) Establish current condition.

A set of procedures should be set-up to allow real-time updating of facilities condition data. This should be a periodic process of monitoring or inspection of each component in each infrastructure element and should be entered into an integrated database. This process is carried out so that current condition and trends can be identified or analyzed. Performance prediction models can be developed or improved from current conditions and most importantly, estimates of future performance or change in condition of the infrastructure.

(b) Identify sections/links/areas/facilities at or below the minimum acceptable levels of service.

Inspectors will compare the facility's existing deficiency report file against discrepancies observed and update the list of deficiencies. Obviously those at or below the minimum represent current or "now needs" and should receive attention. However, except where public safety or essential service presents an override, budget constraints invariably mean that some needs, will have to be deferred, based on priorities (see **L12** and **L13**).

L7 a) Apply models (performance/deterioration/useful or service life estimate related) to predict which sections/links/areas/facilities will reach minimum acceptable levels in which years.

This is over the program/life cycle period and provides a listing of year by year future needs.

b) Summarize needs for each year.

While lists of needs are necessary at the operating level, it is particularly useful to summarize these needs in bar chart or histogram form for senior administrators, elected level and the public at large.

L8 Determine whether the LCCA will be year by year or multi year.

Since budget approval is annual for MTO, the LCCA would have to be on a year to year basis. However, because there is a rolling 10-year capital funding plan for information, the LCCA can also be carried out for a 10-year program, with an update each year.

L9 a) Identify feasible treatments or actions to address needs.

In some cases, such as for pavements, a number of such treatments may be feasible for each needs section (e.g., thin, medium or thick overlay, "mill and fill", etc.). For other infrastructure components, only a specific treatment may be feasible (e.g., for a built-up roof of a building, replacement might be the only feasible treatment); moreover, it may make sense to specify a replacement or repair schedule over the life cycle (e.g., for buildings, this could include windows, doors, siding, roofs, etc.).

b) Estimate service or useful life of each treatment.

In the specified repair schedule of a) above, this would be the time intervals (e.g., an asphalt shingle replacement schedule might be for this to be carried out every 15 years). In the case where more than one treatment alternative exists (e.g., asphalt shingle replacement vs. cedar shake shingle replacement), it is important to estimate the service life of each, for the LCCA.

L10 Establish measures of effectiveness or utilization.

This concept is used mainly for prioritization in some areas of infrastructure. The Cost-Effective (CE) equation may be used as a guide for both qualitative and quantitative purposes such as comparing alternatives and for priority analysis.

CE method can be a very useful way of achieving priorities within a fixed budget when it is combined with LCCA (see **L11** below). Effectiveness can be defined as:

(i) The area under the curve of condition vs. age multiplied by number of users, or
(ii) Number of users of a facility per unit of time, or
(iii) Number of service interruptions per unit of time, or
(iv) Number of responses to public queries per unit of time, etc.

In the case of (i), larger numbers represent a higher degree of effectiveness; the same applies for (ii). However, for (iii) larger numbers represent a lower level of effectiveness.

L11 a) Select discount rate:

This was previously discussed in **L4** since it is a part of the PW method of LCCA. It is noted in **L11** however, because this step covers the actual calculations of the LCCA itself.

b) Calculate costs and reduce to PW of each combination treatment ↔ section/link/ area/facility ↔ needs year. Any maintenance or operating costs, if applicable, should also be reduced to PW. The calculation of costs can range from an overall estimate (e.g., replacing a swimming pool liner) to a fairly time-consuming calculation where benchmark unit costs have to be assigned to a number of component quantities in the treatment alternative.

c) Calculate the effectiveness or utilization of each combination in **b)** and divide by the PW of costs. While this is an “apples divided by oranges” type of thing, the resulting cost-effectiveness (C/E) ratio represents a consistent means of comparison (within an infrastructure component).

d) Rank each of **c)** from highest to lowest C/E ratio by needs year. The highest ranking would represent the highest priority, and so on.

L12 a) If the budget is year by year, start in Year 1 and assign that year’s cost, in the rank order of **L11d)** to the needs list of that year.

b) When the budget is exhausted, the combinations in the list above the budget line should be recommended for action. Any below the budget line will have to be deferred to Year 2 and thus added to the backlog of needs. It should be noted that those falling below the budget line will not necessarily be funded in Year 2; e.g., the needs of that year may have higher C/E ratios, and thus another year of deferral occurs. However, on a rolling year by year update of the LCCA, deferrals may start to incur excessive maintenance costs and thus move up in the priority list.

L13 Repeat L12 for Year 2's budget, and so on.

L12 & L13 Alternative:

A multi-year analysis can also be carried out where the needs year is a starting point and different possible action or implementation years (before and after the needs year) are added to the combinations. This type of analysis can produce an overall optimization but it is more complex and requires an optimization algorithm (such as linear or dynamic programming) or a near optimization algorithm (involving marginal cost-effectiveness analysis).

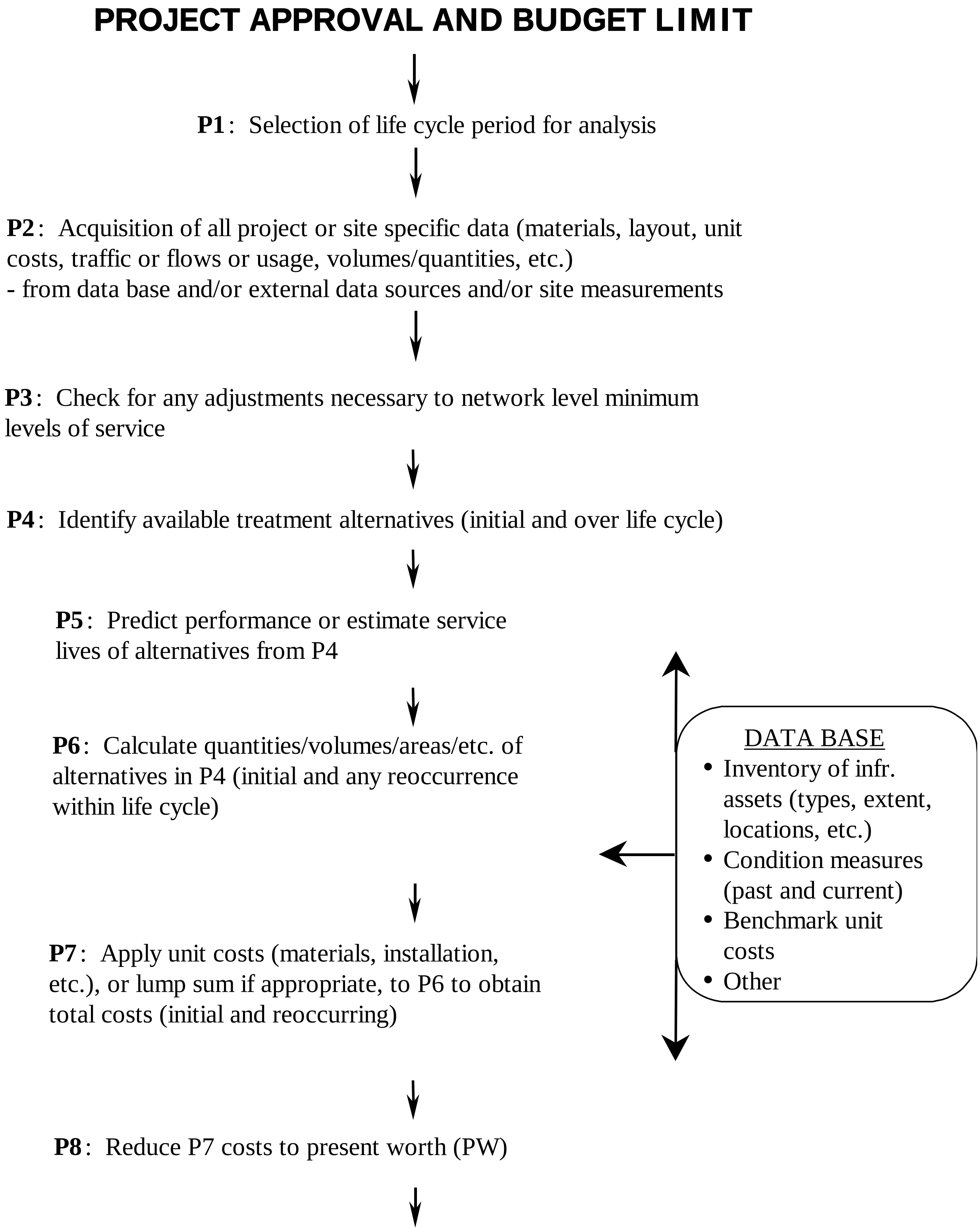
L14 Prepare a recommended year by year by infrastructure component program of work.

This may be modified by committed projects or overrides due to reasons other than the LCCA itself. For example, a planned sewer reconstruction in Year 3 may well indicate that a street resurfacing scheduled for Year 2 or 3 should be deferred to Year 4.

Following the Network LCCA and program approval, the next step is to transfer it to design and construction for implementation. Some of the various activities involve section or site-specific detailed design and LCCA, calling of tenders, actual construction/installation/ building, QC/QA, final delivery and identification of any budget surplus or cost overrun. The LCCA at the detailed level is essentially a fine-tuning of projects coming on line from the network based program. Accordingly, there are projects funded and/or identified and/or committed from outside the capital plan. These would come largely from network expansion or new infrastructure according to Haas. However, project level LCCA is equally applicable to this other funding stream [Haas 01a]. The next section describes the basic steps of a project level LCCA.

5.5 LCCA Generic Protocol: Project or Site Specific Level

The primary purpose of the project level is to physically implement the network level decisions. That also involves development of engineering standards, policies and guidelines for design, construction, operation and rehabilitation. The project level LCCA protocol starts with the assumption that a project has either been approved or is being considered for approval, as shown in Figure 5.4. In other words, funding has been allocated, or is awaiting approval, and the function of the LCCA is to identify the best design, construction/installation and operating/maintenance alternative for the project.



PROJECT APPROVAL AND BUDGET LIMIT

P1: Selection of life cycle period for analysis

P2: Acquisition of all project or site specific data (materials, layout, unit costs, traffic or flows or usage, volumes/quantities, etc.)
- from data base and/or external data sources and/or site measurements

P3: Check for any adjustments necessary to network level minimum levels of service

P4: Identify available treatment alternatives (initial and over life cycle)

P5: Predict performance or estimate service lives of alternatives from P4

P6: Calculate quantities/volumes/areas/etc. of alternatives in P4 (initial and any reoccurrence within life cycle)

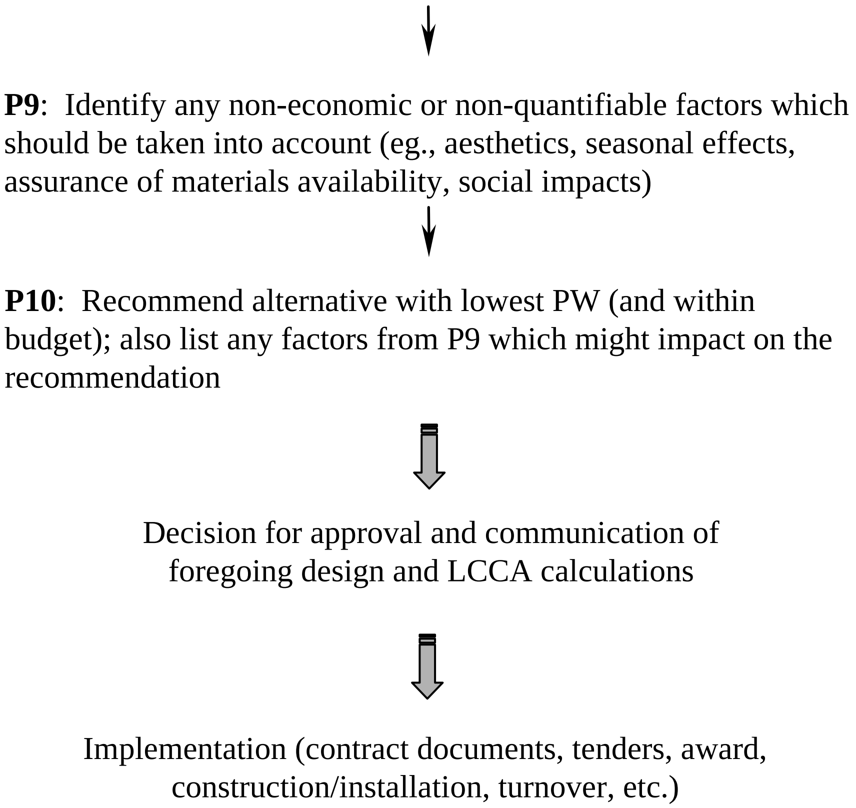
P7: Apply unit costs (materials, installation, etc.), or lump sum if appropriate, to P6 to obtain total costs (initial and reoccurring)

P8: Reduce P7 costs to present worth (PW)

DATA BASE

- Inventory of infr. assets (types, extent, locations, etc.)
- Condition measures (past and current)
- Benchmark unit costs
- Other

Figure 5. 4 Major Steps in a LCCA Generic Protocol at the Project or Site Specific Level



P9: Identify any non-economic or non-quantifiable factors which should be taken into account (eg., aesthetics, seasonal effects, assurance of materials availability, social impacts)

P10: Recommend alternative with lowest PW (and within budget); also list any factors from P9 which might impact on the recommendation

Decision for approval and communication of foregoing design and LCCA calculations

Implementation (contract documents, tenders, award, construction/installation, turnover, etc.)

Figure 5.4 Continued

The following is a brief elaboration on the various steps in the project level LCCA protocol of Figure 5.4.

P1: Selection of life cycle period. This need not necessarily be the same as at the network level. It depends on the infrastructure asset involved (e.g., vehicle fleet with a relatively short period and parks with a very long period). Generally, however, there should be consistency with the network level.

P2: Acquisition of data. Basically, this involves all data needed to calculate costs over the life cycle. Ideally, much of the data would come from the data base but in most cases data has to be acquired on available material types and unit costs, construction/ installation costs, quantities or volumes or areas involved, flows or traffic or usage, etc.

P3: Check for adjustments to network level minimum levels of service. Where this is relevant can be those cases where the network level assumptions are unrealistic or need to be adjusted because of the particular nature of the project. As well, if a sensitivity analysis concerning the effect on LCCA of varying levels of service is desired, then obviously adjustments up or down would have to be made.

P4: Identity available treatment alternatives. This can range from numerous alternatives (e.g., layer thicknesses and material types for pavement resurfacing) to perhaps only a single feasible alternative. Included would be not only the alternative(s) for initial rehabilitation, but also in future years of the life cycle when the infrastructure reaches a minimum acceptable level of service.

P5: Predict performance or estimate service lives of **P4**. For some infrastructure (e.g., again in the case of pavements), models exist for this purpose. In other cases, only estimates of the service or useful life of the alternative would be necessary.

P6: Calculate quantities/volumes/areas/etc. of alternatives. This would be for the initial rehabilitation and any recurrences during the life cycle.

P7: Apply unit or lump sum costs to P6. The purpose is to obtain total costs.

P8: Reduce **P7** costs to present worth (PW). The procedure is the same as at the network level.

P9: Identify any non-economic or non-quantifiable factors which should be taken into account. This may not be relevant, depending on the infrastructure asset. But certainly if one alternative is, for example, only marginally more cost effective than another, for example, with better aesthetics, more amenable to seasonal effects, represents better assurance that the materials will be available, etc., then the slightly higher cost alternative may well be the one that is eventually chosen.

P10: Recommend alternative with lowest PW. This would be subject to any factors from **P9** which should also be considered. As well, any recommendation would have to be within the budget limit.

When a decision for approval of the recommendation in **P10** has occurred, the usual procedure would be to proceed toward implementation. If it involves contracting the work, then the actual costs may be over or under the estimates in the LCCA. Any such differences would normally be communicated back to the network or system wide level for overall budget adjustments.

5.6 DECISION SUPPORT SYSTEMS

The results of the network-level programs should be used as the starting point for the project-level analysis. The network-level analysis of needs and selection of candidate sections can be from any part of the infrastructure management system. The project-level analysis should use the same basic analysis concepts that were applied in the network-level process. However, the entrance of new design and maintenance and rehabilitation needs may require considerable modifications in the list of sections to be addressed. In addition, there will be other factors that affect the selection process that cannot currently be modeled in the network-level system. Hence the need for a decision support system (DSS).

Decision support system (DSS) refers to the use of computers to store, analyze, and display information that is used to support decision-making. This process may become useful after the implementation of the LCCA as a support tool. As an integral component of infrastructure management system (IMS), the use of an information support system, database management or analytical studies, can help engineers make better decisions by:

- Improved identification and information of the infrastructure asset
- Access to condition data, usage, and history
- Delineation of problem areas
- Methodologies for needs assessment
- Evaluation of alternative solutions
- Projection of work programs of inspection and evaluation schedules

Once a DSS is established, the preparation of annual and multiyear work programs for maintenance, rehabilitation/renovation, and replacement/reconstruction (M, R&R) is streamlined as an automatic DSS output. Plans can continually be updated by providing feedback to the database. DSS should be designed to suit the needs of resources available to an agency, and to function within the primary organizational structure. The two main activities in a DSS, data management and study of alternatives, tend to generate meaningful results or insight from the data of information to support decision-making. All in all, the primary role of a DSS is to use data, together with the necessary analytical models, to produce the decision support for the decision makers. [Hudson 97]. An example of a DSS framework of a pavement management system (PMS) for a road structure is shown in Figure 5.6**.**

Examples

An example application of a complete LCCA is presented in Chapter 4 of this report. The example includes the procedural steps involved in conducting LCCA for a pavement section such as:

- Establishing alternative pavement design strategies for the analysis period
- Determining performance periods and activity timings
- Estimating user cost
- Computing Net Present Value
- Sensitivity Analysis of the results.
- Statistical Analysis
- The concept of Effectiveness

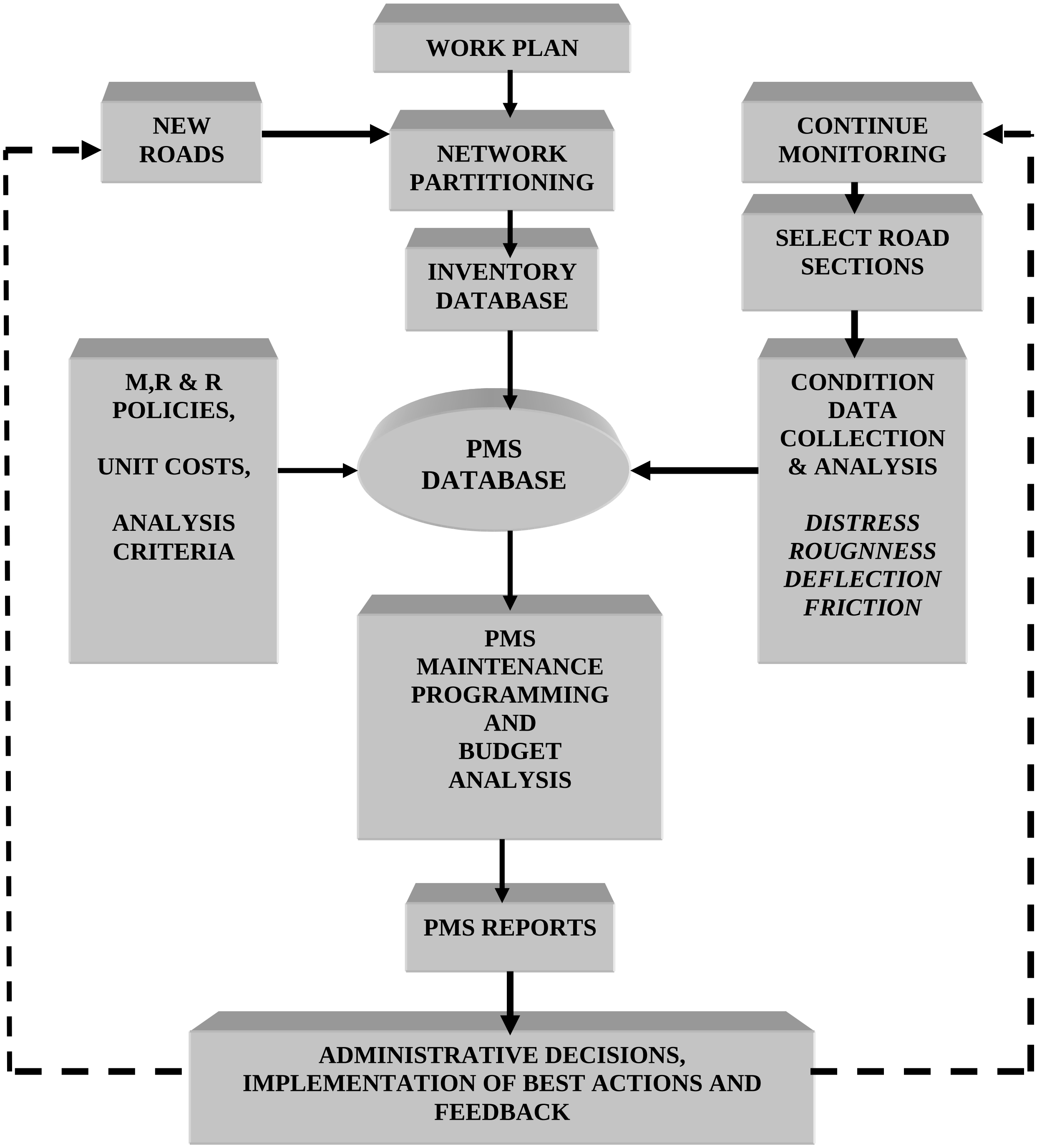


Figure 5. 5 A DSS framework for road infrastructure [Hudson 97]

CHAPTER 6. SUMMARY AND RECOMMENDATIONS

6.1 SUMMARY

There are two distinct integrated levels of management in infrastructure asset management system, namely, the Network level and Project level respectively. Within the network level, information such as objectives, constraints, priorities, schedules, budgets, agency policy costs etc., need to be considered. At the Project level, factors such as standards, specifications, and budget limit, environmental constrains, detailed design and so forth are considered. Ongoing, in service monitoring and evaluation and a database are key elements of the overall framework for infrastructure management.

Alternative strategies and life cycle cost of infrastructure must be carefully planned at the network level. This is important because it is necessary to develop a design strategy of minimum or reasonably economy at the beginning of a project to prevent under funded, incomplete or an excessively costly design. An economic evaluation involves the assignment of costs and benefits to predict the outcome of the project in terms of maintenance and rehabilitation.

6.2 BENEFITS

The benefits attributed from a generic protocol of LCCA of freeway or highway assets system can be divided into two categories. 1) Quantifiable benefits and 2) non-quantifiable benefits.

1. Quantifiable Benefits

- Savings in travel demand
- Increase safety

- Reduction in emitted pollutants
- Energy savings

2. Non-quantifiable Benefits

- Reduction of driver frustration
- More efficient and effective operational interfaces
- Better maintenance operations
- Better data collection and analysis.

6.3 RECOMMENDATIONS

6.3.1 System Development

This project has also been developed to collect and process the information needed by MTO to improve areas related to the maintenance and renovation of the ministry's infrastructure assets or facilities. To meet this objective, MTO may do the following:

1. Optimize the available resources of staff, materials, equipment, and funds to maintain the city facilities at acceptable service levels with minimum long-range costs.

2. Include the following basic elements of a maintenance management system:

    - Facility inventory.
    - Identification of maintenance and custodial tasks.
    - Identification of available resources.

- History of work performed.

The MTO major processes and outputs may include:

- Capture inventory and condition data for assigned facilities
- Schedule work
- Track maintenance work
- Track costs
- Generate reports
- Interface with other city computer systems

6.3.2 **Goals for Maintenance of infrastructure Assets**

The long-range goals for MTO Asset Management System may include the followings:

- Ensure facilities are maintained in a safe, clean, and healthy manner
- Sustain a level of maintenance which will allow facilities to be used, as intended, at the lowest possible cost
- Reduce the frequency of component failures and service interruptions

- Develop proactive maintenance programs which will increase the ratio of planned to unplanned maintenance, and thus reduce dependence on the "crisis" management approach to maintenance

- Ensure all major maintenance actions and capital renewal projects are based on lowest life-cycle costs, where applicable.

- Improve the condition of each facility until it is measured to be in "good" condition and maintain each facility in "good" condition. This can be done by using performance measures as a guide such as Pavement Condition Index (PCI), Present Serviceability Index (PSI), International Roughness Index (IRI), or Ride Quality Index (RQI).

6.3.3 Update Procedures

Procedures should be in place, which allow real time updating of facility condition data. In addition, qualified personnel should perform a formal inspection of each facility for example, every two years. Inspectors will compare the facility’s existing deficiency report file against any discrepancies observed and update the list of deficiencies.

6.3.4 Plan of Action

To achieve the long term goals for maintenance stated above, the following programs may be implemented or refined:

1. Preventive Maintenance (PM): Continue implementing an ongoing maintenance and inspection program to prevent premature deterioration of facility components and take steps to eliminate the underlying causes of deterioration. The program may be expanded to include Parks & Recreation facilities. PM tasks are considered very important and have been proven to be the most cost effective method of maintaining facility components.

2. Condition Assessment: Maintain a system for collecting, storing, and updating information on the physical condition of all facilities for which MTO is responsible.

3. Predictive Maintenance / Component Renewal: Perform testing on equipment to identify problems at an early stage so that corrective action may be taken before component failure. Maintain a database on expected useful lives of major facility components and schedule component replacements. The inspection program is designed to pay particular attention to components nearing the end of their service life.

4. Life-Cycle Costing: Develop and maintain a predictive model to assess the impact of deferring required maintenance. Determine the optimum budget for building maintenance. Review and define Life-Cycle Costing techniques. Identify components for which these cost techniques are applicable. Evaluate different design

scenarios when planning new facilities to determine the total lifetime capital and maintenance costs of each scenario. The lowest overall cost should be selected whenever possible.

5. Reporting Deficiencies: Implement standard methods for reporting deficiencies in all facilities. Determine and track the attributes which are needed for analyzing work histories. Identify and develop standard reports for all levels of management.

6. Levels of Service/Priority System: Identify maintenance tasks and establish a system of priorities for scheduling all maintenance work.

7. Interfacing with Other Departments / Organizations: Identify those circumstances in which engineering, architectural, or other professional assistance is needed to solve maintenance problems. Communicate with departments on programs and facility issues.

8. Maintenance History Files: Create and maintain a database of maintenance histories for all major infrastructure components.

9. Work Order System: Use a computer-generated work order system to assign, track and monitor all work and associated costs.

10. Review Other Practices, Software, and Technologies: Compare facility management practices to industry benchmarks and practices successfully implemented by other cities. New

technologies may be researched, investigated and implemented as appropriate to further refine the asset management system. Chapter 3 of this report summarizes new technology in use today and also provides feedback from three private companies on their views on LCCA.

11. Provide Key Definitions: Key definitions are meant to be simple while conveying important principles that need to be emphasized in the MTO asset management program. A list of key definitions has been developed, based on common facilities management and construction terminology, and is included in Appendix A of this report [Circular No. A-94, 92].

REFERENCES

[AASHTO 86] AASHTO. *"Guide for Design of Pavement Structures,"* American Association of State Highway and Transportation Officials, 1986.

[Barnett 85] Barnett, W.S. *"Benefit-cost analysis of the Perry Preschool program and its policy implications."* Educational evaluation and policy analysis, 7. 333-342. (1985).

[Barnett 93] Barnett, W. S. *"The economic evaluation of home visiting programs,"* The Future of Children: Home Visiting, 3. Center for the Future of Children, the David and Lucile Packard Foundation, 93-112. (1993).

[Berreuta-Clement, 84] Berreuta-Clement, J. R., Schweinhart, L. J., Barnett, W. S., et al. *"Changed lives: The effects of the Perry Preschool program on youths through age 19,"* Monographs of the High/Scope Educational Research Foundation, no. 8. Ypsilanti, MI: High/Scope Press. 1984.

[CB 96] Crystal Ball 4.0, Decisioneering, Inc. Denver Colorado, 1996.

[Cheresource 02] Cheresources, Inc., *"LIFE CYCLE COST ANALYSIS,"*

2830 Providence Creek Road, Richmond, VA 23236. 2002.

[Circular No. A-94, 92] Circular No. A-94 Revised (Transmittal Memo No. 64), *"Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,"* Memorandum for Heads of Executive Departments and Establishments, October 29, 1992.

[Cook 79] Cook, T. D., & Campbell, D. T. *"Quasi-experimentation: Design and analysis issues for field settings,"* Boston: Houghton-Mifflin Co. 1997.

[Cowe, et al, 01] Cowe Falls, Lynne, Ralph Haas, and John Hosang, *"Asset Valuation as a Key Element of Pavement Management,"* 5th International Conference on Managing Pavements. Seattle Washington, August 11-14, 2001.

[Croteau 03] Croteau, Jean-Martin, Personal Interview, Miller Paving Limited, Toronto 2003.

[FHWA 98] FHWA. *"Life Cycle Cost Analysis in Pavement Design Demonstration Project 115 Participant Handbook"*. FHWA-SA-98-400. FHWA, August 1998.

[FHWA 98a] United States Federal Highway Administration, *"Life Cycle Cost Analysis In Pavement Design – In Search of Better Investment Decisions,"* United States Federal Highway Administration, Washington D.C., 1998

[Fickes 02] Fickes, Michael. "*Weighing in on infrastructure valuation,"* American City & County, Jun 1, 2002.

[Fraumeni 99] Fraumeni, Barbara M. "Strategies for Measuring Productive Highway Capital Stocks," presented to the Transportation Research Board Conference for Information Requirements for Transportation Economic Analysis, Irvine, California, August 2000.

[GASB 99] Government Accounting Standards Boards (GASB) Newsletter, "*New Rules for Reporting Infrastructure Information to be Enacted for State & Local Governments,"* April 19, 1999.

[GASB 01] Government Accounting Standards Boards (GASB) Statement 34, *"Capital Assets & Depreciation Guidance,"* August 31, 2001.

[GLCCA 03] Guidance on Life-Cycle Cost Analysis Required by Executive Order 13123 January 8, 2003.

[Haas et al 94] Haas, Ralph, W. Ronald Hudson, & John Zaniewski. *"Modern Pavement Management,"* Krieger Publishing Company. Florida 1994.

[Haas 01] Haas, Ralph, Lynne Cowe Falls, Sue McNeil, Susan Tighe. "*Fitting Pavement Management Into Overall Asset Management,*" 20th ARRB Conference Melbourne. Australia, 19-21 March 2001.

[Haas 01a] Ralph Haas, Lynne Cowe Falls, & Susan Tighe. "*IMPACT ASSESSMENT OF LIFE CYCLE COSTS ANALYSIS (LCCA).*" Final Report Prepared for: Office of Infrastructure City of Edmonton In Connection with The City's Infrastructure Strategy. December 31, 2001.

[Haas 03] Haas, Ralph, Susan Tighe, & Lynne Cowe Falls. "*Generic Protocol for Long Life Pavements Cost Analysis,*" 2003 Annual Conference of the Transportation Association of Canada. St.John's, Newfoundland and Labrador, September 21-24, 2003.

[Hall 89] Hall, K. T., J. M. Connor, M. I. Dater, and S. H. Carpenter, *"Rehabilitation of Concrete Pavement,"* Volume III –Concrete Pavement Evaluation and Rehabilitation System, Report FHWA-RD-88-073, FHWA, U.S. Department of Transportation, 1989.

[Harral 79] Harral, C. G. et al., *"The Highway Design and Maintenance Standards Model (HDM): Model Structure, Empirical Foundation, and Applications,"* PRTC Summer Annual Meeting, University of Warwick, July 9-12, 1979

[Hein 03] Hein, David, Personal Interview, Applied Research Association, Inc-ERES Consultants Division, Toronto ON, 2003.

[Hejek 96] Jery Hajek, Susan Tighe, and John Billings. "*Impact on Pavements by Changing the Vehicle Weights and Dimensions of Trucks in Ontario*," 1996.

[Helali 03] Helali, Khaled, Personal Interview, Stantec Consulting Ltd. Waterloo ON, 2003.

[Hicks 99] Hicks, R.G., J.R. Lundy, and Jon A. Epps. "*Life Cycle Costs for Asphalt-Rubber Paving Materials*." Final Report to Rubber Pavements Association, Vols. I/II, June 1999.

[HPMS 86] Highway Performance Monitoring System Analytical Process, Volume 2, Version 2.0, Technical Manual, Federal Highway Administration, Office of Highway and Planning, January 1986.

[Hudson 97] Hudson, W. Ronald, Ralf Hass and Waheed Uddin, *"Infrastructure Management,"* McGraw Hill. New York, 1997.

[Jacobs 88] Jacobs, F.H. *"The five-tiered approach to evaluation: Context and implementation."* In H.B. Weiss, & F.H. Jacobs (Eds.), Evaluating family programs. New York: Aldyne de Gruyter. (1988).

[Kettner 90] Kettner, P. M., Moroney, R. M., & Martin, L. L. *"Designing and managing programs: An effectiveness-based approach,"* Newbury Park, CA: Sage, 1990.

[Lemer 00] Lemer, Andrew, C. *"Asset Management: The Newest Thing or Same-old, Same-old?"* APWA Reporter, June 2000.

[LTRC 02] Louisiana Transportation Research Center (LTRC). Fereydon Aghazadeh, Gerald Knapp, Thomas Ray. *"Analysis of User Waiting Costs for Construction Projects On Louisiana's Interstate Highway System."* Louisiana State University. Summary of Report Number 372. April 2002.

[Maze 00] Maze, T . GASB 34*: "Establishing a Value for Infrastructure Assets,"* Vive President, Howard Green Company. July –August 2000.

[McFarland 93] McFarland, W. F., J.L. Memmott, and M.L. Chui, *“Microcomputer Evaluation of Highway User Benefits,”* National Cooperative Highway Research Program Report 7-12, National Research Council, October 1993.

[MTO 90] Ministry of Transportation Research and Development Branch. *“Analysis of Cost for Pavement Rehabilitation Strategies,”* Project #21180, 1990.

[MTO 03] Ministry of Transportation Ontario (MTO), 2002-2003 Business Plan.

[ODOT 03] The Ohio Department of Transportation (ODOT), Office of Construction Administration, Columbus, Ohio. 2003.

[PennDOT 98] Bureau of Planning and Research, Performance Monitoring Division, Pennsylvania Department of Transportation, 6th Floor – Forum Place. 555 Walnut Street, Harrisburg, Pennsylvania 17101-1900. *10/7/98*

[Rada 87] Rada, G. R., and M. W. Witczak, *“Project Level PMS Life Cycle Cost Model for Flexible Pavements,”* Sixth International Conference, Structural Design of Asphalt Pavements, Vol.1: Proceedings, University of Michigan, Ann Arbor, Michigan, July 13-17, 1987.

[Rossi 93] Rossi, P. H., & Freeman, H. E. *“Evaluation: A systematic approach,”* (5th ed.). Newbury Park: Sage Publications, pp. 363-401. (1993).

[S of W 97] State of Wisconsin, *“GUIDELINES FOR LIFE-CYCLE COSTING ON STATE BUILDING PROJECTS.”* Department of Administration, Division of Facilities Development. December 1997.

[Seeds 92] Seeds, S. B., B.F. McCullough, and W. R. Hudson, *“A Design System for Rigid Pavement Rehabilitation,”* Research Report 249-2, Center for Transportation Research, The University of Texas at Austin, January 1992.

[Sewell 03] Sewell, M. & Marczak, M. **“***Using Cost Analysis In Evaluation,”* Alternative Methods for Collecting Evaluation Data. Retrieved September 21, 2003, from The University of Arizona Institute for Children, Youth and Families Available: [http://ag.arizona.edu/fcr/fs/cyfar/Costben2.htm]

[Sussman 00] Sussman, Joseph, *“Introduction to Transportation Systems,”* Artech House ITS Library. Boston, 2000.

[TAC 97] Transportation Association of Canada, *"Pavement Design and Management Guide"*, Transportation Association of Canada, Ottawa, 1997.

[US DOT 98] U.S. Department of Transportation, *"Life-Cycle Cost Analysis in Pavement Design,"* Pavement Division Interim Technical Bulletin, September 1998.

[U.S DOT 99] U.S. Department of Transportation, *"Asset Management Primer,"* Federal Highway Administration, Office of asset Management, December 1999.

[US DOT 02] U.S. Department of Transportation, *"Highway Economic Requirements System (HERS),"* Federal Highway Administration, Technical Report, December 2002.

[Walls 98] Walls, James and Michael R. Smith. *"Life Cycle Cost Analysis in Pavement Design,"* Pavement Division Interim Technical Bulletin. Report FHWA-SA-98-079. FHWA, September 1998.

[White 88] White, K. R. *"Cost analyses in family support programs (pp. 429-443),"* In H. B. Weiss & F. H. Jacobs (Eds.), Evaluating family programs. New York: Aldyne de Gruyter. (1988).

[Wilde 99] Wilde, W. James, Steve Waalkes, & Rob Harrison. *"Life Cycle Cost Analysis of Portland Cement Concrete Pavements."* Research Report 1739-2, Center for Transportation Research, Bureau of Engineering Research. The University of Texas at Austin. September 1999.

[Witczak 97] Witczak, M. W., and M.W. Mirza, *"Microcomputer Analysis for Project Level PMS Life Cycle Cost Studies for Rigid Pavements,"* Final Report, Vols. I and II, Maryland University, College Park, Maryland, 1992.

[WWE 01] Webster's World Encyclopedia 2001 Edition.

APPENDIX A

DEFINITION OF TERMS

[Circular No. A-94, 92]

Base Point or Starting Point (Year 0) -- All past, present and future costs and benefits will be expressed in dollar values relative to a base point. This is the point to which these values will be converted or discounted when calculating present values. The starting point is usually the beginning of the study period and generally coincides with the bid date.

Benefit-Cost Analysis -- A systematic quantitative method of assessing the desirability of government projects or policies when it is important to take a long view of future effects and a broad view of possible side-effects.

Bid Date -- The scheduled date for bidding of construction contracts. Project budgets reflect initial costs escalated to the bid date.

Bond Rate (b) -- The interest rate, or cost, the state pays when it sells bonds to finance its capital program. The bond rate is expressed as a percentage annual interest rate, compounded annually. The project cost on a bonded project is spread out in payments extending over the life of the bond, generally 20 years. The purchasing power of the dollars used to make future bond payments is less than the purchasing power of today's dollar because of inflation and the real earning power of money.

Capital Asset -- Tangible property, including durable goods, equipment, buildings, installations, and land.

Certainty-Equivalent -- A certain (i.e., nonrandom) outcome that an individual values equally to an uncertain outcome. For a risk-averse individual, the certainty-equivalent for an uncertain set of benefits may be less than the mathematical expectation of the outcome; for example, an individual may value a 50-50 chance of winning $100 or $0 as only $45. Analogously, a risk-averse individual may have a certainty-equivalent for an uncertain set of costs that is larger in magnitude than the mathematical expectation of costs.

Close-Circuit Television System (CCTV) -- Provides a visual means of monitoring the conditions on the freeway. A CCTV has the advantage of being able to obtain first – hand information without actually having to be at the scene of any traffic congestion. It can be manually controlled by a system operator.

Cost-Effectiveness -- A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective.

Consumer Surplus -- The maximum sum of money a consumer would be willing to pay to consume a given amount of a good, less the amount actually paid. It is represented graphically by the area between the demand curve and the price line in a diagram representing the consumer's demand for the good as a function of its price.

Discount Rate (1) -- The rate of interest reflecting the time value of money used to determine the factor for discounting.

Discount Rate (2) -- The interest rate used in calculating the present value of expected yearly benefits and costs. Discount rates may be expressed as either a nominal or a real interest rate. The nominal rate (d) combines both general inflation and the real earning power of money over time and must be used when costs and benefits are expressed in actual dollars. The real rate (i) reflects only the real earning power of money over time and must be used when costs and benefits are expressed in un-inflated or constant dollars, excluding the impact of general inflation. Discount rates are expressed as a percentage annual rate, compounded annually.

Discount Factor -- The factor that translates expected benefits or costs in any given future year into present value terms. The discount factor is equal to $1/(1 + i)t$ where i is the interest rate and t is the number of years from the date of initiation for the program or policy until the given future year.

Energy Costs: -- This includes the cost of all services for heating, cooling, and power delivered to the building including gas, oil, electric, steam, chilled water etc.

Environmental Costs: -- Environmental costs include the cost associated with waste management, regulatory compliance, pollution prevention, and site remediation.

Excess Burden -- Unless a tax is imposed in the form of a lump sum unrelated to economic activity, such as a head tax, it will affect economic decisions on the margin. Departures from economic efficiency resulting from the distorting effect of taxes are called excess burdens because they disadvantage society without adding to Treasury receipts. This concept is also sometimes referred to as deadweight loss.

External Economy or Diseconomy -- A direct effect, either positive or negative, on someone's profit or welfare arising as a byproduct of some other person's or firm's activity. Also referred to as neighborhood or spillover effects, or externalities for short.

Finance Costs: -- This is the cost of interest paid for tax supported borrowed funds.

Incidence -- The ultimate distributional effect of a tax, expenditure, or regulatory program.

Inflation (1) -- The proportionate rate of change in the general price level, as opposed to the proportionate increase in a specific price. Inflation is usually measured by a broad-based price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index.

Inflation (2) -- A rise in the price level without a corresponding increase in the quantity or quality of goods or services. Inflation is usually expressed as a percentage annual rate, compounded annually and may be either general or specific. The general inflation (j) rate is a weighted average of the inflation rates of major commodities and services in the general economy. A specific inflation (k) rate applies to specific cost items which may be increasing or decreasing, at a rate different from the general inflation rate. The specific inflation rate for most energy resources is higher than the general inflation rate.

Initial Costs: -- This includes all the costs necessary to design, construct and equip the facility including all planning, engineering and architectural fees, building and utility construction, equipment purchases and installation, land acquisition, site preparation and development, and project administration.

Internal Rate of Return -- The discount rate that sets the net present value of the stream of net benefits equal to zero. The internal rate of return may have multiple values when the stream of net benefits alternates from negative to positive more than once.

Life Cycle Cost -- The overall estimated cost for a particular program alternative over the time period corresponding to the life of the program, including direct and indirect initial costs plus any periodic or continuing costs of operation and maintenance.

Maintenance and Repair Costs: -- Maintenance and repair costs include the cost of regularly scheduled preventative maintenance and emergency repairs.

Multiplier -- The ratio between the direct effect on output or employment and the full effect, including the effects of second order rounds or spending. Multiplier effects greater than 1.0 require the existence of involuntary unemployment.

Municipal Service and Other Costs: -- This includes the cost paid to the local municipality to reimburse them for providing police, fire, and other services. It also includes other identifiable costs not covered elsewhere such as insurance.

Net Present Value -- The difference between the discounted present value of benefits and the discounted present value of costs.

Nominal Values -- Economic units measured in terms of purchasing power of the date in question. A nominal value reflects the effects of general price inflation.

Nominal Interest Rate -- An interest rate that is not adjusted to remove the effects of actual or expected inflation. Market interest rates are generally nominal interest rates.

Non-Inflationary Cost Increase (e) -- Occasionally an increase in cost is due to an increase in the quantity of goods or services received. This non-inflationary cost increase is expressed as a percentage annual rate, compounded annually.

Operational Costs: -- Operational costs are directly related to the operation of the facility itself and include custodial care, utilities, security, and employee services.

Opportunity Cost -- The maximum worth of a good or input among possible alternative uses.

Program Costs: -- This includes the personnel or staffing costs, transportation costs, warehousing and distribution costs, training costs, etc. required for the operation of the facility. In a comparative LCC analysis, these costs become critical when the design alternatives influence the quality of service, the efficiency of the operation, or the level of staffing.

Program Life -- The period of time over which an agency is expected to utilize a facility for a specific program objective.

Real or Constant Dollar Values -- Economic units measured in terms of constant purchasing power. A real value is not affected by general price inflation. Real values can be estimated by deflating nominal values with a general price index, such as the implicit deflator for Gross Domestic Product or the Consumer Price Index.

Real Interest Rate -- An interest rate that has been adjusted to remove the effect of expected or actual inflation. Real interest rates can be approximated by subtracting the expected or actual inflation rate from a nominal interest rate. (A precise estimate can be obtained by dividing one plus the nominal interest rate by one plus the expected or actual inflation rate, and subtracting one from the resulting quotient.)

Relative Price -- A price ratio between two goods as, for example, the ratio of the price of energy to the price of equipment.

Replacement Costs: -- This includes the cost of replacing those major building system or components which have useful lives shorter than the original facility.

Residual Value and Salvage Value: -- Residual or salvage value is the value at the end of the study period. Salvage value may be based upon the remaining un-depreciated useful life of the initial building and subsequent component replacements, or it may reflect the projected market value at the end of the study period. Residual value may be negative if disposal costs are significant.

Shadow Price -- An estimate of what the price of a good or input would be in the absence of market distortions, such as externalities or taxes. For example, the shadow price of capital is the present value of the social returns to capital (before corporate income taxes) measured in units of consumption.

Study Period (n) -- The length of time over which alternative investments are evaluated. The study period will extend for 25 years from the bid date for most state projects. This period is a reasonable compromise between a projection of the original program life and the point beyond which it becomes difficult to project benefits and costs. In addition, the present value of costs or benefits occurring beyond 25 years generally has insignificant impact on the total life-cycle cost.

Sunk Cost -- A cost incurred in the past that will not be affected by any present or future decision. Sunk costs should be ignored in determining whether a new investment is worthwhile.

Transfer Payment -- A payment of money or goods. A pure transfer is unrelated to the provision of any goods or services in exchange. Such payments alter the distribution of income, but do not directly affect the allocation of resources on the margin.

Treasury Rates -- Rates of interest on marketable Treasury debt. Such debt is issued in maturities ranging from 91 days to 30 years.

Useful Life or Service Life -- Generally considered as the normal life expectancy of the building or its major systems and components. The useful life is the period of time the original investment is estimated to meet its original objective without extensive remodeling or replacement of the major systems and components. The value of the remaining life of the building systems or components at the end of the study period is dependent upon the useful life estimate. Replacements of building Systems or components with a useful life that is less than the study period should be included I the LCC analysis. A list of typical useful lives for State facilities, building systems and components is included in the appendix. This list is intended only as a general guide and the A/E should determine the appropriate useful lives for each LCC analysis based on use, type of construction, etc.

Willingness to Pay -- The maximum amount an individual would be willing to give up in order to secure a change in the provision of a good or service.

APPENDIX B

TYPICAL USEFUL LIVES OF STATE/PPROVINCE FACILITIES

[S of W 97]

	TYPE OF BUILDING	USEFUL LIFE (YEARS)
l.	Armory	40
2.	Bathhouse	20
3.	Classroom Building	50
4.	Fine Arts Building/Auditorium	40
5.	Food Service Building	30
6.	Greenhouse	30
7.	Science Building	40
8.	Library	40
9.	Maintenance Garage	30
l0.	Medical Clinic	25
ll.	Office Building	25
	l-2 Story	30
	Multi-Story	40
	High-rise	50
l2.	Headquarters or Public Events Facility	
l3.	Park Facilities	
	Flush Toilet/Shower/Laundry	25
	Picnic Shelter	30
l4.	Physical Education Building	30
l5.	Research	35
l6.	Residential	
	Single Family House	35
	Dormitory	30
	Correctional Housing	35
	Patient Housing	30
l7.	Student Center	30
l8.	Heated Warehouse	40
l9.	Central Heating and Cooling Plants	30

APPENDIX C

TYPICAL USEFUL LIVES OF BUILDING SYSTEMS AND COMPONENTS*

Building Enclosure	Useful Life (Years)
Concrete Framing System:	
- Masonry Exterior	45-60
- Metal Clad	40-50
Steel Framing System:	
- Masonry Exterior	40-50
- Metal Clad	40-50
Wood Framing System:	
- Metal Clad	35-45
- Wood Siding	35-60
Roofing System	
Built-Up System:	
- Asphalt	l0-25
- Elastomeric	l5-30
Pitched Roof w/Shingles:	
- Asphalt	20-25
- Metal	40-50
- Clay Tile	50-70
Windows and Exterior Door	
Metal Windows	40-50
Wood Windows	30-40
Aluminum and Glass	25-30
Revolving Doors	l5-30
Overhead Doors	20-40
Interior Construction	
Demountable Partitions	20-30
Acoustical Ceiling	20-30
Carpet	5-l5
Resilent Tile	l0-20
Paint & Wall Covering	5-l5
Plumbing System	
Fixtures	20-30
Water Heaters	l0-20
Pumps	l5-20
Steel Piping	30-40
Copper Piping	20-30
Sprinkler Fire System	25-35

Heating, Ventilating and Air Conditioning Systems	Useful Life (Years)
Boilers:	
- Steel Water Tube	20-30
- Steel Fire Tube	20-30
- Electric	l5-20
Heat Exchangers:	20-30
Burners	l5-25
Economizers	l0-20
Furnaces:	
- Gas or Oil	l5-20
Radiant Heaters	20-30
Air Conditioners and Components:	
- Water Cooled Package Units	l0-20
- Roof Top Units	l0-20
- Commercial through the Wall Units	l0-20
- Cooling Towers	l0-20
- Evaporative Condensers	l5-25
- Air Cooled Condensers	l5-25
- Package Chillers	l5-25
Fans:	
- Centrifugal	25-30
- Axial	20-25
- Propeller	l5-20
- Roof Mounted	20-25
Air Terminals:	
- Induction and Fan Coil Units	20-25
- Variable Air Volume Boxes	20-25
Steam Turbines	25-35
Controls	l5-20
Pumps and Compressors	l5-20

Electrical Systems	Useful Life (Years)
Motors	l5-20
Transformers	25-35
Generators	20-30
Primary Wiring	25-30
Switchboard	20-30
Switch Units	20-25
Secondary Wiring	20-25
Light Ballasts	l0-l5
Fixtures, Fluorescent	l5-30
Fire Alarm	l5-25

Elevators	25-35
Site Work and Utilities	
Concrete Pavement	l5-25
Bituminous Concrete Pavement	l0-l5
Underground Water Pipes	20-40
Underground Sewage Pipes	30-60
Underground Steam Pipes	l0-30
Steam and Chilled Water, Tunnel	25-50

* The above list of useful lives is offered to assist in performing the life cycle costing calculations. It consists of averages derived from a variety of sources and it is recommended that if a better source of specific data is available, that it be used. Other sources are the guidelines of the American Society of Testing Materials, Illuminating Engineering Society of North American, National Electric Manufacturers Association, and American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc.

Obviously, the useful lives of these items vary directly with their initial quality and level of maintenance. The list is based upon good quality components and a level of maintenance consistent with the manufacturer specifications [S of W 97].

Capital Assets of Local Governments Suggested Useful Lives [GASB 01]

Asset Type	**Depreciable Life in Years**
Infrastructure	
Easement	no depreciation
Drainage Systems	25
Water System	25
Sewage Disposal Work System	25
Waterway	
Levees and canals (unlined)	no depreciation
Canal Lining	30
Dams	
Concrete	50
Steel, Sheet-pile	30
Earthen embankment	no depreciation

Roads	
Paved	40
Asphalt - rural	40
Asphalt - urban	20
Non-Paved	50

Average Life Cycles for Depreciated Infrastructure Assets [Fickes 02]

ROADWAYS

Dirt:	10 years
Gravel:	15 years
Asphaltic concrete:	20 years
Concrete:	30 years
Brick or Stone:	50 years

SIDEWALKS

Concrete:	10 Years
Asphalt:	25 Years
Brick or Stone:	50 years

PARKING LOTS

Gravel:	10 Years
Asphalt:	15 Years
Concrete:	35 Years
Brick or Stone:	45 years

BRIDGES (spans of more than 20 feet)

Precast concrete:	40 Years
Prestressed concrete:	45 Years
Steel without truss:	45 years
Steel with truss:	50 Years
Timber/wood:	30 Years
Pedestrian wood:	25 Years
Pedestrian concrete:	30 Years
Pedestrian steel:	30 Years

CULVERTS (spans of less than 20 feet)

Plastic:	25 Years

Treated timber or log:	30 Years
Steel:	30 years
Cast iron:	30 Years
Metal corrugated:	30 Years
Prestressed concrete:	40 Years
Concrete:	40 to 45 Years depending on size

Milwaukee-based American Appraisal Associates has established the following benchmark life cycles for depreciating a variety of infrastructure assets. Company officials caution that the benchmarks may vary between jurisdictions based on differences in climate and use. In addition, the estimates of average asset lives assume that normal maintenance is performed on the assets.

APPENDIX D

REALCOST EXAMPLE REPORT

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