GENERIC PROTOCOL FOR LONG LIFE PAVEMENTS COST ANALYSIS

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ABSTRACT

The justification for long life pavements is derived through positive life cycle economics, less user costs and conservation of materials. It is essential therefore that the life cycle cost analysis (LCCA) is rigorous, employs the most applicable methodology, is consistent and incorporates all the relevant factors.

This paper first reviews the basic elements of LCCA, various practices and applications. It then defines three major levels: (a) strategic, (b) network or system wide, and (c) project or site specific.

A generic protocol for the network level is described in terms of a series of steps. It includes interfaces with the higher strategic level and the project level.

The paper concludes with an application example involving an arterial street network from a Canadian city, plus a simplified project level application example.

INTRODUCTION

Long life pavements, particularly for high volume facilities, have become increasingly important because of the life cycle economics involved, reduced user costs with less maintenance and rehabilitation interventions and conservation of materials.

In the asphalt pavement field, a term that is seeing considerable use is "Perpetual Pavements". On the concrete pavement side, long life pavements would be those that are structurally designed to minimize or eliminate traffic load associated deterioration over the long term. In essence, the intent is the same for either type of pavement.

It is not the purpose of this paper to discuss the comparative technical and economic merits of the two pavement types. Rather, it is directed to a generic protocol that is applicable to either type, over a long term horizon.

More specifically, the objectives are to:

- Discuss the basic elements of life cycle cost analysis (LCCA), including objectives, stakeholders involved, cost factors, analysis period, methods, issues, and roadblocks.
- Review LCCA practices and applications
- Describe the three major levels of LCCA: (a) strategic, (b) network or system wide, and (c) project or site specific, and present a generic protocol for the network level.
- Provide example LCCA, pavement related, applications for the network and project levels.

CONVENTIONAL LIFE CYCLE COST ANALYSIS (LCCA)

Analysis Objectives of LCCA

Life cycle cost analysis (LCCA) uses economic principles to compare competing alternative investment strategies [1]. It incorporates initial and discounted future costs over the life cycle of the alternative investments and attempts to identify the best value or the lowest cost over time. LCCA has always been an important tool in supporting decisions on the most cost-effective structure (roads, utilities, buildings, etc.) or rehabilitation treatment [2].

For infrastructure assets such as roads, a large proportion of the total cost over the lifetime of those assets is incurred after construction, during their service lives. Consequently, when evaluating different road investment options at the time of construction or maintenance, the comparison of current costs alone is not satisfactory and the longer-term consequences of the decisions also need to be considered. A whole life cost approach to the investment analysis can therefore increase the effectiveness of maintenance decisions [3, 4, 5].

There is a difference between LCCA and financial analysis, as subsequently discussed. Basically, LCCA is used to compare the use (s) of funds while financial analysis is concerned with cash flows (e.g., revenues, actual costs, and profits). LCCA uses today's costs for the future cost estimates and then discounts them at the real cost of money. Conversely financial planning must consider or program the actual cost outlays in the future [6].

Stakeholders/Clients For LCCA

The potential stakeholders/clients for LCCA include the following:
Elected level (Council or Legislature)
Senior administrators
Technical/Operating level personnel
Taxpayers
Interest Groups
Contractors/Suppliers
Consultants
Transportation agencies

How these stakeholders view or use the results of LCCA, however, may well vary. For example, Public Interest Groups could see an LCCA as only one element toward a decision (e.g., considerations of equity, political impact, social impact, etc. may also be relevant to them).

Cost Factors in LCCA for Pavements

Agency costs are directly represented by the budget or out-of-pocket costs paid by the owner [6]. The major initial construction and maintenance and rehabilitation costs over the life-cycle that a public agency may consider in the economic analysis of infrastructure project alternatives include the following:

- Initial construction costs

- Future costs of maintenance, rehabilitation, renovation, and reconstruction
- Salvage return or residual value at the end of the design period
- Engineering and administration
- Costs of borrowing (if projects are not financed from current revenue)

Nonagency costs can involve the user of the infrastructure or facility, or they can be incurred by nonusers [6]. They include user delays related to construction, maintenance and rehabilitation interruptions and are described as follows:

User Costs:

- Additional time delays for drivers and/or occupants on the facility
- Additional operating costs due to time delays (vehicles, etc.)
- Accidents
- Discomfort

Nonuser Costs:

- Environmental pollution (emission, noise, visual, etc.)
- Neighbourhood disruptions

Quantification of Costs

The quantification of costs can be determined based on the availability of previous construction and maintenance records [7]. The initial construction, major maintenance, future rehabilitation, and salvage value are most frequently included in the life-cycle economic analysis [2]. User delay costs due to maintenance and/or rehabilitation interruptions can be very substantial particularly for high volume facilities [7, 8]. While the incorporation of user delay costs in LCCA is often a policy decision, failing to do so can significantly skew the results [7].

Analysis Period

A general guideline for selecting the length of analysis period is that it should not extend beyond the period of reliable forecasts [8]. In the case of roads, traffic forecasts are usually only predicted up to 20 years. For freeway and major road pavements, however, it is common to use 30 years or more. By comparison other infrastructures such as bridges, parks, buildings, etc. will generally involve a much longer analysis period (e.g., up to 75 years or more). The length of the period is a policy decision and as such, is dependent upon the agency, circumstances and the infrastructure involved. It has been suggested though that the pavement area should be moving to very long life cycle analysis periods because of resource, environmental and multiple recycling considerations [10].

Another approach is to have the analysis period extend to the point where the discounted costs or benefits become negligible. The analysis period is thus a variable, depending on the discount rate and the level set for negligible discounted costs or benefits. However most agencies prefer to use a fixed period.

METHODS OF ECONOMIC EVALUATION

The economic models that can be used to incorporate costs, or costs and benefits, include the following [1, 8]:

Benefit/Cost Ratio Method: This method has been widely used in the infrastructure area, particularly for large projects such as dams and causeways. The B/C ratio approach is not recommended for several infrastructure types, however, including pavements, because of the difficulty in quantifying benefits.

Internal Rate of Return: This is primarily used in private industry. It 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.

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.

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 weighted by section length [8].

Present Worth Method: this can be used for costs, or benefits, or benefits minus costs (i.e. the Net Present Worth or Net Present Value "NPV" method). Present Worth (PW) is the widely accepted method of choice in the pavement field [1, 8, 11], and is calculated as follows:

$$PW = \Sigma \text{ Costs} / (1 + i)^n \qquad (2)$$

Where: Costs = Initial Construction, Ongoing Maintenance and Future Rehabilitation Costs
i = Discount Rate
n = Year cost occurs

Discount Rate

The discount rate is one of the variables necessary to calculate PW. It should be based on historical trends over long periods of time. Historically nominal discount rates over an extended period of time have been in the order of four percent [12], which is in the range of the real rate of return on long term bonds (e.g., 35 years). In Canada, values of up to ten percent have been used but a range of four to eight percent is more common [8].

It is recommended that constant dollars and real discount rates should be used. Real discount rates reflect the true value of money over time with no inflation premiums and should be used in conjunction with non-inflated dollar cost estimates [1].

Some Basic Issues in LCCA

LCCA should include a sensitivity analysis to address the variability within major analysis input assumption projections, and estimates. Traditionally, sensitivity analysis has evaluated different discount rates or the assigned value of time, normally involving a best and worst case scenario. The ultimate extension of sensitivity analysis is a probabilistic approach, which allows all significant inputs to vary simultaneously. The prevailing term used in private industry for a probabilistic approach is risk analysis [1].

In practice, it is important to quantify the effect of uncertainty and evaluate its effect on performance and design [11, 13, 14]. However, a "point estimate" or single value is often used as an input variable despite the importance of uncertainty [13].

Uncertainty in engineering prediction can be expressed in a number of ways including: uncertainty associated with randomness, namely variation in observed or measured values, and the frequency of those values, and uncertainty with respect to the inference space (i.e. regional construction variation), uncertainty associated with imperfect modeling and estimation and the possible omission of a variable based on limited data [13]. It is apparent that when predicting pavement performance of a road, uncertainty must be considered so that the results are relevant to the "real world". By addressing uncertainty, the as-built performance and life-cycle cost can be predicted more realistically.

Levels of Economic Analysis

The economic analysis of alternatives for most infrastructure types can be conducted for a network or system-wide level or for a single project or site specific level. The major difference between the two levels is the amount of detail and analysis required. Otherwise the principles are applicable for both levels. There is also a higher level of economic analysis involving the corporate business plan of the agency. It is usually referred to as the strategic level, as subsequently discussed.

Using pavements as an example, the objective of network level management is to investigate the relationship between various funding levels and the network status or condition and to recommend a prioritized network level work program based on a set of criteria to support the decision-making. Ideally, at the project level, the alternatives based on the priority analysis at the network level would come "on stream" for implementation (e.g., detailed design and cost analysis, etc.).

LCCA As a Form of Due Diligence

Any investment or expenditure, particularly that of assuming financial liability or obligation (such as a road, purchase of a building, take-over of a business, etc.), should be accompanied by due diligence. In the private sector, this can be very rigorous, involving careful examination of the "books", any existing litigation, any environmental cleanup liabilities, etc. A good part of this of course is economic analysis not only of the current status but also of future expenditures, and revenues.

Infrastructure investments, basically, deserve their form of "due diligence" in terms of life cycle cost analysis. While due diligence is not (yet) a common term in the infrastructure area, a proper application of LCCA could certainly be considered due diligence.

Roadblocks to Acceptance of LCCA

The major roadblocks to acceptance of LCCA may involve varying degrees of the following:

- Lack of understanding as to what is the purpose and applicability of LCCA
- A perception that LCCA might lead to dislocations or large variations in the budget planning process (in fact, the opposite should hold).
- A perception that because of large uncertainties in forecasts of performance, costs, etc., there is no point in doing an LCCA.
- A perception that LCCA removes decisions making responsibilities (in fact, its role is really to support/enhance decision making).
- A perception that LCCA may lead to unfair comparisons or budget allocations between competing infrastructure types.

Review of LCCA Practices and Applications

No where, perhaps, have LCCA procedures been more extensively used than in the field of roads and pavements. The following review is a highly summarized representative sample.

Federal Highway Administration (FHWA), Interim Technical Bulletin [1], 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.

Pavement Design and Management Guide by (TAC) [8] 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.

Ontario Pavement Analysis of Costs (OPAC 2000)[15] 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.

Infrastructure Management Book [6] 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

***Highway Development and Management-4 (HDM-4) System [16*]** 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.
- Programme analysis for preparing single or multi-year work programmes 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.

The Municipal Pavement Management Application, MPMA, [17] 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.

Principles of Cost-Benefit Analysis in a Canadian Context [18] 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.

Summary of LCCA Methods

An overall summary of the foregoing LCCA methods is provided in Table 1. Table 2 provides a summary comparison of the key features of the LCCA methods as well as the advantages and disadvantages.

Table 1 Summary of LCCA Methods

						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 Network (Priority Programming)	Present Worth Present Worth	Deterministic Deterministic	No software (Use Excel Spreadsheet)	No No	No No	No No
Ontario Pavement Analysis of Costs (OPAC 2000)	Project	Present Worth	Probabilistic	OPAC 2000	Yes	Yes	No
Infrastructure Management Book	Project Network (Priority Programming)	Present Worth Present Worth	Deterministic Deterministic	No software (Use Excel Spreadsheet) No software (Use Excel Spreadsheet)	Yes Yes	Yes Yes	No No
Highway Development and Management HDM4	Strategic Network Project	Present Worth Internal Rate Return Present Worth Internal Rate Return Present Worth Internal Rate Return	Deterministic Deterministic Deterministic	HDM 4 HDM 4 HDM 4	Yes Yes Yes	Yes Yes Yes	Yes Yes Yes
MPMA	Network Project	Present Worth Present Worth	Deterministic Deterministic	MPMA MPMA	Yes Yes	Yes Yes	No No
Cost-Benefit Anal. Canadian Context	Project	Present Worth	Deterministic	No software (Use Excel Spreadsheet)	NA	NA	NA

Table 2 Comparison of LCCA Models

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

TOWARD A GENERIC PROTOCOL FOR LCCA

A protocol is a set of rules or codes or procedures governing a process (originally related to diplomatic etiquette but now widely used in various fields). Herein, the process is life cycle cost analysis and the purpose of a set of rules or procedures (e.g., the protocol) is rationality, consistency, practicality and understandability.

In making the protocol generic, the intent is to have it applicable to different areas (in this case, various infrastructure elements), at least in terms of the basics. However, the reality is that some customizing is likely necessary for each application because of their differing conditions, use, behavior, etc. (e.g., roads vs. buildings vs. recreational facilities vs. ……. other infrastructure elements …..)

Why Or When Should LCCA Be Carried Out?

From a public agency point of view, the essential requirements in preserving and operating safe infrastructure at desired levels of service is to identify needs and then acquire the necessary budget or financing to meet those needs. Of course, the available budget is almost invariably insufficient and thus there is a shortfall or "infrastructure gap".

Life cycle cost analysis does not solve any infrastructure gap, per se, but it can be used to achieve best value for available funds and/or to maximize the cost-effectiveness of those funds. In the public sector, this would be best value or maximization of cost effectiveness; in the private sector, this would be a desired rate of return and ensuring that any liabilities, such as environmental cleanups, outstanding debts, etc. are clearly defined and taken into account.

There are situations, however, where rigorous use of an LCCA is not needed for the following reasons: (a) the project or work to be carried out is of limited size so that a straightforward cost estimate is all that is warranted, or (b) only one feasible treatment or alternative is available and it is applied on a regularly scheduled basis, or (c) a multi-year spreadsheet of scheduled expenses for repair/renovation/operation is an alternative.

Difference Between LCCA and Financial Planning

Financial planning is fundamentally concerned with estimating revenues, over some forecasting period, and programming cost outlays through that period.

Life cycle cost analysis is related to financial planning in that it can be employed to compare the alternative uses of funds or expenditures. However, the normal use of LCCA is to compare alternatives within a given budget, where future cost estimates are based on today's costs and then discounted at the real cost of money. By comparison, financial planning must consider or program the actual cost outlays in the future. However, cost outlay needs can be estimated by summing the LCCA results to get an estimate of annual budget needs over a period of time. This is applicable to the situation where a performance or level of service target drives the process.

In essence, financial planning is an activity that any organization, private or public, must do as a matter of good business. Life cycle cost analysis can then assist in making decisions as to the best use of the programmed funds or budgets, usually by comparing alternatives within a defined need. As well, LCCA can be used as feedback to update financial plans and targets over time.

What LCCA Can and Can Not Do

Life cycle cost analysis can identify alternatives representing the lowest cost, or most cost-effective, or highest benefit to cost ratio or highest internal rate of return. It is therefore an important tool in supporting decisions. Moreover, particularly in the case of present worth (PW) analysis, it compares alternatives in present day dollars.

LCCA can not, however, answer questions of equity involving social, political and other considerations. In fact, one of the major issues for any public agency is to achieve a fair allocation of funds or budgets among competing infrastructure elements. Given a budget for an infrastructure element, LCCA is then applicable. But to get to that point requires either tradeoffs/ lobbying/give and take between the stakeholders, which is the usual case, or a multi-dimensional set of criteria or factors. Many of these, however, are either not readily quantifiable and/or involve different measures for different infrastructure elements. Moreover, even when there is an agreement on the applicable criteria or factors, the question then usually arises as to what weights or degree of importance should be assigned.

The Three Levels of LCCA

LCCA has found use primarily at the project level. However, there are actually three levels of applicability, as follows:

- Strategic level, where desired or specified levels of service are defined for the system or network as a whole, and the minimum cost to achieve the level of service has to be determined.
- Network level where LCCA can be used to determine the optimum program (types of treatments, timing and locations) for given budget(s) or funding.
- Project level, where LCCA can be used to identify the most economically effective treatment alternative within a project/section/link/area.

The strategic level, and subsequently the next two levels, must fit within the agency's corporate business plan to be acceptable, useful, practical and understandable. For example, the City of Edmonton articulated a "Corporate Business Plan" (June 26, 2001, available on their web site), and the strategic framework part of the LCCA protocol in Figure 1 is adapted largely from that Plan.

While the strategic framework of Fig. 1 is a highly summarized context, it provides a lead in to the main purpose of the figure, which is to define the major steps in a network level generic protocol. As well, both the strategic and network levels of Fig. 1 are defined in the broader infrastructure sense; however, they are intended to be entirely applicable to the specific (pavements) topic of this paper.

The final step in the network level protocol of Fig. 1 is a transfer to design and construction for project level action. While LCCA for this level is not described herein (a considerable amount of good literature exists; e.g., Ref. [1]), it represents the "fine tuning" of the network/system wide application.

EXAMPLES

The following examples first involve a network level application, where the results could also be viewed as strategic in nature. Next a simplified project level example is presented where the LCCA is concerned only with identifying the lowest cost alternative (e.g., the size of the project is below a designated threshold).

Network Level Application Example

This example, which is presented in a highly summarized form, involves a subnetwork of 266 km of arterial, composite pavements in a Canadian city. A performance model exists for these pavements with subgrade strength, equivalent single axle loads (ESALs) and layer thicknesses as independent variables, and Pavement Quality Index (PQI) as one of the dependent variables. The program period has been selected as 10 years, the minimum acceptable or trigger level PQI as 4.5 (where PQI is on a scale of 0 to 10), and the discount rate as 4%. A computerized package has been applied, which is very closely represented by the generic protocol of Fig. 1, including the steps 12 and 13 alternate which involves an optimization procedure for maximizing overall cost-effectiveness. Treatment alternatives, for sections at or below the trigger level PQI of 4.5, consisted of milling and overlay, plus crack sealing at 5, 10 and 15 years since last rehabilitation. Unit costs are not shown herein as the intent is to present summary results.

Three budget scenarios were analyzed: $0, $500,000/year and $1 million/year. It was desired to see the effect on average PQI (which was initially 5.3 in Year 1) and the percent km below the trigger level PQI of 4.5.

Table 2 presents the results for the three budget scenarios, and Figure 2 illustrates the results graphically. It is immediately obvious that the $0 budget will result in both a very substantial drop in average PQI as well as almost 90% of the network being below the minimum acceptable PQI of 4.5 in 10 years. by comparison, the $500,000 annual budget improves the average PQI and decreases the deficient km slightly to about year 5, and then levels off. Doubling the budget to 1.0 million annually results in a significant increase in average PQI and almost halving the deficient km over 10 years.

In essence, this real example application of LCCA illustrates the effect of different budget scenarios on the performance of a paved road network.

Table 3 Summary Results of the Network Level LCCA Analysis

Year	$0 Budget			$500K/yr Budget			$1.0 m/yr Budget		
	Avg. PQI	km < PQI 4.5	% Total	Avg. PQI	km < PQI 4.5	% Total	Avg. PQI	km < PQI 4.5	% Total
1	5.3	138	52	5.6	128	48	5.7	122	46
2	5.2	146	55	5.7	120	45	5.9	114	43
3	5.0	154	58	5.8	114	43	6.0	112	42
4	4.9	170	64	6.0	106	40	6.3	101	38
5	4.7	178	67	6.1	96	36	6.4	93	35
6	4.6	194	73	6.1	98	37	6.6	90	34
7	4.5	199	75	6.1	101	38	6.7	85	32
8	4.4	213	80	6.0	101	38	6.8	82	31
9	4.2	221	83	6.1	101	38	7.0	80	30
10	4.1	234	88	6.2	98	37	7.2	72	27

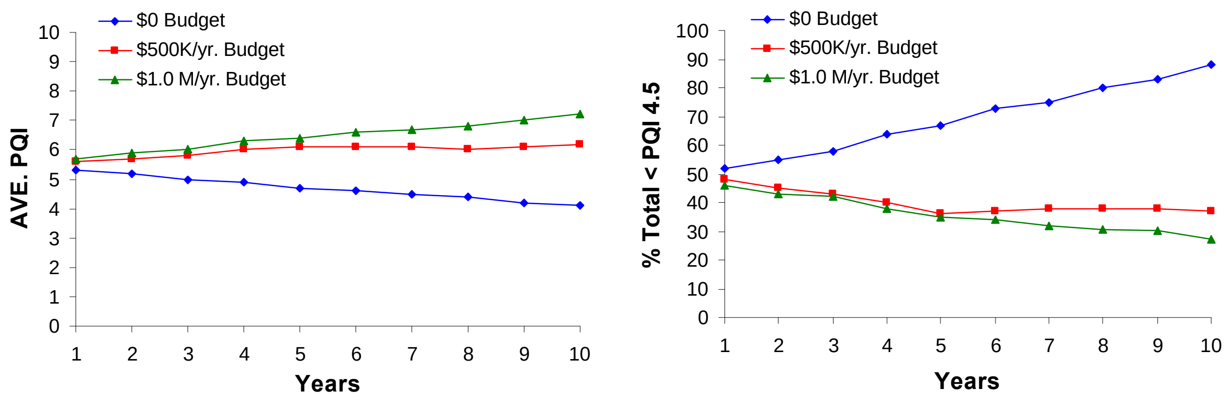

Figure 2 Plots of results for three budget levels

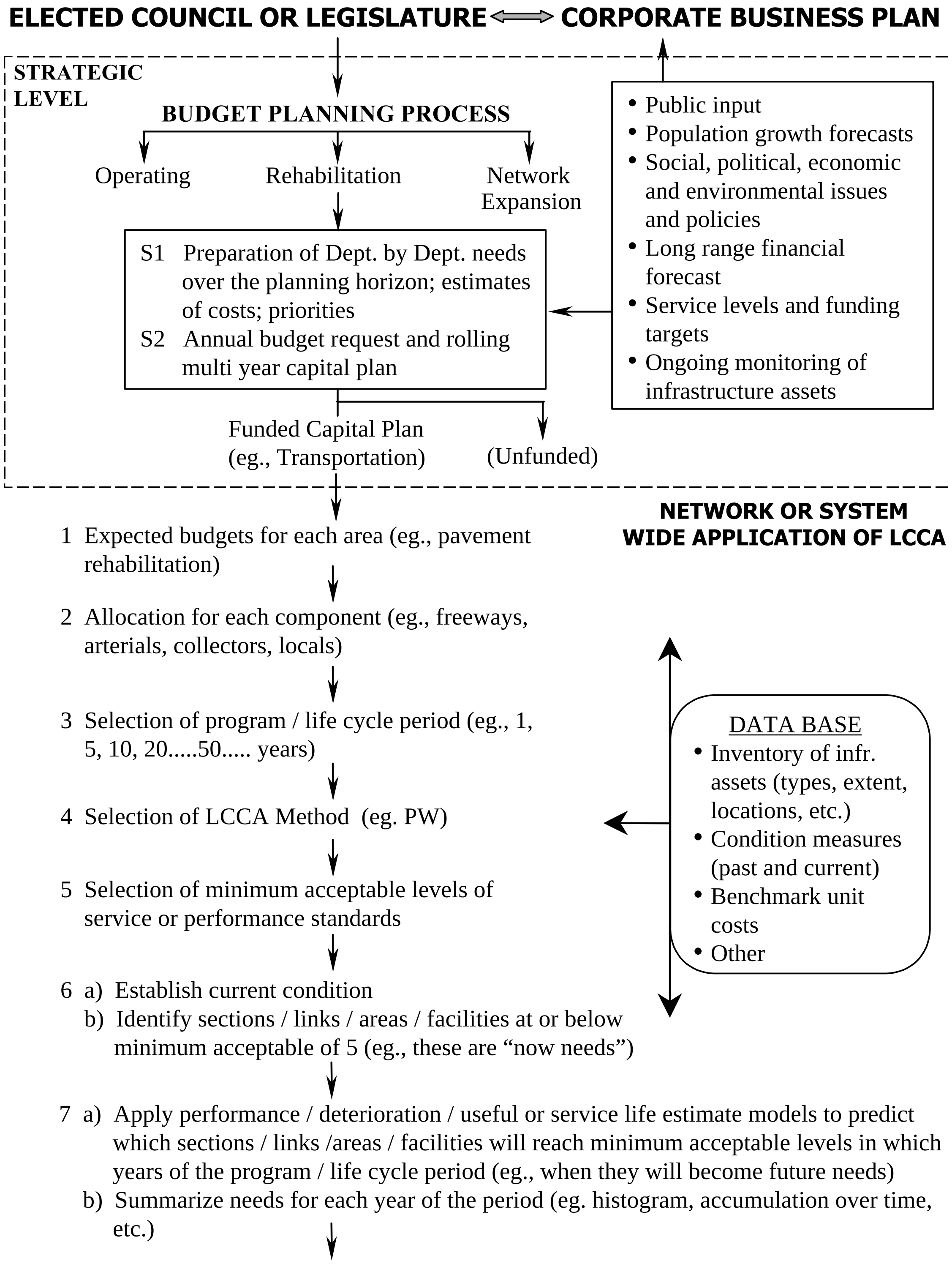

Figure 1 Major Steps in a LCCA Generic Protocol at the Network or System Wide Level

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

↓

9 a) Identify feasible treatments or actions to correct or remedy needs
b) Estimate service or useful life of each treatment

↓

10 Establish measures of effectiveness or utilization of the infrastructure asset (eg., area under condition vs. age curve x number of users; or volume of traffic)

↓

11 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

↓

12 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 (eg., they are added to the backlog of needs, or the gap)

↓

13 Repeat 12 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

↓

12 ; 13 Alternate: If a multi-year analysis is desired (see 8), then each combination of 11 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 (eg., treatment ⟷ section / link / area / facility ⟷ action years) and requires an optimization procedure to determine the overall most cost-effective program

↓

14 Prepare a recommended year by year by infrastructure component program of work

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⇩

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.

Project Level Application Example

This example involves a 3.0 km project length of 2-lane heavy duty flexible pavement on an arterial street. While it is desired to do a LCCA, the threshold limit established by the agency between a simple LCCA and a more rigorous LCCA is $1.0 million for total initial project cost. The project is expected to be below the threshold and thus a simple comparison between the following two alternatives will be carried out:

* Alternative A:
  40 mm surface course (conventional)
  80 mm binder course
  80 mm asphalt base
  150 mm granular base
  450 mm granular subbase
  Initial cost = $150,200/lane-km
  Initial expected service life = 16 years

* Alternative B:
  40 mm surface course (polymer modified)
  80 mm binder course
  80 mm asphalt base
  150 mm granular base
  450 mm granular subbase
  Initial cost = $159,300/lane-km
  Initial expected service life = 20 years

The initial project cost for Alternative A is 3.0 km x 2 lanes x $150,200 per lane-km = $901,200, and for Alternative B it is 3 x 2 x $159,300 per lane-km = $955,800. Thus the total initial costs are below the established threshold of $1.0 million.

The life cycle period for this example is 30 years and the discount rate was selected as 5.0%. Because this was to be a simplified LCCA, a schedule of treatments over the 30 years was identified, together with their estimated costs, as shown in Table 4. The PW of costs was calculated for each alternative, and the totals show that Alternative B is the least cost on a life cycle basis although it has a higher initial construction cost.

Table 4 LCCA Comparison of Design Alternatives (Per Lane-Km Basis)

Alternative A				**Alternative B**			
Year	**Treatment**	**Cost**	**PW of Cost**	**Year**	**Treatment**	**Cost**	**PW of Cost**
0	Initial Constr	150,200	150,200	0	Initial Const	159,000	159,300
3	Crack Seal	470	400	5	Crack Seal	470	370
7	Patching	3,100	2,200	12	Patching	3,100	1,700
15	Rehab	45,500	21,900	20	Rehab.	57,600	21,700
18	Crack Seal	28,700	11,900	23	Crack Seal	6,800	2,200
20	Major Maint.	10,600	4,000	25	Patching	6,100	1,800
27	Rehab.	27,600	7,400	30	Resid. value	(15,300)	(3,500)
30	Resid. value	(17,600)	(4,000)				
		Total	$194,000			Total	$183,570

CONCLUSIONS

The following conclusions are derived from the content of the paper:

- Life cycle cost analysis (LCCA) should consider the stakeholders involved, incorporate the relevant agency and non-agency costs, be based on an appropriate life cycle period, and use the method most applicable to the situation.
- LCCA can be applied at three levels: (a) strategic, (b) network or system wide, and (c) project or site specific.
- A generic protocol for LCCA at the network level has been described and illustrated with a real pavement network example. As well, a simplified project level example application of LCCA has been provided.

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