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Life Cycle Cost Analysis as a Decision Support Tool for Managing Municipal Infrastructure

Authors: Saidur Rahman, Ph.D and Dana J. Vanier, Ph.D[1]

Abstract

Life cycle cost analysis (LCCA) is a process for evaluating the total economic cost of an asset by analyzing initial costs and discounted future expenditures, such as maintenance, repair and renewal (MR&R) costs, and user and social costs over the service life of the asset. The Institute for Research in Construction (IRC) has initiated a three-year project on Municipal Infrastructure Investment Planning (MIIP) to provide managers of municipal infrastructure with decision support tools to optimize their investments and to maximize the value of their assets over their life cycles. A survey of Canadian infrastructure managers and owners, conducted in the MIIP project, found that: 91% of respondents want decision support tools to help manage their assets; 24% identify LCCA as a potential decision support tool; and 70% think that the LCCA process could decrease high levels of deferred maintenance. This paper provides an overview of the fundamentals of LCC calculations and analysis and identifies many of the costs that must be taken into consideration. This preliminary investigation on LCCA for municipal infrastructure discusses the life cycle cost parameters such as life cycle phases, discount rate, agency and user costs, and factors attributed to political and social costs. It describes both deterministic and probabilistic approaches and proposes a nine stage LCCA process with an example for the renewal of a trunk sewer. The state of practice of LCCA and its implementation to help management of municipal infrastructure is presented and discussed in this paper. The paper also reviews various LCCA software applications and discusses their suitability as decision support tools for municipal infrastructure.

1. INTRODUCTION

The life cycle cost (LCC) of an asset is defined as the total cost, in present value or annual value, that includes the initial costs, maintenance, repair and renewal (MR&R) costs over the service life or a specified life cycle. LCC is based on an understanding that the value of money changes with time and as a result, expenditures made at different times are not equal. This concept, referred to as the ‘time value of money’, is the basis for life cycle cost analysis (LCCA). LCCA is a process for evaluating the total economic cost of an asset by analyzing initial costs and discounted future expenditures such as maintenance, operational, user, and social costs over the service life or life cycle of an asset. The term ‘LCCA’ is used throughout this paper to express the application of, and the approaches and procedures related to LCC, for managing municipal infrastructure.

"Municipal infrastructure is a complex technical system that provides a varied range of valuable and essential services to the public" (Lemer 1999). Municipal infrastructure is also a valuable component of any society. In Canada, municipal infrastructure represents 70% of the total value of Canadian civil infrastructure (CSCE 2003) and is estimated to have a value of approximately $1.1 Trillion (Vanier 2001). It is therefore important for municipalities to invest properly in the maintenance and renewal of their infrastructure assets, and to keep them in adequate/satisfactory condition despite limited budgets (Vanier and Rahman 2003).

All municipalities have aging infrastructure and their managers need to identify the required budgets to sustain maintenance and renewal programs. At the same time, the majority of cities and towns continue to grow and expand; thereby creating new infrastructure that must also be maintained. LCCA can be used as a decision support tool to help engineers/managers propose, compare, and select the most cost effective, alternatives for maintenance, renewal, and capital investment programs.

The basic LCCA principles have been known and used in management decision-making for more than 100 years, but the development of a systematic approach to LCCA for civil infrastructure appeared only 25-30 years ago in the United States (TRB 2003). A computer-based model developed initially for the World Bank in the 1960s is an early example of LCCA in public works infrastructure (Lemer 1999). In

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the 1990's, LCCA received support in the USA in almost every infrastructure sector via a number of legislative orders (US Executive Order 12893 1994; and US Executive Order 13123 1999). In the last decade LCCA has been applied in the aerospace, automotive, defence, transportation, energy, and civil infrastructure sectors (SAE 1992; NIST 1996; FHWA 1998; SAE 1999; Chewning and Moretto 2000; TRB 2003).

This paper discusses the application of the LCCA approach to assist municipal infrastructure decision-making. The fundamentals of LCC and its calculation methods are presented first. A proposed and formalized LCCA approach is described next. A brief description and discussion of existing LCCA tools and techniques are given, and discussions and conclusions follow.

2. FUNDAMENTALS OF LCC CALCULATIONS AND ANALYSIS

Every municipal infrastructure asset has a series of life cycle phases from the time it is conceived, through the planning phases, during construction and service life phases, until the asset is declared surplus and is decommissioned. Figure 1 illustrates typical infrastructure life cycle phases, each contributing different types of costs.

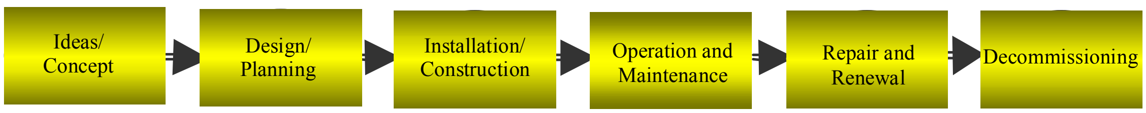


FIGURE 1. Life Cycle Phases for Municipal Infrastructure

Municipal infrastructure managers must have immediate access to reliable cost data to make responsible engineering decisions. For example, the decision makers must take into account: the different methods of LCC analysis, the typical acquisition expenses, the anticipated ownership costs, the probability of future LCCs, and the uncertainties in the LCCA calculations.

2.1 LCC Analysis Methods

The most commonly used LCC methods are: (1) the present value (PV) method and (2) the uniform annualized cost method.

2.1.1 Present Value Method. The present value (PV) is determined for future expenses by taking account of the anticipated inflation of present dollars and discounting that amount by a predicted rate over the period between the anticipated time of future expenses and present time. The discount rate is discussed later in the paper.

$$\mathrm{PV} = \mathrm{FV}\left[\frac{1}{(1+i)^{\mathrm{n}}}\right] \qquad (1)$$

Where, PV = present value; FV = future value of expenses; n = number of years between time of analysis and time of expense; and *i* = discount rate.

In the case of municipal infrastructure, any anticipated future capital renewal at the end of the asset service life is considered a future value (FV) and should brought to present value (PV).

2.1.2 Uniform Annualized Cost Method. The method is used to transform present or future costs into uniform annual costs and is expressed as:

$$\mathrm{A} = \mathrm{PV}\left\{\frac{\left[i(1+i)^{n}\right]}{\left[(1+i)^{n}-1\right]}\right\} \qquad (2)$$

Where, A = end of year expenses, PV = present value from Equation (1), n = number of years from time of analysis to end of life cycle and i = discount rate.

In the case of municipal infrastructure, a cost (PV) at year 0 can be equated to the sum of a series of annual costs over the service life of the asset or inversely an annual maintenance cost (A) over 20 years can equal a present value at year 0.

2.2 LCC Considerations for Municipal Infrastructure

2.2.1 Life Cycle Cost (LCC). LCC should include all costs associated with the planning, development, acquisition, operation, MR&R, logistical support, and disposal of an asset: The LCC for municipal infrastructure should also take into account social costs:

$$\text{Life Cycle Cost (LCC)} = \text{Acquisition Cost} + \text{Ownership Cost} + \text{Social Cost} \qquad (3)$$

Acquisition costs are incurred mostly during the first three life cycle phases shown in Figure 1. Costs in this category include, but are not restricted to: land purchase costs, right of way costs, purchase expenses, purchase commissions, legal services, taxes, land survey fees, design fees, construction costs, lost opportunity costs, bridge financing, capital equipment leases, purchase commissions, site inspection expenses, project management fees, and administrative and technical overhead.

Ownership costs can occur during every phase of the infrastructure life cycle. As it is difficult to completely predict the service life of an infrastructure asset, it is equally difficult to anticipate or forecast its LCC. Ownership costs include all direct costs such as energy costs, preventive maintenance expenses, inspection costs, and MR&R costs. In some instances, it is possible to predict asset failure and to calculate the resulting repair, lost opportunity, and disruption costs. In some organizations, operational costs such as custodial or janitorial services and snow removal are attributed directly to an infrastructure asset (water treatment plants, community centres, etc.). Additionally, there are many indirect costs that should be taken into account in the LCC equation, including: interest on borrowed funds, administrative and staffing costs, and legal expenses.

Social costs include all intangible costs incurred by the general public owing to disruptions of services to the community. These can include costs during construction, maintenance, or repair projects that relate to additional physical stress and loads on detour routes, disruptions to merchants, environmental costs and additional expenses incurred by taxpayers such as vehicular wear and tear. “The vehicle operation costs are related to the fuel consumption, lubricants consumption, tire wear, maintenance parts, maintenance labour, depreciation, interest lost, and crew time” (HDM 1995).

2.2.2 Present Value Calculation. Present value (PV) and discounting for LCC is calculated as (ASTM E917 1994):

$$\text{PV} = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \qquad (4)$$

Where, PV = present value of life cycle costs, C_t = sum of all relevant costs occurring in year t, n = length of analyzed period, and i = discount rate.

$$C_t = AC + EC + MC + RC + OC - SV \qquad (5)$$

Where, AC = acquisition cost, EC = energy cost, MC = direct and indirect maintenance cost, RC = renewal cost, OC = direct and indirect operations cost, and SV = salvage value.

2.2.3 The Discount Rate. A dollar today is worth more than a dollar in ten years time. Similarly, the present value of a dollar that will be spent ten years from now is less than the value of today’s dollar. Discounting takes into account the changing value of money over time. The discount rate is an agreed upon/accepted factor to reflect this time-value of money. The discount rate in the private sector is normally defined as the financial advantage of one investment when compared to a "risk free" annual return on another. The discount rate (i) has three components: the actual opportunity cost of capital (cc); the premium for financial risk for investment (fr); and the anticipated rate for inflation or deflation (pi). Each component is typically stated as percentage of the rate of annual increase or decrease, thus current discount rate can be calculated as (TRB 2003):

$$\text{Discount rate } (i) = cc + fr + pi \qquad (6)$$

There are two types of discount rates: financial and social. The financial discount rate is used to reflect the time-value of money as compared to a benchmark cost of capital. The financial discount rate in public organizations is often based on the organization's cost of raising capital. The financial discount rate in the private sector is often based on "risk free" annual return rate such as a commercial bank certificate of deposit or a government treasury bond. The social discount rate is used to reflect social values and preferences when comparing or measuring economic activities involving large public assets (e.g. infrastructure) with cost/benefit streams spanning very long time periods. A higher social discount rate reflects a greater tendency to defer public costs to future generations (MIIP 2003).

2.3 Deterministic Versus Probabilistic Approaches in LCCA

A deterministic LCCA approach requires input variables that are fixed and distinct in both time and cost. These input values are usually based on historical evidence or professional judgment. Deterministic approaches in LCC computation are straightforward and can be conducted even manually using a calculator or electronically with a spreadsheet. Although a sensitivity analysis can identify those variables that affect the results, the deterministic approach cannot consider the uncertainty in the input variables.

In the probabilistic approach, the variables such as discount rate, maintenance cost, repair and renewal cost, time of rehabilitation, and social cost, are modeled using probabilistic distributions (Herbold 2000). This approach also allows for the simultaneous computation of differing assumptions for several variables: iterative results will calculate the likelihood that a particular LCC forecast will actually occur. Probabilistic LCCA is now more accessible due to the significant increases in computer processing capabilities and availability (Liverpool 2002; FHWA 2003; TRB 2003).

2.4 Uncertainties in LCC

Predicting future costs is fraught with potential errors, owing to the uncertainty in future costs, interest rate and even future events (repairs, renewal, etc.). For example, the usual practice of using market interest rate for calculating the discount rate by assuming that it will be constant over the life cycle of the asset ignores the possibility of variations resulting from changes in national and international monetary and fiscal policies (Rakhra 1980). The prediction of inflation rates over a long-term period (e.g. 30 to 100 years) increases the uncertainty. The general approach with life cycle studies is that “effects of inflation are ignored on the assumption that all costs will inflate at the same rate” (Rakhra 1980). But it is highly unlikely that material, labor and energy costs will change at exactly the same rate; therefore, major cost elements (capital, maintenance, operation, etc.) can vary accordingly.

Another uncertain area in LCCA forecasting is determining the service life of assets and their components. Theoretically, the service life can be related to observed probability of failure (Moser 1999; Furuta et al. 2003). In practice, however, it is difficult to obtain data on the probability of failure as many components are routinely renewed before the end of their technical service life (i.e. modernization, compatibility, obsolescence, and high maintenance and repair expenses). Without an accurate prediction of the service life, forecasting the timing of MR&R activities is very difficult. A probabilistic approach is essential to address this issue: the key parameters for the calculations should be represented as probability distributions (TRB 2003). Monte Carlo simulation is a widely used probabilistic approach for dealing with these computations and provides probabilistic bands of the stated problem. As an example, Table 1 summarizes the Federal Highway Administration input variables for pavement maintenance (FHWA 1998).

3. PROPOSED LIFE CYCLE COST ANALYSIS APPROACH

As mentioned earlier, LCCA should include all appropriate costs including initial construction costs, maintenance, repair and renewal costs, social costs and decommissioning costs. The analysis period under consideration should be long enough to cover the service life of the infrastructure system. All alternatives for maintenance and renewal should be considered. The essence of LCCA is that one alternative may have a higher initial cost, but its costs over the asset’s life cycle may be lower than other alternatives. As an example, the maintenance/renewal plans for a trunk sewer are shown in Table 2.

As costs are not currently available for some of the items in the Table 2 breakdown, assumptions have been made to develop Table 2. For example, an 8% contingency cost was added to the base construction cost (CC) as suggested in Yardsticks for Costing (CMD/Canada 2003). Preventive maintenance, major repair and user costs are assumed as 1%, 50% and 10% of the base construction cost, respectively. A preventive maintenance cost of 1% of CC is proposed for closed circuit TV (CCTV) inspection based on a $5 per meter average for 600 mm diameter pipe (Winnipeg 2001).

TABLE 1: LCC Input Variables for Pavement Improvement Project (FHWA 1998)

LCCA Component	*Input Variable*	*Source*
Initial and Future Agency Costs	Preliminary Engineering	Estimate
	Construction Management	Estimate
	Construction	Estimate
	Maintenance	Assumption
Timing of Costs	Pavement Performance	Projection
User Costs	Current Traffic	Estimate
	Future Traffic	Projection
	Hourly Demand	Estimate
	Vehicle Distributions	Estimate
	Dollar Value of Delay Time	Assumption
	Work Zone Configuration	Assumption
	Work Zone Hours of Operation	Assumption
	Work Zone Duration	Assumption
	Work Zone Activity Years	Projection
	Crash Rates	Estimate
	Crash Cost Rates	Assumption
Net Present Value	Discount Rate	Assumption

TABLE 2. Maintenance/Renewal Plan for a Trunk Sewer

Steps	*Examples and Detailed Activities*				*Action*
1. Problem Statement	Concrete trunk sewer (length 100 m and diameter 600 mm) with breakage and seepage problems.				Appropriate inspection and condition evaluation.
2. Select Analysis Period	20, 40, 60, 80 or 100 years.				80 years.
3. Propose Alternatives	(A) Chemical grouting, spot repairs and joint sealing for every 10 years. (B) Joint sealing and sliplining for every 20 years. (C) Complete replacement of trunk sewer @ 80 years.				Verify alternatives.
4. Choose Economic Cost Model	PV method, Uniform Annualized Cost method, Benefit/Cost ratio or Rate of Return method (discount rate = 4% and $1US = $1.30 CDN).				PV method.
5. Prepare Cost Breakdown (1) Initial Cost (2) Maintenance and Operational Cost (3) Salvage Value	Option and renewal cycle	A (10 yr.)	B (20 yr.)	C	Prepare detailed cost breakdown for every item.
	(1) Design*	3,120	6,000	10,920	
	(1) Construction Cost (CC)	52,000	100,000	182,000	
	Contingency costs (8% CC)	4,160	8,000	14,560	
	Construction cost subtotal	56,160	108,000	196,560	
	Admin. and legal costs (+ 20%)	11,232	21,600	33,312	
	Total construction costs	67,392	129,600	235,872	
	(2) Preventive Maintenance (1% CC/yr)	5,200	10,000	†45,500	
	(2) Major Repair (50% CC each cycle)	26,000	50,000	-	
	(2) Emergency Costs††	10,000	10,000	†10,000	
	(2) User Costs (social, delay, service etc.) (10% CC)	2,500	10,000	†18,200	
	(3) Salvage Value (2% CC)	1,040	2,000	3,640	
6. Cost Estimate	Initial Costs in Present Dollar	70,512	135,600	246,792	Cost calculation in present value (PV).
	Maintenance Cost in PV	80,280	53,182	31,558	
	User Costs in PV	10,132	7,597	10,349	
	Salvage Value in PV	45	87	158	
7. Determine LCC	Life Cycle Cost	$160,880	$196,292	$288,541	
8. Evaluate Results	Analytical Approaches (sensitivity analysis and Monte Carlo simulation), Budget, and Risk Evaluation.				Choose lowest LCC.
9. Decision (choose preferred action)	Alternative A, B or C.				Alternative A.

Note: All costs are assumed for model calculation only and based on constant dollars. In some cases, future costs such as preventive maintenance and salvage value are estimated as a percentage of the construction costs whenever this correlation is applicable.
† Costs considered for every 25 years and ††Lump sum amount.

Salvage value is considered as 2% of base construction cost and a lump sum amount is assumed for emergency costs. New construction and repair costs for the alternatives are taken from projects in USA (AWWU 2003; California 2003). Cost data for repair in Alternative B were proposed in a research report by Zhao and Rajani (2002).

4. CURRENT LCCA TOOLS AND TECHNIQUES

As mentioned earlier, LCCA has formed the basis for decision-making in a wide range of industries from automotive to civil infrastructure. The state-of-practice, tools, methodologies, and techniques vary widely depending on the particular area of life cycle concerns (Salem et al. 2003).

4.1 Handbooks, Manuals and Guidelines

Numerous handbooks, manuals, and guidelines have been published on life cycle cost analysis, most dealing with specific types of infrastructure assets. Examples of LCCA documents are listed in Table 3. A comprehensive LCCA guideline on municipal infrastructure is not yet available.

TABLE 3. LCCA Handbooks, Manuals and Guidelines

Type	*Reference Title*	*Prepared by*	*Date*
Handbook	CBD-212, Building and Life-Cycle Costing – Overview of the concept of total life cycle costing	Canadian Building Digest 212, National Research Council Canada, Ottawa, Canada	1980
Manual	Life-Cycle Costing Manual, Handbook 135	National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA	1996
Guideline	Life-Cycle Cost Analysis in Pavement Design, FHWA-SA-98-079	Federal Highway Administration, US Department of Transportation, Washington D.C., USA	1998
Guideline	Life Cycle Cost Analysis Primer <www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.htm>	Office of Asset Management, Federal Highway Administration, US Department of Transportation, Washington D.C., USA	2002
Guideline	Bridge Life Cycle Cost Analysis – NCHRP Report 483	National Cooperative Highway Research Program, Transportation Research Board, Washington D.C., USA	2003
Book	Life Cycle Costing for Facilities	A.J. Dell'Isola and S.J. Kirk, RSMeans Research, Reed Construction Data™, Kingston, MA, USA	2003
Book	Whole Life-Cycle Costing: Risk and Risk Responses (to be published Nov. 2003 - Not available for review)	A.H. Boussabaine and R. Kirkham, Blackwell Publishing Ltd., Oxford, UK	2003

4.2 Information Technology (IT) Tools

LCCA software applications are becoming more and more prevalent in most industries as time progresses. Information technology tools can quickly and accurately estimate the life cycle costs of infrastructure components and systems, with itemized cost breakdowns they can perform cost comparisons with risk assessment for any type of investment. IT tools for LCCA fall into two main categories: standalone and integrated.

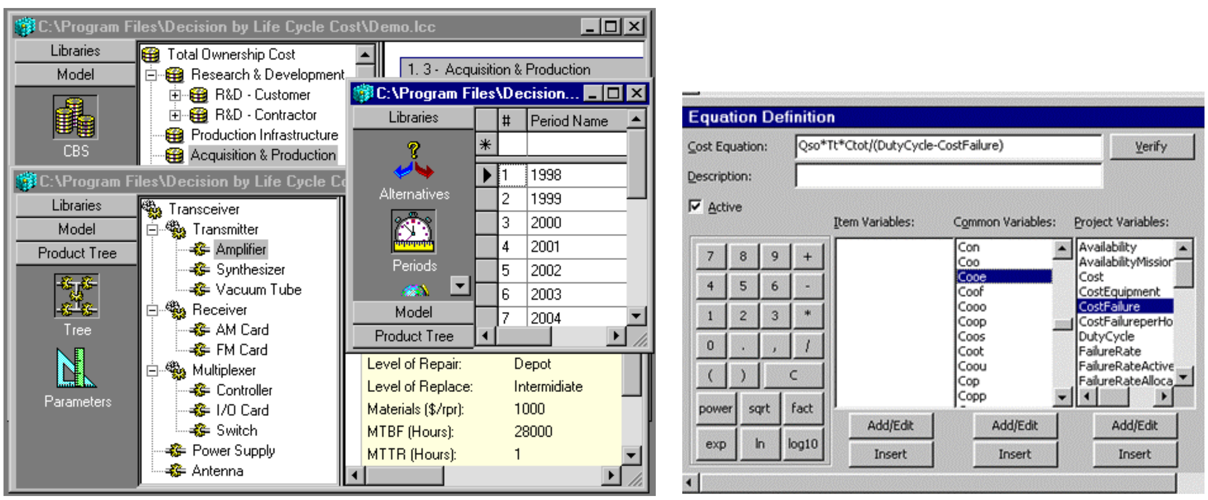
TABLE 4. Standalone Software for LCCA

Software	*Produced by*	*Applications*	*Features*
Microsoft Excel	Microsoft Corporation <www.microsoft.com>	Database and LCC calculations.	Spreadsheet for data analysis, graphical interface, mathematical and statistical functions for cost calculation.
D-LCC	SoHaR Incorporated <www.sohar.com>	Software and hardware reliability, LCC for transportation and aerospace.	Networkable, multi-user options, cost breakdowns, visual interface with costing model, library facility, and report generation capability.
LccWare	Isograph Inc <www.isographdirect.com>	System reliability, maintainability, LCC and integrated logistic support.	Visual interface with cost model, online cost calculator, project wizard, cost library, security model, report generator, and graphing facilities.
Building Life Cycle Cost (BLCC)	National Institute of Standards and Technology (NIST) <www.eere.energy.gov/femp>	Building facilities, nuclear and energy sector.	Two modules for water and energy related LCC for buildings, comparative analysis report, net savings, uses current cost values, user friendly.
Relex7.6	Relex Software Corporation < www.relexsoftware.com>	System reliability, maintainability, LCC of integrated facilities.	Cost breakdown modeling with visual interface, library functions, online help and integrated cost calculator.
WLCC V1.1 (Liverpool)	University of Liverpool <www.liv.ac.uk/abe/index.html>	LCC for buildings and facilities.	Project cost input options and Monte Carlo simulation for LCC calculation.

4.2.1 Standalone. A limited number of examples of standalone IT tools, along with details of their software features, are included in Table 4 to promote discussion of LCCA capabilities. Tables 4 and 5 are not exhaustive lists of applications in this domain and the inclusion of LCC applications in these lists does not constitute endorsement of these products.

Microsoft Excel has incorporated approximately 50 financial functions that can assist in the calculation of life cycle costs. For example, this well-known spreadsheet application has functions to calculate the present value (PV), and the future value (FV), as well as, annualized payments (PMT).

There are a number of reliability-based standalone products that are for specialized areas such as buildings, bridges, pavement management, and machinery parts. For example in Table 4, D-LCC, LccWare, and Relex software have similar data input format and analysis techniques for cost calculations and discounting. These applications support operations such as, preliminary concept to an extensive evaluation of proposed alternatives leading to final decision-making. In Figure 2 (a), D-LCC cost breakdown of elements is represented in the form of a tree structure that is created interactively by the application. A cost calculator with cost function tool is shown in Figure 2 (b) for the Relex software. Generally, these cost function tools perform online calculations with Visual Basic to calculate the net present value (NPV) of the project. In LccWare, a project wizard simplifies the creation of new projects with detailed cost libraries. Sensitivity analysis and report generation are common features for such types of software.



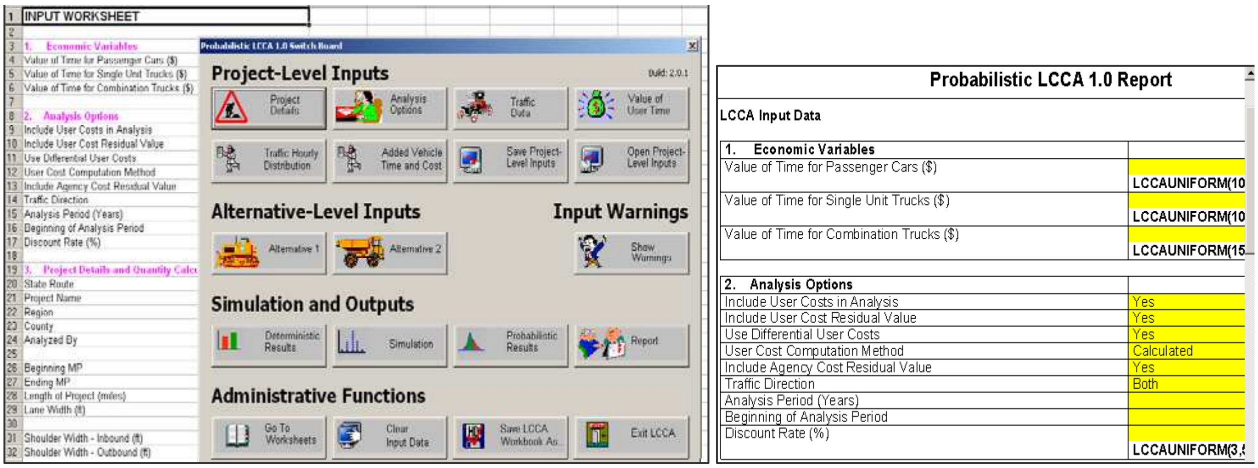
(a) (b)

FIGURE 2. Cost Breakdown, Cost Calculator and Report Generation Display

BLCC is another example of a standalone IT product. It contains two modules for performing energy and water-related LCCA and provides computational support for the analysis of capital investments for federal buildings. The analysis results include the present value of the LCC for a base case and an alternative. The program also calculates net savings, savings-to-investment ratio, internal rate of return, and payback period for each alternative. In addition, it also gives a summary of energy savings and emission reductions (NIST 1996). Although BLCC is not directly applicable to municipal infrastructure, the advantages of using such a tool for planning the maintenance and renewal of municipal assets are readily evident.

WLCC is a simplified reliability-based software tool developed by researchers at the University of Liverpool (Boussabaine and Kilroy 2002). The program requires Microsoft Excel to generate the output from a Monte Carlo simulation. The data inputs include the general project information and project costs such as initial capital costs, residual value, regular maintenance cost, operational costs and other non-regular costs. WLCC calculates the LCC as whole life cycle cost (WLCC) and has the limitation of a maximum analysis period of 50 years.

4.2.2 Integrated Systems. There are few integrated systems available for managing infrastructure facilities. Most existing systems deal with a specific domain such as pavement management and most are not interoperable with other applications. An example of an integrated system is FHWA's RealCost LCCA software (FHWA 2003). It calculates the life cycle costs for both agency and user costs associated with construction factors for pavement structures. In Figure 3(a), a "switchboard" displaying alternatives for data entry is superimposed on a Microsoft Excel workbook. This figure also demonstrates the graphical capability of many of the newer LCCA tools. All project inputs and simulation functions can be accessed through this switchboard. Both probabilistic and deterministic approaches are integrated in the system. The interactively generated report of input records is displayed in Figure 3(b).



(a) (b)

FIGURE 3. FHWA's RealCost LCCA Software (FHWA 2003)

Pipeline Asset & Risk Management System (PARMS 2003), a research product of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, is currently being developed to analyze the whole life cost (WLC) implications of a range of scenarios related to buried infrastructure. Figure 4(a) displays the user input settings including the "Replacement Actions" and "Sensitivity analysis" parameters. The policy summaries and net present value are shown in Figure 4(b). Figure 4(c) displays the age distribution of pipes as length in km on the y-axis and year of construction on the x-axis. Pipeline failure rates (number of failure/100 km) for four different materials are shown on the y-axis in Figure 4(d) with the corresponding future years on the x-axis.

5. SUMMARY AND DISCUSSION

A dilemma exists for infrastructure owners/managers in allocating budgets for new construction or for the maintenance/renewal of existing infrastructure. Using LCCA to investigate design and material alternatives can reduce both initial construction and long-term preventive maintenance costs. However, it is the individual infrastructure manager's decision to choose the cost breakdown method, discount rate, life cycle, and alternatives in any LCCA investigation. Although some published LCCA guidelines exist, they are limited to specific infrastructure types like pavements, bridges, and water works.

A recent survey regarding municipal infrastructure included questions related to life cycle cost analysis. The survey found that 91% of respondents indicated the need for decision support tools to manage their assets; 24% of the respondents identified LCCA as a potential decision support tool, and 70% of respondents think that the LCCA process could provide support in reducing the high level of deferred maintenance. Only a few respondents indicated that LCCA is a current best practice relating to strategic asset management (MIIP 2003). The above findings emphasized the potential for LCCA as a decision support tool for municipal infrastructure management.

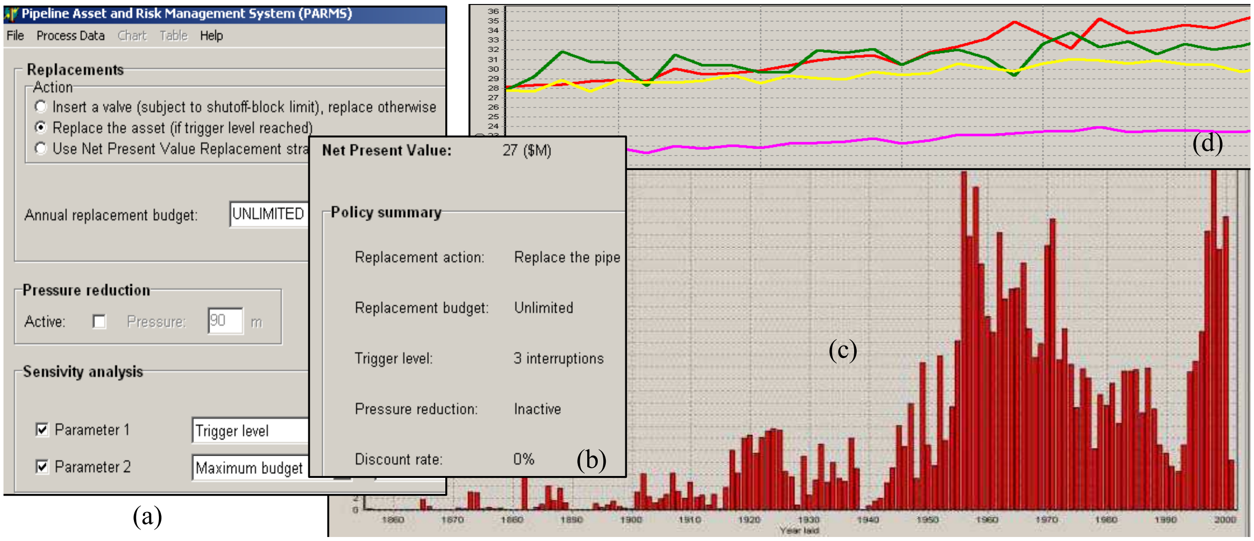


FIGURE 4. Snapshot of PARMS Display (PARMS 2003)

In this paper, a detailed LCCA approach is presented for comparing alternatives for repair/renewal of municipal infrastructure. All cost considerations should be taken into account for the LCC calculation. Infrastructure is vulnerable to "random" natural forces, thus, emergency funds are proposed in the method during every maintenance/renewal cycle (Table 2). These costs have also been suggested by Kong and Frangopol (2003). The importance of hidden and social costs has also been discussed. However, there is a significant lack of cost information on issues such as user delay, service disruption, business loss, customer compensation, political agendas, and environmental and health related costs. A detailed survey on LCCA in municipal organizations shows that very few municipalities are considering these social and hidden costs in the application of LCCA (Arditi and Messiha 1999). Municipalities need more information on these and other life cycle costs; case studies are recommended to obtain detailed information on these issues.

It has been noted that there is limited usage of LCCA in municipal infrastructure management. The reasons are both practical and political. For example, different authorities in the municipalities manage capital investment, maintenance, and operating costs. In addition, infrastructure owners control these issues but many infrastructure assets have long service lives compared to their managing authority. Also the recent amalgamation of several Canadian municipalities sometimes causes complexity in the process of data integration, collection, and analysis.

Another barrier to using LCCA is the inherent uncertainty associated with LCCA parameters. Two analytical approaches, deterministic and probabilistic, have been described in the paper. In the deterministic approach, sensitivity analyses can be performed for the proposed alternatives depending on input variables. Most standalone software described in this paper does sensitivity analyses for model validation. A probabilistic LCCA approach can address the uncertainty associated with costs in the future. In this approach, the probabilistic distributions are generated from calculation or from assumption or expert opinion. However, there are few applications using this approach.

LCCA provides a decision-making process to select the most cost-effective alternative for the maintenance and renewal of infrastructure. “The aim of the decision-making process is to identify the course of action that will most benefit the asset system’s state and performance within pre-determined economical, time, and resource constraints” (Allouche 2002). Decision-making processes for municipal infrastructure typically include the consideration of criteria that depend on infrastructure category and condition, such as service life, material properties, physical characteristics, unit repair costs, condition of related assets, and running performance. The ability to anticipate the future rate of deterioration based on the current condition of infrastructure is another essential aspect in the decision-making process. For example, a number of automated and semi-automated decision-support systems have been developed to assist construction practitioners (Hastak 2000).

IT tools can assist decision support for infrastructure management in the LCCA domain. In the process of calculation, each software application estimates and summarizes life cycle costs as present value based on input cost factors. RealCost LCCA from FHWA deals with uncertainties and risks with probabilistic simulation. PARMS is based on three components: planning (whole life costing), priority (optimized renewal strategy), and risk (probability analysis). Cost modules for different categories of infrastructure and online help options may be added to the integrated systems. However, many applications can be considered "black boxes" with the user knowing little about the internal calculations. In addition, LCCA requires significant data input by the user or extensive data from other applications.

6. CONCLUDING REMARKS

The term 'LCCA' has different meanings for different organizations, but most use the term to mean a model to represent the cost of ownership for the entire life cycle of an asset. This engineering economic model and the associated analytical process can help designers and owners make informed decisions that can minimize construction, operational, and maintenance costs of infrastructure. The approach presented in this paper in Table 2 provides a strategy for the application of LCCA in municipal infrastructure. As demonstrated in this paper, LCCA considerations should include all phases of the infrastructure life cycle, and should take into account all costs for land purchases, planning, installation/construction, maintenance, operation, and eventual decommissioning/disposal. The considerations should also include the social costs and the user costs.

Researchers need to investigate ways to calculate and integrate economic factors, engineering management issues, and uncertainty predictions in LCCA. These can be integrated with visualization tools to provide practical examples or best practice to practitioners. A few case studies involving LCCA should be performed on municipal infrastructure data, perhaps including social and user costs to illustrate its capabilities. More information is required on those social and users costs that play an important role in decision-making about maintenance and operations. These costs could include actual cost data for user delay, service disruption, business loss, and customer compensation. The integrated software described in this paper can assist decision-making when dealing with uncertainty. However, more research is needed for the development of modular-based integrated systems for municipal infrastructure management. In the interim, LCCA can still be used as an effective decision support tool if based on correct data, comprehensive computer models, logical processes, and user-friendly tools.

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