

APPLYING LIFE CYCLE COST ANALYSIS TO ROOFING DECISIONS

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Life-cycle cost analysis is used to determine the most cost-effective roof system purchase; however, its application is limited by the inherent risks of and uncertainties associated with the roof construction. To effectively apply life-cycle cost analysis to roofing projects, an analyst must be aware of these limitations with many of them being universal and applicable to all life-cycle costing analyses. Some are, however, specific to the construction of roofs and must be considered in order to successfully apply the technique.

KEYWORDS

Life-Cycle Cost Analysis/Analyses (LCCA), Expected Service Life/Lives (ESL), Discount Rate, Tangible Costs, Intangible Costs, Residual Value, Salvage Value, Study Period, Period Of Analysis, Operating Costs, General Inflation Rate, Escalation Rate, Average Life, Design Life.

INTRODUCTION

Roofing contractors, consultants and building owners are confronted with a vast array of competing products and systems when designing a roof. The selection of the best system for a building owner's particular needs is a complex and difficult task because of the large variety of options and lack of empirical data.

One method used in the decision-making process is life-cycle cost analysis (LCCA). ASTM Standard E-917, Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, provides for evaluating the life-cycle cost of building elements, comparing alternatives and determining the lowest cost of ownership [1]. LCCA is widely accepted in the building industry and used in the roofing industry as an evaluation tool for choosing among competing roof systems; estimating and justifying maintenance expenditures; selecting reroof, repair and re-cover options; and assessing the environmental impacts of roofing activity. Various LCCA techniques have been successfully used for over two decades to calculate the cost-effectiveness of thermal insulation [2]. However, LCCA is only a tool to assist decision makers in the evaluation and selection process. As a predictive instrument that forecasts what costs will actually be incurred over the life span of the roof system, LCCA is subject to error.

One of the main causes of failure in LCCA is the neglect to clearly determine clients' needs, objectives and constraints. There is a tendency to assume that durability (i.e., duration of service life) is the main concern of all clients; however, different clients value costs differently.

Analysts must ask the following questions before conducting an LCCA:

1. What are the client's primary concerns about the roof system?
2. How long does the client expect to own the roof system?
3. What is the client's source of capital (e.g., borrowed funds, retained capital, government grants)?
4. What is the client's taxation position (which costs can be claimed against taxes, what is the tax rate paid)?
5. Are there any time constraints that indicate some choices and rule out others (e.g., are there gains from rapid completion)?
6. Are there financial cost constraints (e.g., is the client concerned he can't afford a particular type of roof system)?
7. What is the occupancy profile, and what particular needs will it have (e.g., health care facilities may not be able to tolerate any interruptions caused by construction)?
8. Are there any other constraints limiting choices (e.g., is there a requirement to use only local labor or locally produced materials)?

Only after these questions are answered can an analyst apply LCCA to the choices that fall within the established parameters. Any LCCA that fails to take into account the client's objectives serves no useful purpose and may simply become means to justify predetermined alternatives.

CHOOSING THE PERIOD OF ANALYSIS

A common error in choosing the correct period of analysis is the failure to correctly define the "study period," or the length of time over which the roof system's costs are being calculated. Because the outcome of LCCA will be affected by the period of analysis chosen, establishing the correct study period is crucial. The timescale for LCCA is not necessarily the same as the physical life of a roof system. A roof system could have, for example, an expected service life of 15 years, but a major retrofit to the building (including a roof system) is planned in 10 years. In this instance, the latter would be the appropriate period of analysis.

A period of analysis must be defined by the clients and decided on a case-by-case basis. The analysis period is determined by how long a client will be involved in the decision to build, own or use the roof system. The outstanding issue is that of resolving the difference between the period of analysis and expected life of the roof system.

One dilemma results from competing definitions as to what the period of analysis could or should be. Some analysts suggest that the period of analysis should be based on a reasonable expectation of the economic life (i.e., the period of time over which an investment is considered to be the least-cost alternative for meeting a particular objec-

tive) of a building or roof. This should not be confused with the study period (i.e., period of analysis), which is the length of time over which an investment is analyzed. Economic life may be the most important from the view of cost; however, how life span is defined will affect the prediction of what the economic life of a roof system will be and, therefore, the outcome of the LCCA.

When determining the analysis period, analysts may choose from any the following:

- The acceptable life, which depends on who is defining it.
- The average life, which is the time to 50 percent failure of similar construction and usually can only be established after the event (e.g., two systems with the same average life may have totally different failure distributions, and the same systems used in different locations may have different average lives).
- The minimum life. In some situations, no corroborative data are available to assess a system's or product's life. The owner may stipulate that it has to last at least "x" years, although its true life may exceed that time period.
- The design life, which is the life of the system or component specified by a designer in accordance with the specifications or owner's requirements. For any given system or material, the design life should be adjusted depending on the amount and nature of maintenance the client commits to carry out during the life of that system [3].
- The expected service life (ESL), the term for LCCA that uses expert judgment to evaluate a predicted life, is the balance between the minimum and design life. ESL may be inferred from recorded historical performance, previous experience, tests or modeling. It is the length of time over which the roof system can be maintained in an acceptable physical condition.

Minimum life, acceptable life and design life, are for the most part arbitrary values established by the client or design authority. In contrast, average life and ESL imply quantifiable values based on historical information or test data that can be critically reviewed and verified. In most LCCA related to roofing, ESL is used to calculate costs.

An impediment in conducting a sound valuation of ESL is that it is not known with any degree of certainty what are the mean life expectancies of various roof systems. The roofing industry continues to debate the average life expectancies of the many roof systems available. As there is no sufficient or reliable data that will allow us to determine with certainty the life expectancies of low-slope roof systems, estimates range from as low as 12 years to as high as 20 years or more [4]. Making accurate estimates would require a vast number of samples and the identification of hundreds of independent variables that affect service lives. Although limited information may be available in the records of roof consultants, facility managers or manufacturers, it remains for the most part fragmented and proprietary.

In the absence of any reliable estimates of roof system life expectancies, the knowledge and skill of an analyst becomes paramount in the decision-making process. Only through experience with roof construction and performance can reliable predictions be made. The accuracy of the outcomes of LCCA depends on the skill and knowledge of the analyst, quality of the data and rigor used in its application.

Even knowledgeable and experienced individuals will find the ESL of competing roof systems difficult to predict with confidence. There are two important considerations in determining ESL: ESL of the roof system as a whole and of each component. Roof systems are complex and the ESL of each component depends on its relationship to the other parts. For example, in a fully adhered insulated roof system, the wind uplift resistance of a membrane will depend on its adhesion to the insulation, which in turn may depend on the bond of the facer to the foam core. It is impossible to predict the in-place performance of the entire roof system based on a simple summation of the ESLs of the individual components, as interaction effects are not accounted for.

Any product's ESL is determined by both environmental and nonenvironmental factors. Environmental influences include solar and thermal radiation, temperature ranges, water (e.g., rain and snow), contaminants (e.g., biological), and stresses caused by wind, hail or seismic forces. Non-environmental factors are those normally imposed by human activity and include impact, chemical attack, effluence from production, abuse, and those conditions imposed by occupancy or use. Not only will ESL vary with use and occupancy, but also with the frequency and type of maintenance performed. A change in one or more of these variables will result in a change in the roof system's ESL. Consequently, all factors influencing the ESL must be considered.

COSTS OVER TIME

Roof system costs are related to the length of time of ownership. Utility (i.e., value) can decrease over time due to deterioration or obsolescence. Deterioration results in absolute loss of utility and obsolescence results in relative loss of utility. Deterioration is a reduction in value as a function of use and time and is normally factored into LCCA through depreciation prescribed adjustments that result in a reduction of taxes. Obsolescence is the value decline not caused directly by use or the passage of time. The provision of good quality design, application, materials and maintenance can control physical deterioration, but obsolescence is much harder to control because it is influenced by uncertain future events, and irregular in nature.

A roof can be in excellent condition, yet still be obsolete. An example would be a roof system that requires a yearly application of a coating for ultraviolet protection, with this annual cost factored into LCCA. Shortly after installation of this roof system the manufacturer develops a coating-free membrane. The original membrane continues to be functional; however, it is technologically obsolete and the cost of the annual coating becomes the price of this obsolescence.

Obsolescence is usually associated with changes in technology, but this may not be the only cause. In some cases, it may be the result of manufacturers abandoning product line, or leaving the market, leading to higher costs for future replacement or repair. In other instances factors beyond the industry may cause the obsolescence. In 1978, the metric system of measurement was adopted in Canada. For a few years thereafter, asphalt shingles with standard imperial dimensions were readily available and in abundant supply. However, as manufacturers retooled to comply with requirements, production of imperial dimensioned units

were gradually phased out. This meant that when repairs or alterations on shingle roof systems with imperial shingles were undertaken, owners faced high costs to procure them or excessive labor costs because each shingle had to be trimmed to match the existing construction. In this instance, obsolescence resulted from regulation that led to higher-than-expected operating and repair costs.

Obsolescence can be mitigated by specific measures, such as securing adequate support and guarantees from suppliers and long-term product commitment. Contingency measures may include purchase of additional product as stock for future needs. Although deterioration can be overcome at a price, obsolescence may prove more costly because it requires replacement of existing roof system with new ones.

Another form of obsolescence is caused by new information regarding the system or components that require a fundamental re-evaluation of net present value (NPV) estimates. An explicit example concerns the use of phenolic foam roof insulation on steel deck assemblies. It has been alleged that certain of these products, when contaminated with moisture, produced corrosive compounds that aggressively attacked unprotected steel [5]. As a result, building owners were forced to adjust their expected maintenance, repair and replacement costs. In addition, there is some evidence that the value of the buildings with roof systems containing phenolic foam insulation was reduced as a result of the risks associated with this material.

Both deterioration and obsolescence involve the prediction of future costs that should be reflected in LCCA. These may include the costs of adaptation, modernization, retrofit (resulting from changes in occupancy or use), replacement and repair, and work resulting from changes made in compliance with changes in building codes or standards. There can be hidden and expensive difficulties with retrofit and replacement because any building system that is being substantially opened up must be brought in line with current building regulations. Consider the example of an LCCA that evaluates two options: a re-cover system with a new membrane applied directly to the existing one and the removal of the existing membrane followed by the application of a new membrane system. Although LCCA may indicate a higher cost for the re-cover (due to shorter ESL and higher annual maintenance costs), this may not prove to be the most economical alternative. In this particular instance, the existing roof system consists of a built-up roof (BUR) membrane over polystyrene insulation laid directly on a steel deck. As the first option is considered a repair (according to the National Building Code of Canada), the re-cover is permitted without modifications to the existing assembly [6]. Should the membrane be removed, however, this may necessitate the removal of the insulation and installation of a thermal barrier prior to the application of the membrane.

TIME VALUE OF MONEY

Any acceptable investment appraisal technique must take into account all cash flow (costs and benefits) associated with the investment throughout the period of analysis and make proper allowance for the time value of money. For every option considered, the costs must be calculated on the same (like-for-like) basis.

CHOICE OF DISCOUNT RATE

The discount rate used will have a critical impact on the final decision. Generally, NPV of a project is inversely related to the discount rate used within a given period. The appropriate discount rate will depend on the circumstances and objectives of the client. If the project is to be financed through borrowed funds, the discount rate must be equivalent to the actual cost of borrowing money. If the project is to be financed from capital assets (from retained income), the discount rate is determined by the current and future rates of return for the client's particular industry and, ultimately, by the best alternative (opportunity cost) use of such funds. Too high a discount rate will bias decisions in favor of short-term, low-capital cost options, while too low a discount rate will give undue impact to future cost savings. An acceptable level of confidence is required in selecting the appropriate rate to use. In addition, budget estimates must be continually compared to actual expenditures and adjusted to reflect the variance between the assumed and actual rate. To be relevant, the financial analysis must be ongoing throughout the life of the project.

SALVAGE VALUE VS. RESIDUAL VALUE

Some confusion surrounds the terms salvage vs. the residual value of a component or system. Salvage value refers to the scrap value of the components. It is the value of the elements recovered as a part of the alteration or replacement. In most roofing scenarios, the salvage value of the materials is negligible.

The residual value is much more difficult to quantify. The residual value is defined as the satisfaction a building owner can have for the roof system's remaining service life. It is generally assumed that the residual value will be negligible at the end of its useful service life, but it must be remembered that the period of analysis might not coincide with the "expected service life." The residual value should form part of LCCA only if it falls within the study period, even if the roof system's expected service life extends well beyond it.

Residual value is important if it impacts the value of assets. An example of this is when an owner intends to sell a building sometime after the roof system installation but before the end of the roof system's ESL. The remaining period of the expected service life represents a residual value that can be factored into the sale price of the building.

FORECASTING

LCCA is heavily dependent upon forecasts about the future, whether about the expected lives of components, interest rates or maintenance expenditures. Some, if not most, will be no more than expert judgment, best guesses or hunches. A vital element of forecasting is the ability to understand trends and envision what could happen in the future. Forecasting relies on the assumption that future costs can be predicted to some extent by referring to past patterns of cost. Such assumptions hold true only if no outstanding technological leaps occur and the existing stimuli remain constant in type and degree. The farther into the future the forecast, the greater the likelihood of prediction errors.

PREDICTION AND FORECASTING ERRORS

The process of predicting the various costs (or savings) is fraught with errors due to uncertainty about the future. Prediction errors can be broadly classified as measurement and sampling errors. Prediction errors may occur as a result of incorrect assumptions about the discount rate, inflation rate, timing of repairs, replacement costs, escalation rate, service life and maintenance costs. In most cases, errors become evident only after the fact.

Sampling errors can result when a sampling is not representative of the underlying population or when the data being relied on to formulate predictions, such as future maintenance costs, are not directly transferrable to the project being considered. Data used to establish ESLs must be carefully scrutinized to ensure their applicability and suitability for the project at hand. Variations will all require an appropriate adjustment to the estimates.

For example, Ontario Housing Corporation (OHC) released a report in 1989 on the service lives of various roof systems it managed. Based on a sample of 36 BUR systems, OHC estimated the average life expectancy to be 12 years [7]. Could one draw the conclusion that this was an accurate estimate of the average service life of BUR systems? Such an assumption would be unreasonable. In OHC's case, several factors vitiated longer service lives. Because of financial constraints, OHC performed virtually no maintenance on these roof systems. In addition, because the construction was publicly financed, the lowest initial bids were accepted for initial construction, often resulting in marginal workmanship and materials, with few quality assurance measures. Although the life expectancy of BUR systems by OHC was 12 years, it cannot be concluded that this is the average life expectancy of all BUR systems.

INFLATION

A potential weakness of LCAA may result from ignoring inflation effects on the price of future replacement or repair. If inflation increases, replacement roof systems will cost more. However, there may be an offset to inflation, future generations of systems and products may have better performance characteristics and provide additional cost reductions. Some products and materials may experience declining costs due to technological advances or economies of scale.

Expected inflation or possible efficiency gains should be included in the cash outflow analysis; however, making reliable predictions is difficult. There is the practical problem of formulating explicit forecasts of future interest rates. Although long-term inflation rates (trends over 20 years or more) have been relatively stable, roofing decisions are often only concerned with what will occur within five to 10 years, and short-term rates tend to vary widely.

The general approach is to relate all prices to a common base. In this method, an inflation-free discount rate (i.e., real rate of interest) is used and all costs are expressed in constant dollars (i.e., dollars tied to a reference year). In doing so, the effects of inflation are ignored on the assumption that all costs will rise at the same rate, which works as long as all costs rise at the same rate. However, this seldom occurs. Labor and material costs rarely change at exactly the same rate. If different cost elements are

expected to become inflated at different rates, it must be reflected in the LCCA with distinct NPVs calculated for each cost stream.

Inflation is a general increase in the price of goods and services over time in the economy as a whole, without a corresponding increase or decrease in value. Cost growth (escalation) is an increase or decrease in the price of an individual component with or without a corresponding increase or decrease in value [8]. General inflation will affect all alternatives equally. Differential escalation rates are the growth in the costs of individual items over and above the general inflation rate and may have a significant effect when comparing alternatives (e.g., escalating labor rates may affect BUR so single-ply roofing because of the relatively larger labor component).

Many factors influence the escalation rate of the cost elements, with the most obvious being the price effect of supply and demand. However, nonmarket influences can also affect price changes. Consider the case of asphalt BUR. Technical innovation (e.g., mechanization) has resulted in decreasing unit labor costs. However, should BUR application become regulated because of alleged or perceived health effects of exposure to asphalt fumes, labor rates would be expected to rise significantly above the rate of inflation. Another example is the cost of roofing waste disposal, with tipping fees increasing tenfold in the past decade. Along with these increases, there are areas where regulations have been introduced requiring the segregation of certain materials or prohibiting their disposal in landfills. The result is rapidly increasing disposal fees relative to other costs.

IDENTIFYING COSTS AND BENEFITS

Costs are of two basic types: tangible and intangible. Tangible costs usually are easily quantified, but identifying intangible costs require imagination. Their measurement in monetary terms is problematic.

Tangible costs can usually be divided into initial (i.e., capital) costs and running costs. For roof systems, the tangible initial costs include outlays for materials, their installation and associated construction costs. By contrast, tangible running costs are incurred throughout the life of the project. They include:

- maintenance costs
- financing costs or interest paid on borrowed funds (e.g., different amounts may have to be borrowed for different systems)
- decanting costs (i.e., costs of providing alternative accommodation while the roof system is being installed. Different systems may require more or less re-accommodation, or installation times may vary)
- replacement costs
- disposal costs (net of salvage or residual value)
- insurance costs (technical specifications of roof systems related to fire and wind resistance may affect insurance premiums).

Choosing the period of analysis is especially important when considering the running costs and replacement costs of each option. Running costs continue to be incurred with the passage of time, and the amount of these costs will

differ among roof systems. If too short a period is chosen, clients could find themselves locked into an option that is ultimately more expensive. In the case of replacement costs, too short a period may result in an artificially low NPV for a system that replacement has not been taken into account.

INTANGIBLE COSTS

The specifications, measurement and valuation of costs and benefits raises two significant problems: the identification and measurement of all costs and benefits and the reduction of all costs and benefits to a common denominator. Often all benefits and costs associated with a roof system's construction cannot be converted into monetary values. Comfort of the occupants, effect on building operations and impact on the rentability of the building are difficult to quantify in monetary terms. However, if not all of the costs and benefits are included and discounted to a common point in time, the results may be misleading.

Although difficult to measure, intangible costs should be considered in the decision process if they have a decisive role to play. Consider the case of asphalt BUR used at sensitive occupancy locations, such as schools and hospitals. In some instances, noxious odors emitted from heating kettles has resulted in complaints from occupants or even temporary closing of the facilities. These intangible effects (i.e., disruption) carry real costs for an owner. However, such costs are almost impossible to quantify as is the level of risk in incurring them. The risk, determined by an owner, can simply be too great to bear, thus precluding the installation of a hot-asphalt roof system.

The environmental consequences of roofing activity are receiving increased attention as demonstrated by the plethora of "green marketing" strategies of roofing manufacturers and suppliers. Many argue that by minimizing the environmental costs, there will be real economic benefits. Environmental aspects of roofing are becoming much more important; however, these costs are extremely difficult to define, quantify and translate into monetary terms. Before conducting an LCCA, the influence of environmental costs on the decision should be explicitly stated. In some organizations, "buying green" is a mandated purchase requirement limiting the set of alternatives. In others, separate environmental impact assessments must accompany the LCCA. Only those costs deemed relevant to an owner in the decision are to be included.

The measurement of intangible costs often comes down to informed judgment based on the experience of those who have an intimate working knowledge of the situation. These costs, however, should not be incorporated in the costing along with tangible costs. Given the uncertainty of their scale, it is best to consider them separately. The most appropriate way of including them is to ask "how big" would these costs have to be before they would influence the final decision?

RISK AND UNCERTAINTY

More than 60 years ago, the economist Frank Knight defined the difference between risk and uncertainty. Risk refers to a situation where the outcome is not certain, but the probabilities of each possible outcome are known or can

be estimated. It is one thing to say that a particular roof system will have an ESL of 10 years, and quite another to say that there is 50 percent probability of it providing useful service for that duration. Implicit in our assumptions, therefore, is the component of risk. Unless absolute certainty can be assigned to an assumption, it is imperative that the probability of the outcome or objectives be identified. In this context, the knowledge and expertise of the individual conducting the analysis becomes paramount. Only those thoroughly trained and knowledgeable about roof system's behavior and characteristic, and the project's functional requirements should be considered as qualified to make assumptions. Otherwise, these types of analyses merely become theoretical exercises.

The importance of professional judgment cannot be overstated. Assumptions have to be made when any quantitative or qualitative information is missing or unreliable. Sound judgment is required at all stages: in the selection of assumptions, determining and selecting the data required, and choosing the most appropriate forecasting techniques. Analysts with biased assumptions may reach biased conclusions. This problem lies not in the technique, but with the analyst. It is people, not techniques, who make decisions.

The intrinsic weakness associated with LCCA results from the uncertainties associated with the assumptions used as inputs in the analysis. Life expectancies, future costs, timing of such costs etc., are based on estimates rather than known facts. Often they are no more than best guesses. Even when LCCA reveals that one system is preferred over another, there is always the question of the reliability of the underlying assumptions.

Roofing is subject to more risk and uncertainty than perhaps any other trade in the construction industry. The production process is complex, involves the coordination of a wide range of different yet interrelated activities, and is subject to many external and uncontrollable factors. Effective cost planning must take into account the risks and uncertainties, which require the ability to identify a well defined range of possibilities with associated costs. Even if this range is confirmed to a simple three-tiered categorization (optimistic, pessimistic and most likely) with only three variables (initial cost, operating cost and ESL) examined, a complicated matrix will result. Potentially there will be $3 \times 3 \times 3 = 27$ possible NPVs to be calculated. In most cases, this degree of complexity is too cumbersome to be of value.

It has been suggested that risk can be handled by adding a risk premium to adjust the discount rate to reflect the risk. The problems with this method lie in accurately identifying the appropriate risk premium and validity of assuming that the same risk applies to all of the costs equally. Two other methods of dealing with uncertainty are the probabilistic and the sensitivity approaches. The probabilistic approach attempts to measure the degree of uncertainty in by establishing a confidence interval. The sensitivity approach analyzes the change in NPVs that results from variations in the inputs due to uncertainty. As useful as these methods are, they only estimate the risk entailed in the project.

Because risk in roofing activity cannot be avoided, it is essential to be aware of the level of risk the client is willing to accept. If the risks associated with a particular system are overestimated, the optimal alternative will not be selected.

On the other hand, if costs are underestimated, the client will face unanticipated and excessive future costs. Prudent caution may provide a margin of safety for the analyst, but excessive caution may frustrate the objectives of LCCA. Addressing risk in the process requires the identification of a well-defined range of possibilities, costs and environmental parameters.

LCCA IN THE ROOFING CONTEXT

The basic objective of LCCA is to ensure that maximum benefit is realized at the lowest cost. LCCA can be a costly and time-consuming effort. Data collection and evaluation of information require scarce resources. Often, criteria other than long term economic costs may render the entire exercise meaningless. Industry professionals are aware of reroofing projects that have been carried out not because of cost/benefit analysis but to avoid the lapsing of funds from one fiscal year to the next when such projects have been approved within an organization's budget.

Most of the academic literature concerning LCCA has been directed toward comprehensive and detailed economic analysis. In the area of roofing, very few detailed LCCA, based on a systematic and coherent methodology, have been undertaken. In reality, as applied to roofing decisions, the analysis is generally carried out at a conceptual and simplified level, and LCCA is used to make an assessment of the economic aspects based on limited and qualitative information. It is often used to answer such questions as: Is system A significantly different from system B (in terms of total costs), or does system A have clear or unequivocal benefits over system B?

Key decisions in roof system selection do not necessarily need a highly quantitative analysis, but rather, an understanding of relative advantages and uncertainties. Given the uncertainties and limits of LCCA, the simplified approach may be most appropriate in roofing design selection. A simplified LCCA is merely the application of the methodology covering the whole life cycle, but superficial in nature, using generic, standardized data (both quantitative and qualitative) followed by a simplified assessment (i.e., focusing on the most important costs) and thorough assessment of the reliability of the results. The aim is to provide essentially the same results as a detailed LCCA but with a significant reduction in expense and time.

The effective communication of LCCA's results is as important as the analysis itself. It is essential that the results, data, methods, assumptions and limitations be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the study [9]. In comparative studies, systems must be computed using the same functional units. Equivalent methods to determine performance, decision rules and evaluating features must apply.

The use of LCCA to make strategic decisions (i.e., choosing between different roof systems delivering a common function) has often been associated with disputes about the validity of such assessments. The ability to apply and use LCCA in the future is critically dependent upon the ability to actually authenticate it. This requires systematic data collection and maintenance if LCCA is to survive as a quantification tool for assessment. LCCA can be used effectively in the roof purchase decision-making process;

however, it is simply a technique designed to assist building owners and managers to choose the most cost-effective investment. The efficacy of each LCCA will depend on the knowledge and skill of the individual conducting the analysis. A thorough understanding of roof systems and their behavior as well as sound comprehension of financial and managerial principles is crucial.

As LCCA continues to be applied more frequently to roofing situations, analysts will become more aware of its strengths and limitations. As the amount of information relevant to using LCCA as a decision making tool increases, its application in roofing will become more varied and precise. However, the credibility of such exercises will always be questioned unless there are concomitant developments of comprehensive and reliable databases to support the assumptions regarding roof system service lives and associated costs. The fundamental weakness of LCCA continues to be the accuracy of predictions of ESLs. This weakness can be overcome only if the roofing industry collectively commits the energy and resources required for more systematic data collection and maintenance. Some progress is being made through NRCA's project pinpoint, NRC/CRCC Belcam Project and US Army's Roofer Program, but much work is still required if LCCA is to survive as a dependable tool.

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