

## **Risk Analysis Based on the Cost of Life for Projects at the Level of Surface Layer Management**

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### **Abstract**

Investing in ensuring the quality and safety of movement on highways is not a one-time process. Institutions charged with ensuring quality crossing surfaces must constantly monitor and repair the highway network so that it remains in the best possible condition. Because the funds available to maintain the highway network are limited, it is essential that decisions taken to maintain and rehabilitate the highway network are spent justifying each intervention. Layer management systems at the network and project level help with this objective. Strata require a long-term investment of funds over their lifetime to maintain them in the most cost-effective manner. Therefore, the selection of the most cost-effective alternative does not depend only on the initial construction investment [1]. The total cost of the coating over its expected life cycle must be considered to truly assess cost effectiveness. Therefore, we used life cycle cost analysis based on risk management for project level layers.

**Keywords:** Life cycle, roads management, systems, optimisation models.

### **1. Introduction**

The life cycle cost of ensuring a layer is the discounted cost of the required investments that are expected to occur over the life of the layers. Layer improvements are intended to correct structural or functional deficiencies. Current procedures allow the upgrade designer to correct inconsistencies in a number of ways. Unfortunately, these procedures often do not include an assessment of the investment required over the life of the layers to allow the engineer to select the most cost-effective alternative[1]. Life cycle cost analysis is used to address this problem.

In classical life cycle cost analysis, a limited number of alternatives are formulated, such that each one corrects the deficiency in the layer structure. Estimates are then made of the investments required to maintain the layer over a common analysis period. The total investment of each alternative during the analysis period is calculated and discounted accordingly to arrive at the expected life cycle cost[10]. Using these assessments, the decision maker is able to select the most effective life cycle alternative that meets the project's objectives and goals.

These life-cycle cost estimates require the analyst to evaluate many factors that, by their nature, are inherently uncertain. To estimate a life cycle cost

for a layer investment, the analyst must predict the future performance of a layer, material costs, appropriate discount rates, and other factors that greatly influence the outcome of any cost model of the life cycle. In many cases, however, decisions are made using life cycle costs that have neglected the fact that these estimates are not known values but have an inherent variability that can be represented by a distribution of values[12]. This chapter deals with the development of a life cycle cost analysis procedure that takes this variability in the data into account and provides a clearer picture of the effect on life cycle costs of layer treatment alternatives.

Since it is important to estimate the variability involved in choosing an alternative, the question remains of the method of measuring or quantifying the variability across the alternatives used. Many factors used in life cycle cost analysis are variable, and it is possible to use historical data and judgment to estimate the distributions of these factors over the life cycle of a layer. It may not be known exactly how long a particular maintenance or rehabilitation treatment will last, but it is possible to estimate the expected life span through historical data or local experience. Therefore, the analyst must estimate not only the expected values for the variables, but also the distribution of these variables for the data under analysis. Then, using

these distributions of the input variables, the analyst can estimate the distribution of the output variables, which is actually the present value of the investments needed during the life cycle of the layer (life cycle cost).

The distribution of this cost is used to assess the risk of each alternative. The risk of the design alternative is directly proportional to the standard deviation of the total life cycle cost distribution. In short, the higher the standard deviation of this distribution, the more uncertain we are about its actual cost, so the more risk is served

### **1.1 Principles of life cycle costing**

Decisions are not made in a vacuum, but rather with some objective or goal in mind. The main goal of a transport agency is to provide a network of roads where the service is quality and safe while maximizing the benefits obtained from the expenditure on the network. This is the objective on which the economic analyzes in this chapter are based.

The application of economic principles occurs at two levels.

1. When management decisions are required to determine the feasibility and timing of the project and considering many possible projects that may be undertaken at any time.

2. An alternative must be chosen that provides the maximum economic benefits for the project.

This is the typical difference between the road network and the project level in layer management. The feasibility of the project is determined at the network level, while the comparison of alternatives within the project is part of the layer management process at the project level. Economic analyzes are done at both levels of layer management [8]. The major difference in economic evaluations between these two levels of layer management concerns the amount and types of information required. However, the basic principles that apply to economic analysis, both at the project and at the network level, of the management layer remain the same.

These can be summarized as follows:

1. The management level at which the assessment will be made must be clearly defined.

2. The economic analysis provides the basis (information) for a management decision, but does not represent a decision in itself.

3. The criteria, rules or guidelines for such decisions must be formulated separately before applying the results of the economic decision.

4. The economic analysis itself has nothing to do with the method or source of financing for a project.

5. An economic analysis must take into account all possible alternatives, within the constraints of time and other planning and design resources.

6. All alternatives must be compared during the same period.

7. The economic analysis should include all the benefits and costs of project alternatives if possible.

When these basic economic principles are followed, effective use of economic analysis methods will help manage the difficulties associated with project selection (network level) and alternative choice (project level). Better management will occur by improving the time and cost effectiveness of asset purchases and the quality of purchased assets [5].

### **1.2 Requirements for LCCA**

Weston (Weston 1990) lists six necessary steps to follow when performing a life cycle cost analysis for a project. These steps identify the minimum information that must be identified for a complete analysis. These are:

Today, due to the popularity of successful analyzes in decision-making problems, fuzzy logic techniques are being used. Among the principles of fuzzy logic extension, the vertex method with the algorithm of Dong, Shah and Wong (DSW) (2018) *Journal of Transportation Engineering, Part B: Pavements*/Volume 144 Issue 4 - December 2018 that have applied to the LCCA of road layers. The steps of the methods are described in detail. As part of the study, a model involving a traditional probabilistic method was compared with a model based on fuzzy logic by means of a case study. The results reveal that LCCA based on fuzzy logic [10] is a promising alternative approach for transport authorities, especially highway agencies, in making a final decision on the type of road layers to use.

We are remaining in the classic LCCA requirements study.

1. Identifying the benefits and costs of.
2. Estimates of expected cash flow (benefits and costs), including the final value of the asset according to the specified data to be drawn up.
3. The appropriate discount rate must be determined.
4. Expected cash flows are discounted to a present value basis to obtain an estimate of the projects present value.
5. Predicted cash flow risk; and/or information (sensitivity analysis) in relation to the probability distribution of cash flows must be determined.
6. Estimate present values of expected cash flows and sensitivity analyses.

#### **1.2.1 Identification of project benefits and costs**

In evaluating a project, only the cash flows (benefits and costs) that come directly from the project are used. They represent the change in total cash flow that occurs as a direct result of accepting or rejecting the project. When identifying project costs for inputs in life cycle cost analysis, the following principles are followed (MDT 1994):

1. Only incremental cash flows are used. These are the cash flows that come directly from analyzing the project. Lost costs are not used because they have already been incurred and cannot be recovered.
2. Costs used for analysis should reflect the opportunity cost of each resource used, measured by the return on those resources in their most productive application elsewhere. This is usually measured by the market price that represents what society is willing to give up in order to receive a certain benefit.
3. Tangible and intangible benefits and costs should be recognized and accounted for when possible.
4. Benefits and costs can be measured in real or nominal terms. The real benefit or cost is adjusted to eliminate the effect of expected inflation. A nominal benefit or cost equals the corresponding real benefit or cost plus a premium for expected inflation. An important note about inflation is that nominal benefits/costs

include a factor that corresponds to expected or future inflation, not inflation that has been experienced in the past or present. Basically, the answer is that inflation is not used in valuation unless there is substantial evidence that real prices will change. Real price change can be defined as the change in the price of an item that does not follow the general inflation trend of all goods in a society. Some will argue that inflation should be included in the analysis because ignoring inflation leads to underestimation of out-of-pocket costs and therefore budgets will be inaccurate. This argument shows a misunderstanding of the purpose of an economic analysis, which is to provide management with a means of selecting specific options from a set of alternatives. Once the option is selected, a separate budget analysis is required to determine cash flow requirements. Budget analysis generally includes inflation and other factors [3]. It is therefore recommended that only current market prices be used for economic analysis.

#### **1.2.2 Estimation of expected cash flow**

Estimating the expected cash flow requires the determination of two elements: the size of the cash flow and the moment in time when this cash flow will occur. Both of these elements are not current values and are subject to change. To estimate these values, the analyst must estimate the following parameters for each element of each cash flow under analysis:

The average (expected value) of the cash flow or when the cash flow will occur.

Distribution of cash flow (both for its location in time and for its size). Distribution can be assessed in a number of ways. In this software package cash flow timing and size distributions can be entered assuming that the distributions are either triangular or normal. Further research is needed to identify other appropriate types of information dissemination [4]. These distributions, once identified, will be incorporated into the software in future development. The mean and standard deviation are sufficient to define a normal distribution. For triangular distributions, the analyst must specify the expected value, and the range of possible values.

#### **1.2.3 Reduction of cash flow in present values**

The life cycle cost model used to prepare the estimates is based on a cash flow and time value of money diagram. Each cash flow is appropriately discounted in today's lek in order to determine the present value

#### **1.2.4 Projected cash flow risk**

Risk can be described as the amount of uncertainty present in a decision made under unknown or uncertain conditions [3]. For strata investments, many factors cannot be predicted with certainty; therefore, there is a risk involved in any decision made. Since there are a number of design alternatives available that will provide an adequate layer structure for the period of analysis, the final decision depends on the total life cycle cost of each acceptable design[12]. These costs are based on uncertain variables and, therefore, contain some risk. This risk must be taken into consideration during the decision-making process for a truly informed and justified decision.

Risk is defined as the probability that an adverse event will occur[8]. Estimates of benefits and costs are typically uncertain due to inaccuracies in both the underlying data and modeling assumptions. Information useful in an analysis includes the main sources of uncertainty; estimates of the expected value of results; the sensitivity of the results to significant sources of uncertainty; and the probability distribution of project benefits and costs. As stated above, the analyst must determine the distribution of the input variables in the life cycle cost model. These distributions can then be used to perform three types of analysis that, when used together, can present a picture of the risk of a chosen alternative. These analyzes are simulation, sensitivity and scenario analyses.

A simulation analysis is used to construct the total present value life cycle cost distribution for an alternative. Basically the life cycle of the project is simulated using a Monte Carlo technique by randomly selecting values from the distributions of all cash flows expected to occur during the life cycle of the project and then producing an estimate of the present value of the life cycle cost[7]. Therefore each simulation run represents a possible life cycle outcome for alternatives. These simulations are run multiple times and present values are tabulated to produce an estimate of the expected distribution of potential life cycle costs for alternatives.

Sensitivity analysis essentially portrays the sensitivity of the present value of the total life cycle cost to changes in each of the input variables. The life cycle cost for all alternatives is calculated using a range of values for each input variable based on a user-selected range of variables. The results are plotted to show the relative effects of these variables on life cycle cost.

Scenario analysis uses input cash flow distributions to provide worst-case, best-case, and expected life-cycle costs for each alternative. These estimates show the possible range of life cycle costs for each alternative [6].

Using the result of the three analyses, the decision maker can compare each alternative and choose the best one based on the agency's goals and other constraints.

## **2. Visual Software / LCCA**

The Visual /LCCA software developed by TRDI for the Montana Department of Transportation [2] incorporates the analysis procedures developed above. A layer project is a specific length of highway to be rehabilitated or rebuilt, and each is analyzed for life cycle costs[5]. An alternative is a specific design that meets the requirements of the project. Each project can have an alternate number.

Inputs to the LCCA program can be divided into four categories:

### **1- Layer performance inputs**

The performance of the layer section determines when its improvement and maintenance costs will occur. This determines when the spending money is required by the agency. To obtain this data, the software uses performance models from the network layer management system and calculates the expected life of each available treatment based on a user-defined threshold[10] [9]. The user can also associate maintenance activities with each treatment and specify when these activities will occur in relation to the application of the treatment.

### **2- Cost inputs**

These determine the size of the costs incurred after each rehabilitation and / or maintenance action is carried out in the section during the analysis period. Each treatment and maintenance activity has associated unit costs which are determined by the user. The costs used in the LCCA Program are:

- The initial cost of treatment
  - Cost of administration (Design, Planning, etc.)
- Cost of Maintenance [2]
- Cost of user delay (calculated based on traffic composition, construction length, etc.)

### 3- Project inventory

These are parameters that determine the project to be analyzed and do not depend on the alternative being considered. The project inventory includes the following:

- length
- width
- Traffic level
- Description of Traffic Composition (% Trucks, etc.)
- Discount Rate Distribution

Traffic growth rate

Of the input parameters, the following are identified as uncertain variables[11], so distributions instead of point values can be assigned to them in life cycle cost analysis. The distribution of each variable can be specified by the user.

- 1) discount rate.
- 2) traffic growth rate
- 3) Treatment life, the number of years it takes for a coating to deteriorate to the minimum acceptable level after application of a treatment.
- 4) Unit cost of treatments (or material and labor cost)
- 5) Cost of user delay (reflected by changes in traffic)

For this version of the LCCA program[12], two distributions for uncertain variables can be used: (1) the triangular distribution (2) the normal distribution. For the triangular distribution, three variables must be specified: the minimum value (a), the most likely value (b) and the maximum value (c), while for the normal distribution the mean ( $\mu$ ) and variance ( $\sigma^2$ ) must be specified. The user can choose to use any form of distributions for simulation analysis.

### 2.1 Using input distributions for simulation analysis

Simulation analysis randomly calculates a life cycle cost distribution as discussed earlier. During each simulation run, all uncertain variables are randomly

selected from their respective input distributions. These values are then used to calculate a life cycle cost. This process is repeated many times and tabulates the results to give the expected total life cycle cost distribution of the alternative.

#### 2.1.1 Simulation of a triangular distribution

To calculate a random variable X from a triangular distribution the following is used. Figure 1 shows the probability distribution function (pdf) of the triangular distribution whose equation is given by:

$$f(x) = \frac{2(x-a)}{(b-a)(c-a)} \quad (a \leq x \leq b)$$

$$f(x) = \frac{2(c-x)}{(c-a)(c-b)} \quad (b \leq x \leq c)$$

$$f(x) = 0 \quad \text{otherwise.}$$

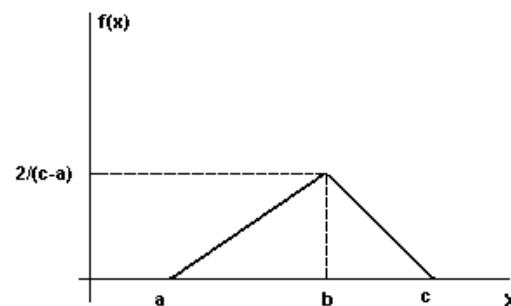


Fig. 1 – Triangular distribution

### 3. Conclusion

The risk-based life cycle cost methodology and the corresponding LCCA program is an effective tool for life cycle cost estimates of layer management [5],[11]. Implementing a comprehensive software layer and system management process is gathering the types of data needed to support the required input distribution estimates to harness the full power of this program. Regardless of the availability of historical data to evaluate changes in pavement costs and performance, the LCCA package is an excellent tool for inspecting the sensitivity of analysis results to critical variables such as grade of slip and pavement performance. It allows a variety of "what-if" types of analysis in an easy-to-use environment and provides clear results that can be used to identify risk in decision-making.

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