COST BENEFIT ANALYSIS OF HIGHWAY SYSTEMS

Darren Thompson[1], Don Chen[2], Nick Walker[3], Neil Mastin[4]

[1] Graduate Assistant, Construction and Facilities Management, University of North Carolina at Charlotte
[2] Assistant Professor, Civil Engineering Technology, University of North Carolina at Charlotte
[3] Graduate Assistant, Construction and Facilities Management, University of North Carolina at Charlotte
[4] Pavement Management Systems Engineer, NCDOT Pavement Management Unit
Correspond to dchen9@uncc.edu

ABSTRACT: Cost-Benefit Analysis (CBA) is a systematic optimization process that allows users to compare different alternatives and to determine if a project is a solid investment. Many state DOTs have included CBA in their pavement management systems (PMSs) to help allocate state funds for maintenance, rehabilitation, resurfacing, and reconstruction of pavements. In a typical CBA, each pavement type has an assigned weight factor which represents the level of importance of this pavement type. To conduct an accurate CBA, it is essential to select appropriate weight factors. Arbitrarily assigning weights factors to pavements can lead to biased and inaccurate funding allocation decisions. The purpose for this paper is to outline a method to develop an ideal set of weight factors that can be utilized to conduct more accurate CBA. To this end, a matrix of all possible weight factors sets was developed. CBA was conducted for each set of weight factors to obtain a population of possible optimization solutions. Then a regression analysis was performed to establish the relationship between benefit and weight factors. Finally, a multi-objective genetic algorithm was applied to select the optimal set of weight factors. The findings from this study can be used by state DOTs to strategically manage their roadway systems in a cost effective manner.

Keywords: Cost-Benefit Analysis (CBA); Pavement Management Systems (PMSs); Genetic Algorithm (GA)

1. INTRODUCTION

When dealing with state funds and tax payers' money, Departments of Transportation (DOTs) are challenged with a limited budget to maintain pavements. That is why it is important funds are used properly to maximize the amount of work done with the allocated money. CBA is a systematic process that helps achieve this goal. By far the most important factor in a CBA is an appropriate set of weight factors. The weight factors ensure that adequate importance is given to each road being evaluated. CBA is an important component that is composed of a state's Pavement Management System (PMS).

Cost-Benefit Analysis (CBA), also sometimes referred to as Benefit-Cost Analysis (BCA), is a systematic process for calculating and comparing benefits and costs of a project at the network level, mainly for two purposes. One is to determine if the project is a solid investment and the second is to compare the different alternatives. CBA takes into account the benefit provided by and the cost incurred due to a project that improves the existing condition of a pavement. If used properly, CBA reveals the economically efficient investment alternative, for example, the one that maximizes the benefits to the public from an allocation of resources.

As mentioned above, a critical component when calculating a more effective CBA is use of an appropriate weight factor. Weight factors give levels of importance based on road types. There are commonly four types of roads within the United States, Interstate routes, United States (US) routes, State (State) routes, and Secondary Road (SR) / Local road pavements. Interstate routes, for example, are the most traveled, meaning they have higher annual average daily traffic (AADT). Therefore they receive the most wear and tear over their service life. Weight factors apply a weight of importance to these specific pavements when conducting CBA in order to account for the significance of the pavement to the user. Generally speaking, an SR pavement will never have a higher weight factor than an Interstate pavement simply because interstate roads hold a higher level of importance to the user.

2. LITERATURE REVIEW

The basic development of Cost-Benefit Analysis (CBA) came as a result of the push provided by the Federal Navigation Act of 1936. It wasn't until about twenty years later in the 1950's that economists tried to provide a rigorous, consistent set of methods for measuring benefits and costs and deciding whether a project is worthwhile [1].

Cost-benefit analysis is considered to be one of the most efficient tools in order to quantify the necessity and opportunity of an investment project. The main advantage

of this method is that it can be very easily utilized in practical situations. However, using cost-benefit analysis has to take into account the certain elements of the analyzed project in order to come up with the appropriate conclusions [2].

CBA is essentially an optimization process. One software that can be used to conduct optimization analysis is LINGO. LINGO is a comprehensive tool designed to make building and solving Linear, Nonlinear, Quadratic, Quadratically Constrained, Second Order Cone, Stochastic, and Integer optimization models faster, easier and more efficient. LINGO allows the user formulate linear, nonlinear and integer problems quickly in a highly readable form [3].

A genetic algorithm (GA) is a class of adaptive stochastic optimization algorithms involving search and optimization. GAs were first used by John Holland at the University of Michigan in 1975. The basic idea is to try to copy a simple picture of natural selection in order to find a good algorithm [4].

3. METHODOLOGY

To complete the objective of developing a set of appropriate weight factors in order to conduct a more efficient CBA there are a few steps that will have to be gone through. The first step will be to determine the benefit of the selected treatment as applied to a pavement. The second is to statistically develop new weight factors that best represent the 4 pavement types.

In order to complete the first step, the benefits are to be determined using a performance curve. A performance curve shows how a pavement deteriorates over time; the higher the pavement condition rating (PCR) the better the road, an example of a performance curve can be seen below in Figure 1:

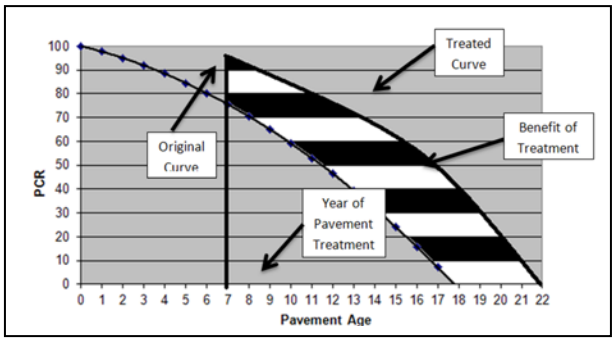

Figure 1. Sample PCR Curve

In order to develop a good set of weight factors for the 4 roadway types, an array of roadway sections along with their treatment types and benefits have to be selected. A proposed 5 roadway sections from each pavement type will be selected for this study totaling 20 sections. A matrix will be developed. This matrix will layout all of the 20 roadway sections with their corresponding benefit, treatment cost, treatment, and specified weight factors. The matrix will display all possible combinations for the pavements and the different treatments that can be applied to each depending on the roadway.

The LINGO optimization software will be used next. The matrix spreadsheet that will be developed with its many different pavement combinations will be applied to the LINGO software. The LINGO software will run its query and will produce the best possible solution of which pavements should be selected first for treatment given the different specified weight factors.

A regression analysis will be performed for a function of benefit for the 4 pavement types. Once these functions are established Matlab [5] software will be used to run a GA on all the optimized solutions produced by the LINGO software. The GA will produce its own set of optimal weight factors from the solutions presented in the LINGO software.

A total of 5 sets of weight factors will be selected from the GA to be presented. The 5 sets will be reviewed by the state DOT. They will then use their own personal knowledge and experience to select the best set of weight factors to apply to the 4 pavement types.

One limitation that might be associated with this course of study is with the learning curve involved with the LINGO software. The LINGO software requires codes that need to be input into the software in the correct way or else it will not read the problem correctly, therefore giving inaccurate solutions. Basic knowledge of the software and its input components will have to be acquired in order to achieve not only the correct results but the optimum results. A flow chart is depicted below (Figure 2) to represent the breakdown of the project.

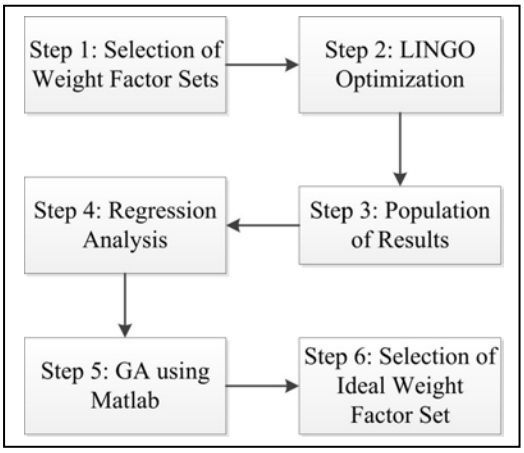

Figure 2. Methodology Flow Chart

4. EXPECTED RESULTS

Expected results from this study should show that the weight factors produced are improved over those already in use by state DOT's. These new weight factors will be backed by a statistical process that takes into account all factors of calculating CBA.

The intermediate step of calculating benefits can also be used by DOT's. Using the weight factors to calculate the benefit can be of great use in other areas besides those

outlined in the study. This relationship also has the possibility of being explored further in future studies.

Because of the uniqueness and originality of this project a new framework is required. The methodology outlined can be used by future studies as a baseline to carry out similar research.

5. CONCLUSIONS

Pavements are the single largest asset owned by Highway Agencies and are extremely important to their users as well as highly visible. They should be maintained in a manner that best benefits the user and the agency. When dealing with state funds and tax payer's money, there is always going to be a limit on how much money is received. CBA helps to improve the process of fund allocation, directing funding to the pavements that provides the most benefit. Appropriate benefit, treatment, cost, and weight factors greatly aid in the entire CBA process for selecting the best road for treatment. Essentially CBA can help give DOT's everywhere the best return on investment.

Expected findings from this research include:

- The method outlined in this paper is an appropriate method for conducting CBA.
- This method provides precise procedures for calculating the benefits of a treatment applied to a pavement.
- The procedures also provide a solid statistical method to select appropriate weight factors.

There are, as in any research, limitations and recommendations to similar studies conducted in the future. For this study those include;

- A PMS must be in place for the CBA process to be implemented.
- Input is recommended from experienced personnel to select the best set of weight factors.
- The results of this study are localized, however the process will be the same for anywhere with an existing CBA.
- The LINGO software used might not be the optimum software.
- Initially, more weight factor sets could be selected for a more comprehensive study.

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