Bridge Rehabilitation Financial Model and Case Study

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Abstract

This article describes a financial model to identify the tangible and intangible costs and benefits associated with externally bonded fiber reinforced polymer (FRP) reinforcement of bridges. It is applied to the analysis of bridge G270 located on Route 32 in Iron county, Missouri, but also applies an approach that can be used with other bridges and structures. This research model represents an approach to address major issues in order to assist in the decision whether or not to rehabilitate specific bridges. Many of these issues are intangible, in that they do not lend themselves to exact or certain measurement. However, they can be analyzed and estimated so that the underlying assumptions are explicitly stated and better understood. This article includes a discussion of the approach that was selected for this model, a description of the methods used to estimate the costs and benefits, and the results and conclusions based on these estimates.

Approach

The objective of this study is to develop methods and tools that clarify the costs and benefits of rehabilitating bridges in order to decide whether to treat specific bridges and develop an effective rehabilitation policy. Many of the impacts of this decision are intangible, in that they do not lend themselves to exact or certain measurement. What is the value of having a stronger bridge? Does it make sense to extend the life of an old bridge? What is the value of having a bridge that can better withstand earthquakes?

Fiber-reinforced polymer (FRP) material systems, composed of fibers embedded in polymeric matrix, provide additional load-bearing capabilities to structures. These material systems include fiberglass, carbon fiber or other synthetic fibers such as Kevlar that are attached to the underlying structure with epoxy or other polymeric matrix. These materials were originally developed for aircraft applications and their application with reinforced concrete structures such as bridges is a relatively new. In addition to adding load-carrying capability, it can make the structure usable after major shocks such as after earthquakes since it is not brittle, and they are also corrosion resistant.

In the application of FRP to bridge rehabilitation there are two major benefits. Because of the additional strength, shock tolerance and weathering behavior, it reduces the risk of damage over time compared to its original condition with a likely reduction of service disruption costs. It also postpones the cash outlay for the replacements. These benefits are compared to the cost of the FRP treatment and other associated costs to determine if the treatment is financially justified.

The model requires the estimation of probabilities of important events, the likely impact of these events to the bridge under various conditions, and the tangible and intangible costs associated with those impacts. As shown on Figure 1, the bridge can be in any one of three conditions. It can be original, treated, or new. Each of these conditions is associated with different costs associated with the risk of service disruption. Costs are generated during the treating process, the rebuilding processes as well as ongoing cost associated with the treated, original and new conditions. After the bridge is treated the costs and benefits under the treated condition are compared to the costs and benefits without treatment. After the untreated bridge is rebuilt the comparison is between the costs associated with the treated bridge versus the new bridge. These differences are estimated on an annual basis and a final comparison developed that summarizes the financial impacts. The method used to deal with the time value of money should be one that is useful and familiar to the planners and decision-makers.

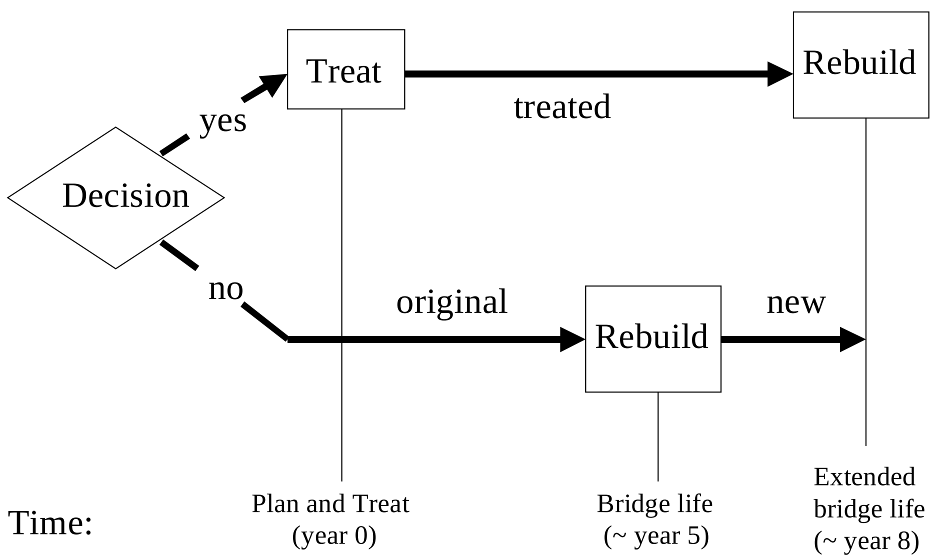

Figure 1. Rehabilitation Timing Chart.

Actual Situation

This research is a collaborative effort between the Center for Infrastructure Engineering Studies at UMR and engineers at the Missouri Department of Transportation. The first step was to create this conceptual model and make rough estimates of the costs. This is the current project status. The next step is to formally work with the Missouri Department of Transportation analysts and decision-makers to:

- Better understand their needs in relation to decision making in this area,
- Present the preliminary model for their review,
- Validate the major premises inherent in the current model,
- Propose changes to the current model,

- Identify sources of the information to make the data more accurate, and
- Identify ways to make the model more useful to them.

The model and the data will then be modified to comply with the decision-maker's needs.

The bridge under analysis is relatively old and small, but is of a design that is inadequate for the loads of modern traffic. Because of that, overweight trucks are required to slow down as they cross the bridge. The traffic is relatively light and other routes are available to bypass this bridge that add approximately 26 miles and one half hour to their trip. The expectations are that the benefits of the rehabilitation of this specific bridge are relatively small. However, the $15,000 cost of the rehabilitation with FRP is also low.

The value of this study is the validation of the approach so that it can be used on a large number of bridges like this one, as well as with more important bridges. Bridges on an interstate, or crossing a major river that would cause a major hardship if it were damaged would generate much larger benefits. However they would also cost more to rehabilitate.

Cost Estimates

Each of the major cost elements are estimated including direct and intangible costs. Traditional cost estimating methods for direct costs can be used since they are generally based on considerable information and experience. This research will develop methods to estimate indirect and intangible costs in ways that are understood by the users. The major cost elements are:

- Treatment Costs
- Rebuilding Costs
- On-going costs of original, treated and new bridges

Treatment Costs

The treatment costs include a $10,000 payment made to subcontractors to apply the FRP for rehabilitation. In addition there are costs associated with the design and planning of the treatment. If this function were performed by in-house personnel, or by others at less than costs, an estimate of those costs would be included. An approach to validate this estimate would be to estimate how much a consultant or other third party would charge to perform that design and planning function. Let's estimate the cost in this case to be $5,000. Assuming there are no other costs, the estimate for the treatment cost is $15,000.

Rebuilding Costs

The rebuilding costs also include the direct, indirect and intangible costs. If the design and planning costs are significant they can be addressed separately, if not they can be grouped with the actual cost to rebuild. The indirect costs can be estimated by the charge that third party organizations would charge to do them. The rebuilding cost is estimated at $400,000.

On-going Costs

This analysis compares the costs and benefits with and without FRP. We are only interested in those on-going costs that are different depending on whether it is in the original, treated and new conditions. Events occur to the bridge that can be major, such as an earthquake, or minor, such as floods and vehicular accidents and the probability of the occurrence of these events can be estimated. These events can destroy or damage the bridge structure and the financial impact of each of these reactions can also be estimated.

The cost of bridge destruction includes the following concepts and estimates.

- The cost to rebuild the bridge. ($400K estimate)
- Incremental planning and rebuilding costs due to the emergency nature of the situation – this can be estimated as a percentage of the standard cost. ($60K estimate)
- The incremental disruption costs to industrial users of the bridge – Based on a likely alternative route, length of disruption (200 days), average truck traffic (100 per day), average cost per mile ($1 per mile) and costs per hour estimates ($50 per hour). This yields an estimated cost of $1,020K.
- The incremental disruption costs to individual users of the bridge – Based on the same alternative route, length of disruption (200 days), average passenger traffic (1000 per day), average cost per mile ($0.25 per mile) and costs per hour estimates ($10/ hour). This yields an estimated cost of $2,300K.
- Possibility of injuries and vehicular damage – Based on estimated probabilities of accidents during or following the event, and the likely related costs that would be generated. ($1K estimate)
- Incremental costs due to detour traffic - If other routes were also damaged at the same time and because this bridge is not available, costs would be generated because the detour traffic had to be routed through a less advantageous route. Based on the probability of this event, and the likely costs to industrial and individual users, cost estimates can be generated. ($17K estimate)
- Total cost of destruction: $3,798K

The cost of bridge damage is structured the same way as for bridge destruction, but the probability values and the cost estimates are different. These differences determine the estimated total cost of damage to be $747K.

The on-going costs for each bridge condition is calculated using the expected value method. Assume there is a 1% chance of a major event with a 20% chance of destruction and 30% chance of damage. Assume also that there is a 2% chance of a minor event with a 30% chance of damage. Then the annual on-going costs for a treated bridge can be calculated to be $12.1K per year. Similar calculations for untreated bridges yield an on-going cost of $16.6K, and $9.4K for a new bridge. Each of these situations uses probabilities and other assumptions that can be easily explained and modified if there is a consensus for a better estimate for any of the values. The costs are based on the total destruction and damage costs calculated previously. Since a new bridge is likely to be stronger, the probabilities of destruction and damage are lower and that generates lower on-going costs.

Table 1 - Time Value of the Investment

($000)	Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8
Cost	(15)								
Benefits	0	4.5	4.5	4.5	4.5	404.5	(2.7)	(2.7)	(402.7)
Cum. Benefits	0	4.5	9.0	13.5	18.0	422.5	419.8	417.1	14.4

Interest rate	Present Worth	Benefit/cost	NPV
at 5%	74.9	5.0	41.4
at 10%	56.7	3.8	65.2

Results

Assuming the bridge under study is to be rebuilt in five years if it is not rehabilitated, but the treatment would extend the life of the bridge an additional three years, a timeline of incremental costs and benefits can be constructed, as shown in Table 1. Year zero has the outlay of the $15K cost of the treatment. The next four years yield a reduction in on-going costs of $4.5K per year, since the on-going costs for the treated bridge are $4.5K less than for the untreated bridge. The fifth year includes the benefit of the $4.5K as well as the avoidance of the $400K rebuilding expenditure. The next two years see a negative annual benefit of $2.7K since the new bridge has lower on-going costs than the treated one. In the eighth year there is the negative impact of on-going costs as well as the $400K rebuilding cost.

Implications

This study makes three significant points that deal with this individual bridge and with the analysis approach. It can be seen in Table 1, that the cumulative benefits are approximately equal to the treatment costs, which shows that the on-going cost savings are minimal. However taking the time value of money into account, a small expenditure enables the delay of a large payment and gives true value to the investment. Depending on the effective interest rates, the benefit to cost ratio ranges from 3.8 to 5. Net Present Value analysis also provides a very favorable analysis to this project. A $15K investment generates a Net Present Value ranging from $41K to $65K.

After looking at the results it is clear that efforts to understand the benefit of this investments should be focused on the estimation of the life extension that FRP rehabilitation provides. It is also important to have confidence in the rebuilding cost estimate. However, more detailed analysis of the other factors considered in this study would not be warranted.

The end result of the full application of this method should yield a user group with better understanding of the key factors to consider for effective decisions. The discussions with the users that question the assumptions and generate consensus agreements provide an excellent forum for organizational learning. For other more important bridges, further analysis into the on-going costs would be warranted. But even in this case, the exploratory analysis provides value. It shows that the major cost driver for on-going costs is the traffic disruption costs. The application of this approach facilitates the identification of the key cost drivers and gives insights into what further analysis is warranted.

Reflections on the Approach

The approach presented in this paper focuses on organizational learning and communication. The traditional approach is to hire a wise decision-maker that would subjectively weigh the tangible and intangible factors to make decisions. Based on their experience, managers can often make very good decisions based on imprecise information. However, sometimes these wise individuals are not available, or the ones available do not have appropriate experience. In the case of bridge rehabilitation with fiber reinforced polymers (FRP) reinforcement, very few have experience in this application, since it is a new concept. Therefore experience is not a very good basis for effective decision making in this area. Another approach is to develop complex stochastic simulation models that can analyze likely outcomes given a set of relationships and probability distributions of possible occurrences. Given the proper assumptions, these models can effectively simulate complex situations. However, it is likely that major factors that affect the decision might not be included since the model builders will probably have little experience in bridge rehabilitation, and the personnel familiar with the decision-making situation might not understand the trade-off's implicit in the model. The third approach is to develop a simplified model that is not as accurate, but more transparent to the decision-makers that facilitates effective dialogue. More importantly it seeks to identify and explicitly state the underlying assumptions. The steps in this approach are as follows.

1. Identify the major ways in which bridge rehabilitation creates or reduces value, which includes the probabilistic avoidance of other less desired outcomes.
2. An estimate is made of the incremental value, using simplified methods that are easy to explain and to modify, as more is learned about the valuing process. This process estimates intangible costs and benefits, which can be substantial. For example, the tangible and intangible economic impact of Michael Jordan was estimated[1] at $10 billion with a similar approach.
3. All the estimates are consolidated and the results are sanity checked by the users. The model is used for sensitivity analysis to identify which decision variables have the greatest impact. The important variables are investigated and modeled in greater detail. As the users learn about the model, they must develop confidence in the model and agree that the results make sense. Any result that does not seem right is discussed until there is a consensus that the method and the results are reasonable.
4. The results are modified to comply with the consensus opinion of the users.
5. The model is used by the decision-makers and continuously modified to reflect the changing realities.

There are many advantages to this approach. It generates a financial estimate that can be compared to other alternatives to facilitate the decision making process. The analysis enables organizational learning since the analysis points out the key factors that generate the value, which are based on explicit assumptions. Compared with more elaborate simulation techniques, this method is faster and more easily understood by the users. Once the major factors are better understood, more complete simulation and optimizing techniques might be used in those areas that have a major impact to the decision and reliable data can be obtained. Compared to more holistic evaluations, this approach can lead to discussions that focus on the explicit assumptions and relationships, instead of the quality of individual judgement. This encourages decisions that are based more on information than feelings and premonitions. It also facilitates the explanation of the reasons for the decisions and to convince others to support its implementation.

REFERENCES:

1 – Johnson, R. S. and Harrington, A., “The Jordan Effect”, *Fortune*, June 22, 1998, pp. 124-138.

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