IMPROVEMENT DECISION IN THE JKR BRIDGE MANAGEMENT SYSTEM

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SUMMARY

In the bridge management system developed by the Public Works Department of Malaysia (called "JKR BMS"), there is a module called the ***Prioritisation Module*** *which provides decision supports for bridge management decision-making. This module is divided into two sub-modules called the* ***Bridge Priority Module*** *and the* ***Improvement Proposal Module.*** *The former is used to obtain a list of candidate bridges for improvement work in accordance with some prioritisation routines. The latter on the other hand is used to make an improvement decision, i.e. to select the actual improvement work that will be performed on each bridge. This is accomplished by examining the needs of the individual bridges and comparing the improvement alternatives for individual bridges using an economic analysis.*

The objective of this paper is to describe the economic analysis used in the Improvement Proposal Module of JKR BMS. The paper describes the various models used in the module and discusses the assumptions that were made in the construction of these models.

INTRODUCTION

Around the world bridge agencies are faced with a common problem in the management of their existing stock of bridges: the ever shortage of fund. This means that money must be spent in the most cost-effective and cost-efficient manner. In tackling this problem, many countries are now either using some sort of a bridge management system or are in the process of developing one. These systems are invariably built on a computerised inventory database and have a suite of computer routines written to manipulate these data to provide timely and useful information for bridge management decision-making.

A bridge management system is more than just a bridge inventory system. Besides providing bridge information, it also seeks to address the question of "*when* to do *what* with *which* bridge?". The various alternative solution to this question could be presented in a 3-D model (Fig. 1). As an example, a treatment option may be *to replace bridge 'A' in the first year* of an improvement program. This may be weighed against another treatment option, that is *to rehabilitate bridge 'D' in the 5th year*, for instance.

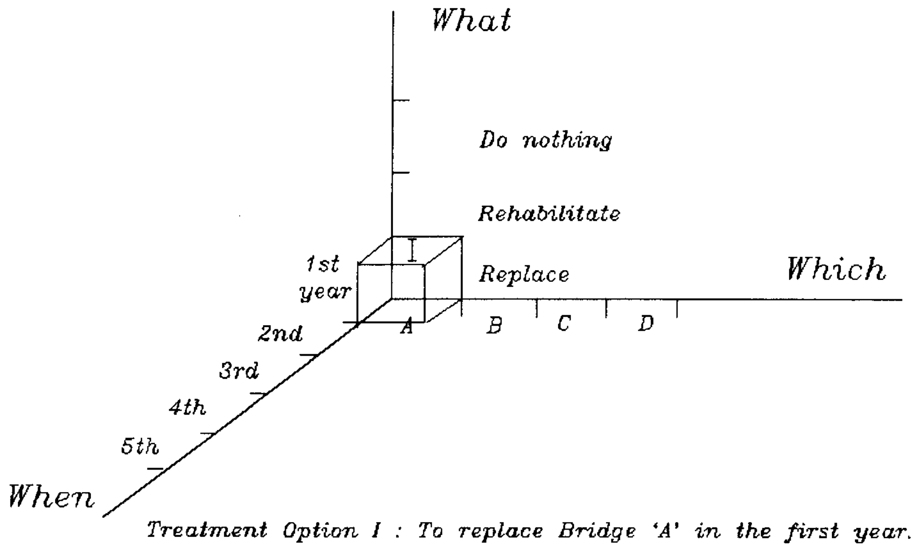


Fig.1 A 3-D model in bridge decision [1]

Many bridge management systems developed today have attempted to address the "when to do what with which bridge" question in one single step considering simultaneously all the three dimensions shown in Fig.1. For example, "ABRAMMS" [2] has an optimisation module which comprises an algorithm to rank the various treatment options (of when to do what with which bridge) in their orders of cost-efficiency. In this algorithm which is based on McFarland et al's work for the U.S. Department of Transportation [3], the incremental benefit-cost ratio of each of the treatment option is calculated and ranked accordingly.

In the bridge management system developed by the Public Works Department of Malaysia (known as "JKR BMS"), the decision *to do what with which bridge* (corresponding the 'what' and 'which' dimensions in Fig.1) is supported by the Prioritisation Module and is made in two distinct steps using two separate modules. First, the bridges to be taken action are identified using the Bridge Priority Module. Work activities are then selected for individual bridges on a project level basis in the Improvement Proposal Module. This is the second step; and is the main concern of this paper.

To complete the discussion on the 3-D model in Fig.1 it is worth while pointing out that in the JKR BMS, the time ('when') dimension has been ignored. This is assuming that the action proposed is for immediate implementation. As a result the benefit or penalty due to deferring a project is not accounted for. The analysis without considering the time dimension will arrive at a near-optimal decision if not *the* optimal one. This is acceptable in the case of JKR BMS because the "which bridge?" decision has been based on some criteria satisfying the organisational objectives of JKR. A bridge thus selected should be taken action immediately if the organisational objectives are to be realised whether or not *that* is the optimal timing for action.

This paper aims to address the economic analysis used in the Improvement Proposal Module for selecting the 'best' improvement option. It describes and discusses the few models created to enable such analysis to be performed. They are the economic model, the deterioration model and the life cycle model.

THE ECONOMIC MODEL

GENERAL

The Improvement Proposal Module in JKR BMS is designed to help the user in selecting the 'best' improvement action for individual bridges identified at the network level. That is accomplished by examining the needs of the individual bridges (in a detailed bridge inspection) and analysing the alternatives for individual bridges at the project level using an economic analysis. This section explains how an economic model could be established to perform the economic analysis and describes the models used in JKR BMS.

ECONOMIC MODEL

The basic treatment options that are available to a bridge engineer after he has conducted a detailed inspection on a bridge are:

i. To do nothing
ii. To rehabilitate
iii. To replace

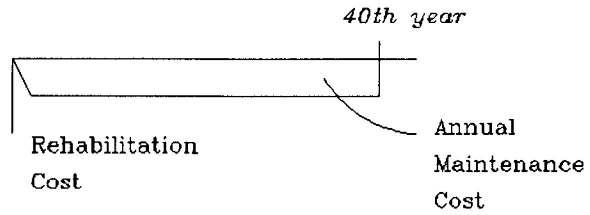
There may be more than one possible way of rehabilitating or replacing a bridge. As such, the engineer may consider several replacement alternatives and/or several rehabilitation alternatives.

It is a well known fact that any bridge in whatever structural condition can be rehabilitated and salvaged. The crucial point is whether it would be more 'worthwhile' or 'economical' to replace it instead. Such comparison must be made by considering all the costs that may be accrued in the complete life cycle of the structure and not merely the initial costs. This is because bridge investment is not a one-time cost. Other costs will need to be laid out during the life cycle of the bridge in order to upkeep it through its service life. This is the subject matter of life cycle costing and engineering economic analysis. In classical engineering economic analysis, discounted benefits and costs of each alternative are calculated for comparison. The interested reader is referred to reference for further details in Engineering Economics [4].

Each alternative treatment option could be represented by a *cash flow diagram* showing the expected cost outlays that may be incurred in the remaining life of a bridge (See Fig.2).

Fig. 2 (a) shows an example of the cash flow that would accrue should a rehabilitation option be selected. In this example, it is assumed that an initial rehabilitation work and subsequent yearly routine maintenance performed on the bridge would extend the service life of the bridge to 40 years. Fig. 2 (b) on the other hand is an example of the cash flow that would accrue should a replacement option be chosen. In this example, it is assumed that an initial replacement of the bridge coupled with subsequent major rehabilitation work at the mid-life of 30 years and yearly routine maintenance would extend the service life of the bridge to 70 years.

(a) Rehabilitation Option:



(b) Replacement Option:

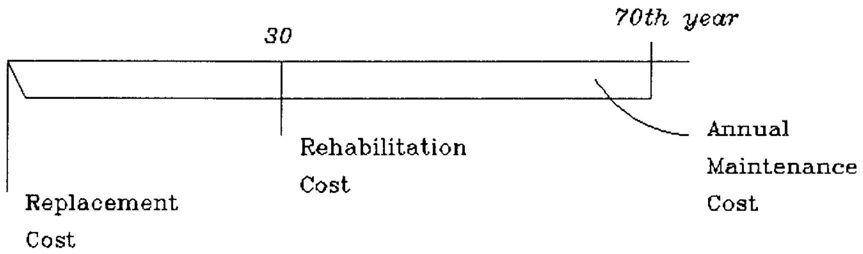


Fig.2 Cash flow diagrams

From the two diagrams, it is evident that each treatment option would extend the service life by a different amount. Apparently, it is not 'fair' to compare alternatives with different life spans. (This subject has been dealt with in standard textbook in Engineering Economics, for example, reference [4]). To overcome this it is assumed that the bridge is to be kept perpectually and thus bring the time scale of the cash flow diagrams to infinity. This implies that subsequent to either initial improvement action, the bridge structure actually comforms to a certain typical life cycle pattern.

THE JKR DECISION MODEL

The decision model outlined above presumes that the costs as well as the extended service life due to an improvement work are known. In the JKR BMS, cost data from previous projects is kept such that standard rates are available for working out the costs. With regards the extended service life, a bridge-deterioration model is being developed which show the relationship of bridge condition and remaining life. To predict the extended life due to an improvement action, the user will input the resulting condition rating for each member improved by the work. The resulting overall condition is used with the deterioration model to estimate the life of the alternative. Discussion on bridge-deterioration model will be made later in the paper.

For JKR BMS, the economic analysis involves comparisons of discounted costs only; that is, it ignores any benefits that may accrue due to an improvement action. Each alternative treatment option is analysed by calculating the present value cost of the alternative which includes all life cycle costs consisting of initial improvement cost, yearly maintenance costs, a mid-life rehabilitation cost in the case of replacement options, and an infinite concrete bridge replacements at the end of the initial lives (see Fig.3). A "do nothing" alternative is also considered which is merely continued maintenance to the end of the bridge's life then infinite repeated replacements with concrete bridges. A default discount rate of 12 % is used to make the present value cost calculations but this value can be permanently changed by an authorised user using the proper password. A sensitivity analysis is allowed such that the discount rate is temporarily adjusted for the current computer session in order to examine the effect of different rates. Once the present value costs for all the alternatives are calculated each is listed for the user. At that point, the user can select the least cost alternatives as being the most appropriate for that bridge and recommend it for detailed design.

In the JKR BMS it is assumed that the bridge in question will be replaced with an infinite number of concrete bridges at the end of life of all the alternatives under consideration (Fig.3). This may seem a valid assumption in view of the fact that most of the new bridges constructed in Malaysia today have been of concrete in concurrence with the current policy.

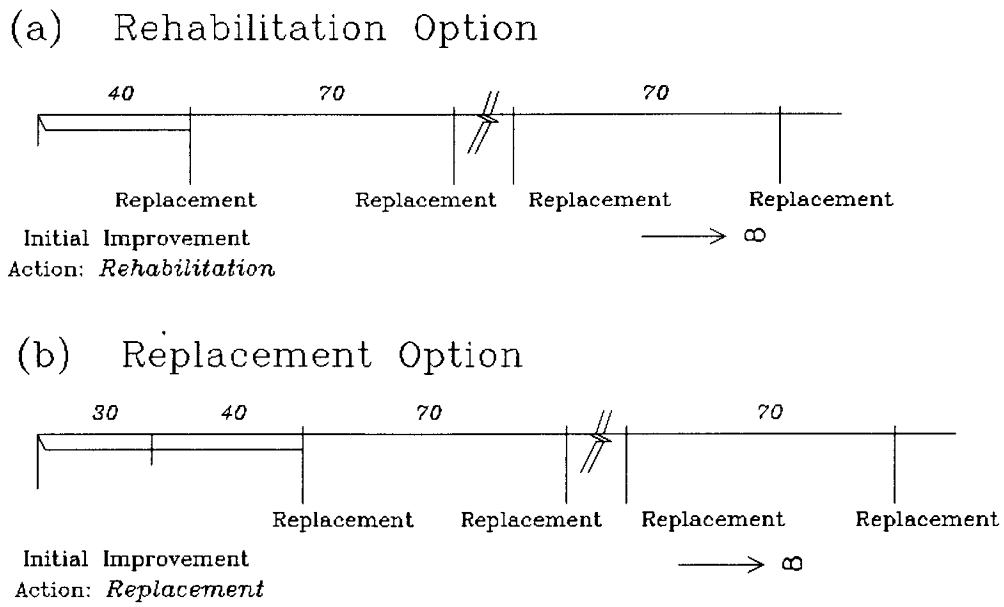


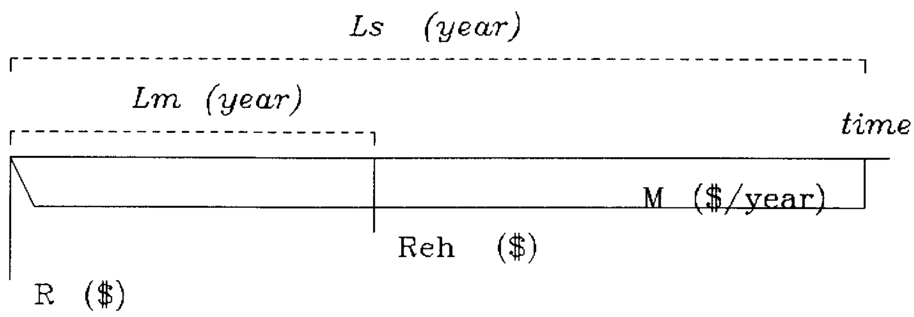
Fig.3 Bridge options extended to infinity

In Fig. 3, each cost outlay (designated as 'replacement') subsequent to the initial improvement action is the present life cycle cost of a new concrete bridge. The replacement is assumed to repeat at an interval of 70 years; this being the service life of a typical concrete bridge.

Some brief discussion of the typical life cycle pattern will be made in the following section.

THE BRIDGE LIFE CYCLE MODEL

In the economic model described above, it is assumed that any bridge improvement action is to be followed by an infinite number of concrete bridge replacements; and that there is a certain typical life cycle pattern for a concrete bridge. In JKR BMS the typical life cycle of concrete bridges is represented in Fig. 4



R = Replacement

Reh = Rehabilitation

M = Annual Maintenance

Ls = Service Life

Lm = "Mid-life"

Fig.4 Typical life cycle of concrete bridges

In the life cycle model shown in Fig.4, it is assumed that a bridge will cost *R* $ initially for construction. This will enable the bridge to last for *Ls* years; provided that some time in the mid-life of the service life, *Lm* there is a major rehabilitation work performed on the bridge (costing *Reh* $) and that an annual maintenance be provided at a rate of *M* $ per year. In the case of concrete bridges, the following values have been assumed:

Ls = 70 years
Lm = 35 years
R = M$ 2,000 per square metre
Reh = 0.6 x R
M = .02 x R

The values above are based on the experience of the JKR bridge engineers. Presently, historical records of improvement work done on each bridge are stored in a computerised database. These data include information like the nature of the work, its total cost and the date of construction. The database as it grows in size, will allow refinements to be made in the establishment of the bridge life cycle model in the future.

THE BRIDGE-DETERIORATION MODEL

One of the most important problems faced in the development of an economic model for the Improvement Proposal Module is the prediction of the remaining life of a bridge structure as well as the extended service life effected by an improvement work. This has been a popular research topic around the world.

In the U.S., for example, there are the Transportation Systems Centre (TSC) in Cambridge, Massachusetts Institute of Technology (MIT), the Wisconsin Department of Transport (WisDOT) and the New York State Department of Transportation (NYSDOT). All these institutions attempt to establish a bridge-deterioration model (which represents the rate of bridge deterioration) using historical bridge data.

Based on studies by the above institutions summarised in [5], bridge condition is a function of many parameters. These are *bridge material type*, *age*, *environmental condition*, *skewness*, *number of spans* and the *number of vehicles* using the bridge.

In the case of JKR BMS, there are presently 1,100 records in the database although there are well over 4,600 bridges in the peninsular of Malaysia. Due to incomplete database, statistical analysis to identify significant parameters could not be carried out. Notwithstanding, based on a preliminary study performed on the 1,100 records in the database, it was found that the overall bridge condition is a function of age, bridge material type and environmental condition.

More than 80% of the bridge records now available in the JKR BMS database are concrete bridges. Analysis on the existing data for concrete bridges show that there is a linear relationship between bridge condition and age. A linear regression analysis is thus used to draw the best fitting straight lines.

For predicting the remaining life of a concrete bridge, JKR BMS used the deterioration curves as shown in Fig.5. These curves show the relationship between bridge condition and remaining life for both severe and moderate environment.

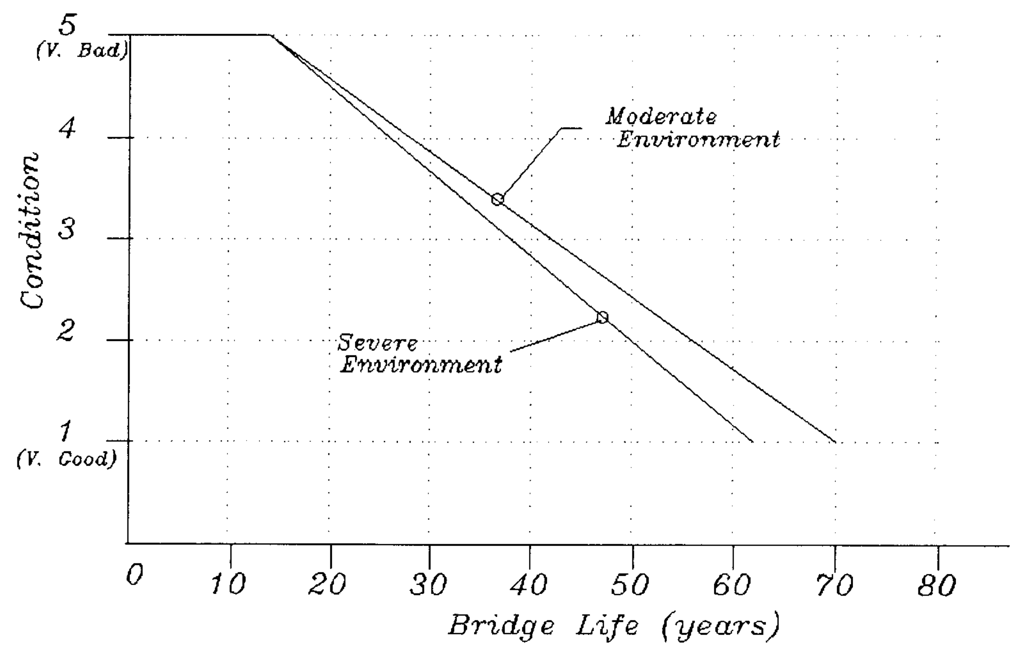
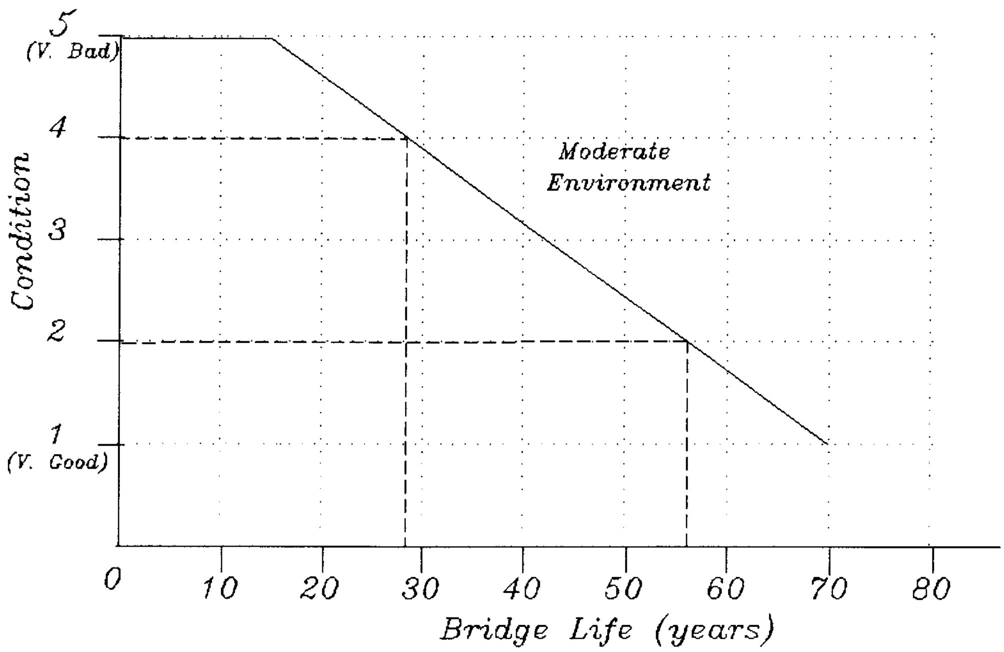


Fig.5 Bridge-Deterioration Model

Using these curves, the remaining life of a concrete bridge could be estimated based on the condition rating. The extended service life could also be read directly from the curves (See Fig.6).



E.g.: Improvement of condition from '4' to '2' extends the service life by 28 years.

Fig.6 Estimate of extended service life

CONCLUSIONS

In the JKR BMS there is a module called the Prioritisation Module which is designed to provide the decision support for bridge management decision-making. This module is divided into the Bridge Priority Module and the Improvement Proposal Module. The Bridge Priority Module is used to select candidate bridges for improvement while the Improvement Proposal Module is used to select the most appropriate treatment option to be performed on individual bridges selected. This is done using an economic analysis in which discounted life-cycle costs of alternatives are calculated for comparison. The alternative involving the least discounted cost is considered the most appropriate and is recommended for detailed design.

There are various problems in the establishment of the Economic Model. First, each alternative improvement action would extend the service life of the bridge by different amount. Second, comparisons of the costs must be based on present and future costs in the life cycle of a bridge; and finally, it is not easy to establish a bridge-deterioration model needed to predict the extended service life due to an improvement.

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