Probabilistic Deterioration Models Used in Bridge Management Systems

Modèle probabiliste de détérioration pour l'entretien des ponts

Probabilistisches Abnutzungsmodell für die Brückenunterhaltung

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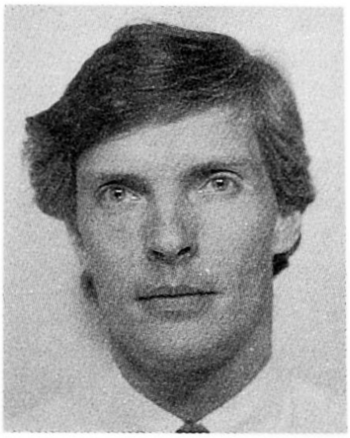

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SUMMARY
A bridge management system project in progress in Finland is presented. The system applies probabilistic bridge deterioration models to find a condition distribution of the bridges that minimizes maintenance and rehabilitation costs for the existing bridge stock.

RÉSUMÉ
En Finlande, on développe un système de gestion des ponts depuis 1986. Le système utilise des modèles probabilistes de détérioration des ponts pour déterminer la distribution optimale des conditions, qui minimise les coûts d'entretien et de rénovation des ponts existants.

ZUSAMMENFASSUNG
Ein Brückenverwaltungssystem, das man in Finnland zur Zeit entwickelt, wird präsentiert. Das system benutzt probabilistische Modelle für Brückenabnutzung, um eine Konditionsverteilung für Brücken zu finden, die die Unterhaltungskosten für bestehenden Brücken minimiert.

1. GENERAL ASPECTS

The Finnish National Road Administration (FinnRA) has started the bridge management system development for its 9800 bridges and 2200 culverts in November 1986. This work is made in co-operation with The Technical Research Centre of Finland, Viasys Ltd of Finland and Cambridge Systematics Inc., Cambridge, Massachusetts, USA, and is planned to be completed in 1993.

The goal of this management system is to provide a reliable support tool in decisions related to fund allocation for maintenance, rehabilitation and replacement (MR&R) of existing bridges. The system will minimize MR&R costs while keeping the bridges safe and on a required level of service.

The aim is to find the economically optimal long term condition distribution of the bridge stock within the safety and minimum service levels. The long term optimum solution is a combination of the optimal condition distribution and the optimal repair action distribution.

The system will be employed by the central administration of FinnRA and its thirteen districts to assist in high level bridge policy, long term planning and programming of MR&R investments, and short term evaluation of bridge repair needs and their costs. The work schedules and recommended bridge repair programs are prepared in the districts.

2. THE ELEMENTS OF THE BRIDGE MANAGEMENT SYSTEM

2.1 The Bridge Database

The whole bridge management system is based on a thorough bridge inspection and condition evaluation. The damages and deterioration detected during the inspections, their exact location and extent are recorded. Also, information on the effect of the damages on bridge bearing capacity, on repair urgency class and the inspector's proposals for repair action and their costs will be described and recorded.

All this information is stored in the bridge database together with bridge structural, administrative and traffic data. Also historical data and information on previous repairs and their realized costs are gathered for further research and bridge age behaviour modelling.

2.2 The Network Level System

The management system, when completed, will consist of two parts: a network (bridge stock) level system and a project (individual bridge) level system. This paper is mainly concerned with the network level bridge management system.

The network level system in turn consists of two parts: the long term module to find the ideal optimal condition distribution for the bridge stock and the short term module to find out how to get the bridge stock from the present condition distribution to the optimal distribution.

2.2.1 The Network Level Long Term Analysis

The long term analysis is based on the general idea that the bridge stock has an optimal condition distribution. This optimum is intermediate in the following sense: keeping all bridges in an excellent state at all times would be excessively expensive and, on the other hand, letting the bridge stock deteriorate badly would cause expensive major repairs. Somewhere in between there is an optimum where the bridge stock can be kept on the same condition level from year to year with the smallest possible amount of funding and still adhere to the safety and level of service requirements.

The optimal condition distribution corresponds to a certain optimal set of repair actions. These repair actions would, in the ideal case, be applied in the same amount from year to year, although naturally to different individual bridges. The set of optimal repair actions and the amounts of each, i.e. the optimal repair action distribution, will keep the bridge stock in the optimal condition distribution perpetually.

2.2.2 The Network Level Short Term Analysis

The short term analysis provides an economically optimal way to reach the long term optimum condition distribution during the next few years. There are separate short term solutions for each coming year. Each short term solution represent a step closer to the long term optimum.

2.2.3 Features of the Network Level System

In reality the long term optimum will change somewhat from year to year because of changes in the variables that influence it. Changes can be expected in repair method costs because of new repair methods and materials. The road policy could change and level of service standards with it. New improved deterioration modelling could affect the optimum, etc.

The network level system offers the possibility for what-if experiments with respect to the safety and minimum service level policy, repair action costs, budget limits and other variables. The system will also provide detailed information for future bridge designers on the deterioration mechanisms of bridge elements and on the life-span cost of different bridge types.

2.3 The Project Level System

The project level system, which deals primarily with individual bridges, uses the results from the network level system to decide on the repair actions in individual repair projects. The project level system is the key tool for everyday bridge repair planning in the road districts.

The project level system is an interactive computer program that helps the bridge engineer to plan and schedule the repair projects for individual bridges based on the recommendations from the short term model and the damage data in the database.

3. MATHEMATICAL APPROACH

The purpose of the system is to minimize total yearly bridge repair costs under given restrictions by doing the right repair at the right moment in the lifespan of bridge components.

The mathematical solution uses a set of probabilistic Markov chain models to predict deterioration of the various structural members of the bridges in the bridge stock. The Markov state space is three-dimensional with one dimension each for structural, surface and corrosion damages. Together with data on possible repair actions for each kind of damage, the respective cost of these actions, minimum bridge condition requirements, and budget limits, linear programming (LP) models can be formulated and solved by computer to yield a recommended long-term optimal solution for the condition state distribution of the bridge stock. The LP models also give the distribution of repair actions required each year to maintain the optimal cheapest state from year to year.

The short term model uses a modified method to recommend repair actions for several consecutive years starting with the present, to move the current distribution of condition states in the bridge stock towards the long-term ideal situation, minimizing cost along the way.

The optimizing long- and short-term models will be used to study different repair strategies and to support budget allocation decisions on both national and district level. In addition, the results are a key input to the project level system.

4. BRIDGE DETERIORATION AND AGE BEHAVIOUR MODELLING

The modelling of bridge deterioration speed and age behaviour is based on the information of damages gathered during the inspections. Because there still is a lack of information of this kind, opinion surveys (Delphi studies) or expert evaluations are also made for getting the first age behaviour curves and models. When more deterioration data becomes available the models can be refined.

These models for predicting the future behaviour of bridge structures and structural members are mathematically based on the Markov chain method as mentioned above. The Markovian condition state transition probability matrixes are calculated using deterministic deterioration models based on data obtained from inspections and actual measurements or on the expert judgment elicited through Delphi studies.

5. THE IMPLEMENTATION OF THE BMS

One requirement in the implementation of the BMS has been that it can be run on an ordinary IBM-compatible personal computer given enough memory and disk space. The central part of the system, the bridge database, has been implemented as a single-user relational database system with readily available software (Oracle 5.1B) and has a customized user interface. Parts of the system are in the C programming language. The bridge register has been in production use since the spring of 1990. A multiuser version of the system is planned for the central administration and for districts willing to invest in some additional hard- and software.