The Development of Practical Asset Management System for the Hanshin Expressway Network

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ABSTRACT: The Hanshin Expressway is a network of expressways in Hanshin metropolitan area of Japan. As one of the most important infrastructures that support there, a high level of maintenance management is required. Maintenance budgets for road structures have been squeezed tight in recent years. For continued proper maintenance of road structures, more effective and efficient measures need to be taken against structural aging in conjunction with future medium- and long-term plans. This paper describes about the Maintenance Information Management System (MIMS), the Hanshin Expressway Bridge Management System (H-BMS) . MIMS is a database system which can store a large amount of asset, inspection and repair date. H-BMS is a maintenance management system which has functions to calculate optimal repair policies by minimizing life cycle costs, to simulate future condition state and repair costs and to determine repair priority. It uses the latest inspection data and traffic data which are stored in MIMS for improving accuracy.

1 INTRODUCTION

Since its foundation in 1962, Hanshin Expressway Public Corporation (HEPC) has built and been operating an urban toll road network in Kansai Metropolitan Area for over 40 years. The network currently expands to 242.0 km in total length and is used averagely by about 900,000 vehicles or about 1,350,000 people per day. In 2005, HEPC was privatized by a policy of the national government, Hanshin Expressway Company Limited (HEX) was established newly. But it is apparent that Hanshin Expressway is playing a very important role for the economic and social activities of the area as a main traffic artery supporting people's daily life in every aspect.

90% of the network is formed by viaduct structures and more than 40% are over 30 years old. The older these structures get, the more important their maintenance/repair treatment becomes in order to keep accommodating such heavy traffic. However, while the route length in service is increasing and traffic volume is steady, maintenance and repair budgets are being curtailed due to the current social and economic circumstances. Furthermore the development of more rationalized allotment scheme of the limited budget is critical as the financial condition is unlikely to be recovered in the near future.

For continued proper maintenance of road structures, more effective and efficient measures need to be taken against structural aging in conjunction with future medium- and long-term plans. It is also necessary that user service be maintained at proper levels. For these, public understanding on importance and significance of maintenance need to be further promoted.

This paper describes about the Maintenance Information Management System (MIMS), the Hanshin Expressway Bridge Management System (H-BMS). MIMS is a database system which was established about 20 years ago, can store a large amount of asset, inspection and repair date. It was developed and made available on line at each office. H-BMS is a maintenance management system which has functions to calculate optimal repair policies by minimizing life cycle costs, to simulate future condition state and repair costs and to determine repair priority. It uses the latest inspection data and traffic data which are stored in MIMS for improving accuracy.

2 MAINTENANCE MANAGEMENT CYCLE

Figure 1 shows the management cycle of the maintenance which is composed of 4 phases, PLAN, DO, CHECK and ACTION. In the PLAN phase, short-, medium- and long-term maintenance plans are established for the road structures. The budgets and the priorities to repair are decided in here. The DO phase is a phase of activities. In the phase, appropriate repairs are operated, based on the budgets which are determined in the PLAN. In the CHECK phase, the conditions of the structures are monitored through the inspection. In the ACTION phase, the methods of maintenance are reconsidered through the verification of the results in the CHECK.

MIMS and H-BMS are tools to operate the management cycle. The data used in the every phases are all placed under MIMS. Maintenance plans in the PLAN phase are facilitated based on the calculation result from H-BMS.

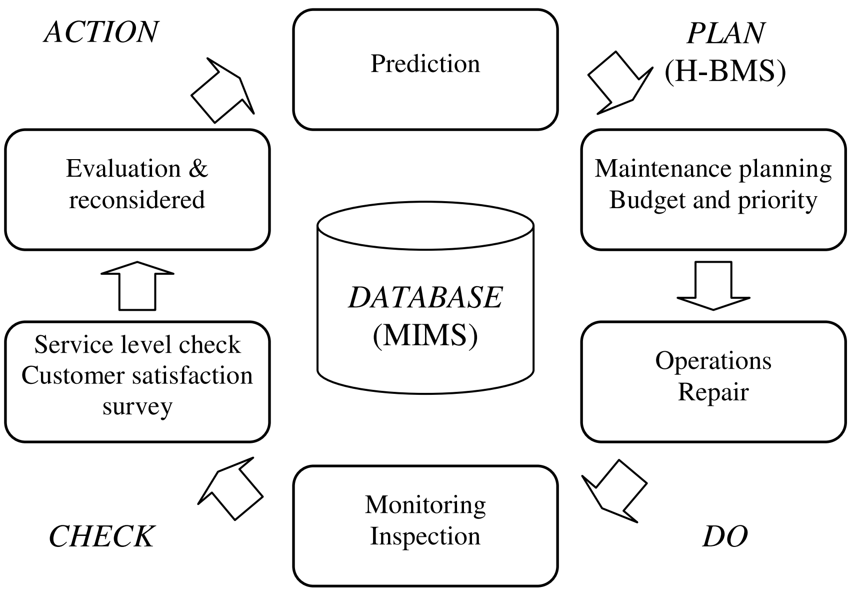


Figure 1. Maintenance management cycle

3 MAINTENANCE INFORMATION MANAGEMANT SYSTEM (MIMS)

3.1 Outline

As an initial stage of MIMS development, HEX constructed structural information database in 1990. After the trial period, the first-phase of database system was completed in 1993 and integrated into the process of HEX's maintenance/repair program making. Put into a regular usage, the system was found to be significantly poor in data compatibility and also to lack in practicability in other applications which is essential for utilizing the system in the future. With the help of progress in computer technology, the original database system was revised and enhanced by the addition of data management system , which not only enables the prompt and continuous database referencing and updating but also facilitates decision-making process of inspection and repair works.

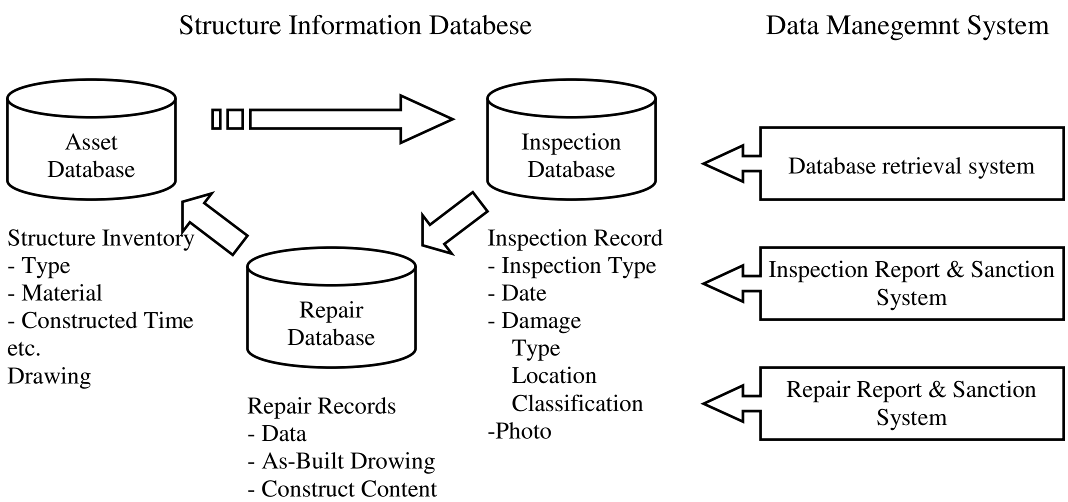


Figure 2 MIMS configuration

3.2 Structure information database

Structure information database stores all information on expressway structures related to their physical features, conditions and the records of inspection and repair. The data is classified by structure element and location which is identified by the bridge management number attached to each span and pier. The contents can be displayed in text format as well as shown visually like drawings and photos. The data is exchangeable with related local offices through a client-server system.

3.2.1 Asset database

Asset data is classified into 22 categories of structural elements including superstructure (girder, deck), substructure (pier and foundation), pavement and expansion joints. Superstructures and substructures are further divided into steel and concrete types, and the steel type contains information on painting. The data items are chosen by taking account of the frequency of reference and the level of accuracy. Data is basically written in ledger format which had been used conventionally in a paper form. Drawings are also incorporated. More than 180,000 units of data are stored in the system at present.

3.2.2 Inspection Database

Here, data collected from regular and overhaul inspection are stored. The results of regular inspection are immediately sent by the inspection work contractors directly to the HEX headquarters via the system network. The digital photos and data in text format are automatically stored in the database. Recently, the results of overhaul inspection which used to be reported in paper sheet and later manually input in the database can be handled automatically as well. The system can now trace the inspection data up to the fiscal year of 1985.

3.2.3 Repair Database

There are 10 categories in the repair database and more than 310,000 units of data are stored in the system. Although it is ideal to store comprehensive records of all repair activities in the past, those conducted after 1985 have been stored in order to save cost required for data processing.

3.3 Data Management System

The data management system allows any client computers in the HEX offices to access to the database in the server computer for retrieval, reference and data updating. All terminals are linked by exclusive network provided by HEX for confidentiality. The main components of this system are database retrieval system, inspection report and sanction system, and repair report and sanction system.

3.3.1 Data Retrieval System

Data retrieval system is a key component of the data management system having various functions for searching and collecting information efficiently. The system has two interfaces for retrieval: multiple keywords retrieval and chart information retrieval. Either one can be used as desired according to the purpose of users.

Multiple keywords retrieval enables to find any desired information by entering a certain searching condition (e.g. keyword matched/unmatched, maximum/minimum/average figure) from the base list of asset, repair and inspection data displayed on terminal monitors.

Chart information retrieval, on the other hand, can extract information of individual structures by using bridge management numbers as a location identifier. The search results are displayed in a list form which provides the overall view of latest information of the designated structure.

3.3.2 Inspection/ Repair Report and Sanction System

Terminal in HEX offices are also connected to inspection and repair contractors. All the due procedures required between HEX and the contractors can be completed with this system. They include data entry of inspection and repairing results, repair work instruction, and confirmation and sanction formalities by the local office in charge. Inspection reports have digital photos of damages attached so that HEX engineers can confirm the information precisely and give the most appropriate instructions for repairing . The paperless and online sanction system speeds up the process remarkably and makes a significant contribution to cost and resource saving as well.

4 HANSHIN EXPRESSWAY BRIDGE MANAGEMENT SYSTEM (H-BMS)

4.1 Purpose

HEX has been working on establishing H-BMS for effective and efficient planning of maintenance. H-BMS has the following purposes.

a) Calculate the expenses required to maintain road structures at proper levels for an extended period.

b) Calculate long-term changes in performance levels and costs and priorities of repair projects, and provide reference materials for maintenance management planning.

c) Provide an explicit basis for repair plans and repair costs to support accountability.

Using the asset, inspection and repair data stored in the MIMS, the H-BMS determines condition of each structure and predicts deterioration, calculates repair and maintenance costs and priorities of repair and maintenance projects required for maintaining proper performance, and establishes budget plans and repair plans.

4.2 *Deterioration model*

H-BMS is designed for maintenance management planning against deterioration of road structures. In H-BMS actual deterioration process information is integrated in the deterioration prediction through estimation of Markov transition probabilities based on the long-time accumulated inspection data using multi-staged exponential hazard models15). For the estimation using the multi-staged exponential hazard model, hazard rate was defined for the health level of each section. The following equation estimates the exponential hazard model with the hazard rates by health levels independent of time.

$$\lambda_i(y_i) = \theta_i \tag{1}$$

Here, i is health level of the member, λ_i is hazard function, y_i is a point on the time axis, and θ_i is a constant (unknown parameter). The health level needs to be expressed as a discrete value to use the Markov transition probability.

For using the multi-staged exponential hazard model, Markov transition probability is expressed as described below in accordance with the degree of deterioration.

(when the health level does not change)

$$\pi_{ii} = \exp(-\theta_i Z) \tag{2}$$

(when the health level changes by one rank)

$$\pi_{ii+1} = \frac{\theta_i}{\theta_i - \theta_{i+1}}\{-\exp(-\theta_i Z) + \exp(-\theta_{i+1} Z)\} \tag{3}$$

(when the health level changes by two or more ranks)

$$\pi_{ij} = \sum_{k=i}^{j}\prod_{m=i}^{k-1}\frac{\theta_m}{\theta_m - \theta_k}\prod_{m=k}^{j-1}\frac{\theta_m}{\theta_{m+1} - \theta_k}\exp(-\theta_k Z)(j = 1,\cdots,J) \tag{4}$$

(when the health level changes to the bottom rank)

$$\pi_{iJ} = 1 - \sum_{j=i}^{J-1}\pi_{ij}(i = 1,\cdots,J-1) \tag{5}$$

Here, Z is inspection interval, i is health level before change, and $j(j>i+1)$ is health level after change. By estimating θ_i in the hazard function by maximum likelihood method, Markov transition matrix (6) can be estimated using equations (2) to (5).

$$\prod(Z) = \begin{bmatrix} \pi_{11}(Z) & \cdots & \pi_{iJ}(Z) \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \pi_{JJ}(Z) \end{bmatrix} \tag{6}$$

As deterioration change is modeled by the hazard function, the expected time length for deterioration to reach a next level (RMD) can be expressed as follows.

$$RMD_i = \int_0^\infty \exp(-\theta_i y_i) dy_i = \frac{1}{\theta_i} \tag{7}$$

Equation (7) provides typical deterioration process. Through these processes, data are classified into some groups by factors dominating the tendency of deterioration change, and performance curves are generated.

Figure 3 shows the performance curve which was calculated by this model using the inspection data of the pavement which was accumulated by MIMS. As shown here, pavement deterioration rate is faster on the earthworks than RC and steel deck was found.

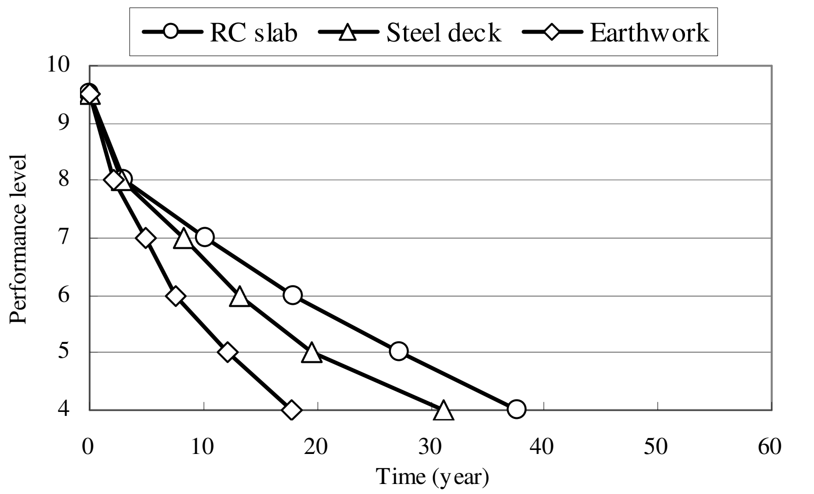


Figure 3. The calculated performance curves by multi-staged exponential hazard models (Pavement)

4.3 Optimum repair level

The function to calculate optimum repair level by the life cycle cost (LCC) is one of the main features of H-BMS. LCC is expressed as a sum of the direct cost which is imposed on HEX and the user cost which is imposed on the road users:

LCC = direct cost (repair cost and maintenance cost) + user cost (vehicle operating cost and travel delay cost).

Figure 4 shows the relationship between the repair level and the LCC. The repair level where the lowest LCC is reached is called the optimum repair level, and the time reached the optimum repair level is called the optimum repair time.

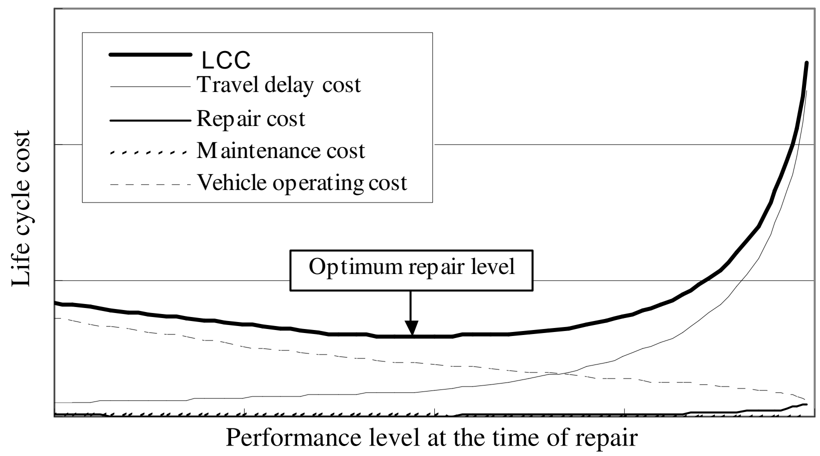


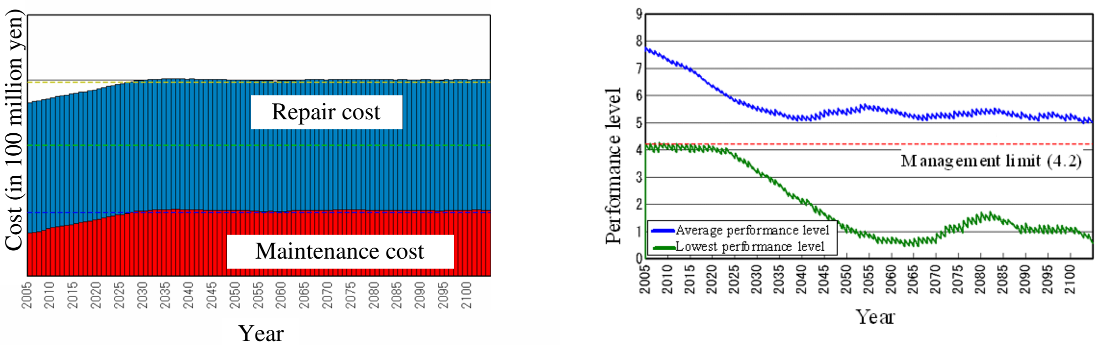
Figure 4. Optimum repair level by LCC

4.4 Repair priorities

If no limitation is imposed on the budget, it is possible to repair all locations or routes where the performance level reached the optimum repair level on the annual basis, achieving the minimum LCC. However, budget is always limited, requiring prioritization of repair locations or sections for each year. H-BMS determines repair priorities according to the descending order of the ratio (repair efficiency = D/C) of the extra on the LCC due to delay from the optimum repair time (D: delay cost) against the repair cost at the optimum repair level (C: Repair cost).

4.5 Simulation

H-BMS can simulate the change of the direct costs and the performance level of road structures in 100 years. Figure 5 shows predicted changes of them of the pavement under the annual budget of "A" x 100 million yen. In this case, performance level goes down continually. Repair carryover accumulates during that period, causing the lowest performance level to decline after about 20 years. As a result, structures performance goes below the management limit specified by HEX. The limited repair cost leaves some pavements in poor condition as they are over the



Budget limit: "A" × 100 million yen/year

Average total cost (1,408 million yen)
Average repair cost (999 million yen)
Average maintenance cost (482 million yen)

Figure 5. Result of direct cost and performance level simulation by H-BMS (Pavement)

optimum repair time. Because of this, the maintenance cost for coping with them starts to increase from 2005 and reaches its limit in about 20 years. In the case to increase the budget limit "A+α" x 100 million yen (cost required for maintaining the optimum management level), average performance level is kept around the current level for an extended period, and the lowest performance level does not go below the management limit. Repairs carried over from the past can be eliminated gradually, making it possible after 35 years from now to execute repairs based on the optimum management level within the annual budget limit. In addition, the total cost (maintenance cost and repair cost) for the 100 years is reduced by about 11%.

5 CONCLUSIONS

This report covers the outlines of MIMS and H-BMS which has been developed by HEX. MIMS is now in a complete version and wholly used for managing the structures from inspection to repair. The report also introduces H-BMS as an effort of putting MIMS into more practical use and to meet the urgent need of preparing a logical and systematic method of building maintenance/repair planning, which used to be dependent rather on empirical approach. Combining the data from MIMS with the consideration of structures' life cycle cost, it enables to give suggestions of efficient and persuasive budget requirement and repair work prioritization even under the tight budget constraints. The prototype which is focused on pavement management will soon be put into practical use after the further examination of its applicability and system refinement.

It should be noted these two systems also help to meet the rising demand of fulfilling accountability in every stage of decision-making process of structural management.

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