DEVELOPMENT OF BRIDGE MANAGEMENT SYSTEMS IN TAIWAN

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Abstract

This paper describes the efforts in developing several versions of bridge management system (BMS) in Taiwan. There were several versions of stand-alone BMS developed in Taiwan prior to the Ji-Ji earthquake that occurred in year 1999. Since many bridges were seriously damaged by this earthquake, the Ministry of Transportation and Communication determined to develop a nationwide BMS to have a better by control on the status of bridge maintenance. Implemented in year 2000, the Taiwan Bridge Management system (T-BMS) is now the dominating and mandatory system used by all the government agencies that are responsible for bridge maintenance. Having more then 25,000 bridges in its inventory, T-BMS has thousands of logins per month to update data in the relevant database. The experiences and difficulties of using such a nationwide bridge management system are discussed. Finally, future plans for BMS development are also proposed in this paper.

Keywords: Bridge management system, bridge inspection, DER&U methodology, geographic information system, web services.

1. Introduction

Taiwan is a mountainous island therefore bridges play an important role in land transportation. In Taiwan, research and development efforts on Bridge Management Systems (BMS) began in early 1990. However, the research results produced in that period were very academic and far from real world applications. In 1995, commanded by Executive Yuan, a long term program was planned by the Ministry of Transportation and Communications (MOTC) that included development of BMS in Taiwan. Several versions of BMS designed for various government agencies were developed one after another since then. These early versions of BMS didn't have the same bridge inventory formats or the same standards for bridge inspections. Among these versions, the first successful BMS in Taiwan was implemented by the Center for Bridge Engineering Research (CBER), National Central University (NCU), with the sponsorship from the Directorate General of Highways in 1998. More than four thousand bridges were built into the inventory of this BMS.

In September 1999, the Ji-Ji (921) earthquake hit Taiwan and caused severe damages to many bridges; as a consequence, traffic was seriously disrupted in many places that made the disaster even worse. Thus, the government determined to develop a nation-wide BMS that can be used by all the bridge management agencies, in order to have a grasp of understanding regarding the conditions of bridges in Taiwan [1]. In 2000, the first version of Taiwan Bridge Management System (T-BMS) was completed and online. Funded by the MOTC, the T-BMS was also developed by the CBER, and is now maintained by the Institute of Construction Engineering and Management at NCU.

2. BMS of the Directorate General of Highways (H-BMS)

BMS developed by Directorate General of Highways was the first successful one developed and implemented in Taiwan in 1998, hereinafter termed as H-BMS. The H-BMS was successful because that it had the largest ever inventory of more than four thousand bridges, and that it had the most functions compared to other versions of BMS implemented during that time.

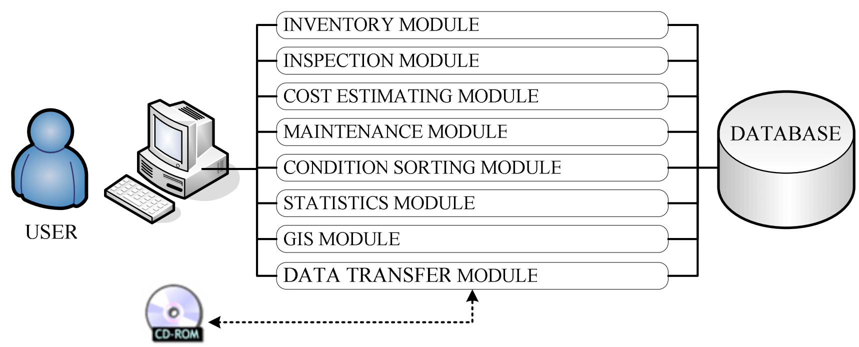

Figure 1: H-BMS consists of eight functional modules.

Figure 2: Screen dumps from the Inventory and GIS Modules of H-BMS.

H-BMS was a stand-alone system running on personal computers. H-BMS had eight modules, as shown in Figure 1: (1) Inventory; (2) Inspection; (3) Cost Estimating; (4) Maintenance; (5) Condition Sorting; (6) Statistics; (7) Geographic Information System (GIS); and (8) Data Transfer [2]. The “Inventory Module” was the core of H-BMS that stored crucial information of bridges including drawings and photos. The "Inspection Module" provided functions to record and search inspection data, including suggested repair methods and deterioration photos of bridges. According to the suggested repair methods and inspection results, H-BMS estimated the repair cost of each bridge via "Cost Estimating Module" and ranked conditions of the bridges via "Condition Sorting Module". The repair history was stored in database via "Maintenance Module", while the "Statistic Module" was able to generate various kinds of statistic graphs if required. The most advanced function of H-BMS was "GIS Module", illustrated in Figure 2; that allowed the user to display a bridge on the map to show its surroundings and to search for replacement route if a bridge was marked as dangerous. It is believed that H-BMS was one of the first BMS integrating with GIS. The "Data Transfer Module" was performed by mailing of CD-ROM discs between headquarter and district offices due to poor Internet quality available at that time.

3. Taiwan Bridge Management System (T-BMS)

The Ji-Ji earthquake, also know as the 921 earthquake, caused severe damages to dozens of bridges. Although H-BMS was able to mark the damaged dangerous bridges and to search replacement route, but H-BMS was limited to bridges on local highways. Thus, the MOTC determined to develop a nation-wide BMS that can be used by all the bridge management agencies in Taiwan, through which the central government can grasp the condition of the bridges in Taiwan and make respond immediately when disasters occurred. In 2000, the first version of T-BMS was completed and online. Funded by the MOTC, the T-BMS was developed by the CBER, and was implemented based on the experience of implementing H-BMS.

The users of T-BMS including engineers and staff from agencies such as MOTC, Taiwan Area National Freeway Bureau, Directorate General of Highways, Taiwan Railway Administration, Ministry of the Interior, and local governments. T-BMS is a web-based system thus every agency can login via web browsers if the computer is connect to the Internet. The major functions of T-BMS are illustrated in Figure 3: (1) Inventory; (2) Inspection; (3) Cost Estimating; (4) Maintenance; (5) Maintenance Performance; (6) Statistics; (7) GIS; and (8) Parameters Setting. These functions are very similar in that of the H-BMS developed earlier. However, inventory format and inspection standards are revised as the standards applicable to each and every bridge in Taiwan. In addition, an Automated Visual-Aids System (AVAS) was also developed to facilitate the bridge inspection process.

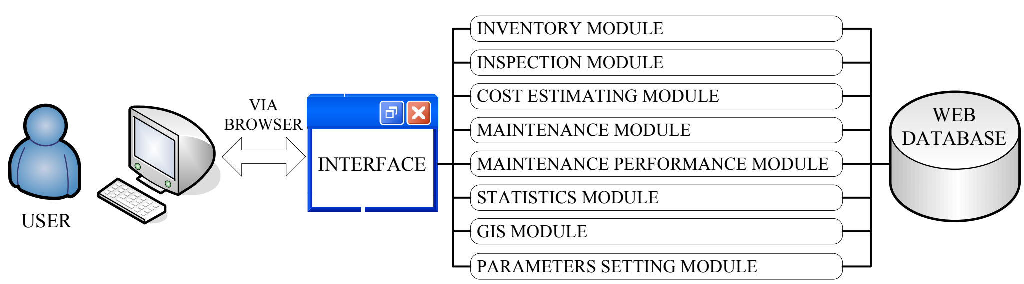

Figure 3: T-BMS consists of eight functional modules.

3.1 Bridge Inventory Format in T-BMS

At the same time when T-BMS was under development, a nationwide bridge survey was conducted. The survey results were input into T-BMS that include data of the inventory as well as data of the first time inspection. Same as H-BMS, bridge inventory is the core of T-BMS; all system functions are meaningless without it. In T-BMS, each bridge is characterized by 57 fields that are categorized into four types they are: (1) Management, (2) Geometry, (3) Structure; and (4) Design data, as shown in Table 1. Notably, the inventory has at least four photos for each bridge, and has a pair of GPS coordinates by which an aero-view can be obtained through the help of Google Map, as illustrated in Figure 4.

Table 1: Type of inventory data of a bridge.

Type of data	Num of fields	Instance
Management	19 fields	bridge name, bridge no., admin. agency, admin. department, county, town, road level, route, mileage, construction date, contract price, designer, contractor, location, crossover object, latest repair date
Geometry	15 fields	length, max & min width, slab area, height of pier, number of lanes, number of spans, max span length, GPS coordinates
Structure	13 fields	bridge type, beam type, abutment type, wing wall type, foundation type, pier type, joint type, bearing type, beam material, pier material
Design	9 fields	designed live load, acceleration, flood level, heights of bank, length of bank, heights of river bed, ground type, falling prevention device

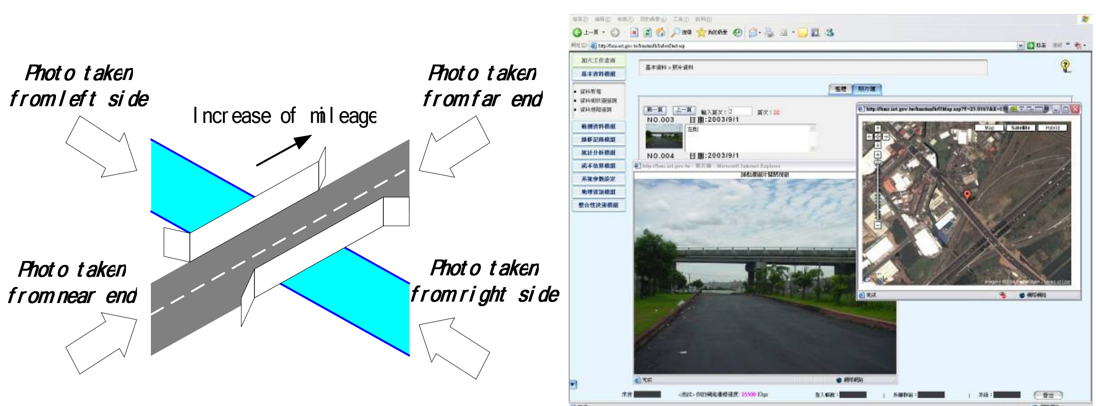

Figure 4: Four photos and aero-view of a bridge.

3.2 Bridge Inspection Methodology in T-BMS

The methodology of bridge inspection and evaluation incorporated by T-BMS is called DER&U, which was initiated by a joined effort of two consulting companies, CSIR and Join Engineering [4]. Before T-BMS was developed, there were several inspection methodology used by different government agencies. However, after T-BMS was online and used by all the government agencies, the DER&U became the national standards for bridge inspection.

Table 2: DER&U evaluation criteria.

	0	1	2	3	4
D	Not Applicable	Good	Fair	Bad	Serious
E	Unable to Inspect	Less than 10%	10~30%	30~60%	Over 60%
R	Relevancy Uncertain	Minor	Limited	Major	Large
U	N/A	Routine	In 3 years	In 1 years	Immediately

In the DER&U methodology, “D” stands for degree of deterioration; “E” represents extent of the deterioration; “R” implies relevancy to safety of the deterioration; and “U” depicts urgency for repairing of the deterioration [5]. All of these indices are numerically rated on an integer scale from 0 to 4, as exhibited in Table 2. While rating the deterioration conditions, the inspector can also input his/her personal comments if deemed necessary.

In the DER&U, 21 components of a bridge are identified for inspection; they are: (1) approaching embankment, (2) approaching guardrail, (3) waterway, (4) protection works for approaching embankment, (5) abutment foundations, (6) abutments, (7) retaining walls, (8) pavements, (9) superstructure drainages, (10) sidewalks, (11) guardrails, (12) scouring protection piers, (13) pier foundations, (14) piers & columns, (15) bearings, (16) earthquake brakes, (17) expansion joints, (18) longitudinal girders, (19) transversal beams, (20) decks & slabs, and (21) others. These components are defined for typical concrete bridges; other types of bridge will have slightly different fields that are currently under investigation.

After each of the 21 components of a bridge is rated and input into T-BMS, a condition index (CI) which represents the overall condition of the bridge, can be calculated automatically by T-BMS. The condition index is based on a deduct point system. Scores of deficiencies will deduct points from a perfect score of 100. In Equation (1) Ic_i is the condition of component “i”, and w_i is the weights of importance of component “i”. Equation (2) shows the calculating formula of $Ic_{i.}$, In this equation, Ic_{ij} is the index of the “j” part of component “i” and n is the number of parts. Equation (3) shows the calculation formula of Ic_{ij} based on values of “D”, “E” and “R”; where “a” is an input parameter to increase the importance of “R”, usually equals to 1 or 2.

$$CI = \frac{\sum_{i=1}^{21} Ic_i \times w_i}{\sum_{i=1}^{21} w_i} \qquad \text{Eqn. (1)}$$

$$Ic_i = \frac{\sum_{j=1}^{n} Ic_{ij}}{n} \qquad \text{Eqn. (2)}$$

$$Ic_{ij} = 100 - 100 \times \frac{D \times E \times R^a}{4 \times 4 \times 4^a} \qquad \text{Eqn. (3)}$$

3.3 Automated Visual-Aids System (AVAS)

Decreasing of experienced bridge inspectors and increasing of personnel turnovers are very common situations in a bridge management agency. Except for enhancement of training courses, an automated system is desired to facilitate the DER&U judgments for a rookie inspector. AVAS is developed for such purpose. AVAS runs on a tablet PC so the inspector can easily take it to the bridge site. Through out the inspection process, AVAS automatically displays relevant DER&U spreadsheets for components of a bridge that is under inspection. Photos of typical deteriorations are displayed for matching with the bridge deterioration to automatically determine the ratings, as shown in Figure 5. The inspection results, i.e., the DER&U ratings as well as descriptions of the deterioration, are saved in the AVAS database and can be automatically uploaded to the T-BMS once the tablet PC is connected to Internet [6].

Figure 5: Inspector using a tablet PC to run AVAS at the bridge site.

3.4 Performance Evaluation of Bridge Maintenance

A nationwide performance evaluation of bridge maintenance is conducted annually by the Institute of Transportation, MOTC. The evaluation criteria involve not only inspection and maintenance works performed but also using of T-BMS. In the use of T-BMS evaluation, completeness of bridge inventory, inputting of inspection data and repairing data, time of the data inputting, and times of logins into T-BMS are all included in the criteria. Currently there are more than two thousand logins per month. T-BMS plays an important role in bridge management in Taiwan.

4. Problems and Difficulties

T-BMS has been online for more than six years since year 2000. T-BMS is used by all of the bridge management agencies to perform bridge management tasks on more than 25,000 bridges in Taiwan. Continues improvements on system interfaces and functions in the past five years have made T-BMS a system generally accepted as a daily use tool by the agencies. However, there are still problems and difficulties in bridge management relating to the use of T-BMS, described below.

4.1 Frequent Personnel Turnovers

One of the most serious problems in bridge management is frequent personnel turnovers. Bridges in Taiwan are public property thus are under the jurisdiction of various government agencies. Bridges have a long service life but the persons on the maintenance job do not, due to promotions or job rotations, especially in the agencies of local governments; they won't stay on the same position for more than two years. Once the personnel turnover occurs, it creates problems such as (1) the new staff is not familiar with T-BM, (2) historical data in T-BMS might be lost due to invalid operations, and (1) issues of responsibility may raise if data in T-BMS are incorrect. However, since the personnel turnover is inevitable, strategies to overcome such problems need to be determined. It was found out that, routine training courses on bridge management, including operations of T-BMS, plus a hot line and an email box, are very helpful to ease such problems. A special service team on call for solving specific problems at the agency should be the last resolution.

4.2 Lacking of Experienced Bridge Inspectors

The DER&U inspection methodology must performed by trained inspectors. However, it still may result in various ratings due to various knowledge, training, and experience of the inspectors. This in turn may create a problem in the long term when the inspection results are used as the comparison basis for budget distribution among districts or bureaus. Since the government agencies usually employ consulting engineers or companies to perform such inspection, a strict standard on their qualification is required. The standard may include a minimum of five years' experience in bridge inspection with proofs of participation in the bridge management training courses conducted by MOTC. Use of AVAS as the inspection tool certainly will reduce this problem.

4.3 Operation Efficiency of T-BMS

T-BMS is a nationwide, network-based system belongs to the central government agency, MOTC. Currently, T-BMS has an inventory that contains more than 25,000 bridges. The huge amount of bridges may cause difficulties in the operation of T-BMS. For example, if each bridge needs 100MB disk space for storing maintenance data and photos, then the T-BMS server must at least have 2.5TB of disk space; and the 100MB for a bridge may be still not enough in a period of time. The problem lies in the efficiency of system operations of T-BMS. The bigger the hard disc is, the slower the efficiency will be. In other words, several terabytes of data and photos will decrease the data search efficiency, thus all of the online users will be affected when using T-BMS. This problem will be worsening if more information, such as as-built drawings and non-destructive testing reports, is uploaded to the T-BMS. However, this problem is expected to be solved automatically by the advancing of computer technology in the future.

5. Future Development of BMS

5.1 Decision Support Functions of T-BMS

The development of T-BMS is aimed at providing a convenient and efficient tool to assist bridge management tasks. Functional improvements are continuous efforts in maintaining T-BMS. A need for decision support functions arises when interviewing users of T-BMS. The desired functions including (1) classifying deteriorated bridges into various degrees of danger based on regularly inspected DER&U results; (2) classifying bridges into various type of safe conditions based on results of a modified quick inspection table after events of natural disasters such as typhoons and earthquakes; (3) prioritizing deteriorated bridges and suggesting repairing methods based on limited budgets; and (4) outlining prioritized maintenance activities based on statistic results of inspection and maintenance data. These functions are expected to serve as a handy helper for the personnel who are responsible for bridge management and maintenance.

5.2 Development of Local Bridge Management Systems

T-BMS provides nationwide standards for bridge inventory and inspection. However, such information is not satisfactory in detail to local bridge management agencies, especially for certain compound or long bridges. The development of local BMS is toward (1) detailed bridge inventory, (2) detailed inspection data, (3) storage of drawings and contract documents, and (4) ability to interchange data with T-BMS.

5.2.1 Inventory Data

Owing to the evolvements and improvement of construction materials or technologies, various types of bridges and viaducts were built. Some of these bridges may have special structure design or may reach up to thousands of meters in length. Usually, long viaducts may across different kinds of terrain such as hills, valleys, rivers, and city areas. In order to accurately record bridge information in enough detail, the inventory data are divided into three layers: (1) basic layer, (2) contract layer, and (3) component layer, as shown in Figure 6. The basic layer stores data such as bridge name, route, and administration etc., of the bridge; the contract layer records information regarding contracts through which the bridge components were built; and the component layer stores design data, geometry data, and structure data for each particular component desired by the agency.

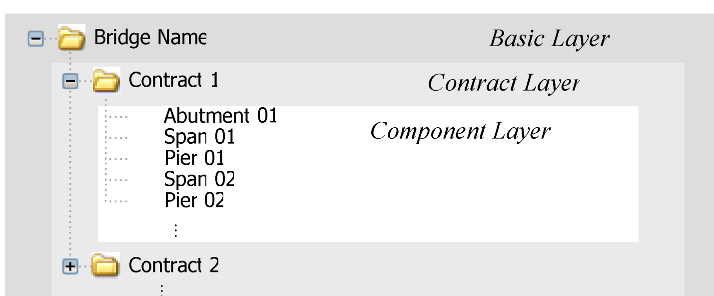

Figure 6: Three layers of bridge inventory.

5.2.2 Inspection Data

There are three types of inspection for roadway bridges, they are: (1) daily patrol, (2) regular inspection, and (3) special inspection [7]. Daily patrol focuses on the deterioration which may cause uncomfortableness or danger to the road user. Regular inspection will be conducted once per two years for overall inspection including the river course. Special inspection is performed after extremely heavy rains and or severe earthquakes exceeding intensity IV. Among these three only results of the regular inspection are recorded in T-BMS. Therefore, local BMS requires storages of the daily patrol and special inspection results in addition to that of the regular inspection.

5.2.3 Drawing and Document Management

The as-built drawings are often stored in hardcopy or CD-Rom formats. However, neither of them is easy to find when needed. In addition, the non-destructive testing reports and repairing contracts are also in the same situation. All of these require a computerize storage of such information.

5.2.4 Data Interchange

Since the T-BMS is a mandatory system required by MOTC, the developed local BMS should be able to communicate with T-BMS for updating data. Web Services, usually built based on ubiquitous and open industry standards such as XML, HTTP and SMTP [8], are the suggested mechanisms due to their independence of operating systems, languages and hardware.

6. Conclusion

The development of BMS has a history more than eight years in Taiwan since 1998. H-BMS was the first effective and successful BMS even though it was a stand-alone system. The more advanced web-based T-BMS was developed in 2000. T-BMS has more then 25,000 bridges in its inventory and is now a mandatory system required by Taiwan government. Use of T-BMS is also part of the performance evaluation criteria for bridge maintenance. Current problems and difficulties in bridge management are related to high personnel turnover rates in the bridge management agencies and lacking of experienced bridge inspectors. Impacts of such problems can be eased by conducting regular training courses and by using of the automated visual-aids system, AVAS. Efficiency of T-BMS' computer server may become an issue from the long term perspective, if its database grows faster than advancing of computer technologies. Future developments of BMS will include implementations of decision support system functions, and local BMS in bridge management agencies that record more detailed maintenance information. T-BMS is expected be the core of bridge management and maintenance in Taiwan in the foreseeable future.

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