TOWARDS THE DEVELOPMENT OF A GIS-BASED BRIDGE MANAGEMENT SYSTEM (BMS)

NG, See-King
B. Sc, M. Sc, MICE, CE

SHE, Tian Hock
B. Sc. Civil Engineering (Hons)

Bridge Engineers,
Roads Branch, Public Works Department Malaysia

SYNOPSIS. Public Works Department Malaysia (JKR) has developed an in-house computerised BMS in 1989. The system which was called JKR BMS was subsequently enhanced in various aspects including the incorporation of picture images in early 1992. Despite the popularity of GIS technology, there is no BMS today that is GIS-based. JKR is about to embark on an in-house development of a GIS-based BMS. The development of such an application certainly requires much consideration in terms of the user requirements and various constraints. This paper aims to outline the concepts, features and the strategy undertaken for the proposed GIS application.

INTRODUCTION

1. While most public and private bridge authorities or agencies around the world are still without a proper and systematic bridge management system, the trend seen today in a few countries is the move towards the development of a computerised bridge management system (BMS). Some examples of these BMSs are reported in (ref. 1). Almost all of the systems that have been developed or under development now are based on relational data base management systems (RDBMS) running on PCs. In Malaysia, the Public Works Department Malaysia (known locally as JKR) started an in-house development of a computerised BMS in 1989 on a PC using DBASE IV data base management system. A prototype system called JKR BMS had since been created in 1990. The system was subsequently enhanced in various aspects including the incorporation of image management facility in early 1992. The need to have a graphical user-machine interface to afford better user-friendliness cannot be overemphasised.

2. Since the first Geographic Information System (GIS) was developed in the middle of 1960s, the technology is becoming popular in the Information Technology (IT) industry as is evidenced by the amount of GIS products and services flooding the market today (ref. 2). The use of GIS in the development of applications in various fields have been reported in many seminar papers or conference proceedings (refs. 3 & 4). Transportation Research Board report (ref. 5) on GIS has proposed the use of GIS in transportation planning and highway infrastructure management including pavement management and bridge management. There are indeed efforts towards the use of GIS in pavement management (refs. 5 & 6). However, the authors are not aware at

the time of writing of any GIS application developed for bridge management.

3. The Bridge Unit of PWD Malaysia is about to embark on an in-house development of a GIS-based BMS. The development of such an application requires much consideration in terms of the user requirements and various constraints. As a strategy, a mock-up system will be created for the purpose of presenting to the JKR management.

4. This paper aims to present the concepts and features of the GIS-based BMS. It also seeks to discuss some of the considerations and strategies undertaken by the Bridge Unit in the creation of a prototype system scheduled to be completed by the end of 1992. A GIS normally refers to an application rather than a tool. In the context of this paper, GIS is treated as a tool to enhance an existing relational database management system.

WHAT IS GEOGRAPHIC INFORMATION SYSTEM (GIS) & WHY GIS ?

GIS simply explained

5. GIS is a computerised system for storing, manipulating, analysing and visualising spatial or geographic data. In the history of man's civilisation, maps have been used as an analog storage device for spatial data; but a GIS is more than just an electronic map. Besides providing a means for spatial display, it provides supports for analysing the interrelationships among the various spatial data elements. Since human activities are spatial in nature or somehow geographically related, GIS also serves as a common platform for the integration of different information systems.

6. Geographic data can be represented using both a relational and a topological model. This approach facilitates efficient handling of the two generic classes of spatial data: *locational data* describing the locations and topologies of annotation, point, line and area features; and corresponding *attribute data* describing the characteristics of these features.

7. GIS can simultaneously store and manage both the locational data and attribute data about a geometric element in an integrated fashion. It provides a live link between map images and their corresponding attribute database through an alphanumeric id which is also attached to that object's corresponding attribute record in the relational database. So the database management operations such as data inputs, editings and checkings can be performed more efficiently.

Why GIS ?

8. There is a long history of man attempting to describe and represent the spatial features around him using images like paintings, maps, photographs; etc. In the case of information system, it was due to technology constraint that man has to resort to non-textual database management system much like the black and white television prior to colour television. This is no longer the case as there exists today the GIS technology which allows representation and manipulation of spatial data. The use of GIS is perhaps the most natural course of event in man's history.

9. In the context of the JKR organisation, there are various Units within the Department which are handling and managing different types of data. For example, the Bridge Unit has the bridge management data, the Research Institute (IKRAM) has the soil and slope condition data, the Highway

Planning Unit has traffic and accident data, the Roads Maintenance Unit has pavement management data; and the Roads Design Unit has digitised land survey data. Indeed, the various Units are now in the process of developing their respective information systems to collect and manage these data. In order to avoid duplication of efforts in the collection and storage of data, a department-wide GIS is called for. Such integration of information systems not only provide data sharing, but would also permit investigations into the relationships of the data elements never done before. For example, an exercise to determine the best site to build a bridge. A department-wide GIS would also serve as a one-stop centre for any information needed for the proper operation and management in the Department.

10. The proposed GIS-based BMS is intended to be a sub-system to the department-wide GIS. The need for such a system will be further discussed later.

THE JKR BMS

Background & features of JKR BMS

11. Bridge Unit of JKR in 1990 developed a computerised bridge management system called JKR BMS. It was designed to help Bridge Managers/Engineers to perform four basic bridge management functions :

* Data Management
* Bridge Decision
* Budgeting
* Bridge Administration

12. In the management function, the JKR BMS provides bridge information and project information at the press of a button. Any combination of data elements based on relational logic can be used in a user-defined query.

13. The JKR BMS also provides decision support functions for the "when to do what with which bridge ?" decision. With this function, bridge managers/engineers will be able to decide on the priority of bridge projects and the most optimal improvement option.

14. In terms of budgeting requirements, the JKR BMS is able to produce a work plan enlisting the recommended projects in their order of priority. The nature of work proposed, cost estimates and proposed year for action are also displayed.

15. Bridge administration includes the general administration of the use of the existing bridges by road users to ensure public safety. In this aspect of bridge administration, the JKR BMS provides information and thus decision support for the issuance of abnormal vehicle movement permit. An abnormal vehicle represents a vehicle that is not allowed to move freely on the roads under the Construction & Use Regulation issued by the Road Transport Department Malaysia. Inevitable movements require a movement permit.

16. Most of the existing computerised BMSs in operation or being developed in the world today are still traditionally purely alphanumeric or textual-based RDBMS. The JKR BMS, like other BMSs around the world, is a PC-based BMS using the most popular relational database software in the PC market which is dBASE IV. Since the existing manual inventory system in the form of bridge inventory card isn't itself just comprising textual inventory data but also photographs and sketches of the longitudinal section and cross-section

of the bridge, it would likewise give a better picture of the bridge and its surrounding environment if the computerised BMS could include photographs of the bridge.

17. Image capturing and image management facility was incorporated in the JKR BMS in 1992. The module is produced by the integration between a graphical software called PicturePower and dBASE IV. PicturePower allows *the capturing of images using a video-camera. Being compatible to dBASE IV* database management system, it allows the captured images to be called and displayed in the dBASE IV routines.

Systems enhancement requirements for JKR BMS

18. For any system, naturally existing or man-made, there must be a continued effort to adapt to changes in the environment or within the system itself. This may come as a need due to any shortcoming(s) within the system or due to any change(s) in the technology without. The need to improve the JKR BMS arises out of these two factors.

19. The shortcoming of JKR BMS can be summarised as follow:

* it provides textual data display only with no graphical data display; and thus is not user-friendly;
* the documents and as-built drawings for every bridge are stored "off-line" in their original medium or microfilms;
* the provision of image management capability through the use of PicturePower greatly slows down the operational time of the system.

20. GIS software packages available in the market today not only provide spatial display in the form of an electronic map, but also provide image and document management facility.

FEATURES OF THE PROPOSED GIS-BASED JKR BMS

21. Features of the proposed GIS-based JKR BMS includes:

i. To be able to display the geographic location and consequently the distribution of all or a certain classification of bridges in the road network on a computerised map for national, state or district level. This includes the ability to identify and display geographically all bridges satisfying a certain criteria or combinations of conditions, for example to select bridges constructed of steel before 1970.

ii. In addition, it must be able to display a list of all the bridges together with its inventory meeting the filtering criteria and display textual database information on any of these bridge records.

iii. To be able to display scanned colour images of photographs as well as longitudinal and cross-section drawing of a particular bridge or group of bridges meeting any selected criteria.

iv. To be able to display geographically all the bridges to be traversed by an abnormal vehicle as well as analyse and highlight the under-capacity bridges amongst them. This would possibly result in choosing an alternative route where possible or involve strengthening the under-capacity bridges.

v. To be able to do statistical analysis on the population of bridges at national, state or district level meeting a certain selection criteria and display them in the form of pie-charts, bar charts, etc.

STRATEGY

Procedures for implementation

22. A great number of papers or articles quoted in the References had discussed in detail the strategic planning needed prior to the implementation of a GIS. They invariably emphasise the importance of non-technical issues, like the need to prepare the organisation for the change, the need to obtain full commitment of the Management for a GIS implementation, the need to conduct a benefit-cost analysis on the feasibility of a GIS implementation and the need to conduct a user-requirement analysis in the GIS system development phase. Indeed, much like the design and development of any database management system, a life-cycle approach is certainly called for.

23. Donna and Duane (ref. 7) have even stressed that "...More geographic information systems have failed through poor system design than from any other cause." and that "...the stages of the GIS design process can be clearly defined and related to similar concepts in the field of software engineering : feasibility analysis, requirement analysis (including conceptual database design); development of specifications; generation of an implementation plan which addresses such matters as system testing and acceptance, initial database creation, physical facilities, personnel and training, and administrative structures."

24. If a department-wide GIS for JKR were to be developed, the same sets of procedures would be followed. However, the intent now is to develop a mock-up system for the purpose of selling the idea to top management and also to familiarise the in-house staff with the subject of GIS.

25. The approach taken by JKR to develop a GIS-based system for bridge management involves the following steps:-

i. Define Objectives, functions & features of the GIS
ii. Select Hardware & Software for prototype GIS
iii. Purchase hardware & software for prototype GIS
iv. Develop mock-up GIS
v. Sell idea to top management for the need of a GIS-based BMS
vi. Plan, organise for the development of the system.

Issues to consider

26. There are a few pertinent issues to consider prior to the actual systems development phase:

i. what GIS software?
ii. data format: raster or vector?
iii. map projection: what coordinate system?

27. GIS software issue. There are indeed many GIS software available in the market today. A list of these are available in (ref. 2). The intention to enhance the present JKR BMS towards a GIS system was made known in the Terms of Reference for consultancy services for the review of Prototype JKR BMS. The fact that the GIS-based BMS would finally be a component of a

department-wide GIS was also expressed to the consultant during the consultancy work provided by ARE Inc., of Texas, USA. Based on the foregoing, the consultant had proposed an approach which involve the purchase of a small scale but full functioning "prototype" GIS product now, before fully researching department-wide needs and requirements (ref. 8). Under this strategy, the specifications for the GIS software to be purchased are solely derived from its intended use in the JKR BMS. The consultant had recommended that a mock-up GIS for BMS be developed using a low cost package, like MAPINFO while simultaneously affording JKR the opportunity to visualise, first hand, some of the benefits of GIS as applied to JKR responsibilities.

28. Data format issue. Data format involves the way of representing the topology of the locational data during a digitisation (that is, the analog-to-digital conversion of an image detail) exercise. Raster format makes use of picture elements (called pixels) to represent a point, line, area and annotation features; while vector format maintains or preserves the analog form of point, line, area and annotation features. For the latter, what constitutes these spatial features in digital terms need further explanation. A point is specified by a coordinate pair, a line by a series of coordinate pairs, and an area by a closed series of coordinate pairs.

29. Many literatures on GIS have discussed the benefits of an integrated GIS system using both the raster and vector formats. In the development of the mock-up GIS for BMS, an attempt was made to obtain a complete set of digital maps of Peninsular Malaysia from the Department of Survey & Mapping, Malaysia (DSMM). Indeed, DSMM has presently completed one of the 177 digital topographic maps for the Peninsula. In the recent seminar on Digital Mapping & GIS, the Director of Computer-Aided Mapping System (CAMS) division of the DSMM has said that it is the objective of CAMS to work towards the production of cadastral, topographic and cartographic maps in digital forms to help other agencies in their implementation of LIS or GIS (ref. 9). Though this objective is much called for and timely, it would take many more years before this is achieved.

30. Map projection issue. Map projection involves the way to transform the earth surface (which is spherical) to a plane. There are an infinite number of ways to transform a spherical surface to a plane one. This is a subject matter in cartography. Today most plane coordinate systems are based on only three common map projections, namely the transverse mercator, the polar stereographic and Lambert's conformal conic. In Malaysia, due to her association with the U.K. historically, the projection system was inherited from the British System during the colonial time. There are now nine different systems of coordinates in use for the 12 states, each with its own origin and reference of meridian. The projection in use is the Cassini Soldner system, which is non-orthographic. All Cadestral Survey Maps in Peninsular Malaysia are plotted on this projection. On the other hand, topographical maps in Peninsular Malaysia are being drawn on the Rectified Skew Orthographic (RSO) projection. This projection is specially derived for countries like Peninsular Malaysia, East Malaysia and New Zealand because of their skewness, for which, if the universally accepted Universal Transverse Mercator (UTM) projection were adopted, a large scale error and unnecessary grid

junctions would be introduced. As a result, any point in Peninsular Malaysia now possess a minimum of two sets of coordinates. At the moment, the DSMM has no intention to recompile all the cadastral maps to the RSO system. There is however a conversion routine developed in-house by DSMM to convert the Cassini system to the national RSO system. For the purpose of this project, the RSO system shall be used.

Development of Mock-up GIS-based JKR BMS

31. Digitising of base map. While awaiting the DSMM to complete the computerised digital mapping of topographic maps for the whole of Peninsular Malaysia to be made available to users from the Public Agencies, the Bridge Unit has decided, for the purpose of developing its prototype GIS-based BMS, to digitise the existing department's road map which features all the Federal and State Roads in the country as the base map. This was done by digitising the existing road map in AutoCAD Rel. 11 running on a 386/33 MHz ALR Business Veisa PC connected to a A0-size Summagraphics Microgrid II digitiser.

32. The road map used, which is slightly larger than A1 size (i.e. 890 mm x 730 mm), is a Rectified Skew Orthomorphic (R.S.O.) Projection map of Peninsular Malaysia printed on a 1:750,000 scale. It was digitised using the same unit as the map i.e. Latitude and Longitude degrees unit. Among the various features digitised from the road map, which was captured in different layers inside AutoCAD, includes the Peninsular coastline, major rivers, major lakes, international, state and district boundaries, the various Federal trunk routes, State routes, tolled-roads routes and major towns. A trade-off or compromise between the digitising resolution and the eventual size of the digital base map had to be arrived at for the GIS prototype system.

33. After the digitising process, the next step was to edit the feature lines i.e. to clean up these lines so that the lines meet each other exactly. This is carried out in AutoCAD using the 'TRIM' and 'EXTEND' commands. Finally, the digitised map is checked and corrections made for any errors found before it is converted into a DXF file to be imported into MAPINFO.

34. JKR BMS Attribute Data. In the existing dBASE IV version of the JKR BMS, almost all the data entry (textual data) for every bridge record in the Federal Road Network has been completed. This actual textual data, comprising 55 fields of textual data for every bridge record, will also be used in the mock-up GIS with the addition of 2 fields, namely the Latitude and Longitude positions of the bridge. It is stored in a dBASE IV database file called STRUCT.DBF. There is up to now approximately 2600 bridge records in this file. These bridge inventory and condition data were obtained from the National Axle Load Study conducted in 1986.

35. Global Positioning System (GPS). What is GPS? GPS is a satellite-based navigation system developed and maintained by the United States Department of Defence (DoD). When completed in 1993, the GPS constellation will consist of 24 satellites. The satellites transmit signals which include an identifying code for each satellite, accurate time information, and navigation data. The GPS receiver automatically selects 4 satellites and determines the precise latitude, longitude, and altitude of the location in

interest.

36. In order for the mock-up GIS-based JKR BMS to be able to display the bridge location on the digitised road base map and link them to the their respective bridge attribute data, the positions of the bridge had to be determined in terms of latitude and longitude coordinates. A hand held portable Global Positioning System (GPS) receiver, called the PYXIS, produced by Sony Corporation of Japan, was used on site to determine them. The position accuracy of the Sony PYXIS GPS receiver, as specified, is between 30 m to 100 m on the ground.

37. Assuming that the accuracy of digitising the 1:750 000 base map for the mock-up GIS-based JKR BMS is 1 mm in tolerance, this would amount to a locational error of 0.75 km on the digitised base map. However, it was found that the reading of the Sony GPS receiver on a particular bridge gave a locational error of approximately 1 km on the digitised road map. This error could be partly attributed to the accuracy of the original base map with which it was prepared and printed on.

38. As of the date of submission of this paper, the mock-up GIS-based JKR BMS has only reached this stage of the development where all the bridge attribute data for some bridges has been successfully linked to the digitised base map. Further programming/coding on MAPINFO is needed to customise the mock-up GIS-based JKR BMS into a full fledge GIS application offering all the features mentioned in paragraph 21.

CONCLUSIONS

39. The trend seen today in a few countries is the move towards the development of a computerised Bridge Management System (BMS). Despite the increasing popularity of the GIS technology, there has yet to be seen a GIS application in operation today for bridge management. Public Works Department, Malaysia (JKR) is currently embarking on a project to create and implement a GIS-based BMS. This system is intended subsequently to be a component of the department-wide GIS that may be implemented in the years to come. In view of the possible constraints that may be encountered in the actual full scale development of a GIS-based BMS, Bridge Unit of JKR has decided to develop a mock-up GIS-based BMS with the aim to gain more insight into the GIS technology. It is expected that when the mock-up system is fully completed by the end of 1992, it would be used to convince the top JKR management on the need for a department-wide GIS.

40. It is hoped that this paper will encourage other bridge agencies to explore the use of the GIS technology in bridge management.

REFERENCES

1. WAHID Omar, NG S-K & SHAMLAN Mohamed Hashim. Systems Approach in bridge management. Proceedings to the 7th Road Engineering of Asia & Australasia (REAAA), Vol. 2, June, 1992, Singapore, 795-802.

2. GIS World, Inc. Geographic Information System Technology in 1991. 1991-92 International GIS Sourcebook, 3rd Edition, Fort Collins, CO, August 1991.

3. URISA. Proceedings of the 1990 Annual Conference of the Urban and Regional Information Systems Association, Vol. II, Edmonton, Alberta, August

12-16, 1990.
4. URISA. Proceedings of the 1991 Annual Conference of the Urban and Regional Information Systems Association, Vol. II, San Francisco, California, August 11-15, 1991.
5. Transportation Research Board. Geographic Information Systems 1990. Transportation Research Record No. 1261, Washington, D. C., 1990
6. TEH H. W. Implementation of a GIS Highway Management System in PLUS. Technical papers for Seminar on Advanced Survey Technology - Digital Mapping and GIS (organised jointly by Department of Survey & Mapping and JICA, Kuala Lumpur, February 11-13, 1992, paper 17.
7. Introductory readings in Geographic Information Systems, ed. by Donna J. Peuquet and Duane F. Marble, Taylor & Francis Ltd., 1990
8. HUDSON S. W. and MOSER L. O. Consultancy Review of Prototype JKR BMS. Final report prepared for JKR, Roads Branch, July, 1991.
9. MOHAMED bin Ismail. Digital Mapping in Department of Survey & Mapping, Malaysia. Technical papers for Seminar on Advanced Survey Technology - Digital Mapping and GIS (organised jointly by Department of Survey & Mapping and JICA, Kuala Lumpur, February 11-13, 1992, paper 1.

ACKNOWLEDGEMENT

The authors wish to thank the Director General of Public Works Department, Malaysia Tan Sri Dato' Wan Abdul Rahman bin Haji Ya'acob and the Director of Roads Dato' Jamilus bin Hussein for their permissions to publish this paper. The authors also wish to thank the following individuals who have provided supports, encouragements and assistance for the project. They are the Sr. Assistant Director of Bridge Unit, PWD Malaysia, Puan Rohani Razak; the Assistant Director of Bridge Unit, PWD Malaysia, Mr. Khoo Chin Leong; the Director of CAMS, Department of Survey & Mapping Malaysia, Mr. Mohamed Ismail and the Deputy Director of Topography Section, Department of Survey & Mapping Malaysia, Mr. Mohaizi Mohamad. Last but not least, thanks are also due to Rimman International Sdn. Bhd. for kindly loaning a copy of the MAPINFO package to JKR for the development of the mock-up GIS-based JKR BMS.