DEVELOPMENT OF A MULTIMEDIA AND GEOGRAPHICAL INFORMATION SYSTEM (GIS)-BASED BRIDGE INFORMATION SYSTEM

Tian Hock She
IT Centre, Public Works Department, Malaysia

Dr. See King Ng
Bridge Unit, Public Works Department, Malaysia

The author graduated with a B.Sc. Civil Engineering (Hons) from Middlesex University, UK in 1982 and served as a Civil Engineer in the Information Technology (IT) Centre of the Public Works Department (PWD) Malaysia for 7 years. In 1989, he was transferred to the Bridge Unit, Roads Branch for 5 years where he was involved in the computerisation of the Bridge Unit. He obtained his M.Sc. degree in Information Technology in Construction from the University of Salford, UK in 1997 where he undertook his research on the development of a prototype GIS-based Bridge Management System. He is currently working at the IT Centre of PWD Malaysia.

The co-author graduated with a B. Sc. Civil Engineering (Hons) From Glasgow University, UK in 1980 and has served as a Civil Engineer in various postings in the Public Works Department (PWD) Malaysia including the Bridge Unit, Roads Branch. He obtained his M. Sc degree in Construction Management from the University of Colorado in 1988 and his Doctorate degree from the University of Pittsburgh in 1996. He headed the development of the JKR Bridge Management System in 1989 and is currently the Senior Assistant Director for the Bridge Maintenance and Rehabilitation division in the Bridge Unit, Roads Branch.

1. INTRODUCTION

The need for a systematic regular bridge inspection program and the subsequent recording, storage, updating of bridge inventory and condition rating data has led many bridge agencies around the world to develop a Bridge Management System (BMS) in one form or another. Although this is a common goal for most bridge agencies, it is imperative to note that the medium and tools used for recording and storing these bridge inventory and inspection records may vary from one agency to the other and usually does so over time due to the advancement in the available technology. Thus we see the original use of manual register books or inventory cards being superseded by the use of computerised textual relational database and more recently, the availability of GIS-based systems incorporating digitised maps. The advent of the Microsoft Windows 95 operating system on the PC has also expedited more PC applications to work in a more tightly integrated multitasking environment through the use of certain Windows tools like Dynamic Data Exchange (DDE) among various Windows applications.

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 the DBASE IV data base management system. A prototype system called JKR BMS had since been created in 1990 (Tham et al, 1991).

Subsequently, the system was enhanced in some respects through the incorporation of a picture image management facility in early 1992 (DOS environment) as well as with a GIS (Ng and She, 1993) and multimedia capability in the Windows 95 environment (She and Aouad, 1997).

However, even though the implementation of GIS technology alone can greatly improve the capabilities of such systems by providing spatial analysis of the data in the system, much of the associated non-textual and other types of data remains excluded. The introduction and integration of multimedia-based data such as raster images, CAD drawings, video and audio clips into a GIS-based BIS can enhance the capabilities already available through GIS technology, while at the same time provide decision-makers with the different kinds of information necessary to facilitate bridge planning and management decisions.

This paper tracks the evolution of the development of the JKR Bridge Management System from its original textual-based dBASE IV implementation in the DOS environment to the present Windows 95 GIS-based prototype system. It describes the development and use of a prototype GIS and multimedia-based BMS for PWD Malaysia and investigates possibilities for future developments and enhancement of the system in line with advancements in the Information Technology.

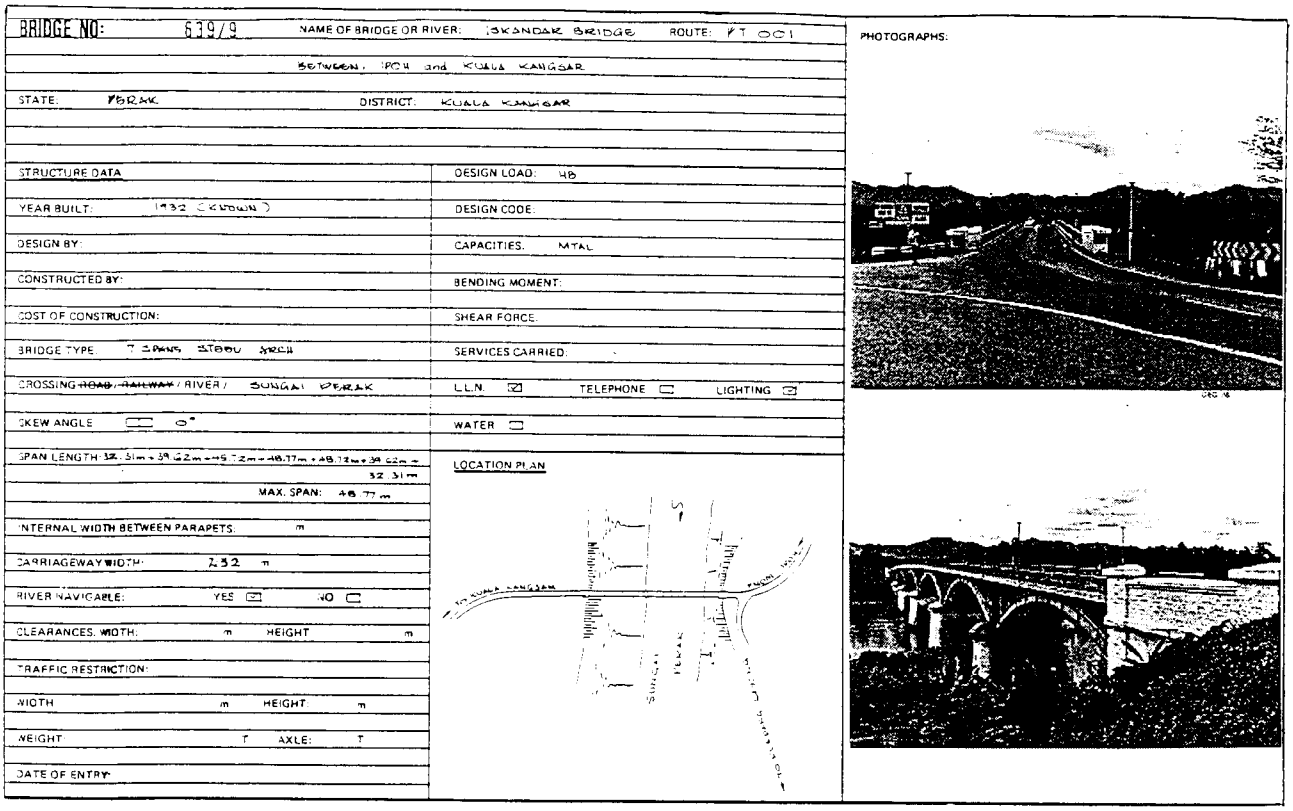
2. BRIDGE MANAGEMENT PRACTICES IN MALAYSIA

In Malaysia, the task of planning and designing new bridge structures and managing existing bridge structures on the federal road network lies with the Bridge Unit within the Roads Branch of the Public Works Department Malaysia (PWD or locally known as JKR). It is the primary federal bridge agency entrusted with the planning and designing of new structures as well as the maintenance & rehabilitation of existing structures for bridges, flyovers,

footbridges and culverts on the federal road network in Peninsular Malaysia [Bridge Unit, 1985].

Between 1986 and 1991, a bridge inspection program was carried out for structures along the major federal routes under the National Axle Load Study Phase I & II. From this bridge inspection exercise, all the bridges in the Study were inventoried and captured onto Bridge Inventory cards as shown in Figure 1 below.

Figure 1 : Bridge Inventory Card



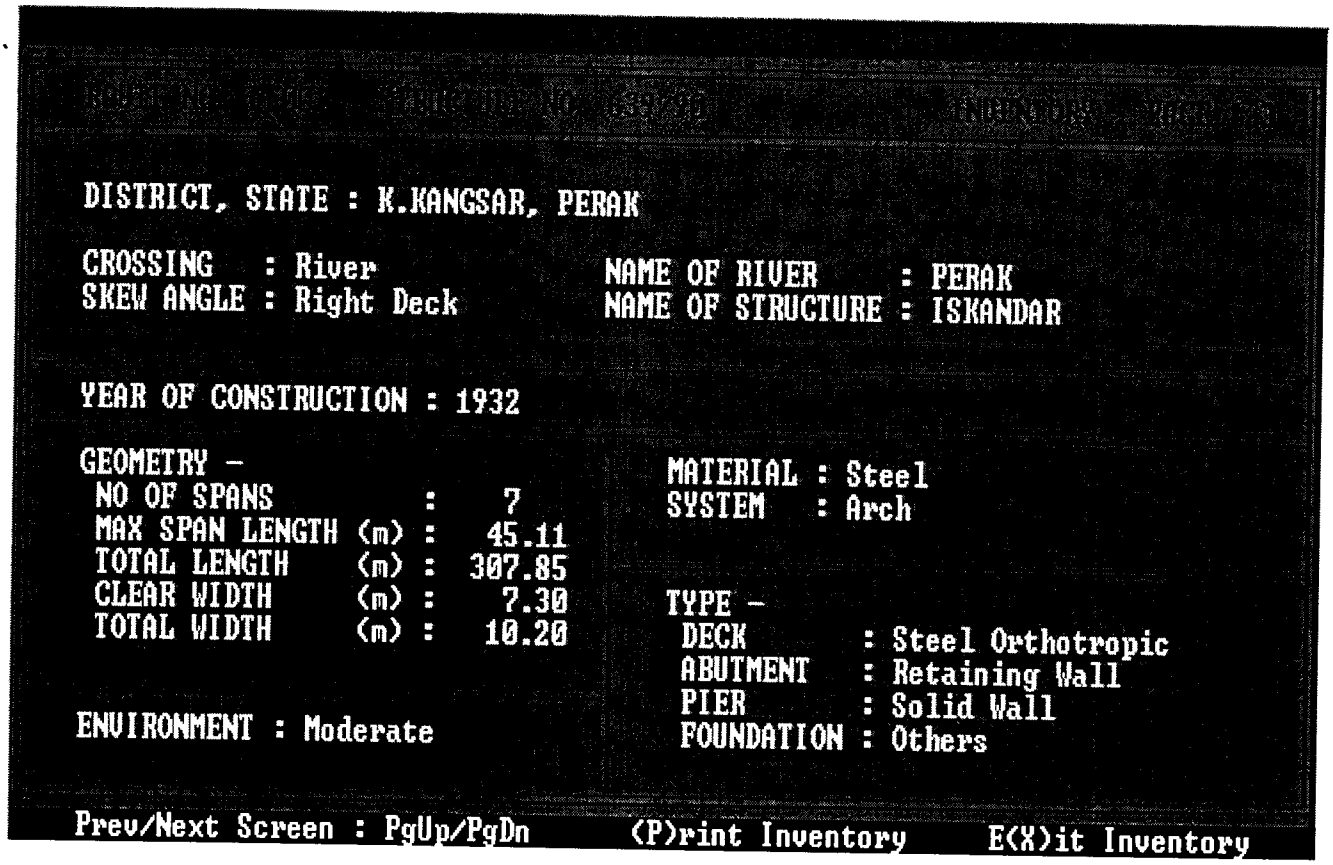
It was reported from the study that out of 2,386 federal bridges inspected in Peninsular Malaysia under the study, at least 500 bridges were rated as in an unsatisfactory condition, in a dangerous state or under capacity. This means that one out of every five bridges in the federal road network is in need of some sort of improvement action [2]. It is estimated that there are altogether about 5000 bridge structures in Peninsular Malaysia under the jurisdiction of JKR.

It is believed that other categories of bridges like state and municipal bridges which are not covered under the National Axle Load Study may be in a worse state and condition. This is generally due to the lack of attention, manpower and expertise at the state and district levels to deal with the inspection, maintenance and management of the structures under their own jurisdiction.

Recognising this need, the Bridge Unit started the development of a Bridge Management System in-house in 1989 called the JKR BMS on the PC using the popular dBASE IV

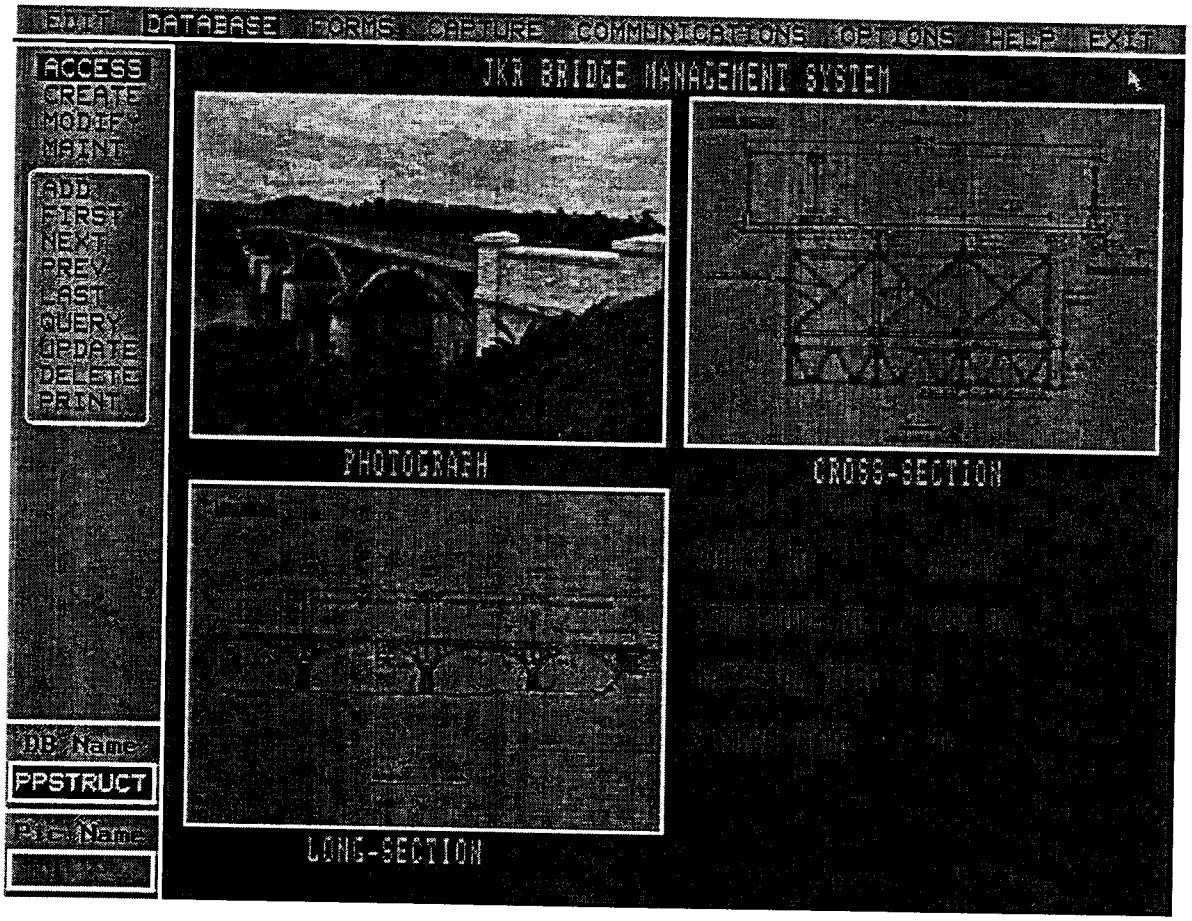
software on the DOS platform [Tham et al, 1991]. A screen sample of the JKR BMS is as shown in Figure 2. After the completion of the prototype JKR BMS in 1991, a review was carried out by an Engineering Consultant firm from USA consisting of a BMS expert as well as a professional System Analyst to recommend enhancements to the system [Hudson and Moser, 1991].

Figure 2 : Screen of DOS-based JKR BMS in dBASE IV Environment



- At the same time, while the prototype system was being developed in dBASE IV in the DOS environment, the use of an image-based database software called PicturePower was explored and developed to enhance the capability of JKR BMS to store and retrieve photographs or drawings into the existing DOS-based dBASE IV environment. This allows scanned bridge photographs and drawings to be displayed or recalled in the JKR BMS dBASE screen. A sample screen of this capability is as shown in Figure 3.

Figure 3 : Screen of Image-based Database in JKR BMS



With the advent and emergence of GIS technology, the Bridge Unit has once again poised itself to take up the challenge of trying to develop a GIS-based JKR BMS. A Consultant is currently being appointed by the Bridge Unit to enhance the present JKR BMS, Notwithstanding this, an exploratory research by both the authors has been ongoing (Ng and She, 1993) and followed through in greater depth by the first author's M.Sc. research at the University of Salford, UK (She and Aouad, 1996, 1997). This paper will focus on the research efforts undertaken by both authors to develop a prototype GIS-based JKR BMS.

3. INFORMATION TECHNOLOGY AND MULTIMEDIA DEVELOPMENTS IN MALAYSIA

The Malaysian Government through the National IT Agenda Council has initiated the Multimedia Super Corridor (MSC), an area of 15 X 50 km linking the capital of Kuala Lumpur with the new Federal capital of PutraJaya, Cyberjaya, an intelligent new city with multimedia industries, and the new Kuala Lumpur International Airport at Sepang, as the national test-bed for multimedia capability development and indigenous participation as well as the International Centre of Excellence for Multimedia. The MSC will bring together, for the first time ever, an integrated environment necessary to create the best global multimedia climate.

The Seven MSC Flagships which have been identified include the Smart school, Multipurpose Card, R&D Cluster, Electronic Government, Worldwide Manufacturing Web, Borderless Marketing and Telemedicine. In this respect although the Construction sector has no direct role to play among these flagships, it would still be possible to identify and

intensify the development of multimedia applications now for the construction industry to play when the IT infrastructure is in place following the implementations of these flagships. The development of a multimedia-based BMS certainly augurs well with the MSC objectives and can be used as a test bed for many other new multimedia-based Construction Sector research and developments to create its own 'TeleConstruction' flagship for the expansion of the MSC.

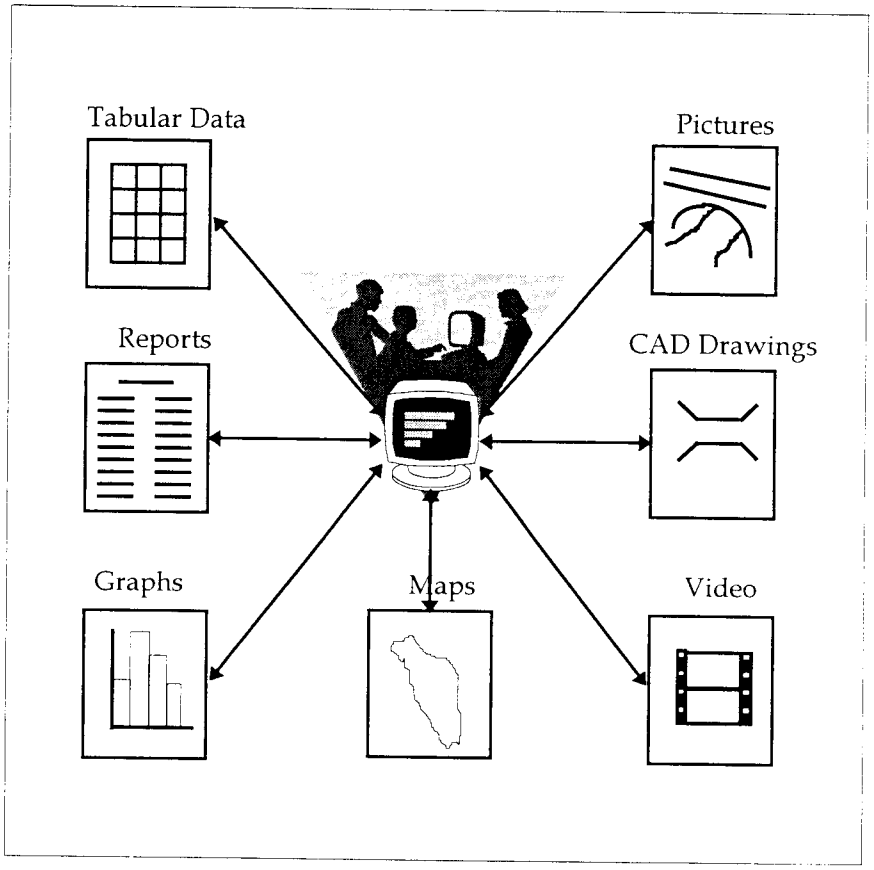
The PWD Malaysia has currently implemented its network infrastructure for local & wide area network within its Headquarters campus using the broadband and high speed Fibre Optics and ATM technology. With the setting up of its own Intranet network infrastructure which is linked to the Internet, it is planning to link up all its State and District offices into the current network and will be poised to take advantage and embrace all the latest technological advancements in the IT world including the MSC electronic government or any other appropriate multimedia applications which can be developed to run on it.

4. AN IMAGE-BASED MULTIMEDIA SYSTEM IN A GIS-BASED BRIDGE INFORMATION SYSTEM

A computerised BMS mainly carries out two primary functions: (I) Bridge Data Management, for collection, storage and retrieval of timely bridge inventory and inspection data and (ii) Decision Support System, to plan and manage the maintenance program with regard to the question of 'when to do what with which bridge' in the road network.

In regard to the first function, the development of an integrated image-based multimedia Bridge Information System (BIS) is proposed in this prototype system to enable the department's engineers to collect and store all the relevant bridge inspection reports, bridge photographs, bridge drawings and bridge events captured on video into a computerised bridge database. Once all these data have been captured and stored in the system, they can be retrieved and displayed on the computer screen simultaneously by multiple users logged on to the network at the touch of a button by pointing and clicking on any particular bridge location in the digital GIS map. This will provide bridge engineers and managers with all the required information to aid them in the decision making process for bridge inspection and maintenance programs. Figure 4 shows a schematic diagram of these features.

Figure 4 : Features of a GIS and Multimedia-based Bridge Information System



Using such a system, it will be very fast, convenient and easy to review a bridge inspection history because all the relevant data is stored in one medium in a digital form. This system will eliminate a host of document management problems that have plagued many bridge agencies for decades. Like many others in the bridge inspection community, it is faced with the problem of storing and retrieving an array of different kinds of documents that detail each bridge's life history, including field reports and tests, inspection reports, design drawings, inspection photographs, and bridge events recorded on video tapes.

The need for several bridge inspectors or engineers to have simultaneous access to bridge inventory and inspection records can also be achieved through the use of such a computer-based system on the local or wide area network. Because much of the inspection process requires inspectors in the field to refer to records of previous inspections, colleagues back at the office were often prevented from doing so until missing documents were returned to the record room when dealing with paper records. Because documents left the office frequently, problems such as paper deterioration, misfiling, damaged and lost files frequently occurred.

The installation and use of a desktop scanning equipment in the department will enable it to capture and store all of the existing photographic data. These stills can be scanned in a few seconds. Once scanned into a predetermined format, the photograph can be viewed by anyone logging on the network with the necessary rights of security. New inspection photographs need no longer be film-based. The advent of digital cameras or video camcorders coupled with a video capture card on the PC will enable the system to capture accurate inspection photographs and other important events directly from the field.

The use of such a system will provide benefits in savings in photo developing costs and paper document management costs. The greatest benefit will be the increased availability, quality and utility of the information.

With the integration of image-based multimedia data in a GIS-based Bridge Information System, the users will be able to easily navigate to the information they need in a natural and efficient manner, i.e. through a point and click operation of the mouse on the digital GIS map.

5. OBJECTIVES OF AN IMAGE-BASED MULTIMEDIA AND GIS-BASED BIS

From the foregoing discussions, the objectives of an image-based multimedia and GIS-based BIS could aid in providing the following functions :

(1) Provide a complete set of bridge information on any bridge structure in the road network in the form of geographical map location, textual reports, bridge photographs, bridge design or as-built CAD drawings, recorded video clips with sounds for important bridge events.

(2) Provide colour coded thematic maps of location of bridges where each colour portrays a given set of characteristics such as material type or structural type.

(3) Provide spatial analysis of any subset or overall bridge inventory and condition rating data on maps and graphs to bridge managers.

(4) Aid in preparing a more efficient and well co-ordinated bridge inspection program and schedule by allowing the use of the GIS map to visualise and analyse the demographic distribution and location of structures to be inspected on the road network.

(5) Provide an online means of storing and viewing important bridge events in full motion video which serves to provide a better understanding of how a sequence of historical or important events was being carried out on the structure as well as to serve as an aid in the transfer of technology to newer engineers joining the department.

(6) Provides a more efficient document management system by eliminating the problem associated with manual document filing system such as paper deterioration, misfiling, damaged and lost files including documents, drawings and video tapes.

(7) Provide useful visual and statistical information to aid bridge designers with regard to improved design practices.

(8) Provide visual and statistical information to identify bridge research needs.

These objectives are in line with the department's objectives to carry out its bridge inspection, maintenance and rehabilitation program.

6. ARCHITECTURE FOR IMPLEMENTING A PROTOTYPE IMAGE-BASED MULTIMEDIA AND GIS-BASED BIS

The architecture for implementing such a suitable prototype GIS-based BIS on the PC has been carried out using 4 different software packages integrated within the Windows environment through a Dynamic Data Exchange (DDE) link as described below :

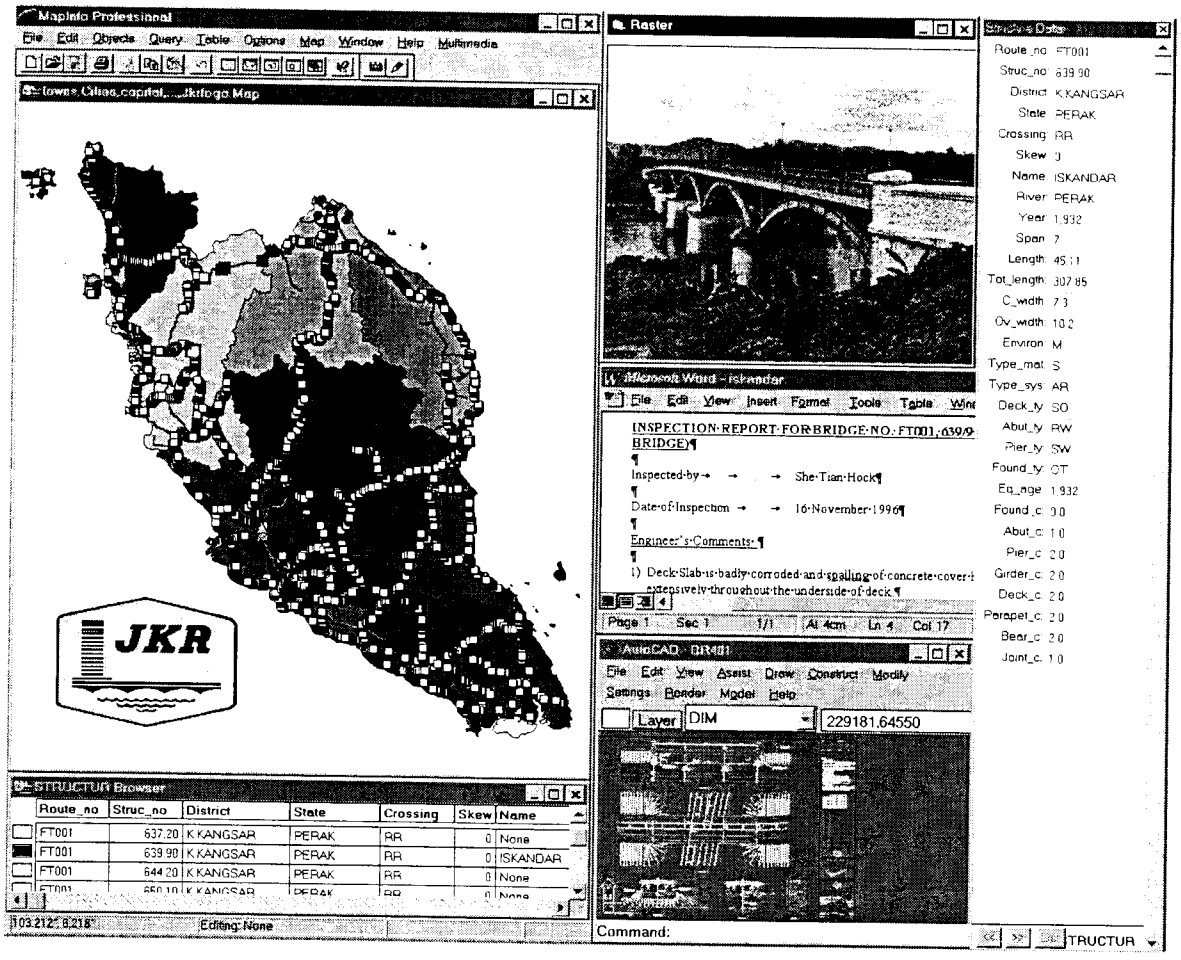
(1) Mapinfo Professional ver. 4.0 for Windows 95 (Mapinfo, 1995) was used as the front-end GIS mapping user interface using its accompanying Mapbasic language tool (Mapinfo, 1995) to customise the different applications into an integrated Windows environment.

(2) Microsoft Visual Basic ver. 4.0 program to retrieve and display the scanned raster photograph for any bridge record selected on the MapInfo map.

(3) Microsoft Word ver. 7.0 to retrieve and display any associated bridge inspection reports or other related documents for any bridge record selected on the MapInfo map.

(4) AutoCAD release 14 for Windows to retrieve and display the associated bridge design or as-built drawings for any bridge record selected on the MapInfo map.

Figure 5 : User Interface of the GIS-based BIS



The user interface is as shown in Figure 5. On the top left hand screen is the Mapinfo GIS interface screen (map window) which displays a map of Malaysia and the network of federal roads including the inventory of 2,546 bridge structures displayed as square boxes. Directly below the map window, a browser window displays a table of the inventory database file. By clicking on any bridge object (depicted by a square symbol) on the map or on any records in the Structure browser window, it will simultaneously display the bridge record in text format (as shown in the Structure Data window on the extreme right hand side of the screen), a photograph of the bridge (as shown in the Raster window), any inspection report (as shown in the Microsoft Word window) as well as the relevant design/as-built bridge drawing (as shown in the AutoCAD window).

Figure 6 : Multimedia Capability for Playing Video Clips

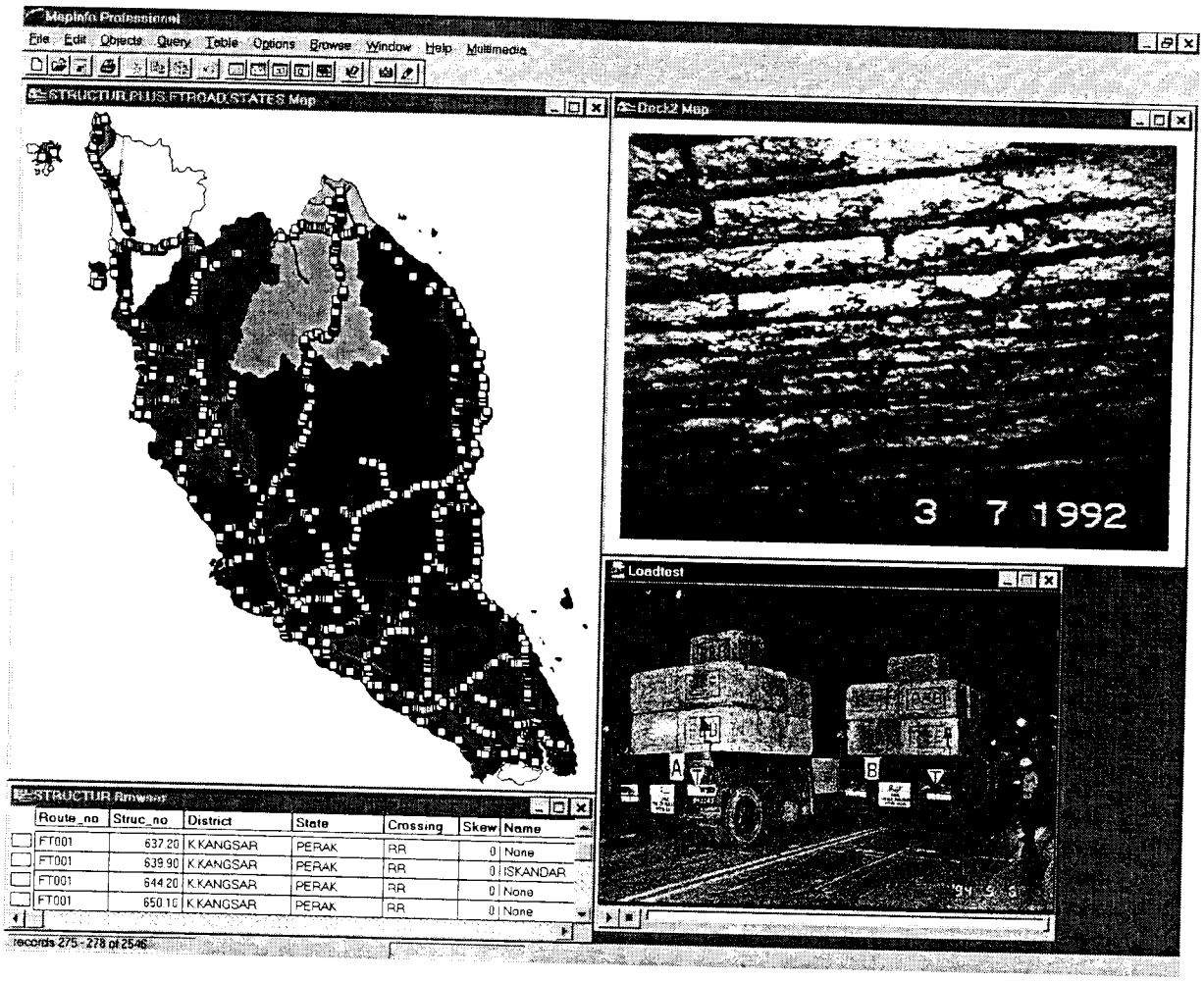


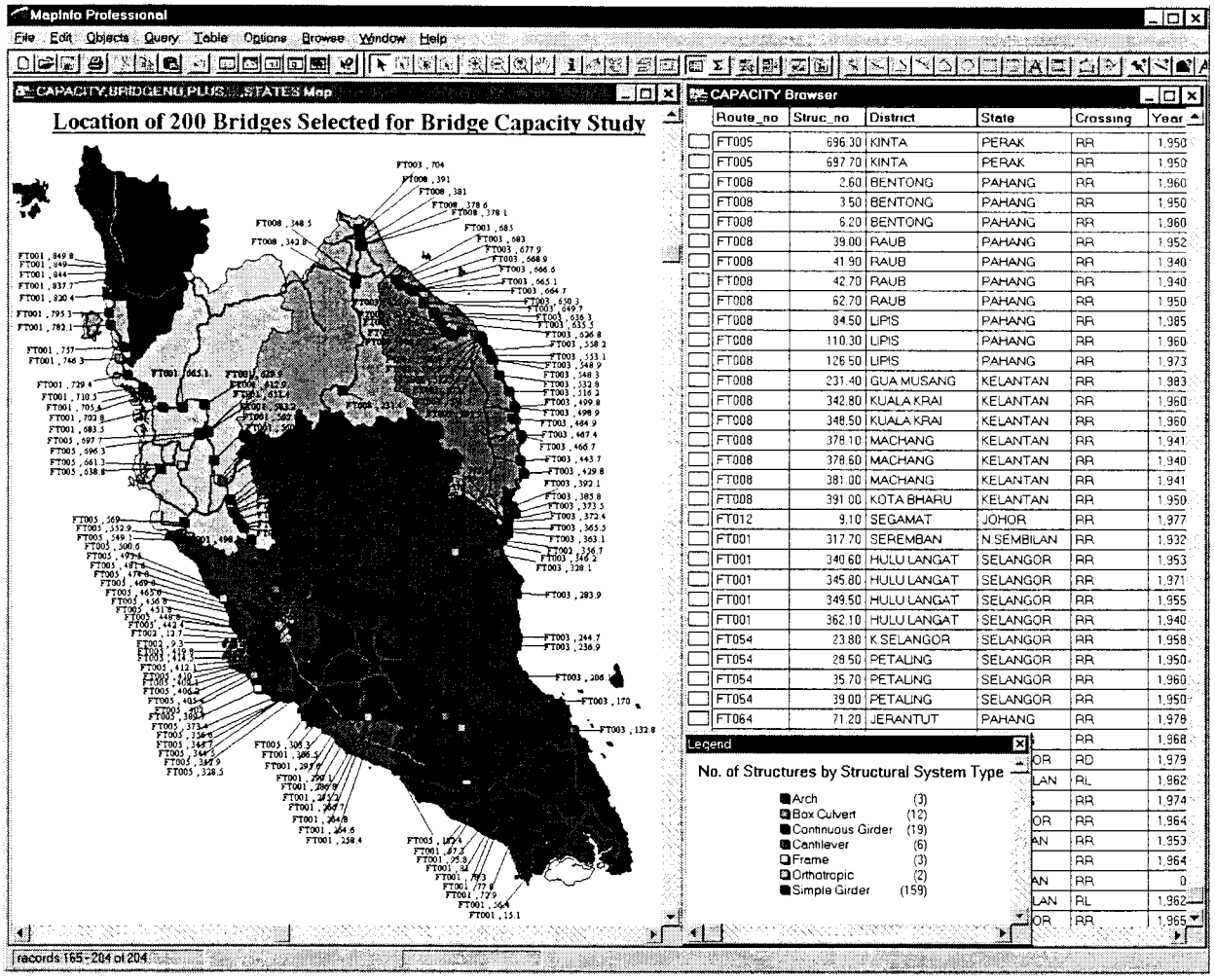
Figure 6 shows another screen output of the interface showing the multimedia capabilities of the system. When a bridge inspector has inspected a bridge for damage, any photographs taken at site showing the damage and their extent can be incorporated into the bridge record. By clicking on the bridge object on the map, a scanned image showing the extent of the damage on the deck of that bridge is displayed on the top right window. Also, any important events like load testing which have been carried out on that bridge and captured on a camcorder and digitised can be played back as a movie file as shown in the bottom right hand window.

Typically, a bridge inspector uses a camcorder at a bridge site to capture important events such as load testing or bridge repair works being carried out. Using a video capture card on the PC, it is digitised into the standard video and audio format (.avi files) to be viewed using the standard Windows Media player (Mplayer) utility program.

7. SAMPLE OUTPUT FROM THE PROTOTYPE SYSTEM

The prototype GIS-based system has been used to select and identify the locations of 200 bridge and culvert structures for a study to determine the load-carrying capacity of these structures. The screen output in Figure 7 shows the location and identification of suitable candidate structures according to structural system type which has been selected from the bridge database for the bridge capacity study. MapInfo provides the facility to label each bridge structure on the map according to some user specified formats such as the combination of 2 fields (Route Number and Structure Number in this case). Through the use of this map, the project team was able to plan the inspection of these structures according to the logistical location and distribution and subsequently carry out load-testing on 16 of these bridges within a tight working schedule.

Figure 7 : Location of 200 Structures for Bridge Capacity Study



8. RECOMMENDATIONS FOR FUTURE DEVELOPMENTS

With the rapid advancement taking place in the IT world, it is hoped that the present JKR BMS would not remain stagnant but could keep abreast and incorporate these newer technologies such as :

8.1 Internet/Intranet Web Capabilities

With the Intranet already in place within PWD Headquarters and the link to the Internet, the present GIS-based BMS running on MapInfo can be made available and accessed on the web through its related Mapinfo Proserver client server solution which provides GIS capabilities to any Internet web users through the web browser. This will allow all State and District PWD offices and even Transportation and Hauling Companies to access our GIS-based BMS for any Bridge related information.

8.2 Use Of An Object-Oriented Database

The above prototype GIS-based BMS was developed on the PC Windows platform using MAPINFO Professional software (MapInfo, 1995) which is based on a relational database data model.(DBASE IV RDMS) The use of an object-oriented database is recommended in future work to provide object-oriented abstraction mechanisms such as generalisation, specialisation, aggregation, and inheritance. These mechanisms are not available in a relational database data model. In an object oriented approach, points, lines, and polygons are treated as objects. Cartographic objects make use of methods to perform functions such as measuring distance, area and direction.

The development of an integrated object-oriented database environment for the constructed building environment has been successfully established in SPACE (Simultaneous Prototyping for An Integrated Construction Environment) (Faraj and Alshawi, 1996) and OSCON (Aouad and Kelly, 1996) , (Tracey et al, 1996) project at the University of Salford.

The same approach could be recommended for the development of an integrated object-oriented bridge database environment to perform the various functions associated with the design, construction and maintenance of bridges.

8.3 Integration with a Knowledge-Based System (KBS)

It is envisaged that the development of the other modules in the Bridge Management system can be better implemented with the integration of a knowledge-based system into the present prototype GIS-based system, for example, to prioritise and rank the bridge structure for improvement works at the network level as well as to suggest remedial works to be carried out on the structures taking into consideration the economic and safety factors for choosing such an option.

9. SUMMARY AND CONCLUSIONS

This paper has described the development of an integrated environment for implementing a prototype image-based multimedia and GIS-based Bridge Information System (BIS) for the

Bridge Unit of the Public Works Department, Malaysia. The use of GIS-based Bridge Information System allows the users to geographically retrieve bridge information and perform spatial queries and analysis on the bridge inventory and condition ratings in the road network. The use of image-based multimedia in the GIS-based Bridge Information System provides an integrated environment for storing and viewing other kind of non-textual information in the form of bridge photographs, CAD drawings, video and audio clips into the bridge database. This will provide the bridge managers and BIS users with the complete information for decision making process with respect to bridge inspection, maintenance and management.

On the basis of the prototype development to date, the following conclusions may be drawn:

(1) The use of GIS technology incorporating CAD drawings and multimedia capabilities provides a better user interface and visualisation tool for the users of a BIS.

(2) The use of an integrated image-based multimedia and GIS-based Bridge Information System enhances the availability, quality and utility of bridge information for bridge planning process such as bridge inspection and maintenance.

(3) Although the prototype as it currently stands is closer to a Bridge Information System, it may be developed further and enhanced with a decision support model to provide the full analysis capabilities of a Bridge Management System (BMS).

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