Digital Evolution of Bridge Management Systems in the Gulf Region

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David Moore
Technical Director – Aurecon, Doha, Qatar

Saeid Naelini
Managing Director – AMX Solutions, Bristol, UK
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Abstract: We are living in a world which has an ever-increasing amount of digitisation: people sip their cappuccinos while reading the Saturday paper on a tablet, university students stream lectures to their laptops without ever setting foot on campus, banking transactions are done with a touch on a smartphone. The digital age is reshaping industries across all sectors, including engineering, education, finance and law. But how is the industry of Infrastructure Maintenance, and in particular Bridge Management Systems, keeping up with digital disruption?

This paper examines the evolution of Bridge Management Systems which are currently in use or being developed in the Gulf Region and how they are evolving to become more digitised and integrated with other digital tools and systems. Until recently, transportation authorities in the Gulf were using traditional methods of structure inspection, defect rating, cost estimation and processing of work orders. The introduction of computerised BMS solutions has initiated a huge leap forwards in terms of access to maintenance information, centralised data storage, effective identification of critical defects and optimisation of maintenance budgets.

We look further at the challenges that BMS solutions are facing in response to the increasing digitisation of interfacing systems, such as Building Information Modelling (BIM), digital 3D surveys and hand-held tablets for the purpose of bridge inspections, and we review the changes occurring in current practices to address these issues. In addition, we touch on the organisational change required within government departments to keep abreast of this digital evolution.

Keywords: Bridge Management System, Digital, BIM, Internet of Things, Photogrammetry, Middle East.
1. **Adoption of Technology**

Over the last decade we have seen a dramatic shift away from traditional methods of bridge inspections and records maintained by Transportation Authorities in the Gulf Region. Up until 2009 the Dubai Roads and Transport Authority (RTA), for example, were using a paper-based bridge asset inspection and management system. Also in Abu Dhabi, the Department of Transport engaged maintenance contractors to undertake road and structure inspections without the use of a standardised inspection form or rating procedure, nor a scientific way to prioritise maintenance works. Voluminous inspection and maintenance reports were produced, providing bills of quantities and repair costs, which the Departments then had to pay from their annual budgets. It was time consuming to manage, and difficult to predict future maintenance budget requirements. Bridge Management Systems, as we know them today, were virtually non-existent.

Today, Bridge Management Systems are being widely adopted by Transportation Departments in the Gulf. This has been occurring for a number of reasons; construction of transportation infrastructure has undergone a rapid expansion in Gulf cities since 2006; Government Departments in the Gulf, for example the Public Works Authority in Qatar, are under increasing pressure to effectively manage public spending (1); Transportation Departments are also adopting strategies and ‘vision statements’ which incorporate long term financial, environmental and social sustainability. In order to achieve these objectives, innovative solutions need to be implemented.

It is also known that cities in the Gulf Region tend to be early adopters of technology, and tend to take up new technology quickly. For example, at Abu Dhabi Islamic Bank, customer bank account access through the internet increased by 25 per cent during one quarter in 2015, and transactions through their banking app (via smartphones and tablets) increased by 71 per cent over 2015 (2).

The United Arab Emirates is particularly ambitious when it comes to implementing new technologies in transportation. Driverless vehicles are already being tested in Dubai, around the Downtown precinct (3). The Dubai Government has an initiative to make 25% of all transportation trips in Dubai via smart or driverless cars by 2030 (4). In addition, the RTA and Hyperloop One signed a deal to pursue a passenger and cargo Hyperloop in the UAE (5), which is a high speed transportation system for passengers and goods through elevated tubes. Cities in the Middle East are setting ambitious objectives for themselves and we believe that digital technologies, including BMS solutions, will be quickly implemented and adopted to help achieve these objectives.

2. **Computerised Bridge Management Systems**

At its core, a BMS is a collection of data which can assist the user in making maintenance decisions. Having access to recent, relevant and contextual data regarding a structure's condition helps the user make the correct and most beneficial intervention decisions. The introduction of computerised Bridge Management Systems in the Middle East provided a big leap forwards in terms of asset management to maintenance departments in the region. While some form of computerised BMS had been available in other parts of the world for decades, the first ‘digital’ BMS was introduced by Aurecon into the UAE in 2011.

Since the introduction of a computerised BMS in Dubai, the system was expanded to include the Abu Dhabi Department of Transport approximately one year later, and Doha, Qatar in 2017. The system is a collaborative effort by Aurecon and AMX Solutions. The main features and modules of the system as detailed below.
Figure 1. Home Page of AMX showing map and asset locations (Doha, Qatar)

2.1 Inventory Module

The Inventory Module records and maintains important identification and physical data about the assets, as well as location, load capacity and relevant contract details, such as the structure value and maintenance contractor. The inventory module drives the creation of the inspection information and ultimately the condition rating of the structure. Inventory module also contains a document database to hold drawings, specifications and other important documents.

2.2 Inspection Module

Based on the asset inventory, the system creates a unique inspection form for each structure, incorporating the asset components and divisions according to the Department's requirements. Inspection data can be captured in the field directly from a mobile inspection device, such as a tablet, or data can be entered in the office after the inspection. The inspector directly enters the structure element rating and captures the repair work required, which can call up the Department's “Bill of Quantities” for the repair works. The element ratings from the inspection module drives the overall condition calculation of the bridge as well as priorities for repair works.
2.3 **Condition Module**

The Condition Module calculates the asset condition based on the inspection ratings for each element of the structure. The asset condition is displayed in the main screen of each asset. This module can also calculate conditions for groups of structures or for the entire network.

2.4 **Maintenance Planning Module**

The user can plan for maintenance on individual or groups of structures, as well as ad hoc repairs that may be required. Works are prioritised in the system according to the Department’s budgets and required level of service.

2.5 **Reporting Module**

Stock and individual asset reports can instantly be produced to the requirement of the client. As well as ad hoc reports, standard corporate report templates are designed and can be exported to common formats. Consolidated management reports are produced utilising data and charts from all other reports saved in the system.

2.6 **Risk Matrix**

The system automatically generates an interactive risk matrix which plots the asset defects from highest to lowest risk, based on the safety, criticality and extent of the defect. The user can click directly on a matrix cell to interrogate the defects for any risk rating.

2.7 **Life Cycle Costing (LCC)**

The LCC module utilises the asset divisions from the Inventory Module, the condition rating of each element in the Condition Module and material deterioration models. The LCC analysis provides for three different maintenance strategies which can be compared for least cost; Do Nothing, Reactive and Proactive. The parameters within the LCC module are user defined, including the level of service for each of the strategies,
the environmental exposure of elements (protected or unprotected) and whether an element is included in LCC analysis.

The module produces a matrix of individual elements as they deteriorate over time with interventions indicated as a cross in the cell. The overall deterioration of the asset can be displayed in chart format for each strategy, as well as intervention costs over time. The user can drag-and-drop interventions within the matrix and the system automatically regenerates costs and charts.

![Figure 3. Life Cycle Cost Matrix within AMX](image)

3. **Improvements to Bridge Management Systems**

Since first being implemented in the UAE, BMS solutions in the Gulf region have undergone extensive digital development to improve the way data is managed and accessed by the user.

3.1 **Web-based system**

Access to the BMS has been improved with the development of a web-based solution, which allows the user to access the BMS from any computer with internet access. Initial implementation of the desktop system was based on Windows platforms which, in IT terms, is cumbersome to manage in corporate organisations.

The web-based system was also developed in response to a multitude of security and system maintenance requirements and, within the available web technologies, maintain all business asset management requirements of the Departments. The look and feel of the web system had to remain in line with the initial design requirements and remain responsive under all operational scenarios.

3.2 **Separation of Structural and Electromechanical Systems**

New construction methods and materials, together with multiple electromechanical systems found on most transportation structures in the UAE, presented unique challenges in maintenance management solutions. The management of structural and electromechanical systems needed to be handled separately, so in response we separated the two systems to create two modules. Appropriate independent inventory, inspection and maintenance processes had to be developed for each system, then recombined in a manner to deliver a unified approach to management operations.

Defects were measured in terms of ‘Degree’, ‘Extent’, and ‘Relevancy’ of the defect to the safety and integrity of both systems and reported on a common scale of 0 to 100% fit for purpose.
3.3 **System Adaptability**

System adaptability to new business requirements and operational improvements is a major requirement for any advanced management system. It ensures scalability and long term benefit for client’s initial capital investments.

The diversity of highway structures built in the Gulf Region requires a solution that can adapt to new inventory and inspection requirements with ease with no development cost to the client. The BMS solution has undergone improvements to address this requirement through total adaptive approach in all its modules including but not limited to the inventory and inspection modules. The advanced user has editing rights to forms and screens, which can be easily modified without the need for programming.

![Figure 4. Typical Bridge Asset Main Screen of AMX](image)

3.4 **Integration to utilize best practice across multiple systems**

Use of multiple systems is common place in large Transportation Departments and seamless integration between systems through middleware is essential in order to deliver correct contextual information and to avoid data duplication.

The integration capabilities of the BMS solution have been improved to allow integration across multiple data resources in a rapid and safe manner. Use of SOAP or REST protocol webservice has been made available for most corporate systems and utilised through middleware seamlessly.

3.5 **Live mobile inspection data feed (mobile devices)**

The BMS mobile device module was developed in response to Departments’ expectations and the rapid adoption of digital technology in the region. It is now a common requirement that mobile devices are available for inventory and inspection data collection. The mobile device module was designed to operate across all common mobile platforms including iOS, Android and Windows.

Field data download and upload using mobile devices is minimising inspectors’ time in the office and considerably improves efficiency of inspection data collection and addressing of urgent safety concerns.
3.6 **Security Compliance**

Complying with Departments’ IT security governance is a growing concern when implementing BMS solutions. Bridge Management Systems are no longer confined to the internal IT network of the client but open to hackers through mobile or hosted services.

Every effort has to be made to ensure data communication remains intact and secured through multi-layer security authentication processes. User authentication through standard AD or Azure AD and token based authentication are utilised.

3.7 **Enterprise Change Management**

Although not a digital enhancement, the incorporation of enterprise change management services into the delivery of a Bridge Management System should not be overlooked. The initial delivery phases of the Dubai and Abu Dhabi BMS solutions in 2011 by Aurecon neglected to address the important aspect of how the Maintenance Departments were going to have to change their processes, procedures and people to adapt to the new system. The required changes in the Departments went beyond the use of the BMS itself, and extended to other enterprise systems, such as Maximo, GIS and Abnormal Load systems.

The early intervention of change management services into the delivery of a BMS will assist in the ultimate successful implementation of the system into the Department. Change management experts initially conduct stakeholder workshops using the approach of design-led thinking. A needs analysis is performed, identifying skill gaps and the impact that the BMS will have on the Department’s business processes. We can then advise the Department on the best institutional set up to optimise the use of the BMS. This then drives the development of the BMS system architecture to best suit the Department’s business functions and integration with existing (or future) systems.

Aurecon recommends that Departments undertake training to upskill their staff in enterprise change management so that they don’t have to rely on consultants to perform this role on an ongoing basis.

4. **Future Evolution**

The digital evolution of Bridge Management Systems is limited only by the cost of new technology, computer processing power and peoples’ imaginations. As technology advances, driving costs down and improving processing power, we are going to see the adoption of Building Information Modelling (BIM), high resolution imagery, mobile data capture and virtual reality / augmented reality into Bridge Management Systems. Much of this technology is already being used, in part, in some BMS solutions.

Incorporating digital enhancements into a BMS does not necessarily make the system better, smarter or easier to use. The development of digital technology needs to focus on helping decision makers to access the right information at the right time, to make more informed decisions. The next section describes some current technology which can be used to assist in decision-making if applied in the right way.

4.1 **Building Information Modelling (BIM)**

Building Information Modelling (BIM) is a 3D model-based process that enables people to plan, design, construct and manage buildings and infrastructure (6). In other words, BIM is an intelligent digital version of physical thing. Unlike a standard 2D or 3D CAD model, BIM can be assigned metadata, or attributes and information regarding the physical properties of elements, reports on condition or the required repairs on an element.

The BIM of an asset, such as a bridge or tunnel, may be produced during the design phase, which is then incorporated into the operation and maintenance phase of a structure, but the vast majority of infrastructure in the world does not have a BIM and therefore needs to be created in the as-built condition.

Creating an intelligent digital version of an asset can provide benefits to the maintenance manager in many ways. Condition ratings can be assigned visually to elements of the structure. Defects and repairs can be assigned to structural elements with high accuracy. With BIM it is also possible to navigate a complex structure as one would navigate through the real world, by visually identifying the area of concern rather
than relying on reference names or numbers. Researchers such as McGuire et al (7) note that BIM is an effective tool in facilitating the inspection and evaluation of bridges.

With the incorporation of BIM into BMS, it is important to provide a reality context to the user which will assist in making the right maintenance decisions. BIM can provide a realistic model of the structure, but without up-to-date metadata assigned to the model, BIM will not provide any meaningful benefits.

4.2 Generating BIM for Existing Assets

There are various way to generate a BIM of an existing asset. A BIM could be created from as-built or design drawings, either by importing CAD drawings into a BIM tool or by creating the model without any previous digital information. However this can be a time-consuming exercise and many structures worldwide were designed and constructed prior to the digital age, therefore have no existing digital designs such as a CAD model.

Below we examine the emerging forms of creating BIM for structures without existing digital models.

4.2.1 3D laser scanning

3D laser scanning is a widely available technology that is used to create a digital 3D model of the surrounding environment. Laser scanners produce millions of points in a ‘point cloud’ which are then assembled in a software package to produce an accurate 3D model of the assets and surrounding environment. This technique is particularly suitable where a digital model is needed for a large area, such as a city street, where the laser scanners can pick up street assets such as light posts, rubbish bins, trees, kerbs and shopfronts.

Laser scanning is a relatively automated, inexpensive and accurate way to create a BIM of an existing asset.

4.2.2 Photogrammetry

By utilizing multiple photo images taken of an object or environment at different angles, 3D coordinates of points can be determined and a 3D model created with reasonable accuracy. Models can be created from an ordinary digital camera with geo-referencing or a smartphone, then assembled in a software package such as Bentley’s ‘ContextCapture’.

In a recent joint project with Bentley, Aurecon produced a 3D BIM of the DP World Interchange in Dubai using photogrammetry. Approximately 5600 photos were taken of the interchange from a Falcon Eye fixed wing drone from various altitudes and angles. The drone has a very accurate in-built GPS and inclinometer, so the location and angle of each photo is known. The photos are then overlapped and aligned using the aerotriangulation process. Bentley’s ContextCapture software was then used to create the textured 3D mesh of the interchange, which is geo-coordinated, as shown in Figure 5.

Up-close photos of the structure can also be incorporated into the model, so that when the user zooms into the structure, finer details can be viewed. The model is meshed and metadata can be added to elements.

Photogrammetry is suitable for capturing both large and small areas for BIM. Large areas can be surveyed relatively quickly with the use of drones, and fine details can be added from hand-held digital cameras or smartphones. Multiple structures can be assembled in the 3D virtual world, which allows the user to visually categorise and group structures together with user-defined criteria.
4.3 **Ultra-high Resolution Imaging**

Ultra-high resolution panoramic images of structures can be generated by taking hundreds of digital images, by the use of a robotic camera mount, then stitching them together to create a single composite image. These images are referred to as 'Gigapixel Technology', which contain over one billion pixels, and can be used by maintenance departments as an inexpensive quality assurance / quality control tool (8). This technology is primarily a recording tool which documents the condition of the structure on the day of inspection. It can be interactive, in that the user can zoom deep into the image for close inspection of aspects of the structure. However the image is not intelligent, does not contain any metadata and is not suitable for accurate measurements.

The capturing of ultra-high resolution images of a structure can be conducted by an inspection team with some training and the appropriate equipment. The image will then form a part of the inspection documentation, which can be later reviewed by the maintenance manager or by other decision makers.

Ultra-high resolution images of a structure are beneficial for post-inspection review of a structure’s condition and defects, where a maintenance expert who is not in the field may want to closely examine aspects of the structures. They can also be used as a quality control tool for post-inspection analysis.

4.5 **Virtual Reality**

Virtual reality (VR) is not a new technology and has been used to supplement bridge inspections previously. One outmoded form of VR is Quick Time Virtual Reality (QTVR), which uses multiple images to record a 360 degree view of the surrounding environment. The still images are stitched together in a software package and the user can pan around the environment, as though in a sphere, to observe all angles both vertical and horizontal, such as described by Jauregui (9).
Modernised evolutions of QTVR have come into existence, such as 360 degree video and Google Jump. The Google Jump camera rig has an array of 16 cameras which record video, and once the footage is processed the user can pan around the moving image looking in all directions as the video progresses.

Similar to high resolution imaging 360 degree videos have been created of bridge structures (10) which are interesting and useful for post-inspection analysis, however they do not contain important metadata. VR video and images can be stored in the BMS database as a record of the structures condition at the time of inspection, which could be used as a quality control tool.

4.4 The Internet of Things

The Internet of Things (IoT) is the internetworking of physical objects via network connectivity (the internet) allowing them to send and receive data (11). One example is ‘smart’ running shoes, which have a sensor to measure distance, speed and altitude, giving the user real-time feedback about his performance. Another example may be on an industrial plant, where equipment is sending data back to the control centre, via the internet, on pressure, velocity or temperature.

In the same manner, data can be collected from structures at specific locations of interest, such as the tension of steel suspension cables or a corrosion ‘hotspot’ on a concrete bridge. The data can be collected via cloud computing which can subsequently be modelled in a graphical BIM display in a BIM (12, 13).

Corrosion of steel reinforcement is the predominant factor in causing damage and early failure of reinforced concrete structures worldwide (14). Song et al. goes on to state that our ability to monitor steel reinforcement in real time could provide more information of the current and future performance of the structure. Imbedded corrosion monitors can reduce costs of inspection and monitoring, and allow a more rational approach to structural assessment.

Looking beyond Bridge Management Systems, making our wider infrastructure network ‘intelligent’ holds promise for the future of our cities. A digital BMS integrated with other ‘smart’ infrastructure that is intelligently connected can enhance relevant functionality (15). In the future, Bridge Management Systems will form a part of the ‘smart cities’ concept. Real-time monitoring of structures through the Internet of Things will reduce the time it takes to discover and solve problems, which historically appear only when they literally surface (16).

5. Conclusions

A BMS is essentially a collection of data: inspection data, condition data, photographs, drawings and specifications. This data can be used in a powerful way to assist the user in making the right maintenance decisions at the right time. Historically, Bridge Management Systems in the Gulf Region have been ‘analogue’ or paper based, and the introduction of digital BMS solutions has been a major step forwards over the last decade.

The digital evolution of Bridge Management Systems has seen an improvement in user accessibility with the introduction of web-bases solutions, improved security, deeper integration with other systems and collection of inspection data using mobile devices.

Bridge Management Systems in the near future will be integrated with other digital technology such as intelligent 3D Building Information Models (BIM) and real-time data collection via the Internet of Things (IoT). In order to be beneficial in decision making, this additional information needs to have context and engineering integrity.

Our goal is that one day Bridge Management Systems will be integrated into the wider network of ‘intelligent’ infrastructure playing a key role in the maintenance of our smart cities.
6. References

(1) Qatar General Secretariat of Development Planning, Qatar National Development Strategy 2011 - 2016, June 2011, Qatar


