Integration of BIM in Bridge Management - Enhanced Predictive Functionality

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Abstract

Bridge Information Model (BrIM) is being evolved as a possible solution to become the one-stop solution for bridge design to management. Research has been ongoing to present a concept of integrating BrIM with Bridge Management System (BMS). Such integration is envisaged to maximize the utilization of the core capabilities of both BrIM and BMS. Integration of BrIM and BMS will yield analytics essential for the prediction of deterioration models, risk analysis and prioritization and optimization of fund allocation. The use of 3D geometric models, Digital photography using photogrammetry software and Structural Health Monitoring to evaluate the performance of the bridge. Integration of SHM within BMS results in a paradigm shift from judgement-based decision-making to scientific observations. Integration of BrIM with BMS has resulted in enhanced sustainability and predictive functions. The efficiency of BMS has increased due to the scientific, real-time, reliable decision-making process.

Keywords: Unified Bridge Management System; Bridge Information Modelling (BrIM); Photogrammetry; Artificial Intelligence; Deterioration model.

1 Introduction

Due to the significant increase in the age of infrastructure globally, maintenance of existing structures has been prioritized over the construction of new structures, which are very costly. Many infrastructure facilities could not be managed efficiently due to a lack of well-trained staff and budget limitations. Most of the current BMS's are based on 2D information systems and do not utilize data related to shape, orientation, and geospatial information. To overcome these problems, studies of BMS based on bridge information modelling (BrIM) have significantly increased in number. The service life of a bridge, which is governed by safety and serviceability criteria, can be extended by regular maintenance and timely rehabilitation interventions [1]. To this end, bridge management systems implement deterioration models that allow condition forecasting [Predictive analysis], maintenance cost and risk modelling to estimate optimal maintenance interventions or maintenance scenarios. These models necessitate high-quality data, which is typically stored in databases that are either part of the BMS or external data sources [2]. Inventory data, inspection data, and data on maintenance interventions are all stored in these databases. Bridge Information Models (BrIM) will be used to provide more accurate and useful inventory representation beyond the alphanumeric representation in current bridge databases. It seems reasonable to enhance BrIM with the data that is needed for bridge management systems. It should be noted that, in addition to data on inspections and maintenance interventions, the digital representation of bridge elements constructed during maintenance or improvement interventions is critical for bridge management. This means that BrIM must track the evolution of bridge conditions over time, i.e., temporal BrIM is required. The development of temporal BrIM should, in concept, gain financially from existing real-time and dynamic databases. Currently, many researchers focus on the extension of the BrIM, which would include historical bridge data, including open issues related to changes that bridges experience over time disregarding whether they are caused by deterioration or maintenance interventions.

EN 1504 enabled the definition of the principal and secondary Causes that result in distress propagation in concrete. This enabled the shift from symptoms-based protocol to Cause based protocol. It was felt essential to include this emerging understanding of how to implement rehabilitation intervention [7]. Many BMS to date rely on symptom-based protocol due to difficulties in data analysis for the past years for which data related to symptoms is only available. Enabling a shift from these symptoms to causes is the first step that the new system will need to address. Further, it is critical to introduce performance criteria to decide the progression of distress in the structure. It was critical to correlate the progression of symptoms defining the severity of the distress with the cause of distress. The challenge is to correlate this decrement in performance to increments of distress. The correlation will allow changing the Cause matrix to a Performance-based cause matrix. The cause matrix enables the formation of the Deterioration model which forms the basis for risk estimates and further optimization of fund allocations. These features have been evolved by the research team using a 3D geometric model, Digital photography using photogrammetry software and Structural Health Monitoring to evaluate the performance of the bridge. By using Structural health monitoring (SHM), it is possible to monitor the bridge periodically. SHM is important for maintenance planning to find a cost-effective solution. SHM for bridge structures is commonly referred to as a damage detection or characterization strategy for real-time structural condition assessment. Predominantly, there are two types of SHM systems, that can be used in assessing structural performance under different loading conditions. SHM is widely used in many bridge structures around the world. By monitoring the safety data of the bridge and analysing the maintenance status, can accurately understand the service status and service life of the bridge, distinguish the more damaged parts intuitively, and make timely and correct treatment. The monitoring data collected by the system is transferred to the operation and maintenance management system in real-time to identify major structural damage and respond promptly.

Bridge management needs to focus on the optimization of fund allocation to address the deteriorating condition of the bridges ensuring that sustainability is maintained without compromising the economic potential of the area. Till recently, most of the decision-making was based on visual inspection by bridge inspection teams. This led to judgement-based conclusions which were used to decide the optimization of fund allocation. This at times may not be reliable because some damages are difficult to detect, quantify visually, or are subject to human interpretation. Bridge management is an essential part of any bridge's lifecycle. It's important to monitor and maintain bridges and other structures to ensure that they remain safe for public use. Proper bridge management helps to prevent bridge collapses, reduce traffic accidents, and extend the life of a bridge. Bridge management also helps to ensure that all relevant safety standards are met. BRIM application studies for bridge maintenance include safety diagnosis, schedule management, visualization of historical information, maintenance decision-making, and efficient asset management. Studies on detailed techniques for safety diagnosis using BrIM began to be conducted to develop techniques to express damage in 3D models using photography generated during safety diagnosis to minimize the error of damage between the actual structure and the 3D model.

Currently, the inspection procedure also provides sufficient geometric data of various elements of the bridge to be used to generate a full scale-down 3D geometric model of the bridge. This 3D model helps us to understand the bridge geometry and structural placement. It also allows us to mark the distressed elements. Based on the inspection data it is also possible to have a clear picture of the severity of distress in the element.

This study aimed to establish a BrIM-based BMS for the sustainability of bridge maintenance based on the maintenance data schema and its information system, including detailed bridge information relating to diagnosis, maintenance, remaining life, and valuation in a usable data format. Detailed information in the data format of the BMS can improve the usability of information, ensuring cost-effective maintenance is available through connected activities such as proper decision-making. To achieve these goals, the research team provide the required information for safety diagnosis and maintenance and the integration of the Bridge Information System (BrIM) in Bridge Management to provide a possible solution by ensuring the Sustainability of bridge infrastructure which is kept focused on all the Analytics tools it deploys. Structural health monitoring integration with BMS offers realistic observations not linked to any bias or judgment. In this, one has developed a procedure to modify the Cause matrix whenever the Performance is observed to have decreased. This ensures that Performance monitoring based on SHM is linked to the decision-making process within BMS. This combined with the resultant cause matrix offers reliability in the estimation of the deterioration model and further in the risk analysis and optimization of funds. LCCA, when applied in BMS is one such tool that remains focused on sustainability.

2 Overview of BrIM

Bridge Information Modelling (BrIM) is a digital representation of a bridge that uses three-dimensional (3D) modelling technology to create a virtual model of the bridge. This model contains all the information about the bridge, including its geometry, materials, and structural components. BrIM is an extension of Building Information Modelling (BIM) and is specifically designed for the management of bridges.

2.1 Benefits of integrating BrIM and Enhanced Predictive Functionality in Bridge Management:

Improved accuracy: BrIM provides an accurate and detailed representation of the bridge, enabling better decision-making, and planning.

Enhanced collaboration: BrIM facilitates collaboration between different stakeholders in bridge management, such as engineers, contractors, and maintenance personnel.

Improved visualization: BrIM provides a 3D visualization of the bridge, making it easier to understand the structure and components.

Improved efficiency: BrIM can be used to simulate different scenarios and evaluate the impact of different maintenance and repair strategies, improving efficiency.

Improved risk management: The integration of BrIM and Enhanced Predictive Functionality allows bridge managers to identify potential risks and hazards and take preventive measures, reducing the likelihood of accidents.

Real-time data analysis: By utilizing real-time data, bridge managers can make informed decisions about maintenance and repairs, ensuring that resources are used effectively.

Reduced downtime: By identifying potential problems before they occur, the integration of BrIM and Enhanced Predictive Functionality enables bridge managers to schedule maintenance and repairs, reducing downtime and minimizing disruption to traffic flow.

Increased lifespan of bridges: By taking a proactive approach to maintenance and repairs, the integration of BrIM and Enhanced Predictive Functionality can extend the lifespan of bridges, reducing the need for costly replacements.

2.2 Challenges of integrating BrIM and Enhanced Predictive Functionality in Bridge Management:

Data integration: The integration of BrIM and Enhanced Predictive Functionality requires the integration of data from multiple sources, which can be a complex process. Present IFC will need to be extended to include certain critically essential data fields.

Data quality: The accuracy and reliability of BrIM depend on the quality of the data used to create the model. Data quality can be a challenge in cases where the bridge data is incomplete, inconsistent, or outdated.

Standardization: There are no industry standards for BrIM, which can lead to inconsistencies in data management, making it difficult to compare data across different bridges.

Cost: The cost of implementing BrIM can be a challenge, particularly for smaller bridge management organizations that may not have the resources to invest in the necessary technology and training.

Resistance to change: The adoption of BrIM requires a change in the traditional approach to bridge management, which may be met with resistance from stakeholders.

Skillset requirements: The integration of BrIM and Enhanced Predictive Functionality requires a unique skill set, which may not be readily available within existing bridge management teams.

Cost: The integration of BrIM and Enhanced Predictive Functionality can be expensive, requiring investment in technology and training.

Privacy and security concerns: The integration of BrIM and Enhanced Predictive Functionality raises concerns about privacy and security, particularly about the collection and use of real-time data.

3 Integration of BrIM and Enhanced Predictive Functionality in Bridge Management

The integration of Bridge Information Modeling (BrIM) and Enhanced Predictive Functionality in Bridge Management involves the use of BrIM to create a digital twin of the bridge, which is then utilized by Enhanced Predictive Functionality to generate real-time data and predict potential risks and problems. This integration allows bridge managers to take a proactive approach to bridge maintenance and repair, leading to improved safety, reduced maintenance costs, and extended lifespan of bridges.

3.1 Key function for the objective of BMS:

A bridge management system or BMS is a means for managing bridges throughout the design, construction, operation, and maintenance of the bridges. As funds available become scares, Road authorities around the world are facing challenges related to bridge management and the escalating maintenance requirements of large infrastructure assets. Bridge management systems help agencies to meet their objectives, such as building inventories and inspection databases, planning for maintenance, repair, and rehabilitation interventions systematically, optimizing the allocation of financial resources and increasing the safety of bridge users. Several basic components comprise a BMS to make it a fully integrated system able to analyse the database and then interact with other components with incoming information. The output should ideally be in the form of a limited schedule listing the ailing bridges in priority of need (which requires some form of condition rating) followed by a prediction of the costs of various maintenance strategies [3].

4 Global Analytics for Bridge Management [GABM]:

During the inspection process, each bridge element is inspected by the bridge inspectors from a close hand-touch distance. Such inspections yield an understanding of the behaviour of the bridge structure. An inspection enables the bridge inspectors to correlate various symptoms that are recorded. The inspector can draw his inference as to the probable cause of distress. Based on the prognosis of the deterioration process the inspector assigns ratings from 1 to 5 for various agents of distress. This process is done easily by procedure of eliminating one of the agents of distress. The matrix resulting from this is called the "Cause Matrix ". Based on the assigned ratings primary cause of distress can be identified. All other contributory causes are called secondary causes.

Research is ongoing to allow Artificial Intelligence to evolve the Cause matrix based on the symptoms observed by the bridge inspector. This innovation will pave the way easily to migrate from a symptom-based system to a Cause-based system, which will then be evolved into a performance-based system. The Cause-based systems will continue to be the base of the decision-making protocol. Performance observations will further enhance and fine-tune the cause-based evaluated results to account for the dynamics and real-time behaviour of the bridge structure.

Once the primary and secondary causes are defined, it is important to be able to determine the deterioration process. Deterioration is the propagation of distress over a period and extent. For correct estimation of the deterioration process, multiple observations are essentially compared to define the probability of a particular type of deterioration process occurring over time. Based on the defined deterioration process, estimates for the balance service life of the bridge can be made for various factors affecting the bridge structure. This provides a guideline for evaluation of the risk involved due to deterioration not being arrested. This entire exercise of defining the deterioration process and risk analysis is based on elements of the bridge. Structural behaviour is based on the location of loading and the reaction to the loading varies (among many factors) with any discontinuity in the section subjected to loading. The location of such discontinuity also affects the response of the section.

Brendan McGuire in his research listed three main reasons for the need for identification of the location of damage being critical to the structural evaluation and the deterioration process. He implied that different modes of failure are location-dependent and that assume criticality based on their location along the length of the element. Secondly, he stated that the strength of the element is evaluated using the deteriorated cross section which in turn could affect the load capacity of the member along the length of the element. None of the existing BMS including GABM can provide accurate digitized data relating to the location of the damage or distress.

These shortcomings within BMS are required to be overcome by using all available new innovative technologies. Integration of technologies, that can provide data regarding the correct geospatial location of distress would be the first phase in the refinement. Moreover, the next phase is to identify the critically distressed elements and evaluates the performance of such severe distress elements under live loading using Structural health monitoring [SHM] for short durations only. Using this data as base data, we shall need to repeat our SHM observations over time to create a time series data that is used to compare with base data collected initially. The sequence of application in the bridge management will require us to refine the following, keeping in focus that performance shall be the driving factor:

A. Location, extent, and severity of distress: Identification using photogrammetry tools.
B. Structural Health monitor: Real-time analysis of the structure under live load.
C. Application of computing algorithms to SHM to evaluate performance.

4.1 Identification of distress using photogrammetry tools [6]:

The first step in refinement shall need us to define a 3D model of the bridge. Sufficient data collected within the inspection process enables us to use 3D open-source software to generate such a 3D model of the entire bridge. Such 3D models for bridges are termed Bridge Information Models (BrIM). This 3D model helps us to understand the bridge geometry and structural placement. It also allows us to mark the distressed elements. Based on the inspection data it is also possible to have a clear picture of the severity of distress in the element. The most severe distressed elements can be identified and pinpointed. Our research was focused on the need to establish the geospatial location, the extent, and the severity of distress in the various bridge elements. This digital imagery provides geospatial data on distress. The use of Drones changes the way inspection can be done. The use of drones/UAVs to capture still photos of distressed areas and videos of bridge components/ elements will enhance the usefulness of indicating the location and extent of distress. UAV/ Drone can capture multiple photos with large overlaps or video files which are then used by photogrammetry tools to create a 3D model of individual distressed elements. All such imagery had embedded geospatial information. With the geospatial information of distress, it becomes possible to identify the elements which can be monitored for performance evaluation.

4.2 Structural Health Monitoring – Real-Time Assessment:

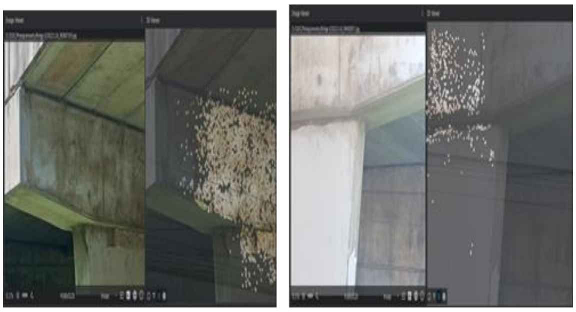
Having identified the geospatial locational details along with the extent and severity of the distress in the element, the Bridge inspector can then focus on the identification of the most severe distressed elements. Such elements will need to be subjected to Structural Health Monitoring. Structural Health Monitoring (SHM) needs to be integrated with Bridge Management System (BMS) to enable BMS to become more robust, realistic, and efficient. The search to supplement this system of reaching conclusions brought Structural Health Monitoring [SHM] to the forefront. Innovations in SHM is playing a significant role in recent times because of their potential to capture real-time performance data, which helps in reduction of the maintenance costs resulting in an overall increase in the reliability of bridge structures. The focus of SHM is on damage detection which causes distress leading to the deterioration of structures. SHM applies real-time monitoring under live loads and applies digital techniques for analysis [6].

By using SHM, it is possible to monitor the bridge for the short term periodically. It is possible to monitor the response of the bridge structure which reveals modifications to the material and structural properties. SHM is important for maintenance planning to find a cost-effective solution to reduce costs and extend the life of critical assets like bridges. SHM has been widely used in many bridge structures the world over. This has resulted in a lot of bridge SHM data being available for analysis. This has facilitated the evolution of tools that have been developed to help government agencies manage bridges efficiently. There is an abundance in the variety of sensors, which are useful to assess the real-time behaviour of the structures. Historically, monitoring devices were contact-based but recent innovations render it possible to remotely monitor the structures. The evolution of algorithms, to link SHM data to modification in the cause matrix, provides much-needed solutions. SHM enables bridge management to move the decision-making process to rely on real-time performance-based data. The analysis of the performance will enable us to understand the magnitude of decrement that occur in the performance. Such decrements are then correlated to the increment in distress in the elements. Correlation empowers us to define a new cause matrix which is based on decreasing performance of the bridge elements. We aim to shift Cause-Based Bridge Management to Performance-based Bridge Management.

5 Integration of BrIM

GABM's system has evolved to cater to and provide solutions to the needs of its users. Many of the functionalities and tools in GABM are innovative. Further needs for data relating to the precise location of distress have emerged to correctly determine the progression of distress and its manifestations over time. Such data will ensure that the deterioration model emerging from the data collected during the inspection is more realistic and hence reliable. The solution to this is to integrate BrIM with BMS. All previous studies and research were aimed at transferring the capabilities of a Bridge management system into BrIM. This needed creating and defining many parameters and incorporating the dimensions of time into the BrIM.

This scenario was tricky and partial integration of GABM and BrIM was discussed considering the difficulties. With the help of GABM, a functionality that offers geographical data about structurally disturbing elements is being developed using the same ideas that were utilized in the construction of BrIM. Data is currently being gathered to identify the distressed elements. Geospatial information is required for the qualitative information about the location of the distress contained within that element. Using a photogrammetry tool, one can determine their current geometry [5]. At most, the model that forms will be a 3D geometric model. Present-day BMS are fully web-based and automated in the sense that decision-making is automated. Once input is provided by field engineers in the inventory and inspection modules, the decision to assign confirmatory tests required for various elements can be provided in automated mode. The principle of remedial measures/intervention can be defined. The area to which such intervention is to be provided is automated and so is the calculation of quantities. Such capabilities within any BMS need not be duplicated in BrIM. The functions of deterioration modelling, risk assessment and fund allocation are all time tested and functional within GABM, which can be adopted by BrIM.



5.1 Following are the steps for the Integration of BrIM [4]:

A. Each bridge in the GABM database provides geometrical information. The data relates to the number of spans and the geometrical dimensions of different elements within each span. Each type of element has a library of standard shapes in GABM. An automated schematic 3D model of the bridge is produced based on data about the arrangements of the elements, their shape, and fundamental geometrical details. Since it contains all the bridge's geometric information and allows for the addition of more information, it is known as the Bridge Information Model (BrIM). As it lacks design and construction details, this BrIM is not a digital twin. The only thing there is a geometric 3D model with a distress mark on it.

B. Information about the distressed elements is also available from GABM. The integration of 3D models for such elements is made possible by such information. The Location of Distress in the Element (LODE) concept is used in these 3D models. Consequently, they are known as 3D LODE models. These models are miniature 3D representations of the element in distress. A greater number of LODE models connected to a bridge suggests that the bridge is severely distressed. Drone and UAV images and videos of damaged objects are used to construct LODE models. Every time an inspection is carried out over a period, precise geographical data about the location of the distress is recorded. These time-series models make it possible to understand how the element's distress develops over time. This existing knowledge base enables the possible impact to be evaluated of the distress on the performance of the element. This step eliminates the shortcoming of an absence of geospatial data relating to the existence of distress and the severity of distress on that element. Models of time-series photos or videos enable the progression of distress in the element to be pinpointed.

Figure 1. Model Generated from Photogrammetry Tool

C. Such LODE models enable the evaluation of geometric details of distress for quantity estimation and the progress of deterioration in the element. The final evolution of the deterioration model for a bridge with geospatial details of distress is possible. Such LODE models, being only geometric in nature, will render it impossible to evolve the performance of an element over time and hence will need details of performance changes to be captured in a time series of observations.

D. Incorporation of structural health monitoring for two to three days under actual live loads for the distressed elements will enable monitoring of the performance of that element under the given state of distress. Progressive updates regarding the above every time an inspection takes place will enable a knowledge base to be created on the progress of diminishing performance and thereby assist in the completion of an actual deterioration model for the bridge based on the geospatial location of distress and linked to the performance of the bridge under the progressing distress within the bridge. The structural health monitoring (SHM) of critical elements provides time-series data for those elements showing very severe distress. The starting severity of distress is known from physical observations. Once the SHM time-series data is analyzed, the progression of distress in that critical element can be established. Such a progression is established by an algorithm that correlates the performance decrement with the increment of distress (the extent and severity). This correlation is key to integrating SHM with the analytics in GABM. SHM performance observations enable the generation of a probability matrix. This is then used to modify the judgement/ prognosis-based cause matrix. Such a modified cause matrix is now based on actual factual data provided by SHM. A cause matrix generated by this process is called a performance-based cause matrix.

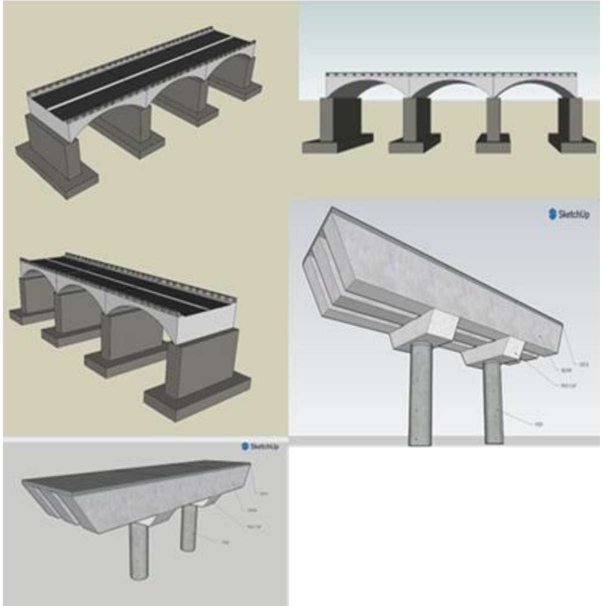


Figure 2. 3D Model Generated from Geometrical Details

An increment in distress generates a scenario wherein the cause matrix generated by the judgement/prognosis of the bridge inspection engineer/team can be modified. From acceptance of the judgmental prognosis, a situation exists wherein the cause matrix is modified by actual observation of the performance of the bridge and its elements. Integration of SHM within the analytics of GABM replaces person-dependent judgement with actual observation and performance-based decision-making procedures.

Within GABM, the functionalities of deterioration modelling, risk analysis and fund allocation were to date based on theoretical evaluation and observation of increments of distress in the bridge. This approach of partial integration makes it possible to produce a realistic performance-based deterioration model that is more accurate. The model will accurately associate the changes in the performance of the bridge elements with changes and increments of distress in the elements. The science of predicting changes in distress has been mastered in the world but correlation with performance has not been incorporated into any part of the bridge management domain. The partial integration of BrIM with GABM ameliorates this shortcoming. This upgraded system has the platform of bridge management as its front end and manages to use only a partial functional tool within BrIM to meet the requirements of bridge management with an advantage.

6 Conclusion:

Most of the current BMS are based on 2D information systems and do not utilize bridge maintenance data. To overcome these problems, studies of BMS based on bridge information modelling (BrIM) have significantly increased in number. The service life of a bridge, which is governed by safety and serviceability criteria, can be extended by regular maintenance and timely rehabilitation interventions. To this end, bridge management systems implement deterioration models allowing condition forecasting, maintenance cost and effectiveness models to estimate optimal maintenance interventions or scenarios. Bridge Information Models will be used to provide more accurate and useful inventory representation beyond the alphanumeric representation in current bridge databases. It should be noted that, in addition to data on inspections and maintenance interventions, the digital representation of bridge elements constructed during maintenance or improvement interventions is critical for bridge management. Currently, many researchers focus on the extension of the BrIM, which would include historical bridge data, including open issues related to changes that bridges experience over time disregarding whether they are caused by deterioration or maintenance interventions. The cause matrix enables the formation of the Deterioration model which forms the basis for risk estimates and further optimization of fund allocations.

These features have been evolved within GABM using a 3D geometric model, Digital photography using photogrammetry software and Structural Health Monitoring to evaluate the performance of the bridge. By monitoring the safety data of the bridge and analysing the maintenance status, can accurately understand the service status and service life of the bridge, distinguish the more damaged parts intuitively, and make timely and correct treatment. The monitoring data collected by the system is transferred to the operation and maintenance management system in real-time to identify major structural damage and respond promptly. Bridge management needs to focus on optimising fund allocation to address the deteriorating condition of the bridges, ensuring that sustainability is maintained without compromising the area's economic potential. BrIM application studies for bridge maintenance include safety diagnosis, schedule management, visualization of historical information, maintenance decision-making, and efficient asset management. Currently, the inspection procedure also provides sufficient geometric data of various elements of the bridge to be used to generate a full scale-down 3D geometric model of the bridge. Based on the inspection data it is also possible to have a clear picture of the severity of distress in the element. This study aimed to establish a BrIM-based BMS for the sustainability of bridge maintenance based on the maintenance data schema and its information system, including detailed bridge information relating to diagnosis, maintenance, remaining life, and valuation in a usable data format. Detailed information in the data format of the BMS can improve the usability of information, ensuring cost-effective maintenance is available through connected activities such as proper decision-making.

To achieve these goals, the Research team provide the required information for safety diagnosis and maintenance and the integration of the Bridge Information System (BrIM) in Bridge Management to provide a possible solution by ensuring the Sustainability of bridge infrastructure which is kept in focus on all the Analytics tools it deploys. This ensures that Performance monitoring based on SHM is linked to the decision-making process within GABM. This combined with the resultant cause matrix offers reliability in the estimation of the deterioration model and further in the risk analysis and optimization of funds. Future scope involves the use of AI and machine learning to identify the critical elements of any bridge structure and then evaluate the level of distress in such elements based on the Location of distress element [LODE]models. This study and evolution will take time to create sufficient data from ongoing projects to enable machine learning and AI engines to be designed.

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