ENHANCED SUSTAINABILITY BASED ON RELIABILITY APPROACH TO BRIDGE MANAGEMENT

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ABSTRACT

Bridge management plays a key role in ensuring the sustainability of bridge infrastructure. Most countries have a large population of distressed bridges. Their management assumes importance in this era. Management is done in progressive incremental steps that originate with inventory and inspection data collection. Inventory is the first and most prominent step in any bridge management system. It performs a key role in maintaining a systematic record of bridges' conditions and behaviours. The data collected provides information useful to plan repair and rehabilitation strategies. Compilation of the cause matrix is the first of the many steps that lead finally to optimization in fund allocations. Historically, Bridge management did not provide any input to ensure sustainability or manage economic growth. Extensive research resulted in the evolution of algorithms needed to integrate various technologies with the management procedures of Bridge Management. It enables one to move from a judgment-based system to a realistic, performance-based dynamic approach to Bridge Management. This results in time series data revealing the percentage of decrements in the performance of the bridge structure. Such decrements in performance are linked by the developed algorithm to modify the cause matrix. Further integration of UAV imagery and short-term SHM performance time series data decides the extent and type of rehabilitation interventions. Optimization is achieved by the integrated application of Life-Cycle Cost Analysis [LCCA]. Enhanced LCCA within the Analytics tool of Unified Bridge Management System [UBMS] is more realistic. It provides enhanced application by accounting for intangible benefits resulting from Social, Economic, and Environmental parameters. This results in enhancement in the maintenance of sustainability without compromising economic growth. Research is ongoing to further enhance the efficiency of Bridge management.

1. INTRODUCTION

Concrete structures are built to provide a service for a limited time, and, in some cases, the need for maintenance is foreseen[1]. The durability of concrete has been a social concern due to the poor performance of concrete caused by various environmental, physical, and chemical factors.

EN 1504 highlighted the relevance of the identification of the cause. Based on the cause of distress, the definition of remedial intervention for different elements of the bridge started taking root. It was critical to correlate the progression of symptoms defining the severity of the distress with the cause of distress identified at an elemental level and not at a component level [3] . The process to identify and define the primary cause of distress is affected by a process of elimination. The resulting matrix is called the “Cause Matrix.” This cause matrix is assigned based on engineering judgement or a prognosis. Based on the prognosis for the deterioration process, the inspector assigns cause ratings to various agents of distress. Being a process dependent upon judgement, it was felt that a more scientific approach would be more realistic. The performance of bridge elements provides this realistic and dynamic approach. It is factually established that increments in distress lead to a decrement in performance. The performance of bridge elements can be evaluated by Short-Term Structural Health Monitoring [ST-SHM]. So in effect, Structural Health Monitoring [SHM] is used to monitor the dynamics of the bridge performance. The challenge is to establish and correlate this decrement in performance to increments of distress. The correlation will allow us to implement changes to the Cause matrix based on the dynamics of the Performance of bridge elements [2] . The cause matrix enables the formation of the Deterioration model, which forms the basis for risk estimates and enables us to optimise fund allocations. An increment in distress generates a scenario where one can modify the Cause matrix generated by the prognosis of the bridge inspection engineer/ team.

The initiation of the Bridge Management system starts with the collection of data required in the Bridge Information system [BIS]. Data collection during the Inventory, Inspection and Testing process contributes to this process. A Bridge Management system [BMS] begins when BIS data collection ends. The definition of the Deterioration mechanism is the first step of BMS. Once the primary and secondary causes are defined, it is essential to be able to determine the deterioration process. Research to integrate and upgrade the Unified Bridge Management System [UBMS] resulted in the evolution of Global Analytics for Bridge Management [GABM]. GABM relies on the realistic estimation of the deterioration model to be able to utilize all other tools of UBMS. Deterioration model preparation is the first step in using all other management tools within GABM. Deterioration models presently depend on the cause of distress in various elements of the bridge. This deterioration model is used in risk estimations and to optimize fund allocation. This renders the present BMS as a Cause based system. This entire exercise of defining the deterioration process and risk analysis is based on elements of the bridge. The current inspection procedure also provides enough geometric data from various bridge elements to generate a full scale-down 3D geometric model of the bridge. This 3D model helps us understand the bridge's geometry and its 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. Integration of photogrammetry allows the creation of 3D geometric models of the bridge structures. UAV/ Drone can capture multiple photos with large overlaps or video files which are then used by photogrammetry tools to create 3D models. Such 3D models for bridges can be termed Bridge Information Models (BrIM) [4] .

By using Structural health monitoring (SHM), it is possible to monitor the bridge periodically. It is critical to thoroughly assess the safety, serviceability, and sustainability of bridges during their service life, and hence SHM systems are being actively developed to fulfil the task [2] . SHM is considered a key solution to provide information about the performance of the structures under examination and has been widely used in many bridge structures the world over. This has resulted in a lot of SHM data being available for analysis. This has facilitated the research which resulted in the evolution of tools that have been developed. 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, dynamic performance-based data. Many bridge management systems have tried to focus on research to balance sustainability and economic growth.

The key function of the Bridge Management System [BMS] must include and achieve maintaining a balance between the preservation of a sustainable environment and managing the economic benefits due to the extended life span of bridge structures without compromising the economic growth of the area. Management of Sustainability during the concept evolution, design, construction and maintenance of infrastructure is ensured with the help of Life-Cycle Cost Analysis [LCCA]. This LCCA is used to estimate the overall financial investment cost of various project alternatives and helps to choose the design that ensures the facility has the lowest cost of ownership consistent with its quality and function. LCCA becomes more realistic if the benefits resulting from Social, Economic, and Environmental parameters are also accounted for in the evaluation process[5,6,7] . GABM considers the management of this delicate balance between sustainability and economic growth as an important and critical focus area.

Bridge Management System is intended to manage a network of bridges with a limited budget and resources. Several researchers have addressed individual aspects of bridge management system components such as deterioration models, condition assessment, and life cycle cost analysis, all of which are critical to funding optimization.

The research is aimed at developing a comprehensive system that will use algorithms to evaluate the deterioration model, optimise fund allocation and optimization, manage life cycle costs, and make it sustainable. The system should provide decision-makers with tools for optimising bridge maintenance plans and repair strategies over multiple years within a budget limit and other constraints. The analytics module within the GABM provides a possible solution by ensuring the sustainability of bridge infrastructure without compromising the region's economic growth potential. Integration of SHM with GABM offers data based on realistic observations, delinking it from any bias or judgment. This integration results in a procedure for modifying the Cause matrix whenever it is observed that

Performance has decreased. This ensures GABM decision-making process is performance-based. When combined with the use of socioeconomic parameters collected in the GABM, it ensures that the balance between sustainability and economic growth is maintained.

2. STRUCTURAL HEALTH MONITORING INTEGRATION – FORCE MULTIPLIER FOR DECISION MAKING

The majority of the world's bridges were constructed about 50 to 60 years ago. We are saddled with an ageing population of bridges nearing the end of service life. All these bridges are becoming obsolete and necessitate much more frequent inspections, repairs, or rehabilitation to remain safe and functional. Furthermore, due to limited construction and maintenance budgets, bridge owners must balance the safety considerations arising from the structural condition of their bridges with the cost of maintaining them. This delicate balance has to be maintained. BMS, the world over is striving hard to manage this situation. Various techniques are being deployed. Structural Health Monitoring is one solution that can address the need for frequent inspections. SHM has been in use for decades but the full potential of this technology is not exploited.

Bridge management necessitates a deep understanding of the bridge's design and construction techniques used alongside a total understanding of the present structural status and condition. The procedure of collecting this vital data begins with the inventory and inspection of network bridges. During the bridge inspection process, the bridge inspection engineer must collate and aggregate data on the many manifestations of distress that arise in various bridge elements. Details regarding the locational specifics, extent, and severity are captured by the inspection team. The bridge components and more specifically the individual elements are in varied states of distress. It is the elements that demonstrate the most extreme distress that fails first. Locational information, intensity, and extent of discomfort are thus critical for bridge maintenance[2,10] . The Bridge Inspector can now concentrate on identifying the most severely distressed elements after determining the geospatial locational data, the extent, and the severity of the distress in the element. It is essential to identify elements that are severely distressed.

Within the GABM protocol, the initial decision-making process relies largely on the inspection results. All bridges on the network must be inspected every year. This inspection leads us to identify the bridges in need of rehabilitation interventions. However, due to budgetary constraints, not all bridges will be provided with essential rehabilitation interventions. Bridges to which such rehabilitation intervention cannot be provided, are assigned to the set defined as BUOM: Bridges Under Observation and Monitoring. Short Term Structural Health Monitoring [STSHM] is applied to such bridges. The inspection process has identified elements showing severe distress. Such elements under severe distress are subjected to STSHM under live loads. In a span of 12 to 18 months, a minimum of 3 and at times 5 cycles of STSHM are applied. A decrement in performance in these elements indicated an increment in distress. The maximum decrement value is used in the evolved algorithm. This algorithm defines the changes in the Cause matrix which yields risk estimates. This use of STSHM and algorithms shifts the bridge management decision-making process from being judgement based to a more realistic scientific approach. It is possible to analyse the data produced by SHM in several ways. The effectiveness of the structure may be assessed thanks to this investigation. To be employed in bridge management, this performance must be converted to predetermined criteria for which data has been gathered over a long period. Such short-term monitoring can be carried out using a variety of methodologies and sensor types. The cause of the distress will determine the kind of sensors to employ, the methods, and the parameters to be monitored. The Cause of distress is defined by three main processes [2] . Eleven additional sub-processes are defined under these three primary processes.

Two types of SHM are envisaged to achieve the objective: Remote or No contact SHM and Close contact SHM. A system where the crucial metrics, such as the vibration signature, amplitude, acceleration, frequency, and strain, are all recorded using technology without any physical contact with the bridge falls under remote or no contact techniques. Contact SHM are wherein Major strain, stress, linear displacement equations, inclination, vibration, frequency, acceleration, and corrosion potential are all measured by sensors near different desired bridge components using a system that includes strain gauges, linear variable differential transformers (LVDT), tilt metres, inclinometer sensors, acoustic emission sensors (AE), fibre optic sensors, corrosion sensors, and accelerometers.

The dynamics in the Cause matrix are related to the changing performance recorded by STSHM. By using a complex algorithm the performance of the bridge is correlated to the changes in the Cause matrix and finally, this results in the initiation of the bridge management decision-making process.[4,10] This alternative is more effective from a scientific standpoint than relying only on engineering judgement. Therefore, by combining performance-based Analytics, we improve the Cause matrix developed by Engineering judgement to more properly reflect the change in distress.

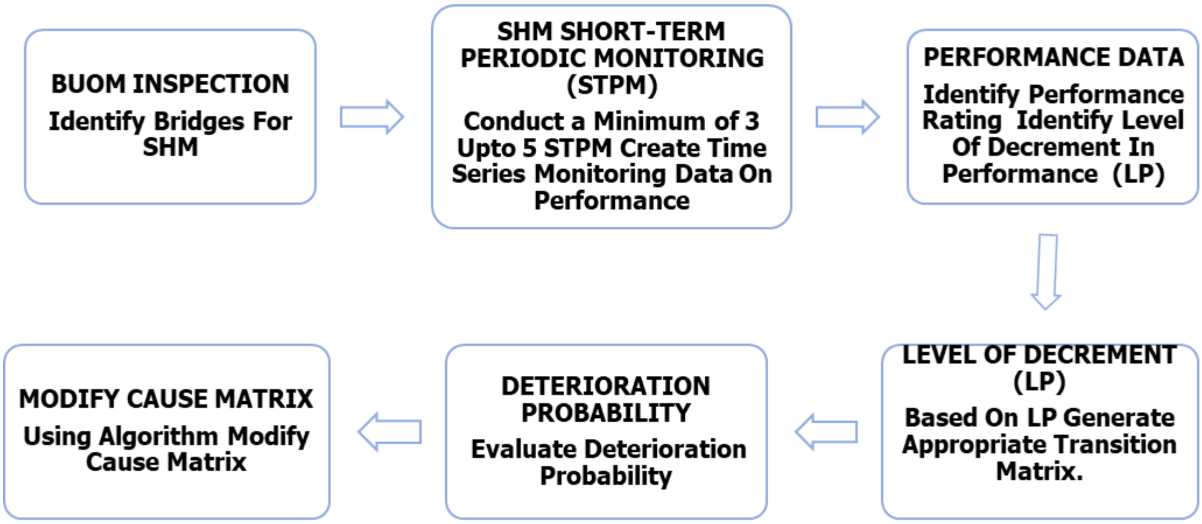


FIGURE: FLOW CHART INTEGRATION OF SHM AND GABM

3. APPLICATION OF LCCA WITHIN GABM

Sustainability is increasingly important in today's world, and to ensure the sustainability of bridges, a Life Cycle Cost Analysis (LCCA) should be conducted. Application of LCCA in GABM enables evaluation of the sustainability of the bridge. Such evaluation is critical in the decision-making process when the bridge is in critical condition. For bridges which have low sustainability but require a very high budget for rehabilitation, it may be prudent to consider demolition and reconstruction.

LCCA is an important tool to help bridge organizations achieve sustainability goals. LCCA is a technique used to measure the total cost of owning, operating, and maintaining a bridge over its entire lifespan. It considers the cost of construction, maintenance, repairs, and rehabilitation. By conducting a life cycle cost analysis, it is possible to identify cost-effective solutions that will ensure the long-term sustainability of the bridges. Additionally, deterioration models can help to identify structural areas where cost savings can be achieved to further reduce the long-term costs of bridge ownership and operation.

The primary deterioration model is more realistic and is founded on actual performance data. For more analytics applications, a detailed financial analysis of a bridge infrastructure is important with the help of LCCA. This enables the bridge owners to evaluate the impact due to tangible and intangible costs and benefits.

3.1. Life Cycle Cost Analysis [LCCA]:

LCCA is a systematic approach used to evaluate the total cost of ownership of a bridge over its lifetime [5,7] . It is used to compare the estimated costs of different bridge designs and identify the most cost-effective solution. The analysis considers the initial cost of construction, the costs associated with maintenance and operation, and the eventual cost of demolition once the bridge reaches its end of life. This analysis helps bridge owners and designers make informed financial decisions about bridge management during its life span related to construction and maintenance. The analysis involves several steps, including:

1. Identifying the costs associated during each phase of the bridge's life cycle: initial construction, maintenance, and demolition.
2. Estimating the cost of each component of the bridge, including the materials, labour, and any special equipment that may be required.
3. Assessing the expected life span of the bridge and its components.
4. Estimating the cost of repairs, rehabilitation, and other associated costs.
5. Calculating the total life cycle cost of the bridge. The results of the LCCA can be used to compare the cost of different bridge designs and to compare the estimated costs of different bridge materials. This analysis helps bridge owners and designers.
6. Some terminologies used in LCCA for the decision-making process such as- Time Value of Money, Discount Rate, Present Value, Benefit-Cost Ratio, and Internal Rate of Return [IRR] are also evaluated.

The most financially efficient bridge preservation strategies and appropriate design alternatives are compared and evaluated using the LCCA. For a certain set of distress criteria, there are several options for bridge maintenance and improvement. For project-level choices, each alternative is then examined together with its activity profiles and cash flows. Determine the constituent tasks for each competing project option. Establish the frequency and duration of work zone maintenance, and a timetable for future maintenance tasks, including when they will happen, where the money will go, and how long they will last. For each alternative, it is best practice in LCCA to include direct costs/ expenditures (such as those for construction, maintenance, rehabilitation, or replacement activities). Investigations should only focus on expenses that demonstrate disparities between options. The expenses of the activities are then calculated in detail. Vehicle running expenses, travel time costs and collision costs are the main topics of interest. The main cause of user expenses is a bridge's functional flaw, such as a load posting or clearance limitation. Because of diversions, wasted travel time, and accidents, these functional shortcomings might result in increased operating expenses for vehicles. Calculate the Life Cycle Costing [LCC], which is the total of the multiple cost streams for updating or replacing the nuclear fleet in other countries. Calculating the total LCCs for each choice and estimating how much each would cost over the course of the project are the objectives.

3.2. LCCA application in GABM

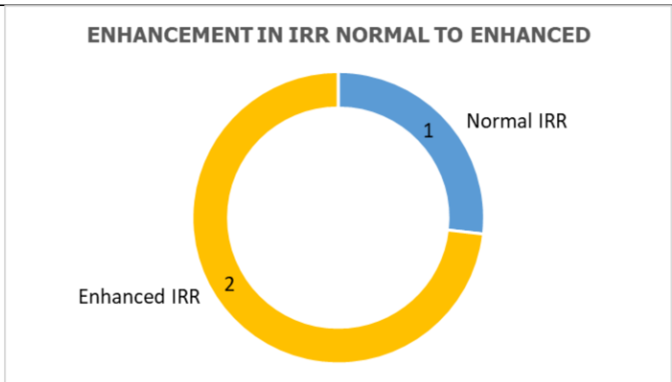
Typical LCCA in GABM is used to calculate the total economic cost of project alternatives and to determine which design would result in the facility with the lowest ownership costs while maintaining its quality and functionality. If the advantages brought about by Social, Economic, and Environmental aspects are also taken into consideration, LCCA becomes more plausible. This maintenance of the equilibrium between sustainability and profitability is one of GABM Analytics' key emphasis areas. This guarantees that the bridges will have a sustainable life cycle in the most economical way possible.

GABM applies for intangible costs and benefits within LCCA calculations, and the resultant benefit-cost ratios are found to be more dynamic and realistic. If the intangible benefits of bridge infrastructure derived from socioeconomic aspects [which account for all the benefits arising indirectly due to social, economic, and environmental factors] are considered in the financial calculations, the benefits and savings are increased. Increased movement of goods and traffic on the network and bridges in particular results in increments in the intangible benefits calculated for the bridge. GABM ensure that this dynamic scenario is captured annually by modification in the Socio-Economic parameters.

In GABM, Socio-Economic Rating Number (SERN) can help to identify the intangible benefits of a bridge by providing an understanding of the economy, environment, and the potential impacts of the bridge on the local population. This data can be used to measure the impact of the bridge on the economy, employment, and quality of life in the area. It can also provide insight into the potential for increased economic activity, that could be generated by the bridge. By providing an understanding of the local economic environment, socio-economic ratings can help to identify the potential for intangible benefits from the bridge. Except for direct costs and benefits, there are a few intangible impacts due to the presence of the bridge. These intangible benefits and cost benefits are dynamic in nature. It may also change over a period. With the help of real-time monitoring, observations, and records of the bridge management system, it is useful to link the dynamics of these parameters and easy to estimate the total costs and benefits of the distress bridge [7,11] . Within the GABM application, the existence of the Socio-Economic parameter records the changed scenario on the social and economic aspects due to the bridge. Such records are updated every time an inspection is carried out. Linking the Socio-Economic parameter to evaluate the intangible costs and benefits was possible due to various previous studies and research in this sphere.

Internal Rate of Return [IRR] is a financial metric used to evaluate the fair value of an investment. Intangible costs and benefits within LCCA calculations and the resultant IRR and Benefit-cost ratios are found to be more dynamic and realistic in the GABM application. The benefits are enhanced due to the inclusion of the intangible benefits for bridge infrastructure accrued from socio-economic aspects.

LCCA of different bridge structures in the network is based on dynamic, robust, and real-time monitoring information. Factors that result in changes in the cost of maintenance are recorded based on real-time monitoring of structures, such as their vibrations, movement, increments in distress, impact on the cause matrix, and resultant dynamic alterations in risk estimation [2,4] . This enables the financial analysis with GABM and contributes immensely to the Bridge Management System decision-making process.

LCCA of different bridge structures in the network is based on dynamic, robust, and real-time monitoring information. Factors that result in changes in the cost of maintenance are recorded based on real-time monitoring of structures, such as their vibrations, movement, increments in distress, impact on the cause matrix, and resultant dynamic alterations in risk estimation [2,4]. This enables the financial analysis with GABM and contributes immensely to the Bridge Management System decision-making process.	

STSHM provides relevant information on structural health prognosis for existing structures. This information can be used to improve the accuracy associated with structural performance predictions and lead to more rational life cycle management of civil infrastructure systems under uncertainty. LCCA helps to validate the possible effects of STSHM on structural performance and service life prediction. LCCA used in conjunction with STSHM becomes a very potent tool for the management of bridges [2] .

The application will contain all computations that have been compiled for subsequent years. Based on the intangible advantages acquired as a consequence of indirect benefits related to bridge construction, LCCA within GABM produces an enhanced and realistic IRR. IRR assessment is improved by more than 80%.

4. RESULTANT SUSTAINABILITY

The sustainability of bridges is of great importance for their long-term integrity and safety. By adopting sustainable practices, bridges can be designed to last longer and be more resilient to extreme weather events and other environmental challenges. Sustainability applies to give the optimal range of service, safety, and maintenance to the existing and future bridge users in a safe environment with investments made in a cost-efficient manner [11] . Sustainability is characterised as both preserving the current social, economic, and environmental framework for the current generation while also ensuring that it is preserved for future generations to come. LCCA usage enables the Bridge Management system's decision-making process to ensure sustainability. GABM facilitates the engineering management of the bridge's life cycle while ensuring sustainability. LCCA is a decision-making tool that is especially helpful from the bridge's conception to its decommissioning. As it anticipates lifetime costs and supports inspection management and maintenance operations, it ensures the evaluation rate of return for bridge design. All the infrastructure, especially bridges, should be viewed as a crucial component of the local economy contributing to the quality of life. Currently, more sustainable materials are being used to build bridges, assuring a favourable influence on the environment, as well as economic and social factors. LCCA guarantees that this can be used as a tool for the comparison and calculation of project life cycle costs. Environmental performance is frequently not taken into account in the decision-making process while designing a structure, even though economic, technical, and safety considerations are taken into account. If interventions are applied on time, using a bridge management system allows for the maintenance, strengthening, repair, and rehabilitation of bridges. This ensures maximising the life span of bridges without the need for replacement. Such interventions ensure that the cost of the life cycle is reduced, as well as the environmental impact, by reducing the use of raw materials. These interventions enhance environmental and economic management throughout the entire life cycle by maximising the benefits for the given costs. The timely provision of interventions ensures economic benefits by managing the cost-effectiveness of the design of such interventions and by ensuring to reduce the detour travel time, congestion, and traffic jam delays, resulting in the avoidance of productivity loss and its impact on the reduction of GDP in the area of influence of the bridge. Such intervention also ensures increased social benefits by reducing or avoiding failure or collapse and increasing network reliability, which impacts travel safety, life loss, and timely delivery of goods and raw materials, all of which are critical to maintaining productivity, which ensures a stable GDP. The avoidance of traffic jams and longer journey times due to detours ensures environmental goals of minimising carbon emissions in the event of a long-term bridge closure when collapse occurs. Sustainability ensures the delivery of the optimal level of service safely to existing and future bridge users in the most cost-effective way. LCCA enables the owners to anticipate and plan investments in a very cost-efficient manner. It also enables optimization of the costs essential to ensuring the bridge is functional for the entire service life span.

5. INPUTS AND RESULT IN SCREEN FORM GABM

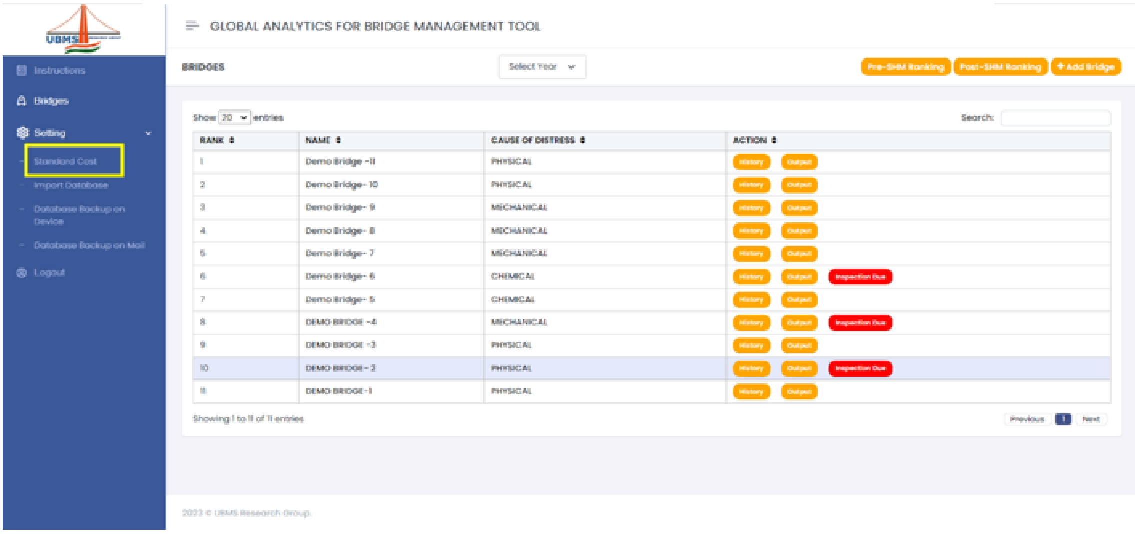


FIGURE: SETTINGS SCREEN & BRIDGE LIST [HISTORY & OUTPUT]

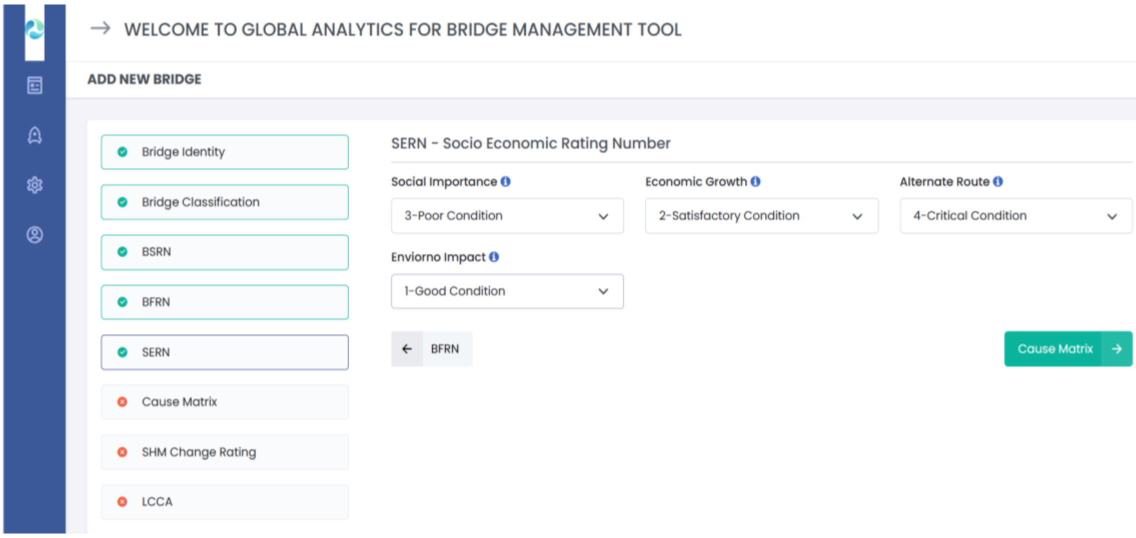


FIGURE: INPUT SCREEN-SOCIO-ECONOMIC RATING NUMBER (SERN)

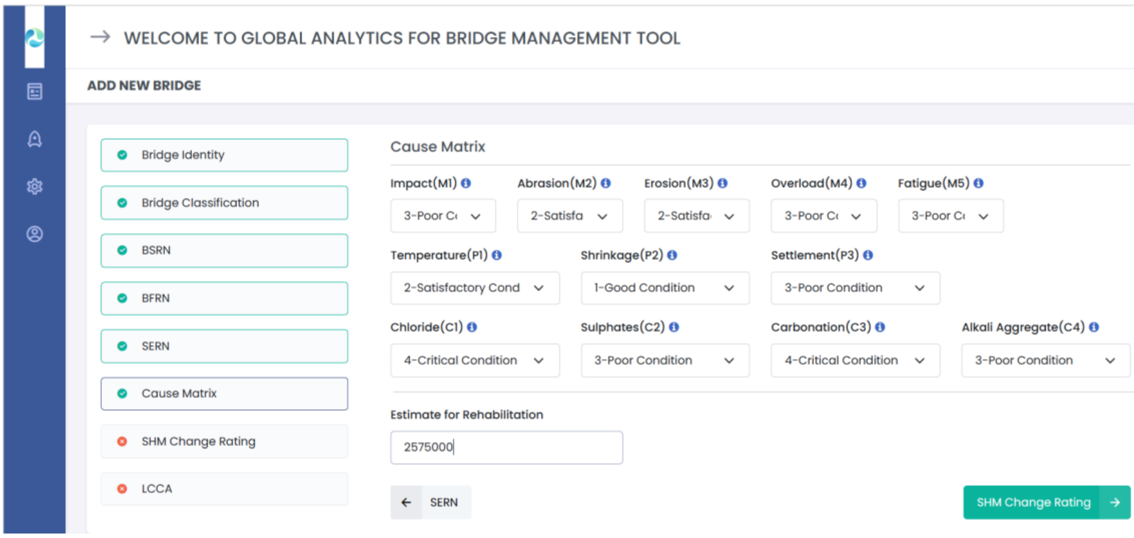


FIGURE: INPUT SCREEN-CAUSE MATRIX

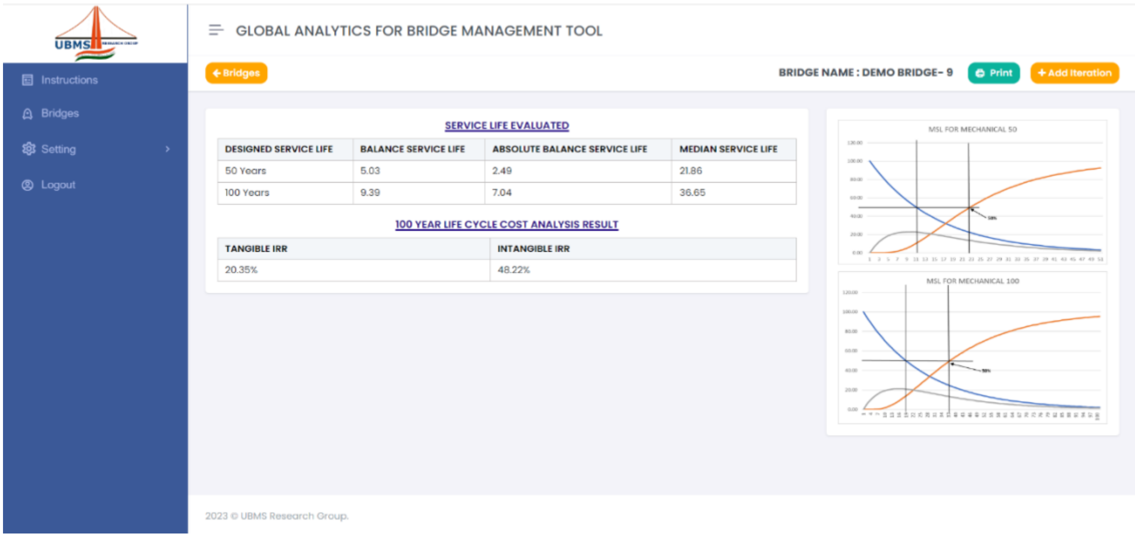


FIGURE: RESULT SCREEN-OUTPUT WITHOUT SHM

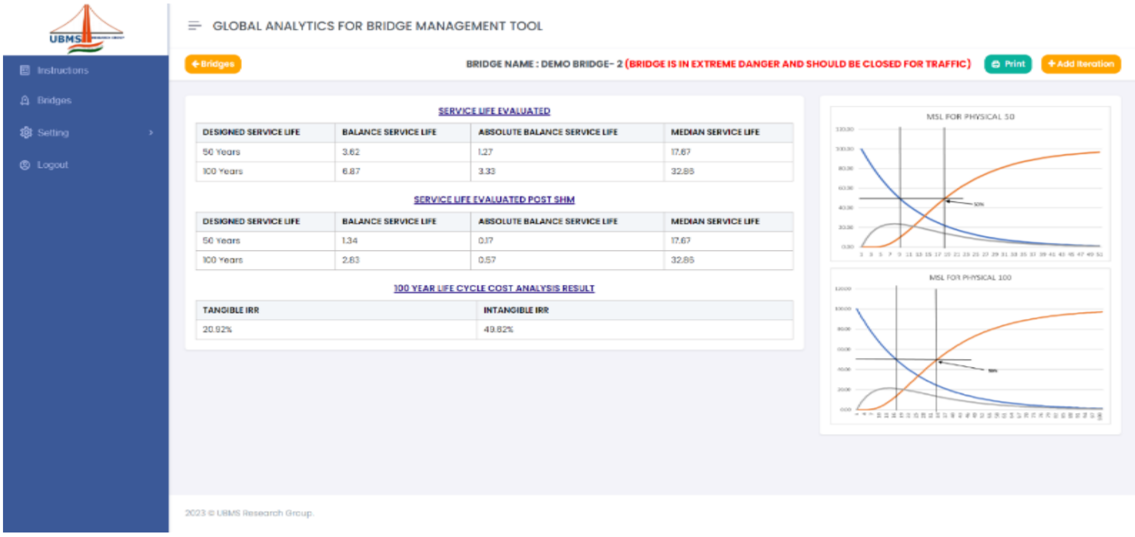


FIGURE: RESULT SCREEN WITH SHM AND ALERT

FIGURE: RESULT SCREEN HISTORY WITH ALERT

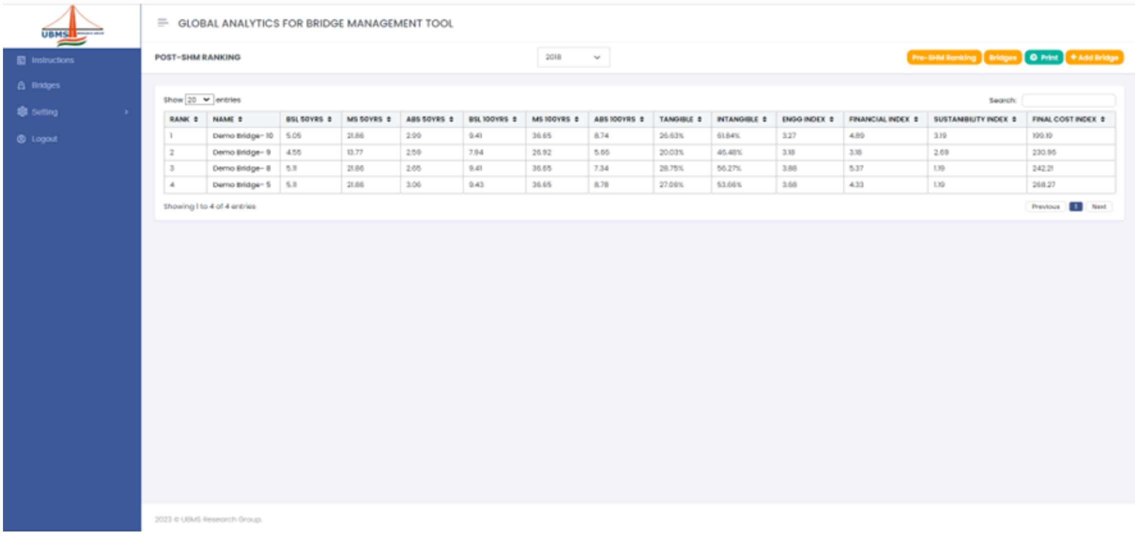


FIGURE: RESULT SCREEN-POST-SHM

6. CONCLUSION

Current problems with various road infrastructure networks include rising annual maintenance costs, ageing bridges in the network, distressed bridge infrastructure, and the effects of climate change. Management requires trustworthy data, which is gathered throughout the Inventory and Inspection process. During the inspection process, inspectors record specific information about the distressed structure and draw conclusions based on their observations. The correctness of the outcome is determined by the engineer's expertise and judgement. The vast majority of bridge management systems rely on this judgement. The majority of networks are suffering from an ageing bridge population with acute distress issues. Bridges with ages more than 40 to 50 years are obviously in a situation of severe distress. This requires the implementation of realistic management systems. So far, deterioration modelling, risk analysis, and fund allocation within BMS have been based on theoretical examination and observation of increments of distress in the bridge.

This creates a situation which results in impacts on the Sustainability of the bridge structure. To ensure sustainability is not just maintained but enhanced, it is prudent to redefine the Bridge Management processes. Research has shown that the BMS decision-making process is more realistic and effective when STSHM is implemented on distressed bridges. Integration of this technology hereto results in the removal of judgment-based observations being used in the decision-making process. STSHM ensures that the performance of bridge elements which show severe distress is monitored. The research resulted in the evolution of an Algorithm that mirrors the dynamics of changes in performance to modify and redefine the deterioration model. The deterioration model so evaluated is more reliable as it uses data collected by an efficient scientific approach. Further application of LCCA to study the financial implications of all engineering interventions results in the use of the most cost-efficient method being adopted. Sustainability of the entire network and more specifically of distressed bridges increases. GABM application evolved is a tool aimed at helping achieve the most important objectives of the Bridge Management system. GABM deploys reliable information collected by using STSHM technology. Performance dynamics define deterioration model evaluation in GABM. Of course, the starting point is the engineering judgement to define the cause of distress. This judgement is validated, modified and enhanced by recording the dynamics of changes in the performance of distressed elements of the bridge structure under live loading conditions. This reliance on the performance of bridge elements makes the whole judgement-based decision-making process to be now transferred to a decision-making process which is based on scientifically accurate information about the current and realistic performance-based. Enhancement in sustainability is ensured by adapting the LCCA for evaluation of financial prudence in the whole process of Bridge Management.

Sustainability is characterized as both preserving the current social, economic, and environmental framework for the current generation while also ensuring that it is preserved for future generations [10] . GABM bridge management system ensures sustainability is maintained or enhanced in its decision-making [11] .

The key strength of this approach is identifying the source of the distressed structure and then using short-duration real-time monitoring to detect changes in the behaviour of the distress bridge under live loads. This allows engineers to track performance and changes. The use of developed algorithms links the existing real-time performance of the distressed elements causing degradation of structures to the decision-making process. This technique extends engineers' observation and judgment-based findings to a realistic performance-based approach.

GABM bridge management Analytics includes using precise and realistic data to generate degradation models and using socioeconomic aspects to analyse the advantages [tangible and intangible cost] that accrue to the area of influence beneath the bridge. Finally, the LCCA tool is used to evaluate the life cycle cost implications that are employed in decision-making across the life cycle. Data from various Socio-Economic indicators collected under the GABM protocol allows for the evaluation of intangible benefits or costs resulting from a bridge structure to be utilised to access the economic effect. Using the expanded LCCA technique guarantees that the decision-making process is grounded in reality. This technique also ensures sustainability goals, ensuring that bridges meet current needs without jeopardizing future generations' capacity to meet their own. A sustainable path of action balances the three essential components of social, economic, and environmental challenges. Sustainable bridges help to support the environmental, social, and economic systems on which we rely.

It can be said that Enhanced sustainability is ensured by the GABM application by modifying and shifting the decision-making process from being exclusively engineering judgement based.

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