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The Application of Structural Health Monitoring System (SHMS) at Bridge Structure to Utilize Economical Value of Infrastructure Investment

ABSTRACT

Structural Health Monitoring System (SHMS) is a system to assess the health or damage of a building or road with structure or during construction using an instrument. (Andersen & Vesterinen, 2006) *The purpose of SHMS is to increase the security and flexibility of infrastructure systems with protection before reaching critical. Benefits of Structural Health Monitoring Systems (SHMS) can be used to prevent problems or damage to building structures or construction, in addition to the early protection of problems that will occur, will help prevent damage, such as collapse of bridges, sinking of building foundation, damage to building structures and many more problems that will occur.* (Wang, Meng, Roberts, & Dodson, 2004) *SHMS will affect many things such as can save human safety and can improve the economic sector. Focus at elevated road and bridge structure in Infrastructure, the use of SHMS can help monitoring the prevention of structure damage during construction, and to monitor structure health after it services.* (Nababan, 2008) *In economical, Highway and road management authority, can monitor the weight and load vehicle using many instrument integrated in SHMS without using the truck weight scale, it can support the law enforcement in using road and bridge by the government.. The misuse of the road and bridges in service period can affect the structure damage, lately it can be causing economical problem among the infrastructure investment and benefit. This paper will evaluate the benefit of SHMS application, and will give suggestion of more instrument that reliable to add to support the idea.*

Keywords*:* Structural Health Monitoring, Transportation, Bridge Structure, Infrastructure Investment

Introduction

Bridges are important infrastructure. It is important because it has been designed specifically and designed to accommodate loading designed conditions. For any different loading condition applied to the structure, bridge can fail. This may consider to other permanent loads, such as dead load, earth & water strain. There are also occasional loads such as forces from the earthquake, live load of vehicles, wind forces etc. Deformations also can occur due to shrinkage. So, any combination of those cases can be the key part of structural damage. Considering the principle of longevity, corrosion and sea-water impact is a very emerging issue for existing bridges. (Raihan, Chowdury, & Islam, 2015)

An alternative to this issue is applying Structural Health Monitoring (SHM) to track structural activity in real time by assessing structural performance under various loads and detecting structural damage or degradation (Raihan, Chowdury, & Islam, 2015).

One of the key benefits of using SHM is its inclusion of the cost management related to testing and help to mitigate natural infrastructure disasters risks. Additionally, it reduces the need for emergency maintenance and improves the safety. In overall, it improves the cost-efficiency of public financing way more reasonable. SHM can be of assistance in the successful use of public funding and investment parameter. Essentially it can avoid unwanted maintenance of good-health systems such excessive periodic maintenance that need close the traffic of bridge which is already in good health. Eviting shutdown to enhance operations the economic efficiency of the system through increased Returns On Investment (ROI) (WorldScientific.com, 2005).

Structural Health Monitoring

Structural tracking of safety isn't a new technology or. Since ancient times, engineers, architects, and craftsmen have been study the actions of built structures to extend their knowledge, discover any signs of deterioration, and improve future structural design (Glisic & Inaudi, 2007). They built higher buildings and larger domes, and longer bridges and sometimes failed during construction or after a short time. Those failures and their analysis have resulted in new insight and improved future structure design. As with any issue with engineering, having accurate data always the first and crucial step towards seeking a solution. Monitoring structures is a way of collecting objective data on structures and helps us make educated decisions about their safety and fate (Inaudi & Walder, 2005).

The advantages of having a bridge-installed structural health monitoring system or other significant structure are numerous, and depend on the particular application (Inaudi & Walder, 2005). The more common of the advantages are:

1. Monitoring brings down uncertainty,
2. Monitoring discovers hidden structural reserves,
3. Monitoring discovers deficiencies in time and increases safety,
4. Monitoring insures long-term quality,
5. Monitoring allows structural management,
6. Monitoring increases knowledge.

Structures which are well maintained are the best and most robust structures. Measurement and research monitoring also plays an essential role in the management work.

The data deriving from a monitoring program aims at optimizing operation, maintenance, repair and replacement of a structure based on objective and reliable evidence. Structural health monitoring is a process which aims to ensure accuracy and timeliness (Inaudi & Walder, 2005). Data on quality and efficiency of the structures consists of constant, continuous or periodic recording of representative parameters, in short term and long term. In general, the information obtained from the monitoring is used to plan and design maintenance activities, safety increased, hypotheses verified, uncertainty reduced and widened awareness of the system under surveillance. (Glisic & Inaudi, 2007)

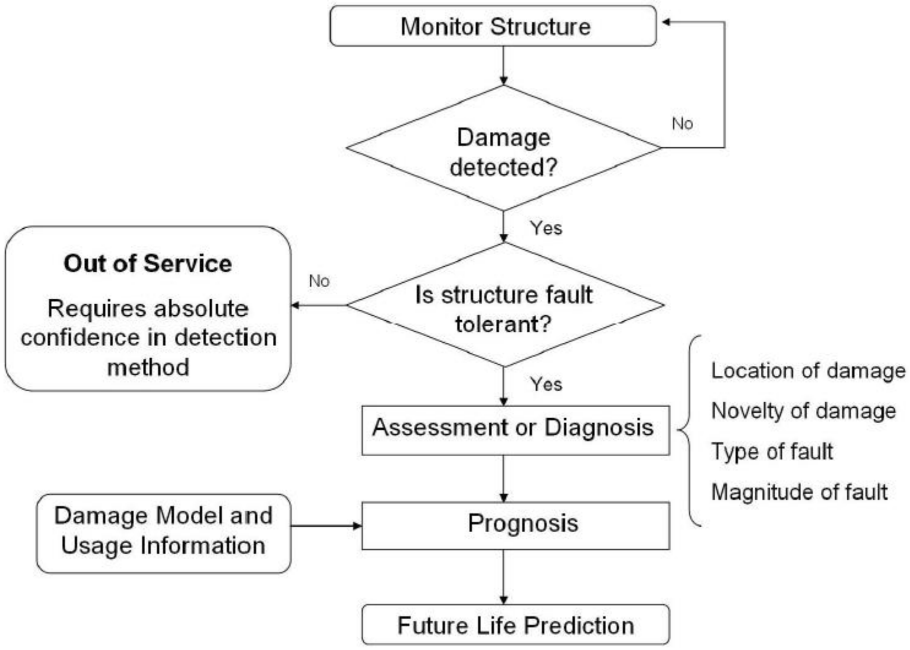

Figure 1: A general flow chart of a SHM system including the 4 stages in which SHM is most commonly divided: Detection, Location, Severity and Prognosis

Source: (Raihan, Chowdury, & Islam, 2015)

Besides helping engineers consider bad structural conditions, advances SHM, also help professionals identify potential building hazards caused by ageing, and other environmental, and safety issues. SHM is of particular utility to avoid damage to water and floods caused by dams that collapsed, other pipelines, and similar structures. SHM practically ratings state of the condition of the structural structures to be measured their health and performance levels are in well function (WorldScientific.com, 2005). If the condition is correct, assessment allows for bad results compared with repair processes are started immediately of the desired ones, that structural reparations are invoked only when serious damage occurs to the structural system. So as to prepare for a preventive maintenance schedule, SHM is used as one for service time and economic planning of the basic methods of engineering reliability. In addition, SHM enables long-term and short-term cost savings in respect of maintenance and public structure repair. That will reap the economic benefits benefit to a large extent on the construction industry. SHM overall aim is to provide a satisfactory performance in its present condition, of the structural system. Facilities investment not always just for new construction but also for new construction that require some maintenance. There could be a slack-down time investment growth, under economic recession can become essential for maintenance. During those times, maintenance of old can be the focus of major investment current structures (WorldScientific.com, 2005).

The Benefit of Structural Health Monitoring in Infrastructure Application

Transition from simple experimental observation to structural health monitoring can mitigate risk and consequences of using modern and uncommon construction materials. SHM can support functional obsolescence to economic infrastructure and, as an alternative availability of innovative instrumentation that is inexpensive, powerful and durable and hardware or software tools for complex data collection and signal processing functions. SHM is actually just the traditional combination structural experimental or theoretical mechanics, electronics, material sciences and information and communication engineering. The physical and the technical the properties of these building materials appear to degrade at a fairly significant rate speed and therefore the economic value of the network resource is lost over time (Del Grosso, 2013).

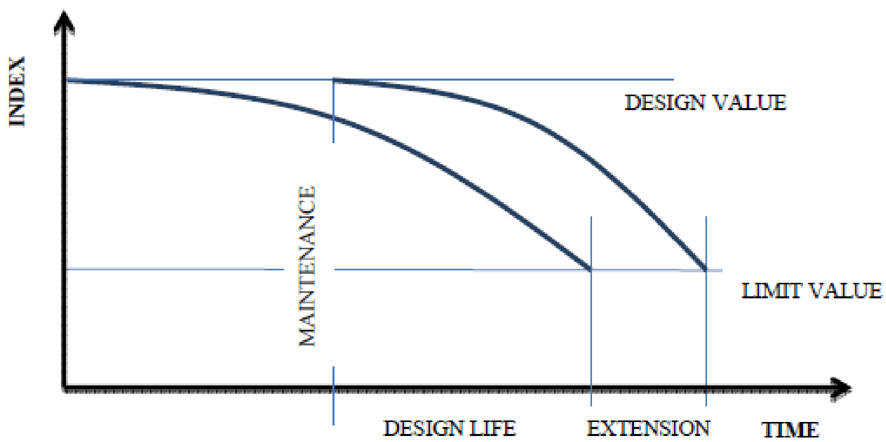

Figure 2: Typical lifetime function and the effect of maintenance.

Source : (Del Grosso, 2013)

Because of the great economic effort needed to sustain current and future infrastructure networks in efficient and safe conditions, several studies and practical applications have been under way in recent years of services methods and cost optimization of the services. The method has focus on which has gained significant attention recently and which is considered the most the desirable use of lifetime functions for functional applications (Del Grosso, 2013).

At any time during the life of the structures, a maintenance operation should be able to increase the index at the limit, recover the design value of the index itself, extending the life expectancy. In the cycle both preventive and condition-based maintenance can be considered. Maintenance can be repeated many times and the operating life will in theory be extended as long as economically feasible, enables a life-cycle cost to be defined the heuristics-based optimization method and knowledge-based law (Del Grosso, 2013).

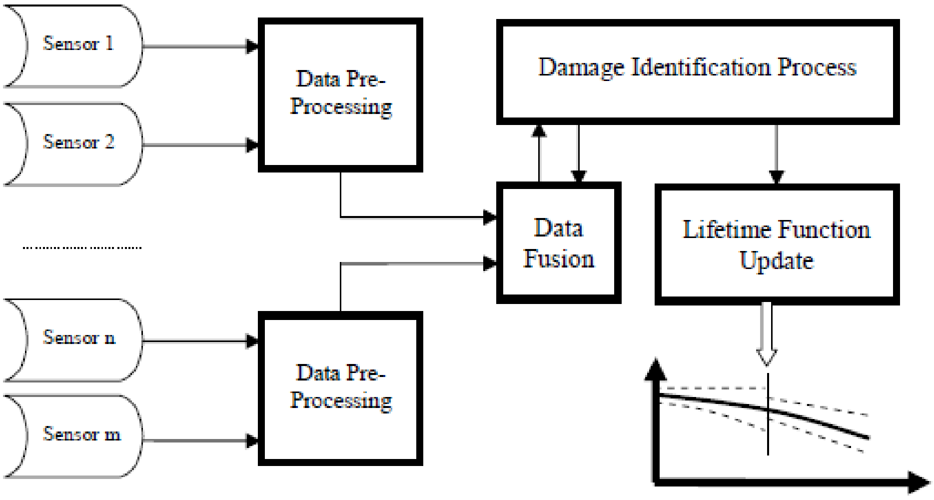

Figure 3: Lifetime function update via SHM

Source: (Del Grosso, 2013)

The long-term goals of infrastructure project were to develop and validate a bridge SHM instrumentation package that was subjected to overweight trucks, and to develop pilot-scale plans for field deployment of the instrumentation (Schmidt, 2016). Ultimately, the goal is to accurately compare field performance data with the bridge behavior expected by the analysis and rating program. The field instrumentation package includes the use of optical fiber sensors, specifically Fiber Bragg Gratings (FBGs), to monitor stresses at critical locations in bridges that are considered most vulnerable to overweight truck loads and are most difficult to effectively rate with software currently in use (Schmidt, 2016). SHM would directly contribute significantly towards the following strategic objectives:

1. State of Good Repair: An successful SHM program for highway bridges can, over time, enhance bridge engineers' ability to predict the impact overweight vehicles can have on their bridge condition. As engineers get feedback on bridge performance to validate or

recalibrate their rating methods, they will be able to predict bridge long-term durability. They will also be able to route overweight trucks more effectively and specify suitable reconfigurations of trucks which would otherwise not be allowed on certain routes.

2. Safety: Precise real-time bridge response monitoring can enhance bridge operational safety during overload events by managing the severity of the overload. Long-term safety will also be enhanced by using the monitoring system to identify and quantify unforeseen events involving overload. Additionally, improved precision in defining the weight distribution in overweight trucks plus refinements in bridge response monitoring would reduce the inherent demand randomness (applied loads) as well as the variability in structural capability to allow more precise bridge performance predictions.
3. Economic Competitiveness: The SHM system will provide the project with the initial economic advantage, using relatively low-cost equipment with low power demand. The second benefit lies in increased bridge longevity and life-cycle predictions. An efficient and easy to use sensing network at the bridge should enable successful scheduling of inspections and maintenance. With adequate sensing network experience and configuration, engineers will be able to detect changes in bridge response which may indicate deterioration or damage, triggering more timely inspection and maintenance work. An SHM system that can be deployed rapidly will be useful in cases where a bridge would otherwise have to be restricted or closed due to advanced deterioration or damage to an impact. Monitoring a structure as the repairs are being designed could also help ease the traveling public's burden.

The Benefit of SHM in Transportation Management

As the transport infrastructure has grown in size and spatial extent, it has also become clear that the traditional, largely manual approach to maintenance, operations, and security simply does not effectively scale out. Information technology provides a chance to help dramatically enhanced transportation network control and management. In addition, many monitoring and management systems of relatively small scale were implemented (Chase & Feeley, 2012). These systems were therefore developed and implemented to support different transport infrastructure elements. These programs were not incorporated, and were not used in company applications. As mentioned above, current monitoring and management systems have been developed and are run by agency divisions directly responsible for a single transport network "class." Examples of such systems are set out below:

1. Traffic Operations Systems,

2. Bridge Monitoring Systems,
3. Pavement Management Systems,
4. Environmental Monitoring Systems,
5. Asset Management Systems,
6. Weather Systems.

While these systems have demonstrated benefits within their specific domains, the integration of the systems (i.e. data sharing, collaborative decision-making, distributed control, etc.) is likely to result in significantly greater benefits (Chase & Feeley, 2012). Examples of the anticipated benefits resulting from integration are given below:

1. Each system will have a richer set of data to support their functioning,
2. Systems may share resources, such as communications infrastructure, resulting in substantial cost-savings,
3. Systems may provide fail-safe back-ups for each other, creating greater resiliency,
4. Infrastructure security will benefit from the ability to monitor the overall transportation infrastructure from a holistic perspective.

SHM for Bridge Assessment

Owing to the reliance on experience, traffic disturbance and frequent visual inspection at high cost do not reflect the true bridge performance components exactly(Raihan, Chowdury, & Islam, 2015). Some wide bridges justified using SHM technology for regional or national applications targeted systemic performance evaluation using the prolongation of service life bridge preservation, or verification of design assumptions and initial baselines for performance bridges with new signature. The downside of massive, complex surveillance systems need more costs, and the large amounts of data collected require sophisticated protocols for storage and actionable substantial analysis (Transportation Research Board Washington D.C., April 2019).

Some of those systems were shut down after a couple of years on the realization that very little actionable data was being collected. Reconstruction of an old bridge may be more cost-effective instead of replacing it, but with a visualization, owners can decide if the remaining members or structural elements are in good shape enough to repair or not. It is also probability that no action will be taken if the bridge can be determined better than expected, based on visual inspection findings. SHM is an application that has proven successful monitoring the development of visual defects, such as splitting, bending out of the plane or proper bending process holding. SHM has proved successful is the provision of data for intent determination secure load efficiency using the AASHTO bridge evaluation handbook. The other benefit is to assess load demand by temporarily leaving the sensors in place to assess the strains stresses of traffic using the structure. This utilization provides useful data for systemic risk management or to help load enforcement behavior (Transportation Research Board Washington D.C., April 2019).

Importantly, new technologies and ambitious project goals for SHM developed every year, both by SHM technology suppliers and owners. Accelerometers are typically used to determine a global structural model response, it’s such a sensor to capture a substantial amount of data, which can be difficult and expensive to analyze, and have weaknesses in determining where structural abnormalities arise after the model changes. Strain sensors are the most versatile and cost efficient type of sensor used to determine the production of single structural members or of the entire superstructure.

There is a whole selection of sensors strain on the market, with varying degrees of precision and expense. Any can be added to a variety of applications; other applications for catching tensile stress only. Inclinometers are extremely useful in determining minute movements of the substructure as tilting or proper operation of the bearings. Such sensors are fairly cheap but highly accurate and justifiably reusable. Acoustic Emission (AE) technology is typically an autonomous application, recording and storing noise from recent or propagating steel splits, cable breaks post-tensioned on box beams or other structural defects (Transportation Research Board Washington D.C., April 2019).

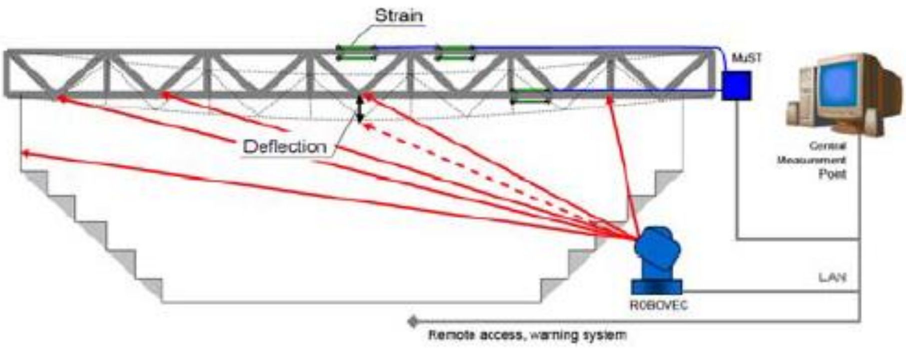

Figure 4: Setup with strain and deflection sensors.

Source: (Glisic & Inaudi, 2007)

Displacement sensors (strain, cracks, and detection of cracks) can be used to assess whether bridge bearings operate properly, expansion joints, concrete or steel crack-width travel monitoring, spreading of cracks, or bending. The inclusion of temperature sensors in any monitoring scheme is crucial. Its enables statistical correlation with the displacement captured strain sensor data to determine the temperature changes, it will impact on strain data observation. The opportunity to get statistics separate the effect of temperature induced displacement live-load data which is essential for determining the uncontrollable impact of controllable factors such as live load when considering the overall structural integrity and structural capacity.

Laser-based instrument technology is used to capture important structural elements displacements, usually from ground position, for example deflection. Usually, fiber optic sensors transmit pressure as well as temperature on a single fiber cable. Especially useful for long structures, where one cable can carry a considerable number of the sensors are individual (Transportation Research Board Washington D.C., April 2019).

SHM for Vehicle Load Monitoring

Although SHM can be a powerful tool, those with field experience often see resources applied repeatedly to the same poorly posed questions resulting in inadequate inputs for decision making. Repeated attempts to use SHM to calculate the dynamic load allocation (DLA) for use in the bridge evaluation process are among the most common examples. The standard approach includes instrumenting a particular bridge (or bridges) and running vehicles of known mass and configuration at various speeds over the respective structures and using the results to inform the DLA assessment (Heldt, Lake, Ngo, Seskis, & Eskew, 2019).

Actual DLA is known to be quite variable and sensitive to a number of factors including:

1. Vehicle characteristics (suspension type, speed etc.),
2. Bridge and bridge component characteristics (span, form of construction etc.),
3. Site specific details (approach road geometry and profile),
4. Vehicle mass and multiple presence.

Considering decision framing, use of any measured advantage would require consistent process control over time of these factors. A brief consideration of these parameters reveals that in some cases, the parameters (e.g. vehicle characteristics) are outside the span of control to be consistently controlled (e.g. bridge approach road profile). In this way, the data is devalued as an input to the decision, additionally, these measurements are taken at loads approximating service loads, but at the ultimate load the primary use of the DLA parameter (Heldt, Lake, Ngo, Seskis, & Eskew, 2019).

Using rain flow period counting, the fatigue life assessment of a system subjected to a non-constant amplitude charge can be performed in the periodic of time. The rain flow method is used to count the cycles of fatigue (stress-reversals) and obtain equal constant amplitude cycles from the calculated data on pressure. To define the main load excursions, this approach is implemented in order to reduce a continuum of varying stress into a series of tensile peaks and compressive vales. Several cycles and half-cycles with different amplitudes are obtained as a result of the counting.

With the advantage of the accumulation theory of fatigue damage e.g. Miners law, the algorithm gives the possibility to measure the predicted fatigue life under random loading conditions, subject to material property availability, e.g. S-N curve. In order to achieve this, measured strain responses are analyzed to identify the number of load cycles and the corresponding stress range the structure.

Reliable collection of live traffic data is essential to successful pavement life prediction, fatigue estimation, vibration management, bridge structure maintenance and condition assessment. Bridge weigh-in-motion (BWIM) is a technique using an instrumented bridge to determine the axle and gross weight of trucks traveling at standard highway speed. Vehicle speed, number of axles, and axle spacing are crucial parameters and most BWIM algorithms need determination. Nothing-on-the-road (NOR) strategy recommends using the strain signals calculated at certain different positions below the deck or bridge girders to obtain this information (Runcie, Alamdar, Pitman, & Khoa, 2015).

Economic Value of SHM

There are several types of approaches for complete economic assessment, including cost-benefit analysis (CUA), cost-effectiveness analysis (CEA), cost-minimization analysis (CMA), cost-benefit analysis (CBA), and cost-consequence analysis (CCA). Otherwise, such structured techniques were found to be inadequate for bridge inspections to evaluate remote sensing technologies. The incompatibility is due to the technical innovation and the cutting edge nature of the work evaluations to address these challenges. The considerations discussed below will affect final evaluation methods during the economic review process.

1. Time Period of Analysis,
2. Geographic Scope of the Analysis,
3. Scale of Implementation,
4. Available Inspection Days,
5. Service Life (In Uses),
6. Cost and Benefit Analysis (Dam & Bond, 2005).

Conclusion

The new monitoring system was built with the goal of monitoring many different systems at the same time over a wide field. A distributed information is guaranteed and any part of the network will work depending from the others. Structural health monitoring is becoming increasingly important its ultimate aim is the ability to monitor. The system is designed to reduce maintenance requirements and subsequent downtimes throughout its working life. Currently, visual inspection is the standard method used for health assessment of structures, along with non-destructive evaluation techniques (Rainieri, Fabbrocino, & Cosenza, 2008) .

The main objective of this analysis is to review the implementation of systemic safety monitoring in the bridge management were based on defect and condition. The studies have considered deployment of SHM on existing or new bridges. Tools for improvement costs for optimizing SHM were also considered. The study found the full SHM implementation will depend on the technology costs as well as road controlling authority specifications. For a particular group, full SHM implementation of small to medium bridges is impossible. For major or notable bridges are more readily justified is complete application of SHM. Latest analysis reveals risk-based condition index analysis is well associated with investment bridge finance and the SHM data can be incorporated into the status indexes and used regularly performance tracking and reporting can be more readily justified on the use of SHM (Carten, 2008).

In the civil engineering market, controlling It's still a significant topic with various infrastructures. Transport infrastructures get different worry amongst them. Bridge is a most critical part of every transport network. They are projects are often costly and any project failure is capable of causing a major disaster. For a thorough analysis of the calculation of the structure's remaining lifespan, the present stage of the structure doesn't suffice. Longer life span of bridges and infrastructure project will bring a new value to the project. SHM also can be used to monitor the overweight vehicle. Comprehensive information on the trend of deterioration with future stresses is required for empirical reasons surveillance. Visual inspection is historically the most common method of monitoring systems. (Raihan, Chowdury, & Islam, 2015).

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