Alternate Methods to Obtain Facility Condition Assessment Data Using Non-Engineering Resources

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***Abstract*—The Department of Defense has adopted the BUILDER application which will act as a single enterprise solution to performing facility condition assessment on their 2.2 billion square foot facility footprint. Alternate methods to performing on-site facility condition assessments need to be investigated to reduce the amount of engineering or subject matter expert resources required for a facility inspection. This study proposes several alternate methods including (1) the use of remote sensing devices to collect facility component distress information, (2) the use of building occupants to assess non-equipment components within a facility, (3) the use of maintenance professionals to assess equipment components while performing preventative maintenance actions, and (4) the use of frequent pattern data mining techniques to make future condition assumptions on associated components.**

***Index Terms*—Facility condition assessment, frequent pattern association, remote sensing, sustainment management systems.**

I. Introduction

A. Background

The Department of Defense (DoD) issued a policy memorandum in September of 2013 to standardize facility condition assessments (FCA) across the entire DoD. Prior to this, each military service and DoD agency used different FCA tools and methodologies. The DoD standardized this process in order to create a level playing field on the reporting of facility conditions which factors into annual sustainment, restoration and modernization (SRM) budgets. The FCA standardization will also help the facility condition data be audit ready as per other financial guidance within the DoD. This FCA standardization policy memorandum requires the use of the Sustainment Management System (SMS) BUILDER which is developed by the U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). The policy memorandum is requiring that the BUILDER baseline inventory and assessment is completed by September of 2018 [1].

In a Base Structure Report of Fiscal Year (FY) 2013, which summarized the DoD's real property inventory, the DoD reported that they occupy 290,605 buildings throughout the world, valued at over $567 billion comprising over 2.2 billion square feet [2]. Therefore, 2.2 billion square feet of FCA data for DoD alone will theoretically reside in SMS BUILDER by the end of 2018.

B. Makeup of a FCA Team

A facility condition assessment is generally conducted by a multi-disciplinary team of architects and engineers, working closely to receive valuable input from local facility engineering staff members. The predominant makeup of a typical facility assessment team consists of the subject matter experts (SME) shown below as well as their respective facility component responsibility areas for the assessment. The ASTM Uniformat II building classification system is used to divide the building up into level 2 group elements [3].

1) Architect / SME: A10 Foundations, A20 Basement Construction, B10 Superstructure, B20 Exterior Enclosure, B30 Roofing, C10 Interior Construction, C20 Stairs, and C30 Interior Finishes.
2) Mechanical Engineer / SME: D10 Conveying, D20 Plumbing, D30 HVAC, and D40 Fire Protection.
3) Electrical Engineer / SME: D50 Electrical.

C. Baseline Facility Condition Assessment

A baseline inventory and assessment using SMS BUILDER is required as per the policy memorandum by September 2018 when there has not been a SMS BUILDER assessment already completed for a facility. A typical baseline FCA can cost anywhere between $0.06 and $1.50 per square foot of facility. This cost varies based on site location, the use type of the building, the current DoD security measures required at a military installation due to National threat levels, and other scope requirements set by the DoD organization.

D. Facility Re-Inspections

After the baseline inventory and assessment is accomplished, the organization will go into a cyclical, out year inspection schedule. Instead of crudely choosing a fixed inspection interval, such as requiring a re-inspection every three (3) years, SMS BUILDER uses a technique called a Knowledge Based Inspection (KBI). The KBI algorithm can generate a long range schedule of when components require an inspection based on enterprise configured inspection triggers set to the individual facility component types. The KBI methodology in SMS BUILDER provides the organization an opportunity for a significant cost savings by only re-inspecting the mission-critical and condition-critical components of a facility instead of arbitrarily re-inspecting everything [4].

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E. The Problem

Although the use of techniques such as KBI can greatly reduce the re-assessment cost of the enterprise facility footprint, further ways to reduce this assessment cost need to investigated. The current FCA model of performing assessments, whether baseline or a re-inspection, is based on an engineer performing an on-site survey of facility components. One idea of assessing facility components in a reliable manner without the need of an on-site survey by an engineer would be to use sensors as a way to monitor the health of facility components. The use of sensor data could assist decision support models to be able to predict component failure. Although the use of sensors to evaluate facility components has pronounced potential, the condition predicting algorithms based on this sensor data in facility components does not currently exist. This correlation between sensor data and the effect on the component's condition is specific to each respective component. Because the lifecycle (or service life) of most facility components is at least 20 years, a short term research study is not feasible to study the relationship between a set of sensors and the component condition unless accelerated test methods are used. Certain foundation and superstructure components can have a lifecycle over 100 years which makes the use of sensors for reliable condition prediction of those components even farther off. Furthermore, for mission critical items such as equipment components, an engineering based survey may continue to be required regardless.

So, what other condition assessment methods can be done in the more near term future to alleviate the use of costly engineering based facility surveys for facility components? One possible solution is to allow non-engineers such as building occupants to perform assessments on non-equipment facility components. Another solution is to allow maintenance professionals to collect facility component distress information on equipment during routine preventative maintenance activities. Yet another solution is not to use a physical person at all, but rather perform data mining techniques on existing data to determine frequent patterns in condition ratings. Component types within a building that had a frequent pattern of condition ratings in the past could receive automatic assessments if one or the other was given a new rating – thus assuming they still are in an identical state of condition. This is somewhat of a risky solution since there are no physical eyes on the component to log the condition.

II. BUILDER SUSTAINMENT MANAGEMENT SYSTEM

Before discussing alternate methods of facility condition assessment, a summary of the SMS is required. One definition of SMS is the systematic use of engineering technology to determine when, where, and how to best maintain facilities or their components. This broad definition describes the claimed intent of many asset management initiatives, but not the methodology to follow. Key to the SMS BUILDER concept is the structured techniques, procedures, and processes necessary for effective sustainment management. Included in this concept is the fundamental need for facility or component condition assessment information that supports the infrastructure investment decision making process. While SMS's are expert systems, they do not provide a definitive "answer". Instead, a SMS is a scientifically based method that provides timely and accurate information to enable sound business decisions in support of facility operations.

The Fig. 1 shows a generalized deterioration curve for what could be an exterior door, a roof membrane, a building equipment item, or other facility component.

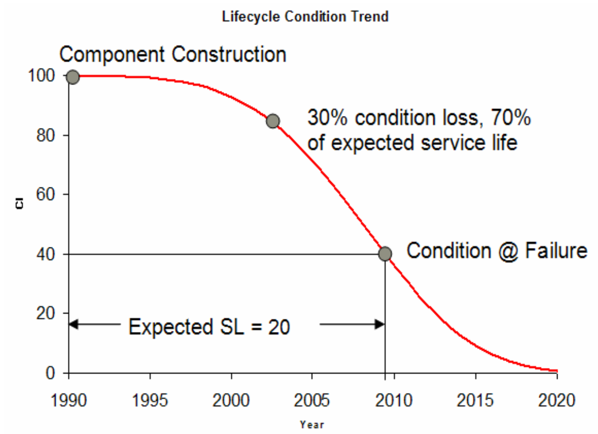

Fig. 1. Typical builder lifecycle condition curve.

As time passes, quality or condition decreases due to friction, wear, UV exposure, fatigue, freeze-thaw cycles, and many other degradation mechanisms. For some asset types, these "distress" mechanisms interact and compound, accelerating condition deterioration over time. Eventually, this condition deterioration directly affects the performance of day-to-day facility operations. If performance drops below the threshold level, recapitalization, restoration, or repair becomes necessary. The cost of these actions increase substantially as condition further degrades, and if not performed, premature failure may result in unrealized asset service life. Thus, a real penalty cost in terms of dollars exists for deferring work past a certain condition.

If the lifecycle deterioration curve in Fig. 1 could be sufficiently established for any specific asset or component of an infrastructure, facility managers could easily determine condition at any point in time. They could then make the prudent decisions regarding when to do work. The true deterioration trajectory differs among individual pavement sections, roof sections, or building components of varying types. The BUILDER SMS strives to establish the accuracy and confidence of any lifecycle deterioration curve through a standardized condition assessment methodology - the Condition Index approach and the resulting Condition Index metric.

As the foundation to any management process, metrics must be objective, repeatable, and most importantly, affordable within the business operating environment. The Condition Index process was designed to model the summary experience of the diverse yet knowledgeable engineering community in measuring an asset's condition or physical health [5].

III. USING REMOTE SENSORS FOR CONDITION ASSESSMENT

The first step in analyzing possible uses of sensors in facilities condition assessment is to take a look at what commercially available sensors are currently on the market. In terms of assessing condition, sensors can be broken into two categories – 1) Remote Sensing and 2) Remote Monitoring. Remote sensing tools are products that an inspector would use to assist in an on-site physical inspection. These remote sensing tools give the inspector the ability to either perform an assessment more efficiently or give the inspector capabilities of analyzing aspects of a component which he would not be able to perform without. Remote monitoring is the concept of physically emplaced or attached sensors that continually collect or read data points in order to monitor the health of a component.

One recent study evaluated a set of commercially available remote sensors for use in condition assessment of highway bridges [6]. In this study, each sensor technology was rated for accuracy, commercial availability, the cost of measurement, pre-collection preparation, the complexity of analysis, the ease of data collection, standoff distance and traffic disruption. The twelve sensing technologies which were reviewed as well as a brief summary of how these technologies could be used for facility condition surveys.

A. Three Dimensional Optics

This is a technology that can provide depth and height info that cannot otherwise be derived from regular photography. Three dimensional optics could be beneficial to a facility inspector to assess the surface condition of A10 foundations, A20 basement construction, B30 roofing, C10 interior construction and C30 interior finishes systems. Whereas the volume of surface spalls could be calculated for bridge assessments, the volume of any surface distresses could be calculated for various facility components. For example, if a surface distress is being recorded as part of a distress survey condition assessment; 3D optics could potentially be used to calculate volume of surface distresses such as blisters, holes, deterioration, defective joints, and corrosion.

B. Streetview Style Photography

This is basically the same concept as the “Google” street view technology in which photographs are projected into a 360 degree viewing environment. Since a majority of facility components are not viewable from a street view, this remote sensing technology has limitations for a facility. However, the B20 exterior enclosure and B30 roofing systems (from an aerial view) could be evaluated for surface deterioration and defects.

C. Optical Interferometry

This technology is a nondestructive technique that involves combining two or more light waves to obtain finer information in an image. Surface cracks at the millimeter and sub-millimeter scale have been detected with this technology [7]. This technology is stated to be one of the few that can help measure fine structural cracks in concrete or steel girders and beams due to the high resolution used [8]. This technology could best be used in the A10 foundations, A20 basement construction, B10 superstructure, B20 exterior enclosure and B30 roofing facility systems. The B10 superstructure system specifically has the largest potential of use in measuring fine structural cracks in concrete or steel girders and beams.

D. Spectral Analysis

This analysis is the measurement of a target surface’s spectral reflectance or absorption of light (both visible and IR). It basically detects areas where large amounts of radiation are absorbed or reflected. Characteristics of other surface features could be evaluated with this technology in the future if spectral reflectance models were specifically developed for the respective component [6]. This technology may have a limited use for a facility. However, there is potential in the A10 foundations, A20 basement construction and B10 superstructure systems in regards to the detection of chemical leaching and how the component condition is affected.

E. Digital Image Correlation

This technique consists of the correlation of two images that are separated by time. The technology detects changes from previous pictures. Many times paint spots or some other markings are used as baseline reference points [6]. The A10 foundations and B20 exterior enclosure systems could use digital image correlation to monitor foundation settlement and exterior envelope movement and variations over time.

F. Remote Acoustics

This is a well-established method to detect bridge subsurface deterioration. This technology utilizes sound waves to measure certain factors and deduce component element condition [6]. Concrete facility component systems such as A10 foundations, A20 basement construction, B10 superstructure and B20 exterior enclosure could be assessed using this technology in order to detect subsurface deterioration. Methods of using remote acoustics for facility component assessment need developed as well as the respective correlations between the remote acoustic data and the facility component condition.

G. Thermal Infrared

This technique is based on the measurement of the radiant temperature of a material. This has been used in bridge condition assessment to evaluate the subsurface issues in concrete. The notion is that a surface delamination will appear hot during the day and cold during the night [9]. This assessment technique for bridge deck surfaces is described in ASTM D4788 [10]. A literature review did not find any studies where other surface defects were studied with thermal imagery. However, it is expected that other surface defects would exhibit thermal abnormalities such as roof damage or wet insulation [6].

This technology can be viewed as the most relevant and promising in evaluating the current condition state of facility components. All facility systems [3] could be assessed for thermal variations which are outside the expected range for that system. Thermal imaging devices are already being used in many facility inspection scenarios [11]. Further research is needed on the specific correlation of the thermal infrared data to the component’s current condition.

H. Other Remote Sensing Technologies

Five other commercially available remote sensing technologies that were evaluated [6] will be grouped together in one category given the similarities of what facility components might be applicable.

1) Electro-Optical Airborne and Satellite Imagery [12]
2) Light Detection and Ranging (LIDAR) [6]
3) Radar [13]
4) Ground Penetrating Radar (GPR) [6]
5) Interferometric Synthetic Aperture Radar [6]

These remote sensing technologies could mostly be applicable to the B30 roofing system in terms of an aerial surface and subsurface assessment. Given all the possible remote sensing applications for the B30 roofing system, a further study to just analyze the potential of these sensors in roofing components is recommended.

IV. Using Building Occupants to Assess Non-Equipment Inventory

Most of the components within a facility require a subject matter expert (SME) or engineer, to perform a condition assessment due to the specialized nature of the materials and subcomponents which comprise that component. For example, the knowledge of a mechanical engineer or mechanical SME is needed to properly assess the condition of D30 HVAC equipment. However, is a SME or engineer required to assess a component from a system such as C30 interior finishes?

Building occupants could adequately assess certain components from the following facility systems due to typical human knowledge of such facility systems: (1) B20 exterior enclosure (exterior doors and finishes), C10 interior construction, C20 stairs, C30 interior finishes, D20 plumbing (only plumbing fixtures), and D50 electrical (only exposed lighting fixtures).

The key to this methodology of collecting a "free" inspection from a building occupant for such components would be not only that the implementation of some type of survey would entice the user to fill out but also that it be crafted in a way that provides an un-biased, objective result set. Due to the nature of what is being collected, it is also expected that building occupants may desire to fill out this type of assessment survey since it would give them a sense of ownership for when facility components would be repaired or replaced.

Some type of computerized touchscreen kiosk would be more desirable for a building occupant to fill out rather than having a paper survey available. The biggest question may be, is the data reliable and what guarantee is there that the occupant told the truth to the survey questions? In one study, it was found that many users just open the survey screen to see what it entails and either immediately turn away or only partially finish the whole survey. Respondents, who are honest in their evaluation, tend to fill out the survey near completely [14]. Therefore, only survey data from this latter case should be used. Furthermore, a case study or further research is needed to determine what level of quality control measures need applied prior to accepting these condition assessment data points directly into an application such as SMS BUILDER.

V. Using Maintenance Personnel to Assess Equipment Inventory

A condition based facility assessment is just one of several types of different facility based inspections. A preventative maintenance (PM) assessment is another facility inspection that is a separate action from a condition based inspection [15]. Therefore, when maintenance personnel inspect a piece of equipment inventory, the results and data points are generally logged in a computerized maintenance management system (CMMS) which generally has no integration or connectivity to a SMS such as BUILDER. The data points for facility inventory are generally different in nature between the CMMS and SMS. The CMMS stores equipment data including PM activities, work orders, meter data and deficiency backlogs, whereas the primary goal of a SMS product such as BUILDER is to collect condition data in order to be able to predict future work actions.

Importing CMMS data into a SMS application would provide condition assessment data points for equipment such as D10 conveying systems, D20 plumbing, D30 HVAC, D40 fire protection and D50 electrical. By deriving condition assessment data points from a routine equipment PM task, a significant reduction in SME or engineering resources would be required as opposed to conducting a full blown, standard FCA re-inspection. The CMMS data that is imported into the SMS would have to consist of an extended set of distress survey data that is useful to the SMS. For example, while maintenance personnel have certain subcomponents of a HVAC unit broken down in order to perform PM, distress information that is useful to the SMS would be collected at that same time.

VI. Using Frequent Patterns from Past Condition Assessment Data

Data mining can be used in facility component condition data to find unexpected relationships and frequent patterns. These frequent patterns of component assessments from past FCA data, such as a baseline assessment, could potentially be used to quickly assess components for a re-inspection. For example, if an exterior wall was associated with an exterior window by a frequent pattern association based on their condition ratings, then whatever rating the exterior wall was given on a re-inspection the exterior window would adopt that same rating, or vice versa. This methodology would not provide a physical "eyes on" approach and therefore, may not provide as accurate assessment information. Besides this simple example of finding frequent patterns between assessment ratings, a knowledge discovery in databases (KDD) approach could be used [16]. The KDD approach utilizes a cluster analysis for text mining. This type of analysis groups objects that are similar within the same cluster and dissimilar to the other clusters. Therefore, aside from simply associating the assessment rating, the assessment comments field, where the FCA inspectors provide specific inspection details, could be grouped in clusters based on the textual mining.

The application of historical frequent patterns to automatically create follow on assessment data within the SMS BUILDER application will need further research and data validation. Furthermore, to fully validate the results, many years of multiple facility re-inspections may be needed to strengthen the outcome of the frequent pattern association results. However, if the cost savings and manpower reduction outweigh the risk of not having an "eyes on" inspection, an organization may opt to move forward with applying a frequent pattern association algorithm to populate future inspection data points prior to waiting for future research and data validation.

VII. Conclusion

The Department of Defense has committed to an enterprise solution of adopting SMS BUILDER to inventory and assess condition of their 2.2 billion square foot facility inventory. This decision will enable them to lean forward with an objective solution for facility sustainment, restoration and modernization by predicting component failure as opposed to the traditional reactive approach to a deficiency backlog. However, with decreasing federal budgets, more ways need to be investigated to be able to reduce facility inspection costs further. This study proposes several options to acquire facility condition assessment data without the need to send out the full scale set of costly engineering resources or facility subject matter experts. The way forward with each of these potential options is more research and development to establish the necessary standard operating procedures, applicable algorithms, required data processing and necessary data quality control.

References

[1] D. DoD, "Memorandum which calls for Standardizing Facility Condition Assessments for the entire Department of Defense".

[2] D. DoD, "Base Structure Report; Fiscal Year 2013 Baseline," A Summary of the Department of Defense's Real Property Inventory.

[3] R. Charette and H. Marshall, "Uniformat II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis".

[4] D. R. Uzarski, M. N. Grussing, and J. B. Clayton, "Knowledge-based condition survey inspection concepts," *J Infrastruct Syst*, vol. 13, no. 1, pp. 72-79.

[5] USACE-CERL, '"SMS BUILDER Website," vol. 2014, no. 02/28.

[6] K. Vaghefi, R. C. Oats, D. K. Harris, T. M. Ahlborn, C. N. Brooks, K. A. Endsley, C. Roussi, R. Shuchman, J. W. Burns, and R. Dobson, '"Evaluation of commercially available remote sensors for highway bridge condition assessment," *J.Bridge Eng.*, vol. 17, no. 6, pp. 886-895.

[7] H. Hatta, M. Aly-Hassan, Y. Hatsukade, S. Wakayama, H. Suemasu, and N. Kasai, '"Damage detection of C/C composites using ESPI and SQUID techniques," *Composites Sci. Technol.*, vol. 65, no. 7-8, pp. 1098-1106.

[8] J. E. Krajewski, '"Bridge Inspection and Interferometry".

[9] G. Washer, R. Fenwick, N. Bolleni, and J. Harper, '"Effects of environmental variables on infrared imaging of subsurface features of concrete bridges," *Transp. Res. Rec.*, no. 2108, pp. 107-114.

[10] ASTM, "Standard test method for detecting delaminations in bridge decks using infrared thermography," vol. D4788-03.

[11] C. Meola and G.M. Carlomagno, "Monitoring materials under impact with infrared thermography," vol. 8, 2013, pp. 177-185.

[12] E. M. Mikhail, M. L. Akey, and O. R. Mitchell, "Detection and Sub-Pixel Location of Photogrammetric Targets in Digital Images," *Photogrammetria Amsterdam*, vol. 39, no. 3, pp. 63-83.

[13] R. M. Morey, "Ground penetrating radar for evaluating subsurface conditions for transportation facilities," vol. 255, 1998.

[14] P. J. Blignaut, "Computerized self-administered questionnaires on touchscreen kiosks: Do they tell the truth?" 2004, pp. 1183-1186.

[15] M. Grussing, "Life Cycle Asset Management Methodologies for Buildings," *J Infrastruct Syst*, vol. 20, no. 1, 2014, pp. 04013007.

[16] H. S. Ng, A. Toukourou, and L. Soibelman, "Knowledge discovery in a facility condition assessment database using text clustering," *J Infrastruct Syst*, vol. 12, no. 1, pp. 50-59.

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