Building Maintenance Modelling and Planning

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Abstract

Building maintenance is an essential activity needed to maintain assets at a certain operational level that is determined by their purpose and use. The building maintenance activities are cumbersome in terms of determining their contents and timing of application. Critical activities can be highly expensive and if not undertaken in time can have catastrophic consequences. In fact building maintenance costs exceed the initial costs of building construction significantly. This paper presents and examines the area of building maintenance research with particular reference to modelling and optimisation. The paper covers the history and importance, social and economical, of building maintenance and discusses the current research in maintenance modelling to support decision making. The building maintenance management approaches presented in literature are also reviewed covering the current application software tools used and those emerging with promising potential including Building Information Modelling (BIM). The paper is concluded with a proposed building maintenance framework discussing the typical stages of maintenance planning cycle .

Key words: Building maintenance, Building Information Model (BIM), Condition Based Maintenance, Maintenance concept.

1 Introduction

Building maintenance is essential to maintain buildings' functionality and it is acknowledged as an important area that is worthy of study. It is broadly appreciated that the cost of maintenance of a building over its life can be much higher than its initial construction cost. Evans et al [1] study of the long term costs of owing and using buildings suggested a ratio of 1:5:200 relating the initial cost of the building to that of maintenance and operations respectively. Whether this ratio exaggerates the maintenance cost that can be open for debate, but maintenance cost over the life of the asset depends on the type of building and its use.

Wood [2] presents brief introduction to the recent history of building maintenance in the UK. He discusses the public policy with regard to building construction and maintenance from the focus on reconstruction following WWII, the slum clearance, introduction of building regulations, the modernisation of slums to the privatisation of council houses and the introduction of the Private Finance Initiative (PFI) and the Public/ Private Partnerships to organise involvement of the private sector in the public sector construction work that was previously carried out by councils.

The first aim of this paper is to review the building maintenance management approaches presented in literature. The paper then explores how can Building Information Modelling (BIM) be used to support building. The paper is concluded with a proposed building maintenance framework.

2 Building Maintenance Management Approaches and Techniques

Interest in research in building maintenance management and planning started to strengthen in the 1960s. Lee [3] published a book on Building Maintenance Management in 1976 which demonstrated the complexity of this area and its social and economical importance. He further stressed the importance of using management techniques in this area. He showed the consequences of delaying maintenance and the importance of inspection, scheduling and the planned/ preventive maintenance. Later in 1979 Gibson[4] edited book on Developments in Building Maintenance-1. This book demonstrates the significant achievement of building maintenance research and the emerging topics that remain of current research interest to date particularly the use of decisions models. Jardine [5] later developed these modelling approaches to optimise maintenance activities which set the foundation of modern maintenance modelling and optimisation.

There is a variety of approaches and techniques published in literature for planning, scheduling and budgeting building maintenance. The most notable of these approaches are discussed below:

2.1 Reliability Analysis

Wu et al[6] argue the use of reliability analysis can lead to improved building performance over its whole life. The Life Cycle Costs (LCC) typically show a drop followed by rise with the increase of reliability. This is explained by increasing construction cost and reducing maintenance cost with increasing the reliability level target. Hence there is need to carefully select the maintenance policy including the frequency of interventions in order to minimise the LCC. Wu et al[6] analysed the impact of reliability on each stage of the whole life cycle of the building system including: client requirements and briefing, design, installation, operations and maintenance and disposal/ reusing and recycling. Reliability analysis based on data collection can help in re-developing or updating the maintenance policies in order to adapt to practical use/ operating environment through optimising life cycle costs and or performance.

2.2 Reliability Centred Maintenance (RCM)

RCM is a maintenance planning approach that was first developed in aircraft industry. Although the formal definition of RCM is that it is an approach for identifying effective and efficient preventive maintenance tasks and intervals according to specific procedure(IEC 1999 [7]), Rausand and Vatn [8] noted that applying RCM can include identification of repair upon failure policies, inventory management of parts optimisation and logistic consideration. Rausand and Vatn [8] identify 12 steps for RCM analysis process ranging from functional failure analysis, critical item selection and failure modes effects and criticality analysis (FMECA) to selection of maintenance action and determination of maintenance intervals.

El-Haram and Horner[9] provide one of few applications of RCM in building maintenance. The objectives of their study was to apply integrated logistics support to the development of cost effective maintenance strategies for existing building stock using RCM approach tailored for application to construction projects. A pilot study was undertaken on 18 residential properties. The study details the four steps used including: carrying out building condition survey, apply FMEA and RCM, evaluate the maintenance costs and comparing the results of the condition survey with RCM. The condition survey identified 4 building elements where 74% of failures occurred. They also identified the causes of failures. Following the application of FMEA to identify all possible ways of each element failure with the causes and effects of these failures RCM was applied to identify the cost effective maintenance tasks and their consequences. The pilot study shows that the potential benefit of applying RCM is a reduction of maintenance cost by 18.5% in addition to other benefits including higher levels of health and safety, help in establishing maintenance programmes and in preparing maintenance budget.

2.3 Key Performance Indicators

The huge spending on maintenance, estimated at 1500 billion Euros in Europe[10], has motivated senior managers and maintenance engineers to measure the contribution of maintenance towards total business goals [11]. Maintenance Performance Indicators (MPIs) are the means to measure the performance of a maintenance process, are ratio of two maintenance related variables and can act as early warning system for maintenance process indicating the present status of the process in order to make prediction and take corrective action [11].

2.4 Condition Based Maintenance

Condition based maintenance policies have advantages over the classic and simpler to apply age based maintenance policies. In a typical age based maintenance an optimal maintenance interval is estimated using variety of mathematical models that are based on assumption of quality of maintenance action e.g. renewal, minimal repair etc. In condition based maintenance, system condition is monitored and maintenance interventions are undertaken whenever the condition drops below certain critical level set by the manager or when a failure occurs. Condition monitoring can either be continuous or carried out at every preset interval of time. Monitoring can be carried out by operators "inspection" or through the use of special equipment that can alert the user to the drop of performance.

There are few publications on the application of condition monitoring in building maintenance. Straub [12] presents a condition based approach using six-point condition scale. Different types of performance loss are identified e.g. technical performance and fire and social safety with each linked to specific maintenance actions. The condition assessment method adapted involves visual inspection followed by deciding the type, intensity and extent of defects. This approach allows building inspectors to provide facility managers with objective data about performance loss and defects in building components. A drawback of the condition assessment approach is the amount of data which should be updated continuously.

Alani et al[13] established from questionnaire responses from 100 companies involved in maintenance and facilities management work that 95% of all organisations used condition based maintenance assessment methods for the prioritisation of maintenance operations. They also undertake a comparative study of 4 methods used to set priorities for building maintenance elements and the results show a good level of agreement on setting priorities for building maintenance at levels 1 and 2 which indicate that the elements which require immediate attention and repair work have been identified. However there were disagreements on identifying priority 3 elements which require long term maintenance.

In a more recent study by Hegazy et al[14] the authors attempt to circumvent inspection problems of subjectivity and the high cost and time required by using reactive-maintenance data to develop indicators for the condition of building components. The study used data for 88 schools and identified 23 building systems. They established a relationship between the condition of a component and the reactive maintenance performed for that component per year showing that the more the reactive maintenance performed the poorer the condition of the component. The authors also presented methods for establishing the condition threshold at which maintenance interventions are introduced.

2.5 Operational Research (OR) Models

Several approaches for building maintenance originated in the field of OR. These include delay time analysis, Markov models and simulation.

Inspection plays a central role in building maintenance. The pioneering work of Christer[15] on delay time modelling had an early application in the area of using inspection in building maintenance. The concept of this approach is that there is a "delay" time elapses between origination of a fault and first detecting it. By studying the distribution of this delay time it is possible to identify the best inspection policy including inspection interval. Christer [15] argues the importance of inspection policies in building maintenance. Since the publication of this paper this area of delay time modelling has expanded and many studies were carried out on estimating this distribution. One of the few applications in building maintenance is the study of Redmond et al [16] on modelling the deterioration and maintenance of concrete structures. A three phase delay time model that covers the cracking and spalling in concrete was developed and models were formulated to predict the cost effects of maintenance and inspection decision options.

Another OR modelling approach used in building maintenance is the use of Markov decision models. There are many variations for Markov models but they all assume the Markov property that the state of a system or process does not depend on its previous state i.e. that the system has no memory. This simplifying assumption has many applications in modelling. Winden and Dekker[17] presents model for using Markov decision process in modelling the maintenance of four building elements, viz. masonry, pointing, window frames and painting. The model can determine the maintenance policy that ensures a specific average quality level at minimal cost.

Al-Zubaidi and Christer[18] uses simulation to model building maintenance manpower for hospital complex in order to investigate the potential gain from using different manpower management and operational procedure. The model can simulate various situations accounting for daily variation in maintenance demand, sickness and holidays and the characteristics of different trades.

2.6 Innovative practices

Wood [2] refers to his research findings in identifying a number of innovative practices in building maintenance. These include: JIT Maintenance by getting the maximum life from each building component, Intelligent Building Maintenance which involves identification of information from data and relating it to creation of comfortable building environment, Call Centred Maintenance to identify its key role in providing maintenance regime and Sustainable Building Maintenance leading to sustainability of buildings and operations. All these innovative approaches can represent best practice in building maintenance.

3 Maintenance and Building Information Modelling (BIM)

Building Information Models or BIM is a relatively recent approach which is essentially a digital representation of the physical and functional characteristics of a facility [19]. BIM covers all stages of a building from design and construction to operations and maintenance. The expansion in the use of BIM will lead to accumulation of maintenance data in BIM models which can support models that are used in effective building operations and maintenance. In a recent paper Ilter and Ergen[20] review the current status and research directions in the application of BIM for building refurbishment and maintenance. They identified 5 subtopics of current research interest including access to and integration of maintenance information and knowledge.

Shariff and Kobbacy [21] stress the importance to start understanding how BIM maintenance information will be used in maintenance management and indeed how the information in BIM can be used to project the maintenance requirements as early as the design phase. In other words the availability of this integrated system will lead to consideration of maintenance requirements at the design stage and hence

maintenance cost will influence building design. Furthermore BIM will provide appreciation of maintenance requirements from the design stage. Large organisations now look primarily at facility performance rather than the physical structure [19]. For example the USA General Services Administration (GSA) has recently awarded contract to design, install and maintain major power facility. Guillen et al [22] presents an up to date study on asset management for building within the framework of building information modelling development.

4 Proposed Building Maintenance Framework

There are a number of approaches for maintenance planning in Literature including: Reliability Centred Maintenance, RCM [8], Waeyenbergh and Pintelon approach[23], Decision Making Grid (DMG) approach [24], Value- driven maintenance planning [25] and Marquez et al approach [26].

Here we propose a building maintenance framework in Figure (1) below followed by discussion of its various stages. In proposing this framework we consider an organisation which has responsibility for maintaining buildings or estates. Such organisation can be a company, council, hospital etc.

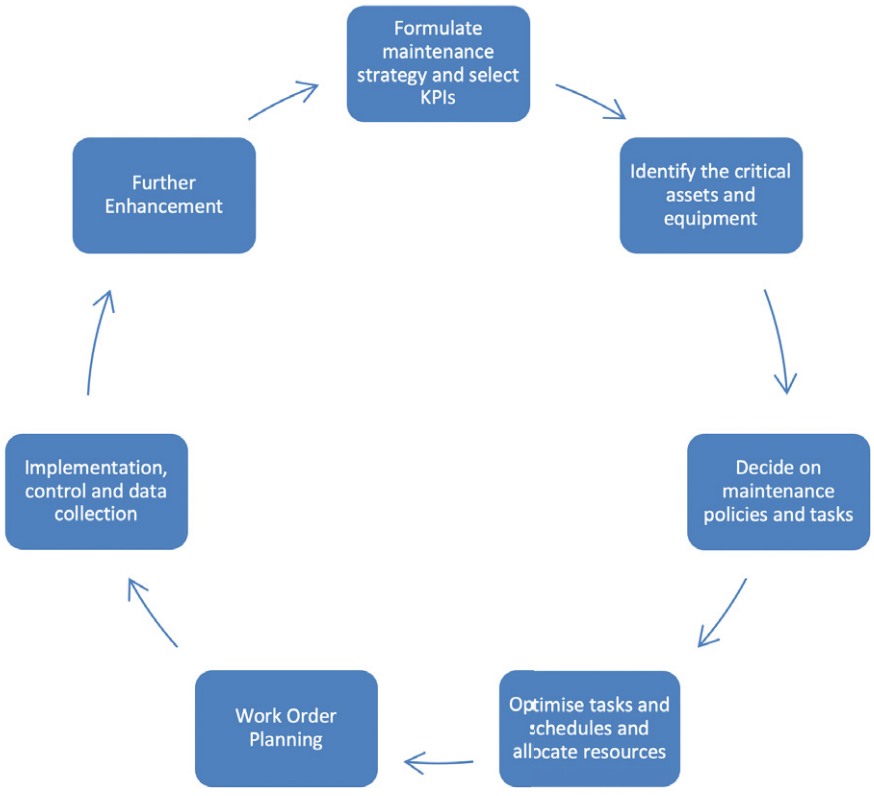

Figure (1) Building Maintenance framework

Formulate maintenance strategy and select KPIs

Maintenance strategy and objectives must be consistent and should support the organization strategy in achieving its objectives. Maintenance objectives can include one or combination of the following: maximise building/ equipment availability, minimise operations, maintenance cost or energy consumption, enhance building/ equipment performance and safety. Key Performance Indicators (KPIs) must be clearly identified and time linked target objectives must be stated and a statement about how they will be achieved. KPIs are measures of achieving maintenance goals and business objectives and can include: down time, building/equipment availability, preventive maintenance backlog and budget compliance.

Identify the critical assets and equipment

This can be rather complex process and there are different approaches to achieve it. In general the maintenance manager must decide on types and levels of risks for asset criticality analysis. Dimensions of risk assessment include: Quality, Reliability, Environment , Safety etc. There are many techniques that can be broadly divided into qualitative and quantitative [27]. Quantitative methods typically use the concept of Probability/ Risk Number PRN and the qualitative methods are used when no data are available.

Decide on maintenance policies and tasks

Various approaches can be used to decide on selection of maintenance policy e.g. Decision Making Grid (DMG) [24], Decision Tree [23] and RCM[8]. The DMG is an interesting approach that aims at answering the maintenance effectiveness questions i.e. which system or building element should we improve and how? There are two stages. The first is the decision making grid DMG which identifies the type of maintenance action based on failure history. Policies are allocated according to the location on the grid. For example if frequency and downtime are low you can use operate to failure and if downtime and frequency are high then use design out approach . The second stage is to use the Analytical Hierarchy Process (AHP) to priorities systems that needs attention.

Optimise tasks and schedules and allocate resources

Optimization of maintenance tasks and resource allocations are essential step in order to achieve efficiently maintenance leading to achieving maintenance objectives e.g. minimizing cost, maximizing availability. Models can vary from simple analytical models to decide on optimal spare parts ordering and stocking policies to complex simulation models that are used to schedule maintenance activities and allocate resources e.g. manpower, tools, etc.

Work Order Planning

This area is seldom discussed by academics though it is of great practical importance. It deals with the operational/ action planning and scheduling of maintenance activities. The book by Doc Palmer [28] on maintenance planning and scheduling views planning as "the preparatory work given to individual maintenance work orders before assigning them to specific craft persons for work execution".

Implementation, control and data collection

Having planned for maintenance activities and assigned work orders to crew, implementation will proceed. Monitoring, recording and reporting of maintenance execution is essential to ensure achieving maintenance objectives. A precursor to monitoring and control of maintenance activities is the collection of appropriate data about the various aspects of maintenance. In modern organizations computerized maintenance management systems (CMMSs) are used.

Further enhancement

Further enhancement starts with Maintenance Performance Management (MPM). Utilization of emerging techniques and technology such as e-maintenance will enable continuous improvement. The use of life cycle analysis is particularly useful in understanding the different elements of asset costs over its entire life such as: planning; research & development; production; operation; maintenance and disposal. This particularly important for capital replacement decisions.

5 Conclusions

This paper is concerned with modelling and planning of building maintenance. We have identified in literature 6 main approaches that are used in building maintenance research. These were discussed and evaluated. The potential benefits from the current development and implementation of BIM on building maintenance have been outlined. We believe that over the coming few years with the implementation of BIM significant amount of maintenance data will be accumulated which will enhance building maintenance modelling and planning. The paper is concluded with presenting an outline design of building maintenance concept, which is a prerequisite for developing effective and efficient building maintenance.

References

[1] R. Evans, Haryott, N. Haste and A Jones, The long Term Costs of Owning and Using Buildings, Royal Academy of Engineering, London (1998).

[2] B. Wood, Towards innovative building maintenance, Structural Survey, V 23, No 4, (2005) 291-297.

[3] R. Lee, Building Maintenance Management, Crosby Lockwood Staples, London, 1976.

[4] E. J. Gibson, Editor, Developments in Building Maintenance-1, Applied Science Publishers, 1979.

[5] A. K. Jardine, Maintenance, Replacement and Reliability. Pitman publishing, London, 1973.

[6] S. Wu , D. Clements-Croome , V. Fairey V, B. Albany, J. SidhuJ, D. Desmond and K. Neale, Reliability in the whole life cycle of building system, Engineering, Construction and Architecture Management, Vol 13, No 2, pp 136-153, 2006.

[7] IEC60300-3-11, (1999) Dependability management – Application guide – Reliability centred maintenance. International Electrotechnical Commission, Geneva.

[8] M. Rausand and J. Vatn J(2008) Reliability Centred Maintenance in "Complex System Maintenance Handbook, Editors K Kobbacy and P Murthy, Springer (2008).

[9] M. A. El-Haram and M.W. Horner (2002) Practical application of RCM to local authority housing: a pilot study, Journal of Quality in Maintenance Engineering, 8(2) pp 135-143.

[10] R. Altmannshopfer (2006) Industrielle FM, Der Facility Manager (In German), April issue, pp12-13.

[11] U. Kumar and A. Parida (2008) Maintenance Performance Measurement (MPM) System in "Complex System Maintenance Handbook, Editors K Kobbacy and P Murthy, Springer (2008).

[12] A. Straub (2002) Using a condition-dependent approach to maintenance control costs and performamce, Journal of Facilities Management, 1 (4) pp 380-395.

[13] A.M.Alani, R.P.Tattersall and M.I. Okoroh(2002) Quantitative models for building repair and maintenance: a comparative case-study, Facilities, 20(5/6) pp 176-189.

[14] T. Hegazy, S.S. Ahluwalia and M. Attalla (2010) Two condition indicators for building components based on reactive-maintenance data. Journal of Facilities Management, 8(1) pp 64-74.

[15] A.H. Christer (1982) Modelling inspection policies for building maintenance. J Operational Research Society. 33, pp 723-732.

[16] D.F.Redmond, A.H. Christer, S.R. Rigden. E.Burley, A.Tajelli and A. Abu-Tair (1997) O.R. modelling of the deterioration and maintenance of concrete structures. European J of Operational Research, 99, pp 619-631.

[17] C. van Winden and R. Dekker (1998) Rationalisation of building maintenance by Markov decision models: a pilot case study. J Operational Research Society, 49, pp928-935.

[18] H. Al-Zubaidi and A.H. Christer (1997) Maintenance manpower modelling for a hospital building complex. European J of Operational Research, 99,, pp603-618.

[19] S. S. Ahamed, J. Neelamkavil and R. Canas (2010) Impact of building information modelling in facility maintenance management. The E-SIM 2010 Conference, Winnipeg, Canada.

[٢] D. Ilter and E. Ergen,(٢٠١٥) BIM for building refurbishment and maintenance: current status and research directions, Structural Survey, Vol. 33 Issue: 3, pp.228-256.

[21] S. Shariff and K. Kobbacy (2016). Building Maintenance Modelling and Optimisation: Current Gaps and Future Opportunities, ESReDA seminars: Safety and Reliability Enhancement throughout Europe, Spain 18-19 May 2016.

[22]A.J.Guillen Lopez, A Crespo Maequez, J.A. Sanz Cordovilla, K Kobbacy, S Shariff, E Le Page and V Gonzalez-Prida (2016) Asset Management for Building within the Framework of Building Information Modelling Development in "Optimum Decision Making in Asset Management", Editor V Gonzalez-Prida, IGI Global (2016).

[23] G. Waeyenbergh and L. Pintelon (2002) A framework for maintenance concept development, Int J of Production economics, 77, pp 299-313.

[24] A. Labib (2008), Computerised maintenance management systems, in Complex System Maintenance Handbook, Springer, 2008 (Kobbacy and Murthy Edts).

[25] T. Rosqvist, K. Laakso, M. Reunanen (2009) Value -driven maintenance planning for production plant. Reliability Engineering and system Safety, 94, 97-110.

[26] A. Crespo Márquez, P. Moreu de León, J.F. Gómez Fernández, C. Parra Márquez, M. López Campos (2009) The maintenance management framework, a practical view to maintenance management. J of Quality in Maintenance engineering, V 15, No 2, 167-178.

[27] Crespo Marquez, A, The maintenance management Framework. Models and methods for complex systems maintenance, Springer Verlag 2008.

[28] Doc Palmer, Maintenance Planning and Scheduling Handbook, McGraw-Hill, 2006.