Performance Based Maintenance Scheduling for Building Service Components

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Abstract. This paper discusses Performance Based Maintenance Scheduling as an enabler for Optimised Building Operation in terms of cost, energy usage, and user comfort, and the role of collaborative networks in achieving these optimal conditions. We finally explain what categories of constraints need to be considered to organize performance based maintenance scheduling in a holistic and integrated manner

Keywords: Performance Based Maintenance, ITOBO

1 Introduction

Performance based maintenance is a meeting point between scheduled and reactive maintenance. It allows for faults which were not foreseen at the time of scheduling to be dealt with before they become a failure, i.e. before reactive maintenance is needed. Also performance based maintenance has added benefit over reactive maintenance due to the fact that cost allocation can be carried out for performance based but not for reactive maintenance. How to achieve this allocation of costs will be discussed briefly, with respect to the information needed to do so, in the following paper.

This paper deals with performance based maintenance so it is necessary to have a facility management model which describes this type of maintenance. For performance based maintenance scheduling one must ensure for easy information transfer, information regarding component status, historical information and operation guideline information. Consider a Public Private Partnership (PPP) contract agreement, i.e. when a construction company is responsible for carrying out the maintenance works in a building for a specific amount of time (e.g. 10 years). The company may be based abroad and may have multiple contracts with locally based service companies. To allow for performance based maintenance scheduling it will be necessary for each of the appropriate entities in the organisation to have access to the necessary data and if possible within the contract rules, to share maintenance trends which have been noticed by individual companies in previous work with the network.

2 Models for Facility Management

This chapter reviews models for Facility Management (FM) being utilized presently to ensure the enactment of maintenance activities. The following is a description of the most widely used models in the Anglo-American world as described in “Facility Management Towards Best Practice” (Barrett & Baldry, 2003):

Office Manager Model – In this model FM is not usually a distinct function within the organization. Instead it is undertaken by someone as part of their general duties such as office manager

Single Site Model - This model applies to organisations that are large enough to have a separate FM-department but are located at just one site. It also applies to organisations who own the buildings that they occupy.

Localised Sites Model - This model applies to organizations having buildings on multiple sites.

Multiple Sites Model - this model is generally applicable to large organisations that operate across widely separated geographic regions. Operational issues are dealt with at regional level.

International Model- this model is similar to Multiple Sites model but applies to large international organisations.

The following table summaries the above mentioned models:

Table 1: Facility Management Models summary

Model Type	Size	Coverage	Decision Making: Headquarter	Decision Making: On site
Single Site	1 site	One site	All – on site	All – on site
Local Site	≥1 site	Site in same metropolitan area	Technical assist., problems, budgets	Simple operational decisions
Multiple Site	Many sites	National geographically separated sites	Set Policy, Guidance to regional HQ	Operation matters
International	Many sites	Multi-national geographically separated sites	Set Policy, Guidance to regional HQ	Operation matters

3 Prerequisites and Current Deficits

The first assumption in this paper is that the use of wireless sensors and meters to monitor and control building services and energy consumption is increasing. This is due to a reduction in the cost of such devices and the decreasing installation costs based on the lack of wires. This leads to an increase in available (bulk) data.

The second assumption is that an integrated tool for holistic information modeling allowing the holistic, multidimensional management and analysis of building performance data in relation to the buildings energy usage will be available. Our colleagues here at University College Cork, under a project entitled ITOBO (Information and Communication Technology for Sustainable and Optimised Building) develop such a tool based on Data Warehouse (DW) technology. This tool supports complex queries and advanced features for aggregating, analyzing, and comparing data. It is also used to discover trends and patterns in data (Ahmed et al, 2009).

DW technology has been introduced to the construction management domain to improve the management of historical data (Ahmed & Nunoo 1999), (Lee & Lee 2002). So it is a natural progression for this technology to now be used in the building management sector especially as the availability of building documentation will lead to efficiency in this sector but however, few efforts have been made to explore the impacts of DW technology on building performance management supporting the creation of sophisticated data aggregation and analysis tools. By introducing collaborative networks into the scenario, it will become possible to ensure valid data and assumptions when aggregating the data and creating the analysis tools.

To facilitate our research with real example data the ERI building, a 4500 m^2 “Living Laboratory” located on the campus of University College Cork, Ireland, is used as Living Laboratory. The building has a wireless sensor network installed along with a wired BMS system. It is equipped with multiple types of solar panels, geothermal heat pumps and an under floor heating system. Building Performance Data is provided by 180 (wired) sensors. Additionally, a test bed for wireless sensors and actuators has been installed since April 2008 in three phases. Sensors include humidity, temperature, CO^2, and lighting sensors. Meters include devices to measure electricity, mains water, cold water, gas, lighting energy consumption, boiler heat, solar heat and under floor heat.

In the case of our example, aggregated performance data can be generated from the sensed and metered fact data and the dimensional data derived from Building Information Models which include information to structure the fact data (e.g. per location, per time, per user, etc.). Therefore, different stakeholders can retrieve customized information about the building performance. However, in future research further problems need to be addressed, such as how the maintenance and calibration for the sensors are organized. The need for “on site” inspection for these sensors should be on the lowest frequency possible. Secondly, manufacturer’s data for HVAC components is very conservative so if this data is used in a diagnostic tool it will give a level of required maintenance which is too frequent. The next difficulty comes in the form of existing companies. Large companies which have worked in the FM-sector for some time will have discovered trends in building service components. For example, they may have noticed that when x amount of vibration is recorded by a sensor on a fan motor then the fan is close to failure. This knowledge is only gained by experience. However, this large company may be unwilling to share this knowledge as it gives them an edge over their smaller competitors.

4 Maintenance Planning Models

Currently, there is a lot of space for improvement in the manner in which buildings are maintained. Performance based maintenance will allow for a reduction in reactive and scheduled maintenance which is necessary in built artifacts. First we will discuss the two most widely used maintenance types, reactive and scheduled maintenance:

Scheduled maintenance includes preventative maintenance activities such as lubrication, visual inspection and testing. It also includes predictive maintenance activities such as obtaining checking filters, taking vibration measurements and drawing lubricant samples for analysis. In short routine maintenance is comprised of nearly all of what is referred to as preventative/predictive maintenance. In case of FM scheduled maintenance has an element of wasteful expenditure. Take for example, an Air Handling Unit (AHU), every six months the filters are cleaned. This is a scheduled event and it takes place without fail. However, depending on the environmental conditions and the intensity of usage the filters need either only is cleaned yearly or in case of extreme use cases 6 times a year. In this case scheduled maintenance will impede the users comfort and will result in unnecessary spending, due to over and under maintenance scheduling.

Reactive Maintenance requires immediate action to address breakdowns and other suddenly developing conditions. Traditionally reactive maintenance consumes excessive maintenance resources. Although an absolute necessity, it is a totally reactive function. Proper attention to the routine work and timely backlog relief will minimize the demand for reactive maintenance, (Kister, Hawkins, 2006). In case of FM reactive maintenance results, firstly, in a diminished level of user comfort due to the waiting time for the maintenance to be detected appropriately and consequently scheduled and also due to the unavoidable disturbance which is prominent during reactive (emergency response) maintenance. Secondly as this type of maintenance may require certain skills or stock at a minimal time delay this also invariably results in higher expenditure.

In case of performance based maintenance scheduling the following scenario is proposed, with respect to the situation described for scheduled maintenance: pressure sensors would be installed at either side of the filters, a vibration senor would be installed on the fan motor and room temperature and humidity sensors would be installed in the conditioned space. Sensed data would be sent to the data warehouse regularly, the data warehouse would analyse the data and discrepancies in the performance profiles (based on historical data and a predicted outcome) would trigger relevant maintenance activities. As a summary of this section, scheduled maintenance has the disadvantages of large cost overheads and unnecessary downtime. Reactive maintenance has no facility to determine costs and includes unexpected downtime. Performance based maintenance has the ability to reduce and control cost overheads and also to eliminate unnecessary downtime.

5 Collaborative Networks

"*A CN is constituted by a variety of entities that are largely autonomous, geographically distributed and heterogeneous in terms of their: operating environment, culture, social capital and goals. Nevertheless these entities collaborate to better achieve common or compatible goals and whose interactions are supported by computer networks.*" (Camarinha – Matos LM, 2005).

In the FM-industry of today, due to outsourcing, technical advancements and contract conditions, CN are constantly being introduced by large since buildings include components of the structural domain, mechanical domain and electrical domain, etc. To maintain all these components, a large variety of skills are necessary. This is an advantage for performance based maintenance.

There are two types of FM-company structures; the first is the in-house structure. This is when all the necessary skilled staff is employed by the company. When a problem occurs the appropriately skilled person will undertake the task. The second structure is the outsourcing company. This is when a company maintains a core number of skilled staff and when a problem occurs which needs the attention of a skill which is not available within the company's staff; the task is outsourced to a specialized company. For each of these two types, performance based maintenance can be used but to ensure cost effectiveness, it is necessary for both types to available of infrastructures set up by other sectors, i.e. document sharing, data sharing. Therefore collaborative networks are a necessity for viable performance based maintenance.

According to Camarinha – Matos "*A collaborative network is characterized by four variables: the external interactions amoung autonomous entities, roles of these entities, the main components that define the proper interactions of these entities, and the value system that regulates the evolution of the collaborative association and the emerging collective behaviour.*" (Camarinha – Matos LM, 2005). For performance based maintenance scheduling the individual components are specified in Table 2 below.

Table 2: Collaborative Network Variables

Type	External Interactions	Role of entities	Main components	Value system
Performance Based Maintenance Scheduling	Periodic virtual meetings, Email notifications	FM provider, Maintenance Provider, Bldg. Owner, Tenants	Invent. Mgmt. & Mainten. Web Interface, Inventory &Task DB	Mandatory regulations, codes, etc. determine contract cond

The overall components for a maintenance scheduling system are: (1) a wireless sensor network to monitor the performance of building service components, (2) the data warehouse which will store and analysis the performance data recorded, (3) the Maintenance task database, and (4) the web-based user interfaces which will allow to view data trends, check stock of spare parts, track maintenance activities, view purchase orders, etc. The main components for a performance based maintenance scheduling methodology – with an emphasis on topics (3) and (4) - their purposes and interactions will be described in more details in the following paragraphs.

6 Maintenance Process Management

The first component discussed is a maintenance template management system, consisting of process models for different maintenance tasks. Each building service component will have their appropriate maintenance tasks recorded in this template system. Each of these tasks templates details the position of the component with regard to the overall building service system, the sequence of actions which needs to be performed, the estimated time for each action, and the required resources (e.g. spare parts, tools, etc.). In our case the template management system will be complied using the ARIS methodology. This methodology was chosen due to its ability to allow for good decomposition and synthesis of complex value chains and the ability to drill down from value chain level to extended Process Chain Level.

More about this methodology can be found in ARIS - Business Process Modeling (Scheer A.W, 2000). By using this methodology it is possible to attach documents and codes to the process models. The responsible actors will also be detailed in these models through the use of organizational units. This will allow the maintenance support system to determine the employee skills type required to carry out a particular task. The task template can be evaluated by the predictive maintenance scheduling components and finally be attached to the work schedule forwarded to the individual member of the collaborative network.

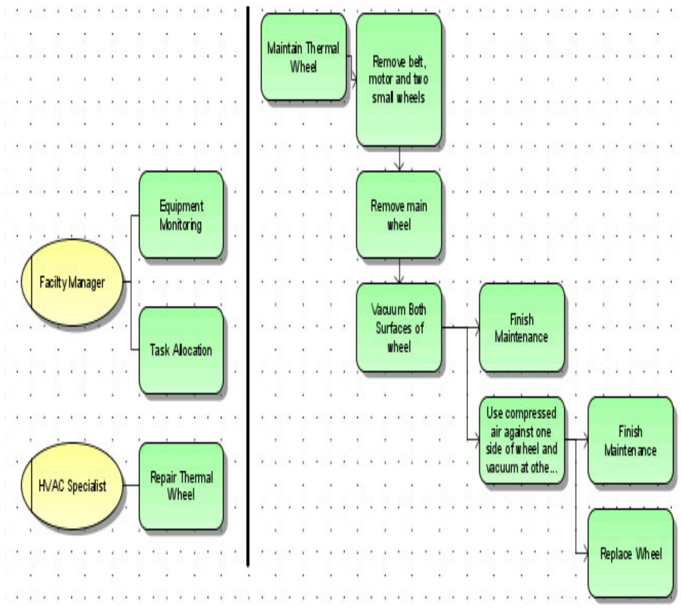

Fig 1: ARIS Maintenance Task Model

The ARIS diagram on the left is for the main wheel section of a thermal wheel component. This component is used for two purposes, as a heat exchanger and as humidity control device.

We envisage triggering fault reports automatically through data analysis of building performance data in the Data Warehouse briefly described in section 3. Since the dimensional data of the DW will contain the multiple dimensions, such as building services system hierarchies, location hierarchies, etc. each fault report could specify the component by tracing the component through a building service component list and recording its position. This will allow the component to be isolated in terms of it whole system down to its own unique purpose and will allow for the exact determination of the maintenance task needed from the ARIS processes.

As performance based maintenance is dependant on past experience and past data trends, it will be possible to update these maintenance task with additional data as a building operational period progresses. As a building may incur a change in functionality over time and as a result the maintenance tasks may vary from original definition. The functionality of a collaborative network is paramount to ensure the transfer of knowledge with regard to such changes.

7 Constraints for Maintenance Scheduling

Performance based maintenance scheduling has to consider various constraints, such as (1) availability of staff, (2) availability of parts, (3) temporal constraints on tasks, (4) building use patterns, (5) criticality of repairs. Criticality of repairs is where the scheduling connects to the aims of performance based maintenance. We assume that we have diagnosis information which tells us the effect the part of the system is having on the performance of the building. The following paragraph describes two components created to deal with the above constraints.

The space management component checks the accessibility of locations, such as rooms, floors, zones to perform a maintenance tasks. It will serve the facility managers or the building operators of the building management company. The facility managers will use it to check the accessibility of rooms and that they need to access to carry out individual maintenance tasks. If rooms are available they will be booked and the maintenance will be scheduled. The tool helps to solve accessibility constraints within the Collaborative Network. The inventory control component checks the availability of spare parts and tools which are needed to perform maintenance tasks. It will serve the building technicians, the building operators and also the purchasing and accounting departments of the building management company. The operators and technicians will use it to book stock that they need to carry out individual maintenance tasks. If there is no available stock, the user will be able to check if a delivery is already scheduled and if not then the user will have the option to order the stock needed. There are a series of constraints that help the technicians pin point the appropriate stock that they need. It begins with the technician defining the location where the task will be carried out and then the type of stock needed the quantity and the time period when it will be needed. The accounting department will also be able to utilize the information gathered in order to analyse the financial constraints. The interfaces for this purpose have no been included here but they would display the history of stock usage and the suppliers most used, etc.

The competency management component checks the accessibility of staff with required skill sets and expertise within the Collaborative Network. It will serve the facility managers and the sub-contractors. The facility managers will use it to check the availability of subcontractors. Subcontractors will use the tools to offer available resources and skills to the Collaborative Network. The tool helps to solve competency constraints within the Collaborative Network.

8 Conclusions and Acknowledgements

The integration of complex renewable energy systems, such as solar panels, geothermal heat pumps etc. increases the complexity of required maintenance activities and the need to access more “specialized skills and competencies”. Both, this need for more specialized knowledge and changing business models for Facility Management create a need for the introduction of Collaborative Network scenarios in the FM sector.

In our paper we propose a scenario and a methodology for integrated information management to support a new paradigm for maintenance management – performance based maintenance scheduling. We argue that the availability of wireless sensing and metering devices complemented by advanced data management and analysis tools will enable the introduction of predictive maintenance in the FM-sector and contribute to the more efficient operation of buildings.

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