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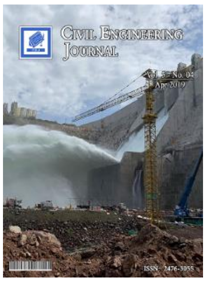

# Predictive Modeling for Developing Maintenance Management in Construction Projects

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**Abstract**

Maintenance is one of the most important global issue and it taking an increasing recognition in numerous study field. Meanwhile, in Iraq with the absence of an efficient building maintenance management and a lack of appropriate predictive maintenance tool of the current buildings can have a significant negative impact on future building development. Currently, there is a paradigm shift in management of building maintenance from corrective to preventive and predictive approaches that is attainable through creating of an evaluative model to evaluate a variety of alternative decisions. This paper aimed at developing mathematical models for the buildings maintenance. This was achieved through the division of building according to the methods of division based on a number of global maintenance manuals and previous studies. Consequently, based on literature review and interviews with experts on building maintenance, questionnaire was designed that included most of the maintenance items of building. Then, the results of the questionnaire were processed using the Statistical Package for Social Sciences (SPSS), to determine the most important maintenance items, the Weighted Sum Model (WSM) technique was used. Finally, this research recommended adoption the model for quick evaluation and appropriately monitoring of buildings. It will also help architects and engineers to make predictions throughout scientific methods instead dependence on personal decisions.

*Keywords:* Maintenance; Maintenance Management; Construction Projects; Mathematical Model.

## 1. Introduction

Buildings maintenance is a process that takes a great interest all over the worlds. The managing maintenance properly helps maintain capital and ensure health and safety in the use of the building [1].

Over time all building materials, services, finishes, and structures deteriorate through an unavoidable process of the impacts of usage, dampness, climate and etc. [2]. The physical lifecycle of the buildings will be increased and this decay process can be controlled if they are appropriately maintained [3]. During the building's life cycle, the major expenses fraction is incurred through operation and maintenance stages, which comprise approximately 60% of the entire cost [4]. The most of the maintenance works in this stage are corrective actions implemented in emergency situations [5]. Thus, this attitude is no longer accepted and maintenance function for any organization is recognized as a strategic element. Hence, there is essential for supporting more planned approaches for maintenance (predictive, preventive), instead of reacting to failures [4].

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Maintenance is carried out to retain value of investment, making the building in a condition in which it continuously fulfils its function presenting a good appearance [6]. Maintenance can therefore be referred to all necessary work done to preserve a building with its finishes and fittings so that it continues to provide the same or almost the same facilities and amenities and serve as it did when it was built [7]. As building components and all elements that make up the buildings unavoidably deteriorate with time due to inherent defects in design and construction and the effects of the environment, it is therefore difficult to produce maintenance-free buildings [8].

Building maintenance can be defined as, series of the technical and administrative activities, inclusive supervision, aimed to retain an asset, or restore it to a condition in which it can do a required function [9]. The main objective of maintenance is to preserve a building at its primary stage and to keep the value of investments in the property [10].

An effective maintenance management method connected with experienced maintenance staff can prevent environmental damage and safety and health problems; produced less breakdowns and longer life of asset; and yield a greater quality of life and reduce operating costs, this is certainly requires a much hard works which is necessary to create a successful and effective maintenance management system [11].

Maintenance have been classified into just two main type, unplanned and planned. Unplanned maintenance (also known as reactive) consists of emergency and corrective maintenance. On other hand, planned maintenance (also known as programmed, proactive, and cyclical) involve condition-based maintenance, scheduled maintenance, corrective maintenance, and preventive maintenance [12].

Maintenance management is the process of overseeing maintenance resources in order to avoid downtime from broken machines and equipment or waste of money on inadequate maintenance activities. Facilities with their machines, equipment and systems suffer wear and tear, damage and destruction [13]. The primary objectives of maintenance management are to control costs, schedule maintenance activities in an effective and efficient way, and ensure regulatory compliance. Poorly organized maintenance program can impose risks of major incidents, damage and accidents to a company and that is why a proper maintenance management is so essential to the success of any company or organization [14].

Modeling is an enormously powerful tool, which provides a significant source of information [15]. Mathematical model can also be described as a complex real world problem simplification, which is perform into the form of mathematical equation [16]. Furthermore, characterized model as a simplified version of complicated thing used in solving and analyzing problems or creating predictions or used as the base for associated system, idea, or process. Accordingly, for building maintenance, predictive modeling can be applied for observing and quick buildings evaluation. This can be performed by assessment of specific building elements, analyze the data with the model and use it to predict the condition of the building in objective way rather than personal way [17].

It is essential to understand the deterioration mechanism to develop adequate repair program [18]. deteriorating asset can be visualized every period of time according to deterioration model related to each element so the condition of each element that suffer from sudden damage can be repair and improve. Moreover, different actions (e.g., repair, replace, preventive maintenance) associated with different costs.

In order to change the maintenance work from the approach that depends on the damages repair when it is occur, which leads to the accumulation of damages, to the predictive approach which helps management to expect the breakdowns that can occur in the building and forecast the required budget for maintenance works, modeling method was proposed, it is a very effective way of simplifying and solving problems.

## 2. Materials and Methods

### 2.1. Division the Building into Elements

Due to the numerous number of elements in the building, and for easy recognition and control of these elements, building and its defects have been division into elements. Consequently, this division will help at better understand the maintenance items and it will assist to set up the mathematical model for various building elements. According to [16], building can be divided functionally into a set of basic components, which divided into a number of elements. Each of these elements will be linked to all defects that need maintenance. This division can be divided into four levels as illustrated in Figure 1.

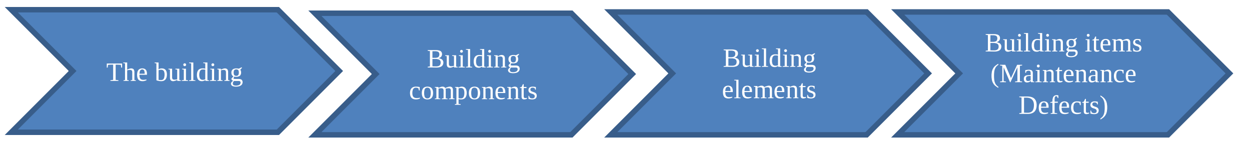


**Figure 1. Divided the building into components**

Figure 2 shown the building components. In this research we only used architectural and structural building components:

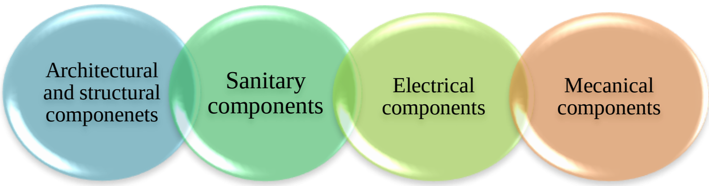


**Figure 2. Building Components**

Maintenance items or defects have been identified through using the French maintenance manual [19], and review of maintenance work carried out on a many government projects, case study project, as well as the interviews through which to identify the most important maintenance works. Then, this maintenance works have been linked to the building elements that were previously divided.

Moreover, there are number of elements associated with each component, for example elements associated with structural and architectural components are (Roofs Isolation, Walls and ceilings, Structures, Doors &Windows, and Floors, ceilings and stairs coating) elements. Additionally, each building element has number of maintenance items (defects) for example, maintenance item associated with Walls and ceiling element are (bricks efflorescence and wall dampness, wall crack and etc.

Some maintenance items have been combined because of their repetition, scarcity and similarity to another items that were merged with them. Figure 3 state building element and its maintenance items.

## 2.2. Qualitative, Quantitative Techniques, and Case Study for Data Collection

In view of the weakness of maintenance works documentation in Iraq, the questionnaire was structured based on a literature review on building maintenance and interviews with the expert engineers. The purpose of the statistical study was to achieve the main reasons for maintenance in the buildings and classification of the maintenance items (defects) according to their importance and linking each item of maintenance with a weighting coefficient (constant).

In order to obtain the first part (constant) of the deterioration model the questionnaire was prepared, its consists of set of architectural and structural maintenance items linked with five important criteria that reflect the importance of the item and its necessity to carry out preventive maintenance, which prevent its happening, and these criteria were: probability of occurrence, danger on facility, maintenance cost, maintenance time, and impact on service level [20].

After obtaining the weighted averages, each maintenance item becomes linked with (5) numbers that reflect (probability of occurrence, danger on facility, maintenance cost, maintenance time, and impact on service life), In order to obtain a single number that reflects the importance of each item, we must combine all the previous number in order to get the one number. The researcher used Weighted Sum Model technique to combine these number.

## 2.3. Weighted Sum Model

(WSM) is the most commonly applied and best known MCDM method for priority setting and assessing number of alternatives and items in terms of a number of decision criteria [21]. This model is used in many multi-objective optimization problems in various fields [22]. Generally, suppose a specified MCDM problem is defined decision criteria n and on alternative m. Then, suppose that Wj represents the criterion's relative significance and Aij is the alternative's performance value of i when it is assessed in terms of criterion j. The formula applied in this model are shown in bellow and this Equation 1 refers to total importance of alternative i.

$$A i^{WSM-score} = \sum_{j=0}^{n} W_j A_{ij} \qquad \text{for } i=1,2,3,m=1 \qquad (1)$$

To apply WSM to MCDM problems, an essential requirement is to combine criteria so that a decision making function is formed. Through, this procedure highlights the need to the incommensurability of criteria overcome, by reason of that various criteria cannot be collected into a single decision. Consequently, it is needed to modify all criteria to a uniform, unit-less scale.

This is achieved by each criterion normalizing such that the criterion value lie in a 0 – 1 range [23]. Therefore, in this research the expert normalized the weights of each criterion. Finally, all criteria's weighted values are added. Mathematically, the purpose is to minimize (in a minimization problem case) or maximize (in a maximization problem case).

After obtaining all the questionnaires, these questionnaires were processed using the "Statistical Package for the Social Sciences" IBM SPSS v.25. After obtaining the weighted average, each maintenance item was linked with five numbers. These numbers reflect the probability of occurrence, danger on facility, maintenance cost, maintenance time, and impact on service level. In order to obtain a number that indicates the item importance to carry out preventive maintenance, we must combine all the previous numbers in order to get the one number by using WSM as following:

First step: Weights of criteria were assigned in Table 1.

**Table 1. Weight of Criteria**

| Criteria | Probability of occurrence | Danger on facility | Maintenance cost | Maintenance time | Impact on service life |
|---|---|---|---|---|---|
| Weights (%) | 10 | 20 | 40 | 10 | 20 |

Second step: the value of AiWSM-Score was determined by normalized each maintenance item according to questionnaire analysis result as shown in Table 2.

**Table 2. Maintenance Items normalized**

| Maintenance Items | Criteria | | | | |
|---|---|---|---|---|---|
| | Probability of occurrence | The danger on facility | Maintenance cost | Maintenance time | Impact on service life |
| Cracks appeared on roof concrete tiles (Craze cracks, hairlines cracks) | 0.334 | 0.52 | 1.04 | 0.32 | 0.444 |
| Expansion joints damage | 0.242 | 0.596 | 1.352 | 0.368 | 0.576 |
| Water leakage from the final surface and expansion joints | 0.312 | 0.488 | 0.848 | 0.288 | 0.246 |
| Bricks efflorescence and wall dampness | 0.272 | 0.62 | 3.04 | 0.27 | 0.632 |
| Plastering partially falling, plaster crack, delamination or plaster dampness | 0.248 | 0.692 | 1.264 | 0.328 | 0.66 |
| Walls crack | 0.298 | 0.552 | 1.12 | 0.286 | 0.596 |
| Paint peeling, paint crack, blistering, discoloration | 0.17 | 0.884 | 1.272 | 0.348 | 0.82 |
| The roof is cracked or has a localized depression | 0.302 | 0.512 | 1 | 0.268 | 0.524 |
| Break and cracking Aluminum partitions joints | 0.302 | 0.76 | 1.296 | 0.278 | 0.632 |
| Deep crack on concrete surface | 0.372 | 0.328 | 0.832 | 0.238 | 0.428 |
| Dampness areas performed on structural elements (Roofs and columns) | 0.34 | 0.5 | 1.144 | 0.298 | 0.64 |
| Steel bars corrosion in the structure elements | 0.324 | 0.548 | 1.096 | 0.284 | 0.456 |
| Spalling of concrete cover on structure elements | 0.414 | 0.668 | 1 | 0.204 | 0.54 |
| Efflorescence and grout failure appeared between tiles | 0.318 | 0.624 | 1.288 | 0.292 | 0.692 |
| Chipped, scratched, dislodgement and grout spalling floors and staircase tiles | 0.344 | 0.74 | 1.184 | 0.34 | 0.628 |
| Move or loss the false ceiling elements | 0.3 | 0.776 | 1.376 | 0.362 | 0.808 |
| Flares defect | 0.362 | 0.8 | 1.432 | 0.354 | 0.86 |
| Windows Defects(opening or closing Difficulty, screeching sound during the open or close, Fractured joint, lock and knob damage and broken glass) | 0.262 | 0.784 | 1.472 | 0.384 | 0.776 |
| Doors defects (rotting wood, opening or closing difficulty, erosion and decay frames of the doors, lock and knob damage) | 0.266 | 0.804 | 1.568 | 0.406 | 0.684 |

Third step: Comparison of maintenance items importance using the WSM as shown in Table 3.

**Table 3. Maintenance Items Importance**

| Maintenance items | Weighted sum |
|---|---|
| Cracks appeared on roof concrete tiles (Craze cracks, hairlines cracks) | 0.5332 |
| Expansion joints damage | 0.6268 |
| Water leakage from the final surface and expansion joints | 0.4856 |
| Bricks efflorescence and wall dampness | 0.602 |
| Plastering partially falling, plaster crack, delamination or plaster dampness | 0.6384 |
| Walls crack | 0.5704 |
| Paint peeling, paint crack, blistering, discoloration | 0.6988 |
| The roof is cracked or has a localized depression | 0.5212 |
| Break and cracking Aluminum partitions joints | 0.6536 |
| Deep crack on concrete surface | 0.4396 |
| Dampness areas performed on structural elements (Roofs and columns) | 0.5828 |
| Steel bars corrosion in the structure elements | 0.5416 |
| Spalling of concrete cover on structure elements | 0.5652 |
| Efflorescence and grout failure appeared between tiles | 0.6428 |
| Chipped, scratched, dislodgement and grout spalling floors and stairs tiles | 0.6472 |
| Move or loss the false ceiling elements | 0.7244 |
| Flares defect | 0.7616 |
| Windows Defects(opening or closing Difficulty, screeching sound during the open or close, Fractured joint, lock and knob damage and broken glass) | 0.7356 |
| Doors defects (rotting wood, opening or closing difficulty, erosion and decay frames of the doors, lock and knob damage) | 0.7456 |

The results obtained after processing the questionnaire results using WSM express the sequence of maintenance items according to their importance and necessary extent of preventive maintenance conducting which prevent the occurrence of this item or defect, The smaller the percentage, the greater the importance of this item.

# 3. Results and Discussion

## 3.1. Deterioration Model Creation

A set of mathematical equations have been adopted to get deterioration model. Each equation consist of two part, by dividing the building into elements and from the questionnaire analysis, the first part of mathematical models has been obtained, it is a constant and consider as coefficient of weighting associated with each maintenance item and remains constant in all buildings. The second part is a variable and reflects the status and condition of the building element, it depends on the evaluation of the maintenance supervising engineer. In order to achieve scientifically and accurately evaluation, paper previously approved by (Australasian Association of Higher Education Facilities Officers, 2000) [24] has been adopted, this paper is based on a building element evaluation condition by giving a mark ranking from [1-5] as illustrated in Table 4 which adapted building condition rating and index used for the adequacy ratings of building physical condition. It shows that building elements and condition rated of components ranges from very poor (1) to excellent (5). All the building/component conditions itemized are well defined, with the condition corresponding rating and index of building condition.

**Table 4. Condition rating scale of asset situation and definitions**

| Building/element condition | General description (definition of rating/condition of building asset) | Condition rating |
|---|---|---|
| Very poor | • building has failed<br>• not operational<br>• not viable<br>• unfit for occupancy<br>• pollution/ environmental issues exist / contamination | 1 |

| | | |
|---|---|---|
| Poor | • badly deteriorated<br>• potential structural problems<br>• inferior appearance<br>• major defects<br>• components fail frequently | 2 |
| Fair | • average condition<br>• significant defects are evident (e.g. non–structural cracks)<br>• worn finishes require maintenance<br>• services are functional but need attention<br>• deferred maintenance work exist | 3 |
| Good | • minor defects<br>• superficial wear and tear<br>• some finishes deterioration<br>• not required major maintenance | 4 |
| Excellent | • as new appearance and condition<br>• asset has no defects | 5 |

All this done in a scientific way rather than dependence on personal decision, in this way we can maintain the durability of the building and Continuation to perform its work perfectly and using a less operating cost.

### 3.2. Deterioration Models of Structural and Architectural Components

The walls and ceilings element previously illustrated was connected with six maintenance items that were evaluated by the questionnaire. Therefore, the deterioration model of the walls and ceilings element as illustrated in Equation 2:

$$Y=M1X1+M2X2+M3X3+M4X4+M5X5+M6X6$$
$$Y=0.602X1+0.6384X2+0.5704X3+0.6988X4+0.5212X5+0.6536X6 \quad (2)$$

M1, M2, M3, M4, M5, M6: Constants or weighting coefficients of the maintenance items associated with the walls and ceilings element.

X1, X2, X3, X4, X5, X6: Evaluation of supervisor engineer on defects condition associated with the walls and ceilings element, where each evaluation multiplied by the associated weighting factor.

Consequently, when compensating the evaluations of maintenance supervising engineer in deterioration model of walls and ceilings element, the result obtain was from (30) because there are six maintenance items associated with this element, the evaluation of each item range from (1) to (5), to convert it to a percentage, the number obtained should be divided by (30).

The previous equation is suitable as deterioration model for walls and ceilings element in different types of buildings, after compensated the evaluation of supervisor on maintenance work in previous equation; the researcher got value that reflects the condition of the walls and ceilings element and its need for maintenance. In a similar way the models for the other elements in the architectural and structural components have been got as illustrated in Table 5.

**Table 5. Deterioration model for architectural and structural building components**

| Building elements | Deterioration models |
|---|---|
| Walls and ceilings element | Y1=0.602X1+0.6384X2+0.5704X3+0.6988X4+0.5212X5+0.6536X6 |
| Structure element | Y2=0.4396X1+0.5828X2+0.5416X3+0.5652X4 |
| Roofs isolation element | Y3=0.5332X1+0.6268X2+0.4856X3 |
| Floors, ceilings, and stairs coating | Y4=0.6428X1+0.6472X2+0.7244X3+0.7616X4 |
| Windows and doors elements | Y5=0.7356X1+0.7456X2 |

Thus, five models of architectural and structural components have been got, which represent its elements and by using these equations we can obtain a deterioration model that expresses architectural and structural components such that the number of variables is equal to the number of elements. Where the value of (Y1, Y2, Y3, Y4, Y5) is a constants or weighting coefficients of elements of the architectural and structural components have been obtained from deterioration model of architectural and structural elements, while (L1, L2, L3, L4, L5) is a supervisor's evaluations of the condition of these (5) elements.

### 3.3. Application of Deterioration Models on Case Study Project

The case study project considered one of the main building in Diyala governorate. It consists of three main offices (Diyala Buildings Directorate, Diyala Housing Department, Roads and Bridges Directorate). Each office has a floor, The total built up area is 950 $m^2$ with 27 rooms in each one.

To confirm the validity and reliability of the deterioration models which have been created in the previous paragraphs, these models have been applied on case study project, evaluation of the engineer supervising on maintenance work was compensated in the these models, In this way, deterioration models were achieved for all components of case study project. For example, by compensated in the deterioration model of roofs isolation element as follows in Equation 3:

$$Y3=0.5332\times3+0.6268\times1+0.4856\times3$$
$$Y3=3.68 \tag{3}$$

The value was rating from (15), where this equation have four values of X, Each was evaluated from (5) ratings marks. This value is rating from (15), to convert this value to a percentage has been divided it by (15).

Y3=4.17/15

Y3=24.5%

In a similar way deterioration models of other building elements have been got as illustrated in Table 6.

**Table 6. Deterioration model for structural and architectural components of case study project**

| Building elements | Maintenance supervisors evaluations | | | | | | Deterioration model value |
|---|---|---|---|---|---|---|---|
| | x1 | x2 | x3 | x4 | x5 | x6 | |
| Walls and ceilings element | 2 | 1 | 3 | 2 | 4 | 2 | 27.8% |
| Structure element | 4 | 2 | 4 | 4 | | | 36.7% |
| Roofs isolation element | 3 | 1 | 3 | | | | 24.5% |
| Floors, ceilings, and stairs coating | 3 | 2 | 3 | 3 | | | 38.4% |
| Windows and doors elements | 3 | 3 | | | | | 44% |
| **deterioration model for structural and architectural components is Z1=0.278L1+0.3895L2+0.245L3+0.384L4+0.37L5** | | | | | | | |

### 3.4. Discussion of deterioration model for architectural and structural components

The evaluation paper that have been adopted through the building elements condition evaluation, it consist of (5) grade ranging from (5) to (1), grade (1) reflects a highly deteriorated status of the element. Thus, the higher grade, the better component. Consequently, the lower deterioration model value will give greater indication of the deterioration of the element condition and its requirement for maintenance work.

As shown in previous table, the deterioration model of roofs isolation element of case study was (24.5%) it was the most architectural and structural elements are urgent for preventive or corrective maintenance. This corresponds to the case study reality which suffers from the expansion joints damage, leakage of water from some area of building roof and some cracks on the roof concrete tiles. The second element in terms of importance is the walls and ceilings element, its deterioration model was (27.8%) where this element extremely suffers from bricks effloresces and plastering falling, plaster crack, and delamination due to high dampness. The third element in degree of importance was structural element with deterioration model (38.95%). The two lowest important element were floors, ceilings, and stairs coating and windows and doors elements with deterioration model value (38.4% and 44%) as these two elements were relatively in good condition as compared to other elements, repair of these two elements can be delayed in the deficiency of the necessary maintenance budget.

## 4. Conclusion

Based on the results obtained from the research, research conclusions are extracted as following:

Currently, in all Iraqi building, it was adopting a corrective maintenance approach in maintaining building rather than proper maintenance management approaches (preventive, predictive), this affects negatively on the quality and cost of building maintenance. In addition, lack of proper and specific maintenance–related documentation methods.

The study proposed approach to develop the building maintenance management by using deterioration models which consists of different routes as follows:

- The building have been divided into components and elements.
- Determining the most important architectural and structural maintenance items of the buildings.
- Deterioration models for architectural and structural components have been obtained by linking the rating of element condition and the maintenance item importance, then application it on the case study project.
- The most important building elements that need to be maintained have been identified according to the maintenance budget availability.

This researcher recommends which includes adopting deterioration models in building maintenance management for the following reasons:

- Quick assessment of building condition.
- Predicting of the required budget for maintenance and distributing it according items priority.
- Considered as a scientific tool which assist in development a plan to provide next maintenance requirements.

## 5. Conflicts of Interest

The authors declare no conflict of interest.

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