Airport buildings maintenance
Maintenance forecast program based on the intervention history

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ABSTRACT

The airport buildings maintenance is a subject that has not been studied in depth because it has specific characteristics. The current work developed in this area came from the entities in charge of this type of structures. This thesis studies this subject, beginning with an approach to the various types of maintenance and followed by an analysis of various models of current maintenance management.

In order to develop the work on this topic, this thesis presents a maintenance management model specifically created for airport buildings. This model includes buildings at the design state, in use and capable of rehabilitation and all the different types of existing maintenance (proactive and reactive). The full application of the model allows the development of a comprehensive maintenance manual for the whole complex, which aims to fulfill all the requirements of the maintenance manager.

The proposed model is applied on two buildings, a Fire Department and a Cargo Terminal at the international Lisbon and Faro airports, respectively. For these buildings the major anomalies were identified and ten years maintenance plan and costs were predicted.

The airport buildings maintenance is a subject that is not deeply studied because it contains specific structures with particular characteristics. Few investigations are developed in this area and originate from the entities in charge of this type of structures.

KEYWORDS

Maintenance management; Maintenance costs; Scheduling activities; Maintenance manager; Airport complexes.

INTRODUCTION

The airport buildings maintenance is a subject that is not deeply studied because it contains specific structures with particular characteristics. Few investigations are developed in this area and originate from the entities in charge of this type of structures.

The dissertation objectives are:

- Develop a management maintenance model focus on airport buildings with the following items:
  - Different procedures for different scenarios guide available for the maintenance management responsible;
  - Inspection sheets for this type of building;
Develop a hierarchy formula to list the maintenance action;
Information needed to be inserted into the forecast maintenance action program;
Procedures for costs forecasting.

Apply the management model to airport buildings with the objective of producing several documents that can be part of the maintenance plans:
- Building anomalies identification;
- 10 years maintenance forecast program;
- Procedures for the maintenance/interventional costs forecast.

THE MAINTENANCE AND THE MANAGEMENT MODELS

The dissertation refers to this subject, beginning with history views of the subject and its origin. According to the ISO 15686-1 (2000) the maintenance is a combination of all the administrative and technical actions that allow the buildings and their elements to produce a good performance during their lifetime.

The maintenance is divided into two large groups: reactive and proactive. In the reactive case the anomalies repairing action occurs after the element degradation mechanism (FLORES-COLEN, 2008). It can be also considered as a reaction to a reported problem.

The proactive is split into preventive and predictive maintenance. The preventive goal is to plan actions before the anomaly or defect happen. On the other hand the predictive maintenance plans inspections that allow verification of the elements condition (FLORES, 2002).

The introduction of maintenance procedures from project phase allows a drastic reduction in the building maintenance costs during the exploration phase, as shown with the Sitter law for concrete elements (MAGALHÃES, 2008). Sitter's law relates the intervention costs, project phases, execution and proactive maintenance (BARROS, 2008). This law demonstrates that the later the maintenance is started bigger the costs associated with the intervention will be. It is essential to start maintenance in the premature construction phase, the conception phase.

The phase of the use of the building is the longest and more cost associated. This is the reason why it is necessary to do the adequate and appropriate planning of the long term maintenance actions with the objective of avoiding reactive actions and inadequate procedures to solve problems in the building. The adoption of preventive maintenance actions have less costs long term and is the one that assures more quality and element functionality during the building’s lifetime.

The building’s lifetime is defined as the time period after the construction where the building and it’s elements equal or exceed the minimum performance request (ISO 15686-1, 2000, cited by ALVES, 2008). Remaining lifetime function is also a concept applied to the elements that are in use and is the difference between the building’s estimated operational life and the remaining service time.

An annual maintenance cost budget can be calculated as a percentage of the construction price related to its age. MARTEINSSON and JÓNSSON (1999), did a study of 220 buildings in Reykjavik, Iceland, with the objective to obtain the value of the annual maintenance related to the building’s age and with the construction price as a reference.
The investigators concluded that the older the building the higher the average annual costs of the maintenance activities. For example a 50 year old building has approximately 2% of the initial construction price in annual maintenance costs.

To smooth the inspection and data collection, it is necessary to split the building in elements. These are named elements on which maintenance can be performed (EFM), because the overall building response to the pathologic stimulus is not an individual process but a result of the interaction between all elements of the chain effect (RODRIGUES, 1989).

For good management it is necessary to schedule maintenance with the objective of keeping the buildings in good state of conservation. For that it is necessary to follow a model that has the possibility to do provisional programs adequate to the reality of the building in study (FLORES, 2002). Due to the specific airport buildings demands, it was decided to study maintenance management models that have the majority of the following base factors:

- Possibility to be used in any building type;
- Adequate execution of maintenance work;
- Elements monitoring degradation state;
- With project phase application.

The models studied in the dissertation have been:

- SIM – Sistema integrado de manutenção;
- Terotecologia;
- EUT – Eindhoven University of Technology.

The studied models of management possess diverse inlaid methodologies, which have been grouped according to the type of results that they supply. The studied methods in the dissertation are the following:

- Methods of evaluation on the basis of the degradation state:
  - MAEC – Método de avaliação do estado de conservação de edifícios;
  - EPIQR - Energy Performance Indoor Environment Quality Retrofit and TOBUS - Tool for Selecting Office Building Upgrading Solutions;
  - MEAREH – Metodologia exigencial aplicada à reabilitação de edifícios de habitação.

- Methods of risk analysis:
  - Failure Mode and Effect Analysis (FMEA) e Failure mode, effects, and criticality analysis (FMECA);
  - Reliability Centred Maintenance (RCM).

- Estimated forecast periods for maintenance work during both its expected lifetime and remaining lifetime:
  - “SIMULA” program;
  - Factor method;
  - MEDIC - Méthode d’Évaluation de scénarios de dégradation probables d’investissements correspondants;
  - MEBI - Méthode d’Evaluation de Budgets d’Investissements.

- Priority methods of intervention:
  - Roué’s formula;
  - Decisions with multiple objectives;
  - Método PIM-CC.
AIRPORT BUILDINGS MAINTENANCE

Airport building maintenance is an all-embracing theme. These complexes are divided into several areas which lead engineers to take distinct measures according to the type of building. Terminals (passengers and cargo), runways, taxiways and ramp, maintenance hangars, fire department and radar, among others, are examples of airport buildings.

There are other structures which, even though they are not airport buildings, can still coexist with them (i.e. office buildings, hotels, car parks, railroad stations, bus stations, among others).

All the singular characteristics of an airport complex lead to creating very particular models of maintenance management. Generally speaking, airports have their own maintenance teams for specific works, but sometimes it is necessary to address external companies who can intervene in restricted access areas, or better solve a more difficult task.

The existence of buildings in various states of repair and various uses, in the same airport, is due to the fact that these buildings cannot be relocated due to lack of space (due to financial, social or logistic factors). Hence it becomes necessary to build or adapt existent structures inside the available space to answer various demands.

In an airport complex there are round the clock services e.g. control tower, fire station, emergency situation response, runways and others. The closure of any of these structures leads to the shutdown of airport operations (mainly take off and landing of aircraft). Any maintenance action to be taken must also take these factors into consideration.

METHODOLOGY DEVELOPED IN THE DISSERTATION

In the present work is a management model built from scratch to airport complex. The model considers the buildings in the design phase, in use and capacity for rehabilitation, encompassing different types of maintenance, proactive and reactive. The model created (figure 1) intends to meet all kinds of requests that the maintenance manager may face.

Equation 1 was developed for the scheduling of operations in the program for the results of this calculation also allows an “extra service time” for maintenance source elements beyond its useful life but which are in good condition. The results of equation 1, was proposed to schedule actions for elements within the lifetime, according to Table 1.

\[
INM_i = IEP \times (17,2EDE + 2,5EL + 2,33EFR + 0,33AM + 3SU + 2,33IE + 0,5PO + 0,8PD) - 29
\]

Caption:
INM = Index of maintenance needs for the element i;
IEP = Importance of facility;
EDE = The element's degradation level;
EL = Long-term consequences of a defective element;
EFR = Consequences in case of a faulty/defective;
AM = Easy access to perform maintenance;
SU = User safety;
IE = Importance of the element within the building;
PO = Occurrence probability;
PD = Detection probability.

Elements that have exceeded their useful life, but according to the formulation developed, are in good condition may continue to perform their functions without being replaced, proposing to estimate the “extra service time”, explained in Table 2.
Table 1 – Suggested stages of action for elements in their lifetime.

<table>
<thead>
<tr>
<th>0% - 65%</th>
<th>66% - 79%</th>
<th>80% - 99%</th>
<th>100% - 120%</th>
</tr>
</thead>
<tbody>
<tr>
<td>It does not need any other action aside from the planned maintenance program.</td>
<td>Maintenance needs to be performed within a year.</td>
<td>Maintenance needs to be performed within a six-month.</td>
<td>Maintenance needs to be performed within a three-month.</td>
</tr>
</tbody>
</table>

Table 2 – Estimation of the “extra lifetime” for elements whose lifetime is over.

<table>
<thead>
<tr>
<th>&lt;10%</th>
<th>10% - 20%</th>
<th>21% - 30%</th>
<th>31% - 40%</th>
<th>41% - 50%</th>
<th>51% - 60%</th>
<th>61% - 65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,7xVU</td>
<td>0,6xVU</td>
<td>0,5xVU</td>
<td>0,4xVU</td>
<td>0,3xVU</td>
<td>0,2xVU</td>
<td>0,1xVU</td>
</tr>
</tbody>
</table>

VU refers to lifetime.

You should calculate the “extra lifetime” based on the lifetime of the element (VU) and “Index of the element’s maintenance needs (INM)” as this reflects its conservation. It is thus proposed an inverse relationship between the INM, and the extra service time, i.e. the lower the INM, the greater the extra service time assigned to the element. The ratio is 10%, i.e. below 65%, 10% is added for extra service life to the element, for each 10% less in the INM. The goal is, the better the state of the element, the longer it will prevail in service, not money being spent replacing an element that can fulfill its function for some time.

To carry out the cost estimates the “life cycle costing (LCC)” is adopted because you can apply this method at any stage of life of the structure.

To use this method it is necessary to know five types of information, four on each element type of the building is the fifth common to them all:
  1 - Program for the maintenance actions;
  2 - Replacement price in year 0 (year to apply the model);
  3 - Ratios of actions predictive and preventive maintenance on the replacement cost in year 0;
  4 - Number;
  5 - Discount rate (used to adjust cash flows to present value) and real price escalation rate.

Based on the information gathered, it is possible to realize the anticipated costs of maintaining a building over the long term, using the technique LCC. This technique provides a "Present Value" for each year, and an "Annual Equivalent Value" which represents the average amount spent annually for maintenance.

**PROPOSED APPLICATION METHOD FOR TWO STUDIES CASES**

The application to the proposed model is the methodology developed and tested in two buildings, the Fire department at Lisbon Airport and the Cargo terminal at Faro Airport. For these buildings the major anomalies were identified and a ten year maintenance plan and forecast costs were estimated.

The fire station at Lisbon Airport was approved on 05/12/1997 and construction concluded on 20/10/1999. It has a total working area of 1780m², divided on two floors. In terms of airport operations this building is of critical importance, in case of emergency, this is where the emergency response team and relevant equipment are based, some areas of this structure must be constantly operational. It is a multipurpose building containing different areas for different purposes.
A ten year maintenance plan was developed along with the relevant estimated costs, presented in table 3 and figure 2. To calculate the costs the discount rate of 7% and the real price escalation rate of 1.5% were applied.

Table 3 – Estimated costs for 10 year maintenance.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fire Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>22.845€</td>
</tr>
<tr>
<td>2012</td>
<td>35.238€</td>
</tr>
<tr>
<td>2013</td>
<td>8.964€</td>
</tr>
<tr>
<td>2014</td>
<td>37.637€</td>
</tr>
<tr>
<td>2015</td>
<td>19.432€</td>
</tr>
<tr>
<td>2016</td>
<td>16.068€</td>
</tr>
<tr>
<td>2017</td>
<td>25.302€</td>
</tr>
<tr>
<td>2018</td>
<td>8.824€</td>
</tr>
<tr>
<td>2019</td>
<td>53.448€</td>
</tr>
<tr>
<td>2020</td>
<td>12.253€</td>
</tr>
<tr>
<td>2021</td>
<td>8.252€</td>
</tr>
</tbody>
</table>

Figure 2 – Graphic indicating the estimated costs for 10 year maintenance and the average yearly cost.

The cargo terminal was constructed in 1977, possessing a working area of approximately 615m², divided on two floors. On the ground floor are the cargo warehouses along with the respective administrative area, while customs is situated on the first floor having been modernized in 2008. In terms of airport operations this area is important as it deals with all cargo except passenger luggage and it also receives international cargo via customs.

A ten year maintenance plan was developed along with the relevant estimated costs, presented in table 4 and figure 3. The taxes applied for estimated costs are the same as those of the fire station.
Table 4 – Estimated costs for 10 year maintenance.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cargo terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>1.641€</td>
</tr>
<tr>
<td>2012</td>
<td>79.288€</td>
</tr>
<tr>
<td>2013</td>
<td>7.210€</td>
</tr>
<tr>
<td>2014</td>
<td>6.445€</td>
</tr>
<tr>
<td>2015</td>
<td>28.394€</td>
</tr>
<tr>
<td>2016</td>
<td>7.440€</td>
</tr>
<tr>
<td>2017</td>
<td>6.383€</td>
</tr>
<tr>
<td>2018</td>
<td>25.026€</td>
</tr>
<tr>
<td>2019</td>
<td>1.629€</td>
</tr>
<tr>
<td>2020</td>
<td>26.819€</td>
</tr>
<tr>
<td>2021</td>
<td>7.201€</td>
</tr>
</tbody>
</table>

Figure 3 – Graphic indicating the estimated costs for 10 year maintenance and the average yearly cost.

CRITICAL ANALYSIS OF THE RESULTS

The application of the maintenance management model created was implemented without difficulty on the case studies. However it was found that its application is both laborious and long, since each building has been subject to at least two visits, where on the first an inspection form of type 1 was completed and type 2 and 3 forms were completed on the second visit. The software used for the calculation of the Index of the element's maintenance needs \( (\text{INM}_i) \) was Microsoft Excel, which revealed to be suitable for obtaining the required results.

The creation of foreseeable maintenance programs and cost estimates were also made on the same software, where the tables obtained, namely for Lisbon airport, were of considerable size, as schedules were made on a monthly basis for 10 years.
However, analyzing the schedule for maintenance actions, it appears to be quite useful for the manager, as it anticipates the short-term maintenance actions (maximum of 1 year) for the most critical elements and plans the actions in its appropriate times for the remaining. Furthermore, to the elements whose life span has ended, and still show a good state of preservation, its continued usage was predicted, according to the Index of the element's maintenance needs (INM) presented. The model contemplates at an early stage, the connection between the planned actions and the teams needed for the intervention, thus facilitating the work of the manager.

Regarding cost estimates, these were based on planned actions, providing the values that should be spent on maintenance each year for a period of 10 years as well as an average value calculated on the same. The values obtained seem credible, ranging from 1% to 3% of the construction value, a range that is mentioned in the theory on this matter and that should be considered in annual expenditure, on proactive maintenance actions.

**FINAL CONCLUSIONS**

The adoption of a proper system in the maintenance management is essential to ensure a good state of conservation of the buildings, guaranteeing at first stage a proper and timely precised maintenance on a building, but also a reduction of the long-term costs. This philosophy when applied to complex airports is even more of utmost importance, because of the high indices of requirements that are expected.

The creation of a full maintenance management model, guiding the maintenance manager in the procedures to be taken in different situations, proved to be quite important, since it showed the path to be taken into account in drawing up the documents focused throughout this thesis.

It is important to note that the model was built to take into account the various entities and documents (resource management, cost management and action records), which can help the maintenance manager taking decisions. Only by exchanging information is it possible to get more accurate data, thus enabling the adoption of the more efficient maintenance actions.

The three inspection forms drawn up to perform the visual inspections have allowed us to collect all the necessary data of the 839 elements evaluated in both buildings. The data collected were applied to the hierarchy formula previously developed and provided good results.

In order to get the hierarchy formula for the ranking of the actions, several important factors related to complex airports were taken into account. Each factor was calibrated individually, in order to obtain the desired results. The formulation created has two characteristics, which are not present in any of the studied formulas:

- Introduction of the factor “Importance of facility”, which allows to highlight all the elements of a given area of the building;
- Calculation of the “extra lifetime”, for elements which have already completed their useful life, but still are in a good state.

The factor “Importance of facility” allows us to group together the building spaces into three categories depending on their importance. In airport constructions, it is highly important, because there are spaces that are crucial for the good working order of the airport. Closing one of these spaces can lead to the suspension of the airport operations.
The “extra lifetime” results from the need to replace an element when it ceases to perform its functions and not when it ends its useful life. The developed ranking formula determines:

- For elements within their useful life, with “Index of the element’s maintenance needs (INM)“ higher than 66 %, the maximum time of intervention on the element;
- For elements which have ended their useful life and which have an “Index of the element’s maintenance needs (INM)“ lower than 65 %, an “extra lifetime”, i.e., the time that we foresee the elements will continue in use due to their good state of preservation, in spite of their working lives having expired.

It should be noted that the “prediction” only provides indicative periods, as the element may resist more or less than the calculated. It will continue to be inspected during the “extra lifetime”, leading us to updated information on its state of preservation and to the need of replacing it at the time it actually may not perform its functions. The replacement of an element at this stage has two major advantages:

- Take advantage of all the maximum service time;
- Reduce the costs, through the replacement of elements, when they really cease to perform their functions, and not before.

About informations that must be included in the programs of maintenance actions, we shall conclude that the adopted ones were appropriate for the ranking of the works. It should be noted that the developed program has two major advantages:
- Allows updates at each proactive or reactive maintenance operations;
- To each action of scheduled maintenance, there is a team in charge of the same.

The procedures for the foresight of the costs were correct, showing only difficulties in the calculation of the discount rate and real price escalation rate to 10 years, since they vary according to macroeconomic factors, on which no control is possible.

In short, the application of the management model developed on the two airport buildings made it possible to obtain for each one of them, the following documents:

- List of building anomalies;
- A program of forecast maintenance needs for 10 years;
- The estimates of the maintenance costs for 10 years.

The previous documents are part of the maintenance plans for each studied building. We can conclude that all the objectives of this thesis were fulfilled.

REFERENCES


