Performance-Based-Maintenance of Public Facilities: Principles and Implementation

Shohet, I.M.
Construction Management Program
Department of Structural Engineering, Faculty of Engineering Sciences
Ben-Gurion University of the Negev, Beer Sheva 84105, Israel
(e-mail: igals@bgu.ac.il)

Abstract

The performance concept in construction implies that the demands of the buildings are specified according to the outcomes of the process rather than according to prescribed detail of the construction method or the maintenance activity. This concept of specification allows concentrating in the outcomes and leaves flexibility for the contractor and the designer. The study was designed on the following hypothesis: Performance-Based-Contract provides an effective procurement platform for contracting maintenance out due to optimization of the technical solution and savings in inspection and control of the contract. Based upon the above hypothesis a maintenance Performance-Based-Contract was designed for outsourcing of maintenance in the public sector. The principles outlining the contract are as follows: establishment of a maintenance performance model and assessment system, Performance-Based-Contracting model based on contractor's Consultancy-Technical prequalification, combined bidding system using technical-qualitative-price criterion for the selection of the winning bid, definition of clear procedure for the transition of the facilities to the contractor, and establishment of defined performance criteria for the facilities along the term of the contract. The study followed 5-stages: (a) Performance model establishment; (b) Performance-Based-Contract development; (c) Benchmarking the facilities according to performance model; (d) Implementation of PBM (Performance-Based-Maintenance) with emphasis on the assimilation of the concept on both contract parties; and (e) Monitoring and comparison of the performance and cost-effectiveness of maintenance between Performance-Based-Contract and Prescribed based contract. The study depicts that PBM contributes to consistent improvement of 20% in the performance-cost ratio of the facilities compared with conventional unit-price prescribed maintenance contract.

Keywords: performance-based-maintenance, public sector, outsourcing
1. Introduction

The implementation of the performance concept in the building market in Israel started in the 1970’s with the establishment of a comprehensive document of Performance Specifications for Residential Buildings, low-rise as well as high-rise. The guidelines were adopted in 1978 by the Ministry of Housing and Construction as part of their formal guidelines for new construction systems in the public building sector.

The construction industry relies on conventional in-situ concrete structures. Building methods are based on heavy-weight reinforced concrete structures (either cast in-situ or prefabricated). Finishing tasks are industrialized with the use of prefabricated units and components such as curtain-walls, windows, roofing, etc, and the use of in-situ industrialized methods for partitioning, tiling, rendering, cladding etc.

Building Standards, many of them with a performance-based underlining philosophy, are developed and issued nationally and uniquely by the Israel Standardization Institution. Building Regulation, undergoing now a shift to performance-based regulations, are issued and mandated by the Ministry of Interiors.

The procurement and legal practices developed first in the establishment of basic knowledge of physical performance and development of the standards that enables performance specifications. Procurement practices follow 5 typical contractual methods: (1) Traditional contractual arrangement (general contractor); (2) Design-Build contractual arrangement; (3) Professional Construction Management; (4) Build-Operate-Transfer (BOT); and (5) Private-Finance-Initiative (P.F.I.). The following paragraphs review the contractual arrangements and the implementation of Performance Based specifications in these contractual protocols.

1.1 Tender theory

The "compulsory tender law" in Israel implies that a tender be issued for construction, maintenance and operation in the public sector. Three types of tenders are possible: (a) Open public tender; (b) Restricted tender; (c) Framework tender. Open public tender is open for bidders who fulfill pre-qualifications according to contractors' classification, and according to scope of activities in terms of turnover, size, and types of projects. Restricted (close) tender is normally open to a list of selected contractors who are selected on the basis of quality, reputation, accumulated, and validated experience. Framework-tender is a tender for a given period within which the contractor will be required to work (construction, maintenance, etc.) up to a given maximum scope (in terms of budget or sq. m.). Such a contract reduces the need for bids in the case of modular/repetitive projects with similar requirements such as maintenance works.

The documentations for the tender and the contract allow two forms of specifications: (1) prescriptive specifications (closed system); and (2) performance based specifications (open system). Performance
specifications shift the focus of the quality control to the end of the process or the construction of the component. Rather than carrying the quality measures along the execution (quality assurance), quality control is focused on the end of execution, and thus requires sophisticated means of tests such as simulations, or laboratory tests.

The paradigm for the definition of performance specifications construction project follows the following stages (Rosen and Regener, 2005):

(a) Site parameters and their effect on performance;
(b) Legislation – referring to safety, occupational health, and safety regulations, building legislation, and legislations regarding welfare;
(c) Performance definitions – this procedure is adapted to the designation of the building.

1.2 Rationale

The research is designed along the hypothesis that Performance-Based procurement of maintenance provides a flexible procurement system that creates the following advantages: (a) Innovation on the contractor side, (b) higher budget certainty for both parties in the contact; (c) clear qualitative criteria for contract management and thus reduction in the contract overheads. The research hypothesis presumes that Performance-Based-Maintenance (PBM) and Performance-Based-Contracting (PBC) may contribute to higher efficiency, effectiveness and performance of maintenance.

1.3 Objectives

The objectives of the study were as follows:
1. Establish Performance-Based-Contracting methodology for public facilities;
2. Implement the methodology in the Public sector and examine the research hypothesis;
3. Compare the outcomes of PBC with conventional Prescribed Unit-Price maintenance contract and discuss the findings.

1.4 Contribution

The study contributes to insight understanding of the essential phases of the procurement of PBC, as well as for comparative examination between PBC and Conventional Tendering for maintenance of public facilities. Four key phases were established and implemented as follows: Maintenance Performance Model indicating Key Performance Indicators, Performance-Based-Specification indicating the given performance at the beginning of contract, the desired performance along and at the end of the contract and required maintenance policy i.e., preventive maintenance strategy for the critical systems in public facilities. Critical systems in public office facilities identified as: Electric power supply, HVAC, Fire Protection, and Communications.
2. Background

Following is a short review of state-of-the-art of Performance-Based-Maintenance and Maintenance standardization.

2.1 Performance based maintenance

Augenbroe G. and Park, C-S (2005) developed a building performance assessment toolkit in which various technical performance aspects such as energy, lighting, thermal comfort, maintenance and indoor air quality were implemented. The Maintenance Performance Indicator in this model is a Performance-Based model. Damnjanovic, I. and Zhang, Z. (2008) examined the risk in performance based contracts; three parameters were considered in the model: preventive maintenance and rehabilitation strategies, reliability based performance model, and the pricing model. Lisnianski et al. 2008 developed a maintenance costs assessment model for ageing system using piece wise approximation for the increasing rate of failure function, their finding regarding the preferred maintenance policy in ageing mechanical system is that breakdown policy is more cost effective. Lugtigheid et al. 2007 researched the repair policy of mechanical units using finite horizon model, the method was implemented to evaluate the quantification of risk and criticality in maintenance contracts. Criticality of mechanical systems in the context of maintenance contracts was defined in this research as "the increase in expected costs in the contract horizon in the case it fails and the probability that this occurs". Straub, (2007) reviewed the objectives of Performance-Based-Contracting (PBC) for maintenance in the public sector in the Netherlands as follows: achieving budget certainty and cost savings, improving maintenance quality, simplifying contract management, and promoting innovation by maintenance contractors. In 2006 condition assessment for buildings has been implemented in the Netherlands and figured out cost savings of 20% in the public sector (Straub, 2009). Straub and Van Mossel, (2007) further report on the adoption of technical and qualitative requirements for selection of the winning bid in PBC in the maintenance sector in the Netherlands. This brief review elucidates that PBM and PBC are increasingly embedded as advanced maintenance tools.

2.2 Maintenance standardization

2.2.1 Israeli standard

The Israeli standardization in maintenance of built facilities evolved in the past two decades from the British standard BS 8210 (1986). The standard is a prescriptive standard based on preventive maintenance of the mechanical systems. The standard implies the appointment of a facility manager responsible for administering all necessary preventive and breakdown maintenance activities to maintain the building at safe and sustainable condition. The standard does not indicate performance levels by which the building performance may be monitored; furthermore, the standard does not allow any consideration of the performance level of building by the owner of the facility (Israel Standards Institution, 1999, 2002). As the buildings stock in Israel expands in terms of complexity
and variety of performance requirements it is evident that it is needed to develop a performance-based standard.

### 2.2.2 The British standard

The British standard classifies building systems according to two criteria: Life Cycle of the building components and the maintenance policy governing the system's maintenance activities: breakdown, preventive or condition-based. The standard relies on the owner consideration for setting of maintenance policy. It is recommended by the standard that the maintenance policy be determined according to three criteria: life cycle, required maintenance, and the implications of failures to the health and safety of the users (British Standard institution, 1984, 1986, 1992).

### 2.2.3 American standard

The American Standard classifies 9 levels of building maintenance performance levels according to which the owner may select the maintenance policy. The highest level – 9 implies setting of maintenance strategy, allocation of manpower, spare-parts and financial resources, and setting of outsourcing policy. The lowest level – 1 does not imply the implementation of a maintenance strategy neither it requires in-house manpower. Only critical spare parts are required to be available within 48 hours (ASTM E-1670).

This brief review indicates that maintenance standardization is in a transition from prescriptive based specification towards the implementation of the performance concept in building maintenance. Advanced standard such as the ASTM defines serviceability and performance requirements as the outline for maintenance policy setting and requires strategic vision of this policy.

### 3. Method of the study

A two year study was carried out in a sample of six public office facilities located in the district of Tel Aviv. The facilities, serving civil servants and public, are owned by the government and maintained by a contractor that is selected based on a combination of technical-consultancy capabilities (15%), quality of prior maintenance projects (15%), and price (70%). The Total floor area of the buildings is 37,200 sq. m., indicating an average of 6,206 sq.m. The average age of the buildings is 35.5 years representing a relatively aged stock of facilities. The occupancy of the facilities is 116.8 visitors/sq.m. per annum, below the standard of 175 visitors/sq.m. per annum for Israeli public facilities (Shohet and Kot, 2006).

#### 3.1 Performance model

The performance model included six KPIs as follows:
Building Performance Indicator (BPI) – monitors the performance and fitness of use of the building and its systems;

Age Coefficient (AC_y) – indicates the effect of age of the building and systems on the annual maintenance expenditure. Its ranges are between 0.5 and 1.6 in office facilities (Shohet and Kot, 2006);

Occupancy Coefficient (OC_y) – indicates the effect of occupancy on the annual expenditure for maintenance;

Annual Maintenance Expenditure (AME_y) – Represent the actual expenditure for maintenance in a particular year, this includes costs of labour, materials, spare parts, and costs of rehabilitation works required to maintain the building at its designated use.

Maintenance Efficiency Indicator (MEI_y) – indicates the efficiency with which the maintenance is carried out in terms of ratio between the performance of the facility and the Annual Maintenance Expenditure and considering the effects of Age and Occupancy of the facility.

Normalized Annual Maintenance Expenditure (NAME_y) – Expresses the Annual Maintenance Expenditure neutralized from the effects of age and occupancy of the facility and thus allows comparing between facilities at different service conditions. Following is a short review of the three KPIs essential for the description of the analysis in the study.

3.1.1 Building Performance Indicator (BPI)

The BPI, adapted here for office facilities, monitors the physical state and fitness for use of the building and of the different systems in it. 9 principal systems in public office building were defined: Structure, Exterior Envelope, Interior Finishes, Electricity, Water and Sewage, Heating Ventilation and Air Condition (HVAC), Fire Protection, Elevators, and Information and Communications. Each building system’s score, defined as P_k, reflects three composites: its physical state, typical failures or defects, and the maintenance policy. The combination of the aforementioned composites represents the performance level of the system (P_k). The weighting of a building system (W_k) is obtained from the Life Cycle Costs of systems. The BPI is then calculated as follows Eq. (1):

\[ BPI = \sum_{k=1}^{n} P_k \times W_k \]  

BPI can be analyzed as follows (Shohet, 2003):

- BPI > 80 indicates that the state and the performance of the building are good or better;
- 70 < BPI ≤ 80 expresses marginal condition, i.e. some preventive/breakdown maintenance activities must be taken;
- 60 < BPI ≤ 70 reflects deteriorating condition of the building; and
- BPI ≤ 60 means that the building is run-down, i.e. comprehensive rehabilitation must be undertaken to restore the original performance of the building.
3.1.2 Normalized Annual Maintenance Expenditure (NAME)

This KPI is introduced here to neutralise the Annual Maintenance Expenditures from the effects of Age and Occupancy of the facility on the maintenance. NAME is defined as follows:

\[ \text{NAME}_y = \frac{\text{AME}_y}{\text{AC}_y \times \text{OC}_y} \]  \[2\]

Where the \(\text{AME}_y\) is the Annual Maintenance Expenditure [$/sq.m.], \(\text{AC}_y\) is the Age Coefficient for year \(y\), and \(\text{OC}_y\) is the Occupancy Coefficient. The Age and Occupancy coefficients are assessed along the following principles:

- AME\(_{y}\), the constant annual preventive maintenance cost (\(M\)), is coupled with the replacement cost (\(R\)) in the end of a life cycle of each building's components.
- Age Coefficient (AC\(_{y}\)) - The Age Coefficient for year \(y\) is determined as the ratio between a 10 year moving average of the Annual Maintenance Expenditure (AME\(_{y}\)) for the year \(n\), and the average Annual Maintenance Expenditure along the entire building's Life Cycle (\(\text{AME}_{\text{avg}}\)) (Shohet et al. 2003).
- Occupancy Coefficient (OC\(_{y}\)) is assessed on the strength of a three-year study of public facilities in high as against standard occupancy. A 33% increase in annual labor input for maintenance was inspected in the highly occupied facility compared with the standard facility. The Occupancy Coefficient depends on the ratio between the actual occupancy of the building and its designed standard occupancy. The influence of this variable fluctuates between -5% (at low occupancy) and +33% (at high occupancy) of the normative maintenance expenditure, which was calculated to be 2.5% of the reinstatement value of office facilities.

3.1.3 Maintenance Efficiency Indicator (MEI)

This KPI represents the maintenance efficiency expressed by the ratio between NAME and BPI as expressed in Equations [3]:

\[ \text{MEI}_y = \frac{\text{NAME}_y}{\text{BPI}} \times i_p \]  \[3\]

Where the \(\text{MEI}_y\) is the Maintenance Efficiency Indicator for year \(y\), \(i_p\) is the building price index, and BPI is the building performance.

The MEI\(_y\) is taken to be an indicator of the efficiency with which the available means are used. The values of the MEI\(_y\) may vary between 0 and values above it. MEI\(_y\) for public buildings is inferred according to the following categories:

- MEI\(_y\) < 0.24 represents a state in which either the budgetary investment is low or the efficiency of the utilization of maintenance resources is high, or both;
- 0.24 ≤ MEI\(_y\) ≤ 0.36 represents the desirable range of maintenance efficiency with sound correlation between the maintenance resources and the actual performance.
- MEI\(_y\) > 0.36 indicates high inputs relative to the actual performance. Such situation expresses either high expenditure on maintenance or low physical performance or a combination of both.
3.2 Contracting model

Contracting model developed for PBM is designed to address three guidelines:

- Assure the quality and capability of the contractor to provide consultancy and high technical services particularly on the critical systems in public office buildings: Electric power supply, Heating Ventilation and Air Conditioning (HVAC), Fire-Protection, and Communication;

- Provide a clear transparent model for monitoring the performance of the facility, and a common denominator for transferring the facility. This model is used for the establishment of an agreed given performance of the facilities at the beginning of the contract as well as for setting a target performance;

- Simplified budget control that will reduce the uncertainties on both parties of the contract.

3.3 Procurement model

The procurement of maintenance services is Performance Based Contract in which the contractor is committed for provision of maintenance services to meet performance at a predefined agreed level according to the performance model. The procurement is thus set along three guiding outlines:

1. **Given performance** of the facilities at the beginning of the contract;

2. Definition of an agreed **target performance** of the facility at the end of the contract;

3. Combined tender based on **technical-qualitative-price competition**. The selected bid is determined on the strength of a score composed of price (70%), Consultancy-Technical competencies (15%) and quality of prior projects (15%) of the contractor.

3.4 Phases of the study

The study followed 5 stages:

- Establishment of a performance model for maintenance of public office facilities – this stage required the implementation of 4 selected KPIs as core indicators for the performance model of the contract;

- Development and assimilation of the PBC procurement model amongst the contract parties;

- Monitoring of the sample of public facilities under conventional unit-price prescribed maintenance contract – this stage sets the given performance of the facilities for the PBC;

- Implementation of Performance-Based-Contract sustained by Performance model on the sample of public office facilities;
- Comparison of performance and cost effectiveness of the maintenance of the facilities sample between years 2007 and 2008 according to 3 KPIs.

4. Findings

A preliminary field survey of the performance of the facilities was carried out in 2007, during this year the maintenance of the facilities was carried out based on a conventional unit-price prescribed specification. This data was used as a reference data of the maintenance of the buildings under prescribed-based specifications contract. In the end of 2007 a Performance-Based-Contract was developed and in 2008 the maintenance of the facilities was shifted to be carried out along the outline of PBM. Along 2008, the procurement model was assimilated on both sides by quarterly escorting control. The performance of the sample of the facilities was reassessed in the end of 2008 and the performance and effectiveness of the facilities maintenance was compared between the two years.

Table 1 compares between the reference performance of the facilities sample in 2007 under prescribed procurement and in 2008 following the implementation of Performance-Based-Maintenance. The performance of the facilities, assessed according to the BPI, improved in average from 73.6 to 79.8 by the end of 2008. This improvement was consistent in all the facilities in the sample. The average Normalized Annual Expenditure (NAME) was reduced by 16.2% and the Maintenance Efficiency Indicator (MEI) depicts an improvement in efficiency by 20% as well (from 0.42 to 0.33).

Table 1: Summary of KPIs of public office facilities – comparison between 2007 and 2008

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>BPI</th>
<th>NAME [$/sq.m.]</th>
<th>MEI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tel Aviv</td>
<td>2007</td>
<td>74.1</td>
<td>24.74</td>
<td>25.52</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>79.4</td>
<td>25.52</td>
<td>0.32</td>
</tr>
<tr>
<td>Kfar Saba</td>
<td>2007</td>
<td>75.6</td>
<td>32.99</td>
<td>19.09</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>80</td>
<td>19.09</td>
<td>0.24</td>
</tr>
<tr>
<td>Netanya</td>
<td>2007</td>
<td>72.5</td>
<td>14.19</td>
<td>19.69</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>82.1</td>
<td>19.69</td>
<td>0.24</td>
</tr>
<tr>
<td>Ramla</td>
<td>2007</td>
<td>78.1</td>
<td>19.32</td>
<td>27.76</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>83</td>
<td>27.76</td>
<td>0.33</td>
</tr>
<tr>
<td>Rehovot</td>
<td>2007</td>
<td>62.8</td>
<td>28.94</td>
<td>26.79</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>73.8</td>
<td>26.79</td>
<td>0.36</td>
</tr>
<tr>
<td>Ramat Gan</td>
<td>2007</td>
<td>78.5</td>
<td>65.91</td>
<td>37.09</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>80.3</td>
<td>37.09</td>
<td>0.46</td>
</tr>
<tr>
<td>Mean</td>
<td>2007</td>
<td>73.6</td>
<td>31.0</td>
<td>26.0</td>
</tr>
<tr>
<td></td>
<td>2008</td>
<td>79.8</td>
<td>26.0</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Comparison of the BPI (Building Performance Indicator) vs. the NAME (Normalized Annual Maintenance Expenditure) provides insight into the variance in the sample as well as an analytical tool with reference to the normative range of efficiency and maintenance performance. Figures 1 and 2 depict the facilities sample BPI vs. NAME for 2007 and 2008 respectively. It can be seen that after one year of performance-based procurement the facilities sample is found in consistently higher performance and in the normative range of efficiency (MEI=0.33). This may be virtually seen in Figure 2 as 5 out of the 6 facilities are found in the normative range of $0.24\leq MEI \leq 0.36$, while in 2007
only 2 of the facilities were found in the normative range (Figure 1). This means that resource allocation is adapted to the age, occupancy, and the performance of the facilities and no facility suffers from lack of resources.

![Figure 1: BPI Vs. NAME for the public facilities sample – 2007](image1)

![Figure 2: BPI Vs. NAME for the public facilities sample - 2008](image2)

5. Conclusion

The Study followed four stages of implementation of PBM (Figure 3):

- Establishment of a performance model based on Maintenance Key Performance Indicators;

- Performance-Based-Specification: combining preventive maintenance on critical systems and performance-based maintenance in other systems. Critical systems were identified in this
study as systems essential for the continuous performance of office facilities, i.e. Electric power supply, Heating Ventilation and Air Conditioning, Fire Protection, and Information and Communications;

- Establishment of Performance-Based-Contracting, composed of Performance-Based tender, selection of winning bid on a combination of Technical-Qualitative-Price criterion. Amongst these, the capabilities of the contractor to provide maintenance consultancy were at a high order of priority;

- Assimilation of PBM in both parties using escorting inspection;

The key parameters for the success in the implementation of PBM are: Clear procurement model that includes qualification of the contractor capabilities to provide consultancy services, assimilation of the performance model in both parties of the contract: the owner (public agency) and the contractor, and performance monitoring of the facilities. The Key phases of PBC are: technical qualification requirements of the winning bid: this includes setting minimal technical qualifications, combined technical-performance-price criterion for the selected bid, and performance inspection model. The study shows a potential improvement of 20% in the overall performance-cost effectiveness of the implementation of maintenance in PBC.

Figure 3: Performance-Based-Maintenance Key Phases
References


