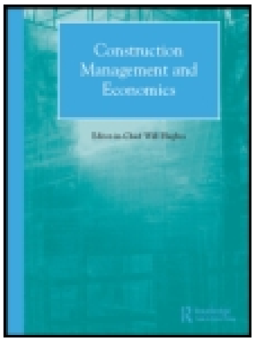

Construction Management & Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

Integrated maintenance monitoring of hospital buildings

Igal M. Shohet , Sarel Lavy-Leibovich & Dany Bar-On

Construction Management and Economics (2003) **21**, 219–228

Spon Press
Taylor & Francis Group

Integrated maintenance monitoring of hospital buildings

IGAL M. SHOHET[1]*, SAREL LAVY-LEIBOVICH[1] and DANY BAR-ON[2]

[1]*National Building Research Institute, Department of Civil and Environmental Engineering, Technion - Israel Institute of Technology, Haifa 32000, Israel*
[2]*Administration for Planning, Development and Construction of Medical Institutions, Ministry of Health, Tel-Aviv-Jaffa, Israel*

Received 26 June 2001; accepted 3 October 2002

The performance of hospital buildings depends to a large degree on the efficiency of maintenance execution. The research objectives were to examine the efficiency of maintenance under alternative maintenance policies and alternative sources of labour (outsourcing vs. in-house). The research focused on main-tenance of hospital buildings as a model for multi-system buildings operating in dynamic environments. The research used a systematic field survey followed by an in-depth statistical analysis. Four key performance indicators (KPIs) were developed. The first, the building performance indicator (BPI), indicates the physical-functional condition of buildings. The second, the manpower sources diagram (MSD), reflects the efficiency of using in-house labour vs. the outsourcing of labour. The third, the maintenance efficiency indicator (MEI), is based on the annual costs of maintenance, the building age coefficient and the building occupancy coefficient. This indicator reflects the efficiency of usage of the resources (labour, outsourcing, materials and spare parts) in maintenance. The fourth indicator deals with the organizational structure of the maintenance division. The proposed KPIs integrate four aspects of hospital facilities management: performance management, composition of labour, efficiency of main-tenance operations and organizational effectiveness. Efficient execution of maintenance management of hospital buildings may be obtained by the simultaneous implementation of the aforementioned KPIs. The proposed indicators may be adapted to other types of facilities, such as office buildings, industrial plants and infrastructure.

Keywords: Facilities management, key performance indicators, life cycle costs, maintenance management, outsourcing, performance

Introduction

The performance of hospital buildings and their components depends to a large degree on continuous and planned periodical maintenance, which challenges owners and facility managers to institute precise planning based on a well-structured maintenance programme. Despite the ever-growing need for lower operational costs, facilities managers must ensure that facilities are constructed and maintained efficiently without compromising safety. Furthermore, decision-makers concerned with the maintenance of hospital buildings are frequently called upon to decide whether maintenance tasks are to be executed by permanent internal personnel (in-house provision) or by external contractors (outsourcing). This paper describes a preliminary development of key performance indicators of performance and maintenance management for the examination of the efficiency of maintenance departments. We discuss the effectiveness of the proposed indicators for the management of large hospital facilities, and their potential implementation in other types of facilities.

*Author for correspondence. E-mail: ishohet@tx.technicon.ac.il

Construction Management and Economics
ISSN 0144-6193 print/ISSN 1446-433X online © 2003 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/0144619032000079734

Overview

Maintenance has become a principal phase in the life cycle of built assets. The high performance of hospital buildings requires that maintenance considerations be taken into account at early stages of design. Maintenance management issues play a major role in the performance of constructed facilities (Amaratunga *et al.*, 2000; Hinks, 2002).

Outsourcing of one or more maintenance services may entail various difficulties, such as various employee-related issues, loss of skills, lack of internal expertise to manage outsourcing contracts, potential loss of control, etc. On the other hand, outsourcing may result in cost savings, improved quality, the transfer of knowledge from outside specialists to internal personnel, etc. (Harris *et al.*, 1998; Atkin and Brooks, 2000; Valence, 2000). Jashapara and Kisters (2000) found that none of the London hospitals studied were interested in input specifications that involved detailing of inputs, such as labour, materials, methods and frequency of inspections. Instead, hospitals favoured output specifications, as they defined the desired performance of the service providers. This enables the latter to utilize their own expertise and to develop innovative approaches to service delivery. Domberger and Jensen (1997) found, in international case studies, that a financial saving of approximately 15% was obtained by the employment of external personnel. Al-Zubaidi and Christer (1997) offer a personnel model that analyses personnel problems in the area of building maintenance and yields the minimum number of professional workers required in order to meet maintenance demands.

Neely and Neathammer's (1991) research focused on American defence facilities, subdividing them into 34 building types (hospital buildings being one of the 34 subcategories). They found that the majority of the maintenance budget in hospitals was spent on interior finishing and interior construction (32%), and on heating, ventilation and air-conditioning (HVAC) (29%). The rest of the budget (39%) was spent on electricity (13%), exterior envelope (13%), water and plumbing (10%), and other electricity systems, such as communications and low-voltage systems (3%).

One method used to assess the efficiency of maintenance proposes seven key performance indicators (KPIs) that provide benchmarks for the asset management (AM) of medical facilities (Pullen *et al.*, 2000). Most of these indicators deal with business and financial performance, and thus are applicable mainly to private-sector medical facilities. These indicators neglect factors such as building performance, intensity of use, sources of personnel, etc. McDougall and Hinks (2000) recognized the fact that it is now generally acknowledged that the financial measures used in practice are inadequate for demonstrating the effectiveness of a workplace. This is the reason the authors emphasized the *functionality* (performance) and *cost effectiveness* in the FM KPIs, compared with *costumer satisfaction, revenue/profit and business growth* in the business KPIs (Hinks, 2002).

While developing the Property Standard Index (PSI), O'shea *et al.* (2000) specified the building's age as one of the factors affecting performance. They concluded with a recommendation to thoroughly investigate the effects of this factor. Barrett (1995) supports the evaluation of user-needs in order to attain better conditions for them. He suggests using a post-occupancy evaluation (POE) process as a management aid.

This survey of prominent studies in the area of facility maintenance management elucidates the need to investigate the role of multiple factors involved in the operation of complex facilities such as hospital buildings.

Research objectives and methodology

The main objective of the present research was to develop key performance indicators for the following parameters: (1) performance management; (2) labour provision for maintenance; (3) maintenance efficiency; and (4) effectiveness of organizational structure. The study focused on the maintenance of hospital buildings in Israel. The research method consisted of a six-stage scheme, namely:

(1) critical literature survey;
(2) field survey, using a structured questionnaire and systematic monitoring of hospital building performance;
(3) statistical analysis of data obtained in the field survey. This analysis included means as well as standard deviations, regression analyses and statistical inference for two samples;
(4) development of quantitative criteria for maintenance of hospital buildings systems, based on the results of the statistical analyses. Some of these criteria were deduced from quantitative analyses (e.g. age coefficient, as explained later in the paper), while other were deduced from findings of statistical results (e.g. occupancy coefficient, as explained later in the paper);
(5) establishment of key performance indicators for the management of hospital buildings; and
(6) application of the indicators to case studies so as to appraise the indicators developed.

The paper describes the first five stages of the research. A follow-up paper describes the implementation of the model to a detailed case study (Lavy-Leibovich and Shohet, 2003).

Field survey and statistical analysis

The field survey covered 17 of the principal hospitals in Israel. Table 1 summarizes the main variables examined in the field survey. The hospitals surveyed include over 700 buildings, which differ considerably in purpose (hospitalization, emergency ward, offices, energy, clinics and laboratories), area and age. The average built-up area was approximately 80 000 sq m, and the average occupancy (defined as the number of patients beds per 1000 sq m) was 8.25. The field survey findings indicated that about half of the annual maintenance expenditure was spent on permanent maintenance staff (51.6%). Over a third of the annual budget was spent on work executed by external contractors (36.7%), while the balance was spent on the acquisition of materials and spare parts (11.7%), excluding energy costs (water, electricity, fuel, etc.) and costs of building renovation or remodelling. The average annual maintenance expenditure (AME) per sq m built-up was $37.2. The mean reinstatement value of hospital buildings was found to be US $1678 per sq m (including management, inspection, overhead costs and VAT). Thus, the average annual maintenance budget constituted only a mere 2.22% of the reinstatement value of the hospital.

Maintenance key performance indicators

The principal objective of this research was to develop quantitative management indicators for the examination of hospital buildings' performance and budgeting of their maintenance activities. The review of previous developments and analyses revealed that key performance indicators for built assets must include the following: performance, manpower, cost-effectiveness and organizational parameters (Domberger and Jensen, 1997; O'shea *et al.*, 2000; Pullen *et al.*, 2000; Hinks, 2002). With this in mind, four indicators were developed:

(1) building performance indicator (BPI) – expresses the physical-functional condition of the building;
(2) manpower sources diagram (MSD) – represents labour composition (in-house vs. outsourcing);
(3) maintenance efficiency indicator (MEI) – evaluates maintenance efficiency in terms of $\frac{\$}{BPIunits * sqm}$; and
(4) managerial span of control (MSC) – reflects organizational effectiveness of maintenance division.

The rationale and the composition of each indicator are discussed below.

Building performance indicator (BPI)

This indicator monitors the physical state and fitness for use of the building and of the different systems within it. The rationale behind the development of this indicator is the need to give each of the building's systems a weighted score, on a scale from 0 to 100, which expresses its physical and functional performance states. In all, 10 principal building systems were defined: skeleton, exterior envelope, interior finishes, electricity, sanitary systems, HVAC, fire protection, elevators, communications and other systems (e.g. medical gases).

The score for each system (denoted Pn) is the sum of three basic elements: the system's physical state, typical failures or defects and the policy governing its maintenance. The combination of these three elements represents the performance level of the entire system (Pn).

Table 1 Summary of the sample characteristics (Israeli hospitals)

Parameter	Mean
Average built-up area (sq m)	79 728
Average number of hospital patients' beds	658.1
Average occupancy (number of beds per 1000 sq m built-up area)	8.25
Average age of hospital buildings	38
Annual materials budget ($US)	347 236 (11.7%)
Annual personnel budget ($US)	1 533 088 (51.6%)
Annual budget for external contractors ($US)	1 088 941 (36.7%)
Total annual maintenance budget ($US)	2 969 265
Mean annual maintenance budget per built-up sq m ($US)	37.20
Annual maintenance budget per bed ($US)	4510
Reinstatement value per built-up sq m ($US)	1678
Average annual maintenance budget (% of reinstatement value)	2.22

Table 2 Weights of hospital building systems (W_n) in BPI

Building system	(W_n) BPI
Skeleton	12.4
Interior finishing	34.8
Exterior envelope	5.3
Fire protection	2.2
Water and waste water	7.6
Elevators	4.1
Electrical systems	12.7
Communications	4.6
HVAC	13.7
Medical gases	2.6

Weighting of each building system (Wn) is accomplished by weighing the contributions of the system's components to the total cost of erection, maintenance and replacement (life cycle costs). Table 2 presents weightings of hospital building systems. Once the systems' functional states have been diagnosed, the BPI is calculated. The BPI is obtained for each system by multiplying its weight by its score (Eq. 1).

$$BPI = \sum_{n=1}^{10} P_n * W_n \tag{1}$$

The BPI value reflects the performance level of the building concerned, according to the following categories:

- BPI>80 indicates that the state of the building, and its resultant performance, are good or better;
- 70<BPI≤80 indicates that the state of the building is such that some of the systems are in marginal condition, i.e. some preventive maintenance measures must be taken;
- 60<BPI≤70 reflects deterioration of the building, i.e. preventive and break-down maintenance activities must be carried out; and
- BPI≤60 means that the building is run-down.

The evaluation methodology is presented in detail in a different article (Shohet, 2003).

Manpower sources diagram (MSD)

This diagram expresses the composition of the maintenance personnel – in-house staff vs. external contractors (outsourcing). An examination of the proportion of maintenance works performed by outsourcing (contractors and external firms) vs. in-house provision shows that hospitals can be divided into two different categories: (1) high-occupancy hospitals (over 10 patient beds per 1000 sq m); and (2) hospitals with standard, or lower, levels of occupancy (up to 10 patient beds per 1000 sq m). The analysis compared total work expenditures and divided them into two categories of labour sources: in-house provision and outsourcing. Figure 1 presents a regression analysis of the relationship between the outsourcing (Y-axis) and in-house provision (X-axis) of maintenance work in standard- or low-occupancy hospitals. The regression analysis shows that when hospital occupancy level is standard or lower, outsourcing results in a saving of approximately 8% ($R^2 = 0.89$). On the other hand, when hospital occupancy levels are higher than planned, as seen in Figure 2, the use of in-house provision leads to a 6% saving in maintenance expenditures ($R^2 = 0.98$). These finding are explained by the fact that under high occupancy conditions the deterioration of some of the hospital building systems is accelerated and a high

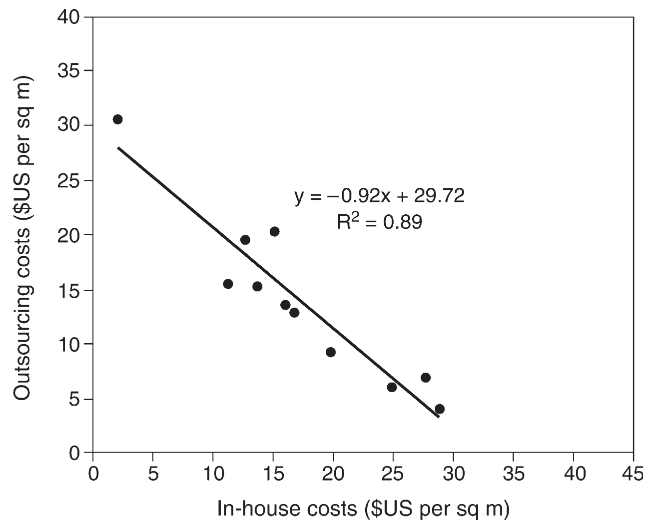

Figure 1 Annual labour expenditures per sq m: outsourcing vs. in-house provision – low level of occupancy

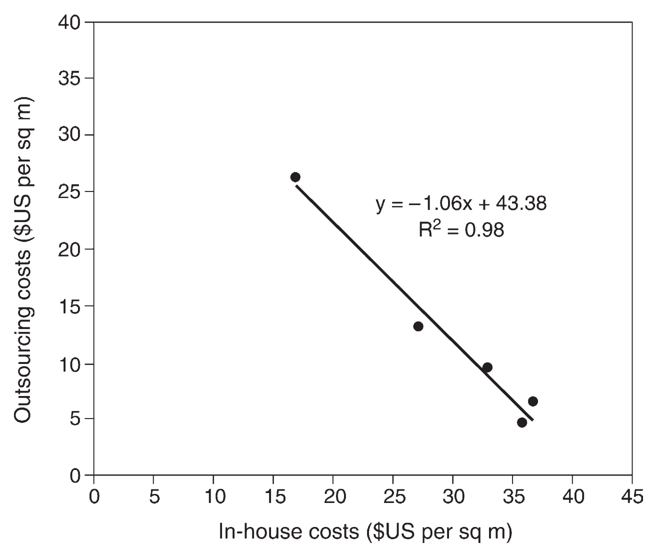

Figure 2 Annual labour expenditures per sq m: outsourcing vs. in-house provision – high level of occupancy

availability of maintenance workers is required for the execution of breakdown maintenance. Therefore, under such conditions, the employment of in-house personnel offers opportunity for savings. This conclusion differs from that of previous studies on the subject (Australian Industry Commission, 1996) and is more complex. At occupancy levels that are standard or lower, there is indeed an advantage and potential savings in the employment of a manpower mix in which the majority of the maintenance workers are external personnel. On the other hand, under high occupancy conditions, there is a clear advantage to a manpower mix in which the majority of personnel are in-house maintenance workers.

Maintenance efficiency indicator (MEI)

This indicator examines the maintenance inputs, as calculated based on the annual maintenance expenditure (AME), with respect to the physical and performance state of the building as expressed by the building performance indicator (BPI). The MEI provides a quantitative indication of the spending efficiency of the available resources. Two additional factors that must be taken into account when calculating the relationship between the budget and the performance of the building are the building's age and occupancy level. The following paragraphs describe the research findings on the effects of these factors:

The effect of the building's age on annual maintenance expenditure

The effect of the building's age was examined by an analysis of the *annual* maintenance costs according to the life cycles of building components, as identified in surveys of energy and construction companies in Israel, and according to additional literary sources (Building Performance Group, 2001).

Annual maintenance costs were determined according to the ongoing cost of maintenance of the building's various components, and the replacement cost of components at the end of their life cycle. An analysis of annual maintenance costs revealed a great deal of fluctuation from year to year, due to the accumulation of a high number of replacements during several specific years (for example, years no. 20, 25, and so on).

In order to curb such fluctuations, the building's age coefficient (AC_y) was calculated according to the value of the moving average (over a period of 10 years) of the ratio of annual maintenance costs for year *y* to the average annual maintenance cost for the building's entire life cycle ($54.2). It was assumed that the building's life service is 75 years, and that a component or system is replaced only if its remaining service period in the building exceeds half of its expected life cycle. Figure 3 and Table 3 present the analysis results. Age Coefficients

Table 3 Age coefficients for hospitalization buildings of various ages

Age of building (years)	Age coefficient AC_y
05	0.55
10	0.67
15	0.90
20	1.18
25	1.33
30	1.22
35	1.20
40	1.30
45	1.22
50	1.05

Figure 3 Age coefficient (AC_y) vs. age of hospital building

range from 0.55 for the first decade to 1.32 for the third and fourth decades. This expresses a high rate of replacement in decades 3 and 4 compared to a low rate of replacements during the first decade.

This coefficient demonstrates the problematic character of maintenance budgeting of complex buildings, such as hospitalization buildings, and the need to investigate this issue in a *systematic, quantitative and scientific* manner. Figure 3 shows that the development of a maintenance budget must be tracked continuously and the budgeting examined both for each specific year separately and in relation to the building's performance.

Effect of occupancy level on annual maintenance expenditure of hospitalization buildings

The effect of the occupancy level on the deterioration rate and annual maintenance results was examined in two ways:

(1) Two identical hospitalization wards located in the same hospitalization building were compared. One ward had an occupancy level of 133% of the standard occupancy rate (13.3 beds per 1000 sq m), while the other ward, the control ward, was an identical ward located in the same building with an occupancy level of 10 patient beds per 1000 sq m, which is the planned occupancy rate for such wards. Table 4 presents a comparison of the maintenance inputs for both wards over a period of three years. This comparison indicates that average labour inputs for the over-populated ward were 22.3% higher than for the control ward (standard occupancy conditions).

(2) Maintenance costs for high and low occupancy rates (as high as 133% and as low as 80% of the standard occupancy, respectively) were estimated by quantifying annual maintenance costs according to the life cycles of building components under accelerated deterioration conditions as opposed to moderate deterioration conditions.

The analysis for accelerated deterioration conditions was based on previous findings, which showed a 25% increase in the replacement rate of finishing components and various building systems (Shohet, 1997). The calculation for moderate deterioration conditions was based on a moderate replacement rate of interior finishing components and some of the electro-mechanical systems. It is emphasized that for certain systems no decrease in maintenance expenditures was seen, since the analysis was based on *preventive* maintenance only. We assumed that maintenance of certain systems – such as elevators, and fire extinguishing and detection – would not decrease, since inspection and replacement activities would continue to be executed even under moderate deterioration conditions.

Our analysis showed that the predicted saving, as a result of moderate deterioration under low occupancy conditions, is but 5%. By comparison, according to the same analysis, it was found that maintenance expenditures would increase by about 20% under high-occupancy conditions and accelerated deterioration of finishing components and electro-mechanical systems. This figure is very similar to that found in the labour input analysis (22.3%), so that both results are reinforced.

The occupancy coefficient was therefore determined to be 1.22 (according to actual labour input measurements) under maximal occupancy conditions of 133%, and 0.95 (according to expenditure analysis) for minimal occupancy conditions of 80%. Figure 4 presents the change in the occupancy coefficient as a function of the occupancy rate, according to a simplified model which assumes the existence of a linear relationship between the occupancy coefficient and the occupancy rate under

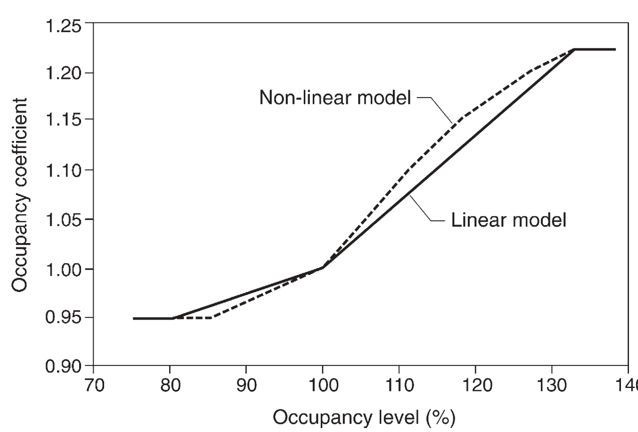

Figure 4 Occupancy coefficient vs. occupancy level

Table 4 Annual maintenance labour input (in hours) per hospital ward for high- and standard-occupancy levels

Ward	Occupancy level (no. of beds per 1000 sq m)			Average annual maintenance labour input (hours)	S.D.
	Standard	Actual	Occupancy rate(%)		
1	10.0	13.3	133	836.2	108.2
2	10.0	10.0	100	683.6	55.5

standard conditions (100% occupancy) and under extreme conditions of high and low occupancies.

In-depth research must be conducted on this issue in order to formulate a more complex and accurate model, such as, for instance, the broken line that represents the second order change of the occupancy coefficient.

Determination of the MEI

Eq. 2 describes the calculation of the maintenance efficiency indicator:

$$MEI = \frac{AME}{AC_y} * \frac{1}{BPI} * \frac{1}{OC} * ic \qquad (2)$$

where MEI is the Maintenance Efficiency Indicator, AME is the actual annual maintenance expenditure, ACy is the age coefficient for year y, BPI is the monitored building performance indicator, OC is the occupancy coefficient, and *ic* is the prices index.

The MEI is considered to be an indication of performance value in terms of maintenance operations. It should be emphasized that the above-mentioned ranges of MEI are subject to change depending on the type of building: The more complicated the building, the wider the range of values, and vice-versa. Figure 5 presents three examples of MEI ranges of efficiency for different types of buildings: Residential buildings (which are the least complicated), office buildings and hospital buildings. The lowest standard efficiency in residential buildings resulted from the lower reinstatement value and from the lower maintenance needs due to the relatively low composition of electro-mechanical systems.

For a hospital maintained at optimal level, we would expect that a BPI of around 90, an annual maintenance expenditure of $54.2 per sq m, an age coefficient of 1.28 (for buildings at an average age of 38), and an occupancy coefficient of 0.96 would yield a MEI value of 0.49. At a BPI level of 70, and an AME level of $37.5 per sq m, an MEI value of 0.44 is obtained. The upper and the lower margins of any range were deduced from the standard deviation of the MEI for the survey population. The MEI values are thus interpreted according to the following categories:

- MEI values below 0.37 represent a state of low budgetary investment or high maintenance resource utilization efficiency, or both;
- $0.37 < MEI \leq 0.52$ represents the desirable situation for a maintenance department, indicating reasonable use of maintenance resources. Nevertheless, the overall effectiveness of maintenance must be assessed using the BPI, which indicates the performance level, the MSD and the MSC (as described hereafter); and
- $MEI > 0.52$ indicates high inputs relative to the actual performance. Such high index values may express high maintenance expenditures, low physical performance or a combination of these two extreme situations.

Managerial span of control (MSC)

A typical hospital maintenance division includes three principal levels:

(1) principal engineer (and a deputy), who serves as the strategic apex of the division;
(2) middle line, which includes the maintenance manager who is in charge of the implementation of break-down maintenance by in-house personnel and preventive maintenance by both in-house crews and outsourcing; and
(3) the operating core, which is composed of various in-house crews that perform the maintenance. In large hospitals, the division may include civil, electrical, HVAC and sanitation engineers who serve as a techno-structure.

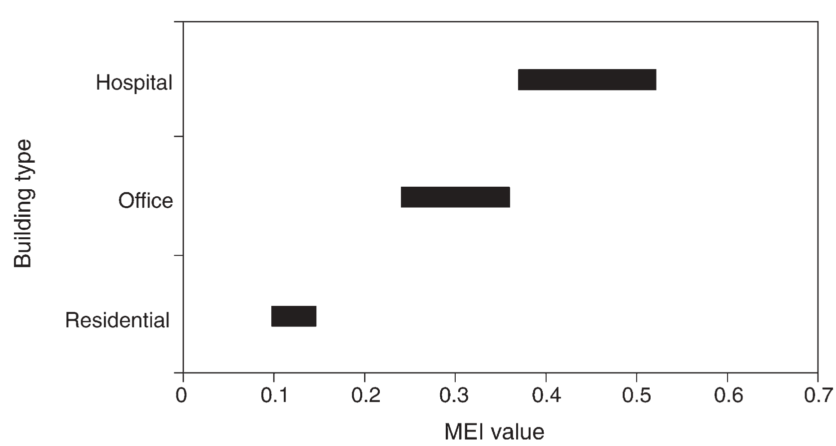

Figure 5 MEI values for standard efficiency in different types of buildings

In all hospitals, two or three employees act as support staff. In large hospitals, the structure of this division falls under the classification of machine bureaucracy, while in small hospitals the organizational structure falls under the category of simple structure. One of the key parameters affecting the effectiveness of organizations in achieving coherence among their component parts is the span of control at key levels such as the strategic apex and the middle line (Mintzberg, 1981, 1989). In a previous study of effective span of control in the construction industry, it was suggested that an optimal span of control for construction foremen in Israel is seven subordinates (Laufer and Shohet, 1991). The managerial span of control (MSC) was examined at two levels, that of the principal engineer and that of the maintenance manager.

This indicator is defined as the ratio between the number of managers and the respective number of personnel directly subordinate to them. The span of control is a managerial parameter, which reflects the ability of a manager(s) to achieve coherence among the parts of the organization. The advantages of a wide span of control are primarily in the savings of overhead expenses, but under certain conditions, a wide span can cause difficulties in control. On the other hand, the advantages of a narrow span of control lie in the low levels of day-to-day co-ordination required and in the fact that the manager has ample time to deal with planning. The overhead expenses, however, are usually high. In certain cases, this indicator, which examines the effectiveness of the organizational structure, helps to identify states of lack of control and communication deficiencies in the organizational and administrative maintenance of hospital facilities. The proposed indicators must be used together in order to obtain a complete diagnosis of the hospital facility maintenance.

The indicators in the survey population

The indicators developed were implemented in a survey of 17 hospitals, which together cover a 1 300 000 sq m area. The indicators were examined at the overall survey level, and were applied in the study of particular cases. Table 5 depicts results for the four key performance indicators obtained from the maintenance survey of public hospitals in Israel. The average BPI was found to be 68.8, a level that projects a deteriorating performance level. This indicator reflects the weighted average of 10 building systems. The maintenance sources diagram shows that 58.5% of the sources of labour were in-house personnel, while only 41.5% of the labour was performed using external contractors. In light of the existing occupancy level (8.25 patient beds per 1000 sq m), and the finding that in relatively low levels of occupancy (as depicted by the occupancy level of the entire survey), one can deduce that a financial and performance benefit could be realized, should the ratio between in-house and outsourcing of maintenance labour be inverted. The average MEI was found to be 0.44, a value that reflects an efficient use of resources considering the relatively low level of expenditure on maintenance ($37.2 per sq m or 2.22% of the reinstatement value), the high average age of buildings in the survey and the occupancy level. The MSC was examined at two levels of management and found to be 3.5 at the principal engineer's level and 7.1 at the maintenance manager's level. The high standard deviations in both variables show, however, that many maintenance divisions in the survey (in large hospitals) have wider spans of control, while others (in small facilities) are narrower.

Table 5 Key performance indicators for public hospitals in Israel

Parameter	Mean (S.D.)
Number of hospitals	17
BPI (building performance indicator)	68.8 (5.3)
AME (annual maintenance expenditure)	37.2 (5.3)
MSD (manpower sources diagram) (in-house)	58.5
MSD (outsourcing)	41.5
MEI (maintenance efficiency indicator)	0.44 (0.07)
MSC (managerial span of control) (principal engineer)	3.5 (2.2)
MSC (maintenance manager)	7.1 (2.5)

Figure 6 presents the sample population on a two dimensional graph, in which the vertical axis represents the BPI level and the horizontal axis represents the normalized annual maintenance expenditure (NAME), which is adjusted for the age of the building (age coefficient – AC_y), and its occupancy level (occupancy coefficient – OC). This variable expresses the level of maintenance expenditure overriding the effects of the building's age and occupancy level. The lines represent equivalent maintenance efficiency indicators (MEI). The graph indicates that 14 of the 17 hospitals covered in the survey had a satisfactory efficiency level of less than 0.50 and enables the identification of facilities with low efficiency of resource utilization, such as the aforementioned facility, at a BPI level of 66 and a NAME value of 43.5 that reflect an MEI level of 0.66.

Conclusion

Hospital engineers, as well as facility managers, are expected to find new ways to improve the comfort, security, safety, energy consumption and cost effectiveness of the buildings they manage and operate. Maintenance engineers in hospital buildings must continuously

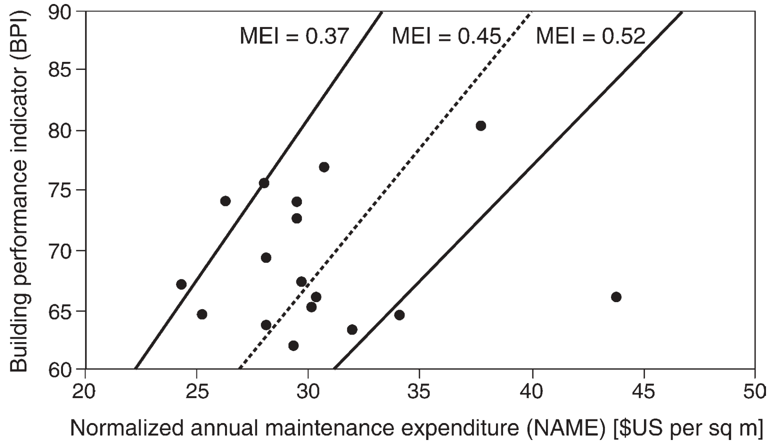

Figure 6 Distribution of BPI vs. the normalized annual maintenance expenditure

contend with different issues, such as maintenance policies, preferred sources of personnel, maintenance organizational effectiveness, and so on. The approach reflected by the indicators developed in the present stage of the study integrates performance, financial, labour and organizational aspects to obtain a systematic evaluation of key parameters affecting the implementation of maintenance as part of the facility management. This paper described the preliminary development of four key performance indicators:

(1) the building performance indicator (BPI) monitors the performance of various building systems;
(2) the manpower sources diagram (MSD) controls and improves the effectiveness of the composition of internal and external labour resources;
(3) the maintenance efficiency indicator (MEI) evaluates the efficiency of resource utilization. This indicator takes four factors into consideration, namely the performance of the building, the level of annual maintenance expenditure, the age of the building and its occupancy level; and
(4) the managerial span of control (MSC) as a parameter of organizational effectiveness in the implementation of the maintenance strategy.

The BPI provides LCC-based performance monitoring procedure. This indicator enables to find out the overall performance of a facility as well as insight into its systems and components. The MSD indicates the composition of manpower. Facilities managers may prefer high employment of outsourcing in low level of occupancy, i.e. low extent of breakdown maintenance, and vice versa. Nevertheless, the employment of outsourcing highly depends upon its availability and reliability. Facilities managers may use the MEI for overall performance-based evaluation of cost-effectiveness of maintenance operations. High MEI values indicate surplus of resources and a need to reduce budgets, while low values of MEI indicate efficient use of resources – however, in extreme cases, it may support provision of additional resources. The MSC provides indication of the organizational effectiveness and may support organizational changes in the maintenance department structures in order to improve its efficiency.

This phase of research led to the conclusion that the following topics warrant additional research:

(1) examination of performance level patterns vs. maintenance level of expenditure;
(2) investigation of additional factors, such as intensity of use, and their effect on maintenance; and
(3) development of additional key performance indicators to reinforce the approach and adapt it to the private hospitals sector.

Acknowledgment

This research was supported by the Israel Ministry of Health.

References

Al-Zubaidi, H. and Christer, A.H. (1997) Maintenance Manpower modeling for a hospital building complex. *European Journal of Operational Research*, **99**, 603–18.

Amaratunga, D., Sarshar, M. and Baldry, D. (2000) Process improvement in Facilities Management: the 'SPICE-FM' approach. Proceedings of CIBW70 International Symposium on Facilities Management and Maintenance, Brisbane, Australia, pp. 161–70.

Atkin, B. and Brooks, A. (2000) *Total Facilities Management*, Blackwell Science, Oxford.

Australian Industry Commission (1996), Competitive Tendering and Contracting by Public Sector Agencies, Report no. 48, Australian Government Publishing Service, Melbourne.

Barrett, P. (1995) *Facilities Management – Towards Best Practice*, Blackwell Science, Oxford.

Building Performance Group (2001) *Building Services Component* Manual, Blackwell Science, Oxford.

Domberger, S. and Jensen, P. (1997) Contracting out by the public sector: theory, evidence, prospects. *Oxford Review of Economic Policy*, **13**(4), 67–78.

Harris, A., Giunipero, L.C. and Hult, G.T.M. (1998) Impact of organizational and contract flexibility on outsourcing contracts. *Industrial Marketing Management*, **27**, 373–84.

Hinks, J. (2002) Lies, damned lies, and KPIs? Moving towards more meaningful performance measurement for FM. Proceedings of the International Research Symposium in Facilities Management, University of Salford, 9–10 April.

Jashapara, A. and Kisters, R.P.H. (2000) Facilities services contracts: the search for effective contract structures for outsourcing agreements in London hospitals. *Proceedings of the CIBW70 International Symposium on Facilities Management and Maintenance*, Brisbane, Australia, pp. 447–54.

Laufer, A. and Shohet, I.M. (1991) Span of control of construction foreman: situational analysis. *Journal of Construction Engineering and Management*, **117**(1), 90–105.

Lavy-Leibovich, S. and Shohet, I. (2003) Integrated maintenance management of hospital buildings – a case study. Submitted to *Construction Management and Economics*.

McDougall, G. and Hinks, J. (2000) Exploring the issues for performance assessment in facilities management. Proceedings of the CIBW70 International Symposium on Facilities Management and Maintenance, Brisbane, Australia, pp. 251–7.

Mintzberg, H. (1981) Organization design: Fashion or fit? *Harvard Business Review*, **59**(1), 103–16.

Mintzberg, H. (1989) *Mintzberg on Management – Inside Our Strange World of Organizations*, Free Press, New York.

Neely, E.S. and Neathammer, R. (1991) Life-cycle maintenance costs by facility use. *Journal of Construction Engineering and Management*, **117**(2), 310–20.

O'Shea, J., Then, D.S. and Tucker, S.N. (2000) The development of a property standard index – Queensland Department of Housing. Proceedings of the CIBW70 International Symposium on Facilities Management and Maintenance, Brisbane, Australia, pp. 49–55.

Pullen, S., Atkinson, D. and Tucker, S. (2000) Improvements in benchmarking the asset management of medical facilities. Proceedings of the CIBW70 International Symposium on Facilities Management and Maintenance, Brisbane, Australia, pp. 265–71.

Shohet, I.M. (1997) *Criteria and Guidelines for maintenance of buildings in Israel Electric*, National Building Research Institute, Technion. (in Hebrew)

Shohet, I.M. (2003) Building evaluation methodology for priority setting of maintenance in hospital buildings, Submitted to *Construction Management and Economics*.

Valence, G. (2000) Strategic Management and outsourcing maintenance of public schools in New South Wales. Proceedings of the CIBW70 International Symposium on Facilities Management and Maintenance, Brisbane, Australia, pp. 439–46.