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Enterprise resource planning system for performance-based-maintenance of clinics

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ABSTRACT

The intensive use of community clinics in recent years has emphasized the importance of non-core activities in facilities supporting patient care. This study poses the following hypotheses: The maintenance and performance of clinics can be monitored with accuracy and reliability by following key performance indicators (KPIs) based on criteria for performance and life cycle costs, and implementation of such principles can contribute both to cost savings and improved performance. A performance-based model was developed for clinic facilities by integrating eight KPIs into an enterprise resource planning (ERP) system for the maintenance of public clinic facilities. The ERP system has an inference engine designed to establish maintenance policy by deductive inference of the clinic's profile and inductive reasoning generated by the KPIs. Implementation of the model in a sample of 42 clinics resulted in increased efficiency (+25%).

1. Introduction

One of the most important attributes of a healthcare organization is its built-assets and their location, performance, strategic maintenance, and performance management. The facilities in a community healthcare system create the capability for healthcare service provision and are crucial for the quality of healthcare services provided. Investment in the development of new facilities, as well as in the maintenance of existing ones, accounts for 3%–4% of the annual turnover of the health maintenance organizations (HMOs) in Israel [1]. In the past, the design, construction, operation, and management of an HMO's buildings was carried out in accordance with short-term guidelines. Global trends such as increased in-patient admissions and the shortening of hospitalization periods has led the HMOs to seek alternative healthcare delivery schemes, such as delivery of healthcare through community clinics [2]. These trends have intensified the pressure on the service conditions at the community clinics, which is reflected by the rising number of patients and visitors [3].

The increased number of in- and out-patient admissions in healthcare facilities can lead to intense wear and tear of building's components and systems, including the electro-mechanical systems, interior finishes, and the exterior envelope. Managing the facilities without considering these service conditions can result in a rapid degradation of the components and increased cost of breakdown maintenance, as well as a reduction in the performance level provided to the public and the staff.

When successfully implemented, the integration between facility management (FM) and enterprise resource planning (ERP) facilitates the better management of the dynamic environment both inside and outside the organization, with consequentially high potential benefits [4]. These systems can be formulated as a tool and programmed to direct numerous functions, including those involving accounting, inventory control, and human resources. The goal of such a system is to facilitate the flow of information between the various business functions [5]. ERP systems are able to integrate previously ignored organizational information, with the administrative function, allowing managers to monitor the performance of all the facilities in real time [6].

The implementation and use of ERP systems in the service sector, and specifically in the healthcare sector, requires a different approach to that used in manufacturing, and may entail various difficulties [7,8]. The present study introduces the integration of a decision-making tool for strategic maintenance and performance management into an ERP system, in order to support the strategic and tactical maintenance management capabilities of the facility managers. The research focus is on the existing gap between the economic and financial aspects of FM and the performance and engineering maintenance management.

2. Literature review

The quality and sustainability of healthcare facilities are crucial factors for the maintenance of the quality of healthcare services. However, in most HMOs, facility managers are not part of the strategic core of

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decision-making [9]. Payne and Rees [10] found the involvement of facility managers in the decision-making processes of healthcare organizations to be essential for the effectiveness of its healthcare services.

The core business of the healthcare sector can be identified as patient care, and the objective of the maintenance of an HMO's clinics must be the assurance of high levels of continuity (availability) and functional safety. These high levels are critical in order to counter or reduce the risk of failure [11].

Gallagher [12] discovered seven significant key success factors that could be associated with FM in the NHS (National Health Service), including strategic maintenance planning and maintenance benchmarking. In addition, Andaleeb [13] indicated five key factors associated with consumer satisfaction with healthcare services, including quality of healthcare facilities.

2.1. Maintenance performance and outsourcing measurement key performance indicators

Outsourcing of one or more maintenance services may entail various difficulties, such as 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, and the transfer of knowledge from outside specialists to internal personnel [14]. Ciarapica et al. [11] reported similar conclusions from a research study on facility management in Italy's healthcare sector. This study showed that, for small hospitals, both the level of performance of maintenance services and cost-effectiveness are higher when internal personnel are employed, whereas the best solution for large hospitals involves the outsourcing of global services. The authors also discovered that the simple transfer of the ownership of the facilities from the public to the private sector could have only limited results in some cases. While there are many potential benefits of outsourcing, the selection of which services to outsource, as well as the selection of the contractors and the ratio between in-house and outsourced personnel must be carefully considered.

Straub and Van Mossel [15] analyzed the problems involved in the performance-based contract selection of contractors for the outsourcing of maintenance jobs. The traditional practice of issuing tenders for maintenance contracts uses a prescriptive and detailed specification of the services required, while performance-based contracts are based on a predefined set of desired performances or predefined service levels, in accordance with the specific needs of the owner of the facilities. The contractor and the owner must define a shared performance model. The successful implementation of a performance-based contract requires that the contractor must act as a maintenance-engineering consultant, providing advice concerning the maintenance strategies and the design of maintenance scenarios, and conducting customer satisfaction surveys.

The benefits of a shift from prescriptive-based contracts to performance-based ones have been analyzed by Straub [16], whose study found that performance-based contracts are on the average 20% less expensive than prescriptive specification ones. The savings can be attributed to the reduced time spent by the owners on the specification and selection phases (where they can predefine performance levels instead of specifying all the various services that must be provided). However, the downside is the amount of time expended prior to the post-contract phase (due to the need for performance measurements that must be carried out at the end of the work).

The implementation of performance-based contracts switches the attention away from the work that has to be carried out and towards the results in term of the predefined targets for the maintenance performance. This has led HMOs to focus on the performance measurement of the maintenance work.

According to a study carried out by Meng and Minogue [17], performance measurement models based on KPIs are considered very effective or effective systems by practitioners. The reasons for this can be defined as follows. KPIs (1) cover multiple perspectives, (2) are relatively easy to use, (3) link performance with objectives and processes, and (4) drive performance improvement and increase client satisfaction. The shortcomings of these models have been identified as involving the difficulties in adjusting the KPIs to meet the changing needs of the organization.

Lavy et al. [18] conducted an extensive literature review of the performance indicators used for facility management and identified the major facility performance measurement practices as benchmarking, balanced scorecard, and KPIs. They also noted that the public or the private nature of the organization influences the relevant type of performance measurement, which should be tailored to the needs of the organization. Public organizations focus on non-profit-oriented performance measurement, for example, government organizations aspire to improve the delivery of goods and services to the public. The study reported a surfeit of KPIs in the literature due to three main reasons: lack of applicability of the KPIs, lack of a holistic approach, and improper categorization.

Muchiri et al. [19] who analyzed the maintenance performance measurement system in 40 Belgian industries, found that there was a low level of satisfaction with the performance measurement system among maintenance managers, and that this was correlated with the low percentage of decisions triggered by the use of the KPIs. The study also pointed to an overall low correlation between the KPIs used to measure performance and the objectives of the maintenance strategy despite the fact that the maintenance indicators should be directly influenced by the maintenance objectives that the organization has designed in accordance with the needs of the firm. This situation indicates an absence of applicability criteria in the process of selection and in the use of the KPIs.

As suggested by Marquez and Gupta [20], the objectives for each level of maintenance management [21] are to transform business priorities into maintenance priorities (strategic level), to determine the proper assignment of resources for the performance of maintenance actions (tactical level), and to ensure the correct execution of the maintenance work (operational level). Van Horenbeek and Pintelon [22] also suggested that KPIs should be developed with a bottom-up approach for each maintenance level, in order to facilitate the creation of a global view of the performance of the facilities. Such a global view of performance would allow maintenance managers to review the tactical and operational levels in order to understand the root cause of problems in the organization and performance of the maintenance work. A similar approach was adopted by Shohet [23] in his proposals for the development of the building performance indicator (BPI). This was designed to facilitate the emergence of a strategic and comprehensive view of the performance of the facilities and permit (a) an effective review of the performance of the components of each system (Pn), (b) the identification of the root cause of each problem, and (c) the establishment of maintenance priorities.

Progress in the understanding of KPIs for healthcare facilities has led to the development of computer-aided decision analysis tools [24] over the past two decades and, more recently, to the creation of facility information management systems [25].

Dukić et al. [26] studied the maintenance cost of 30 residential buildings in Serbia. Their study demonstrated improper management of maintenance, with the subsequent need for many repetitive maintenance activities. The root cause was twofold: inadequate analysis of defects of the buildings and the absence of records concerning the correct maintenance practices. According to the authors, accurate data relating to the building conditions is necessary in order to successfully control building maintenance management. For this purpose, they designed a computer-aided building maintenance program for the collection, selection, and representation of the data in a proper manner. Their approach may be further improved by the development of an additional module that can analyze the data using KPIs and help managers reach conclusions and make recommendations.

2.2. Information technologies and facility management

The progress of IT is the most significant change that has taken place in the FM, resulting in the development of powerful systems for FM and building management. The integration of FM with such systems offers many benefits including cost-savings, faster communication, higher productivity, and increased health and safety [27].

Recent trends are expected to expedite the implementation of computer-aided facility management and FM will be progressively integrated into ERP systems [28]. In particular, a growing use of building information models (BIMs) in healthcare FM is expected [29]. ERP systems can help organizations to generate greater business value, empower employees, and improve customer service [30]. Research in the infrastructure industry [31] as well as in the manufacturing industry [32] shows that the integration of a BIM with an ERP system for performance-based maintenance presents potential economic advantages, and can lead to the introduction of innovative maintenance methods that could improve the performance of the facilities. Others potential benefits of ERP and FM integration identified by Redlein and Zobl [4] are: a decline in inventory, breakthrough reductions in working capital, process optimization, increase in productivity, real-time access to operating and financial data, and cost savings.

Babič et al. [33] analyzed the integration of a BIM with an ERP system for a construction firm in Slovenia. The two problems identified in the study were a lack of common tools for the management of the construction process and the difficulty involved in the integration of this process with others within the construction firm (for example, with the manufacturing of building elements). The study illustrated the importance of common and transparent information exchange within an organization.

The importance of such information exchange was also analyzed by Darmian and Walters [34] and has been highlighted in several additional studies. It should be noted that a large number of organizational information exchanges are still managed manually, resulting in data loss, wasted time and higher costs for the organization.

The assimilation of a BIM process for facility management during the operation and maintenance (O&M) stage in the building industry is still limited. The following factors can be held responsible: lack of awareness of the benefits that can be attained in the O&M phase through the adoption of a BIM process, lack of a standardized definition for data exchange in the O&M phase, lack of clearly defined applications, an information gap between the design stage and the O&M phase, data fragmentation, and the lack of a consolidated database covering the lifecycle of the building [35].

Implementation of a BIM in FM necessitates detailed information about components and equipment, including the service zone, installation date, installation type, maintenance history since completion, and physical properties [35]. The level of details required in a BIM will depend on the level of required functionality. Maintenance and operation require a high level of detail but must deal with incomplete, obsolete or fragmented building information typical of existing buildings. The construction of a detailed model is justified only if the model is additionally used for other functions, such as structural analysis, energy simulation, etc. In such cases, an informational structure and data exchange with the model are necessary to guarantee that there will be effective interoperability between the BIM and other O&M models with no loss of information. With the introduction of the COBie standard [36], stakeholders can store maintenance information in a BIM in a structured way, thereby increasing interoperability. A handover model for the FM was developed by East, Nisbet, and Liebich [37]. The study reported by Volk et al. [35] focused on inadequate research for modelling and on insufficient use of BIMs for FM in existing buildings. They discussed the challenges that will have to be dealt with in future research studies including automation and data capture in the creation of a BIM, the updating and retention of information in the BIM, and the processing and modelling of uncertain data from existing buildings.

As noted by Shen et al. [38], the interoperability of the tools used in architecture, engineering, construction, and facility management (AEC/FM) can be exploited to generate a common data model for the various factors involved in the process, requiring only a single compilation of the building information. For an existing building, the creation of a common data model, such as a detailed BIM, requires a major initial effort. On the other hand, this model can subsequently reduce time and costs for the development of additional models of the building, and can enhance project quality through the elimination of errors and inconsistencies in the data recreation process.

There have been many recent applications of a BIM in FM, and current research is focused on integrating the different management systems of a building in order to support decision-making inside the organization. The main issues in this sector today are poor access to data/information/knowledge, lack of interoperability between the various software programs, and the lack of an integrated view of multiple domains that could support the decision-making process [39].

Lucas et al. [25] developed a BIM-based system that can facilitate the storage of lifecycle information. The BIM-based information framework was applied to management of facility maintenance events, such as planned and unplanned maintenance, in order to reveal safety hazards for patients in hospitals.

Motawa and Almarshad [40] stated that one of the key challenges in FM projects is the need to obtain sufficient information about the products available for each maintenance operation and that lack of information could result in ineffective maintenance in such projects. Building maintenance requires an information system that is able of capturing and retrieving full information about the building's components. Their research study developed a system that incorporates knowledge management principles from case-based reasoning (CBR) into a BIM process, thereby transforming building information modelling into building knowledge modelling.

The use of radiofrequency identification (RFID) networks for the maintenance of assets was analyzed by Ergen et al. [41], whose study demonstrated that RFID networks can improve routine maintenance and inspection activities and reduce unrecorded maintenance activities. The data storage capability of such a network can improve the accuracy and completeness of maintenance data. The reliability of an RFID system in a real-life environment has not yet been proven, as noted in the study by Taneja et al. [42].

3. Rationale, hypotheses, objectives, and method

The research rationale, hypotheses, objectives, and method are presented in this section.

3.1. Research rationale

The integration of FM into IT systems can yield positive results as suggested by Meng [27]. Similarly, using KPIs to integrate maintenance management into an ERP system can guarantee shared, transparent information exchange between FM and core services of the organization [34], using a common database and thereby reducing the risk of information loss [38].

The use of KPIs have various benefits [17]. This research study describes the development of an application by which KPIs are used to assess the maintenance performance of a facility at different managerial levels [22]. The evaluation is based on life cycle principles that are able to control the variable maintenance expenditure during the life of the facility. The proposed model enables the management of different performance levels according to the organizational needs [18,29].

3.2. Research hypotheses

The present research study was developed in accordance with the following hypotheses:

- KPIs based on principles of performance and life cycle costs (LCC) can be used to monitor the maintenance, performance, and effectiveness of clinics, systematically and with a high degree of accuracy and reliability.
- Implementation of these KPIs together with an integrated ERP system can contribute to savings in maintenance expenditure and to improved performance in the clinics.

3.3. Research objectives

The objectives of the present study were as follows:

- Development of a performance-based model for clinic facilities.
- Development and adaptation of a set of key performance indicators for the maintenance and performance management of clinic facilities that would take principles of life cycle costs into account.
- Establishment of a decision-making database for an ERP system for community clinics that could be used for strategic maintenance and for performance management.
- Implementation of a developed ERP system in community clinics and validation of the method.
- Recommendations for further research.

3.4. Research methods

The research was carried out in the following stages:

1. Literature review of maintenance and performance management of clinic facilities.
2. Development and adaptation of the key performance indicators for the clinics. KPIs originally developed for hospital facilities were adapted here for clinics, with adjustments made for the principles of life cycle costs and parameters that are specific for clinics.
3. Questionnaire for data-gathering in the field.
4. Field survey Phase I: preliminary data-gathering and clinic profiling.
5. Use of the inference engine of the ERP system to establish a policy for corrective maintenance and performance management.
6. Use of decision criteria supported by the KPIs, particularly building performance indicator (BPI), maintenance efficiency indicator (MEI), and normalized annual maintenance expenditure (NAME), to implement the corrective maintenance policy.
7. Field survey Phase II regarding implementation of corrective strategy and validation.
8. Validation of the proposed model through the implementation of a corrective maintenance policy according to the diagnosis results provided by the model.
9. Inferential statistical analysis of the results with a Student *t* test.

4. The performance and maintenance model

Previous studies on the topic of hospital facility management found that core KPIs for healthcare FM can be classified into four core domains [3,23]:

Development—age coefficient (AC_y) to adapt the maintenance and performance to the actual age of the facility, occupancy coefficient (OC_y) adapts the occupancy of a healthcare facility to the intensity of use expressed by the occupancy.

Performance—building performance indicator (BPI) indicating the actual performance of the facility.

Cost-effectiveness—indicators that assess the efficiency and cost-effectiveness of the maintenance activities.

Management—maintenance sources diagram: indicating the level of in-house as opposed to outsourced services; managerial span of control (MSC): indicating the effectiveness of the managerial scheme.

The eight KPIs adopted in this study and adapted for clinic use strongly support the above-mentioned four core domains for effective facility management.

4.1. Key performance indicators (KPIs)

The following KPIs were adapted for clinic performance and maintenance management:

1. Age coefficient (AC_y)
2. Density coefficient for patients in the clinic (DC_y)
3. Building performance indicator (BPI)
4. Annual maintenance expenditure (AME)
5. Normalized annual maintenance expenditure (NAME)
6. Maintenance efficiency indicator (MEI)
7. Maintenance sources ratio (MSR)
8. Managerial span of control (MSC)

The following paragraphs briefly describe the guiding principles and rationale behind the selection of the above KPIs. The composition of the indicators is described in detail by Lavy and Shohet [2,43].

4.2. Age coefficient

The age coefficient is defined as a coefficient for the adjustment of maintenance needs to the actual service life of the facility. This indicator reflects the reduction or increase of the maintenance expenditure in accordance with the age of the building and the systems. An age coefficient that expresses the multiplier of the specific year's maintenance activities is calculated using a 10-year moving average of the predicted maintenance based on the life cycle of the building components.

Fig. 1 shows the age coefficient of a clinic with a designated life cycle of 50 years. The AC_y is less than one until the clinic reaches the age of 14 and then reaches the highest value of 1.6 at the age of 26 years.

4.3. Density coefficient of a clinic

The density coefficient expresses the effect of the density of clinic patients on the deterioration of building components. Standard density was defined empirically from the design parameters as 175 patients per square meter per annum and is benchmarked as 100% patient density. The impact of the density of patients on the degradation of building component was deduced from an analysis of the life cycle of the building components, and validated through empirical studies of clinics under different conditions of patient density. The values of the density coefficient as opposed to the relative annual occupancy are presented in Fig. 2.

4.4. Building performance indicator (BPI)

This KPI enables the evaluation of the overall state of a clinic or of a clinic's portfolio, in accordance with the performance of its components and systems. The indicator is defined by a combination of physical condition of the components, frequency of failures affecting the service provided, and preventive maintenance carried out on the system. These factors are used to assess the condition of each system in the building and then, the conditions of the building systems are combined using a weighted sum based on life cycle principles. The method is described in detail in [44].

The desired BPI range is above 80; any system or component with a performance score lower than 70 will require corrective maintenance measures.

The performance condition of each component in each system in the BPI can be used to define priorities in the maintenance actions according to the objectives and priorities of the organization. It is also possible to benchmark the asset's performance in relation to other clinics or

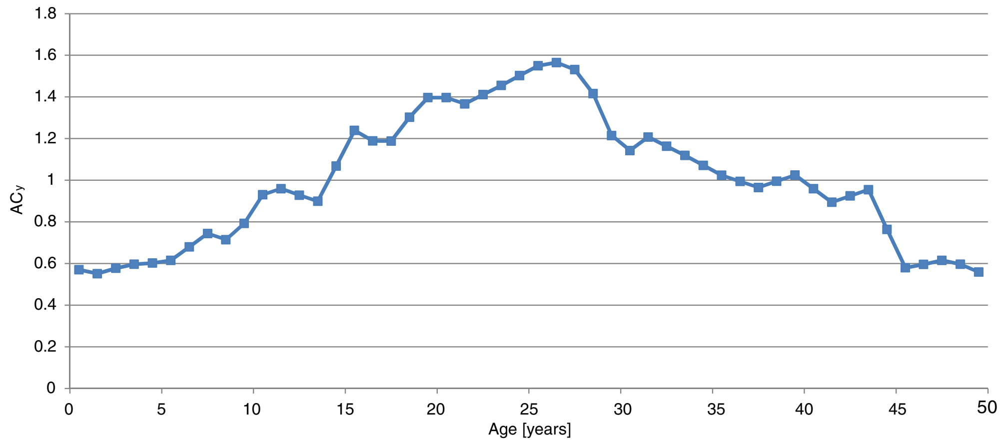

Fig. 1. Age coefficient of clinic facility vs. age of the building.

facilities (inter-organizational benchmarking), and to benchmark the clinic's systems in order to compare the efficiency of the various maintenance crews (intra-organizational benchmarking).

4.5. Annual maintenance expenditure (AME)

This KPI defines the annual maintenance expenditure per built sq.m. It includes the cost of the management staff, materials, labor, spare parts, and outsourcing; excluding cleaning, energy, and security expenditures. It is used to assess the investment in maintenance from an organizational point of view.

4.6. Maintenance efficiency indicator (MEI)

This indicator expresses the investment in maintenance with respect to the clinic's performance and thus reflects the cost-effectiveness of the maintenance activities.

The MEI can be analyzed as a two-dimensional interdependency between BPI and the normalized annual maintenance expenditure (NAME), where NAME expresses the annual maintenance expenditure neutralized from the effect of age (AC_y), and the clinic's patient density (DC_y).

A clinic maintained at the desired level is given a BPI of 100. The average annual maintenance expenditure (AME) per sq.m. was analyzed to be 2.50% of the reinstatement value of a clinic calculated at $1180 per built sq.m. A facility with an age coefficient of 1.00 (the standard), and a density coefficient of 1.00 would obtain an MEI value of 0.30. The upper and lower margins of the desirable range were deduced from the standard deviation of the MEI for the clinic sample population. The MEI values are interpreted according to the categories shown in Table 1.

4.7. Managerial span of control (MSC)

This indicator is defined as the number of subordinates reporting to a given supervisor and reflects the scope of managerial resources invested in the FM department. The MSC expresses the number of employees who are directly subordinate to the manager. The optimal span of control can be defined as six at head-of-organization level, and eight at the maintenance manager level. These standard values were determined based on previous research [45] and were validated empirically in the present research.

4.8. Maintenance sources ratio (MSR)

This KPI expresses the percentage of outsourced maintenance resources compared to the total labor resources allocated for maintenance of the facility.

4.9. Architecture of the ERP system

The decision analysis of the ERP system is composed of three modules: input interface, inference engine, and output interface (Figs. 3 and 4). The input inference database includes data on the clinic facility (history of maintenance, building information data, organizational costs, and performance data), and the clinic conditions database where the service conditions are dependent on the service regime and location factors such as density of users (patients) and distance of the facility from the seashore. A profile of the facility is developed in the system's database with the use of the above-mentioned KPIs and the facility is characterized according to its performance, maintenance efficiency, and the profile of the services provided (outsourcing versus in-house).

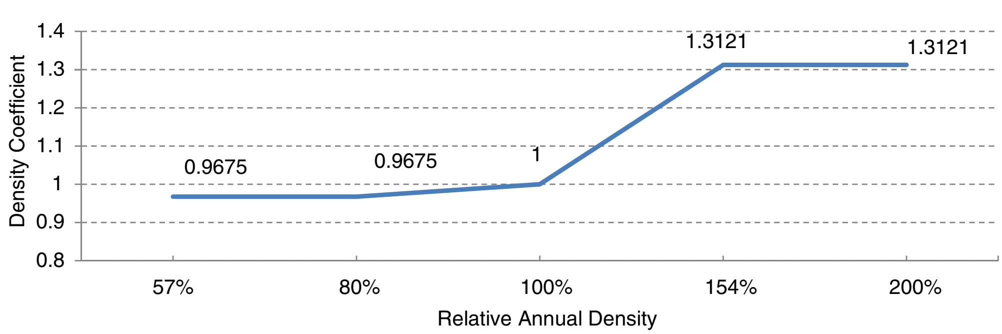

Fig. 2. Density coefficient vs. relative annual occupancy.

Table 1
MEI values.

MEI < 0.24	0.36 ≥ MEI ≥ 0.24	MEI > 0.36
High efficiency	Standard range of efficiency	Low efficiency

Fig. 5 shows an example of an output report from which the ERP user (FM decision-maker) can infer the clinic performance in general and the performance of its systems and components in particular. The ERP generates a detailed report for each system that can be used for performance control and improvement. In this case study, the performance of the clinic is high (BPI = 96). Fig. 6 shows a BPI-MEI report from which the overall performance and cost-effectiveness of the clinic maintenance can be transparently deduced. The clinic is analyzed on a two-scale graph that enables the FM decision-maker to examine the performance of the clinic as well as its cost-effectiveness. In this example, it can be seen that the performance of the clinic is high; however, the cost-effectiveness can be improved as the clinic is found close to the MEI upper marginal boundary (MEI = 0.36). Despite its high performance, a potential 30%–40% savings can be attained under the present conditions by reducing the MEI from the existing level (0.34) to a desired level of 0.24. The analysis of the facility is carried out in two phases. Firstly, clinics are classified according to four categories of performance (high, standard, marginal, and poor) and three categories of efficiency (high, standard-normative, and low). Decisions are then made in accordance with the clinic's maintenance efficiency and performance, and maintenance policy is determined. The inference engine combines effectiveness–performance data with organizational parameters (MSC, NAME, and AME) and enables managers to allocate resources and set the performance target. The inference engine comprises seven stages of diagnosis and analysis:

1. Effects of the clinic's service condition (age and density)
2. Diagnosis of the prevailing performance conditions
3. Actual and normalized annual maintenance expenditure (AME and NAME)
4. Performance cost-effectiveness of the maintenance work (MEI)
5. Managerial effectiveness using the managerial span of control
6. Resource management analysis using maintenance source ratio (MSR)
7. Corrective maintenance policy setting

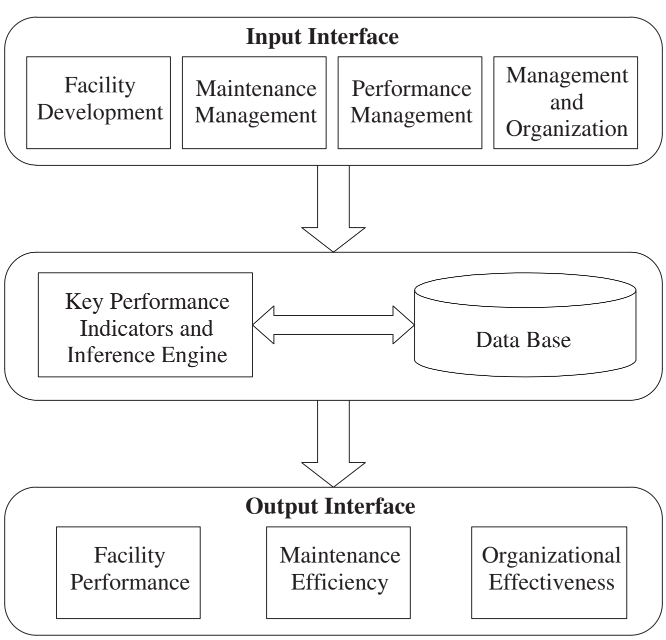

Fig. 3. Architecture of ERP system for clinic facilities.

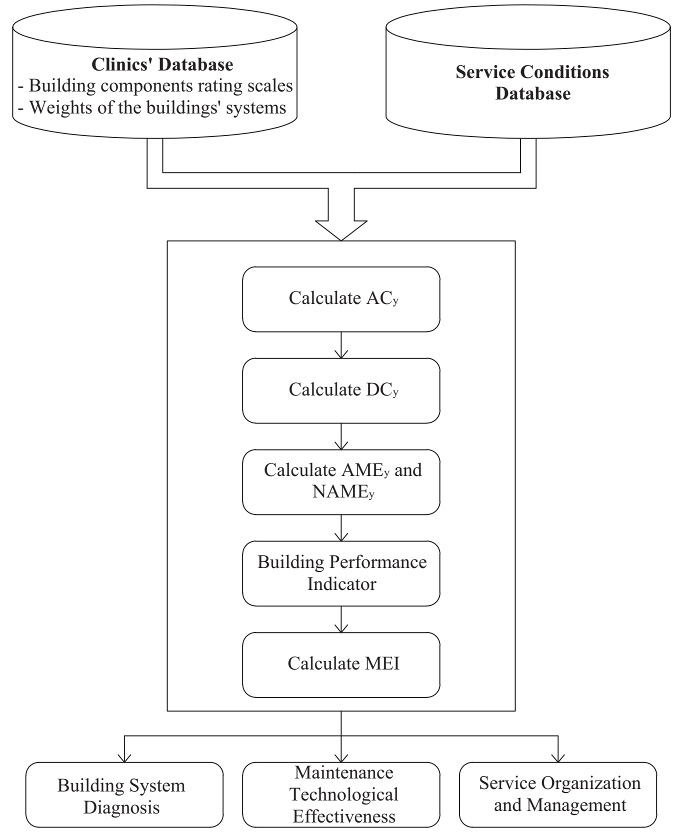

Fig. 4. ERP system: details of the clinic database.

4.10. Implementation and validation

The proposed ERP system was implemented and tested in a two-phase study in clinic facilities. A total of 42 clinics participated in Phases I and II of the study. Following the first stage, a corrective strategic policy was established to improve the MEI, mainly through systems maintenance and cost-effective activities.

5. Results and discussion

From an analysis of the results, the overall performance was improved by more than 5%, while overall costs were reduced by 21%. These two results were achieved by an allocation of resources determined by the cost-effectiveness of the MEI. The rest of the KPIs were not significantly different. The overall effectiveness of resources improved by 25%, as reflected by improved performance. The results for the two phases of the study are shown in Table 2. The higher cost-effectiveness was expressed by savings of 25% in the labor inputs.

A statistical inference analysis was carried out on the obtained data with a 95% confidence interval (see Table 3). The results show that the mean value of BPI in Phase I ranged from 89.2 to 92.8, whereas, in Phase II, it ranged from 94.6 to 96.4, with an improvement of variability of about 50% (Fig. 7). For the NAME, the analysis gave a mean value ranging from $30.40/sq.m. to $42.30/sq.m. in Phase I, and from $23.60/sq.m to $33.50/sq.m. in Phase II, with an improvement of variability higher than 16% (Fig. 8). The mean overall performance of the clinics, as defined by the MEI, ranged from 0.33 to 0.46 in Phase I and from 0.25 to 0.35 in Phase II, with a decrease of variability higher than 20% (Fig. 9).

6. Conclusions

This manuscript presents a theoretical scientific infrastructure based on a framework of KPIs that was used to develop a 3-module ERP system for the maintenance of clinic facilities. This depends on a

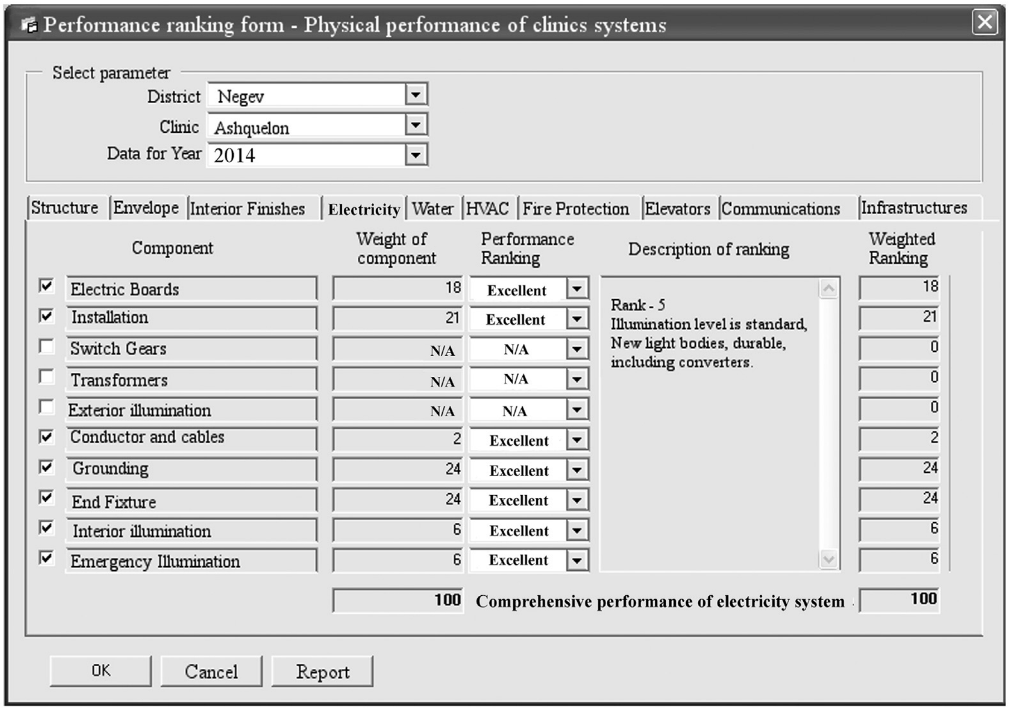

Fig. 5. Example of a performance ranking form for the electricity system of a clinic.

framework of KPIs selected and adapted specifically for clinic facilities. These were chosen to enable an evaluation of the following:

- Analysis of the clinic's performance
- Maintenance efficiency analysis
- Derivation of maintenance policy of the systems at the clinic facility.

The proposed ERP system is generic because it is based on three principles of reasoning: (a) performance benchmarking, (b) adjustment of the maintenance expenditures in accordance with the effects of age and other service conditions, such as patient density, and (c) benchmarking of maintenance efficiency. The system was validated by the application of the above principles in a two-phase pilot study, which showed an

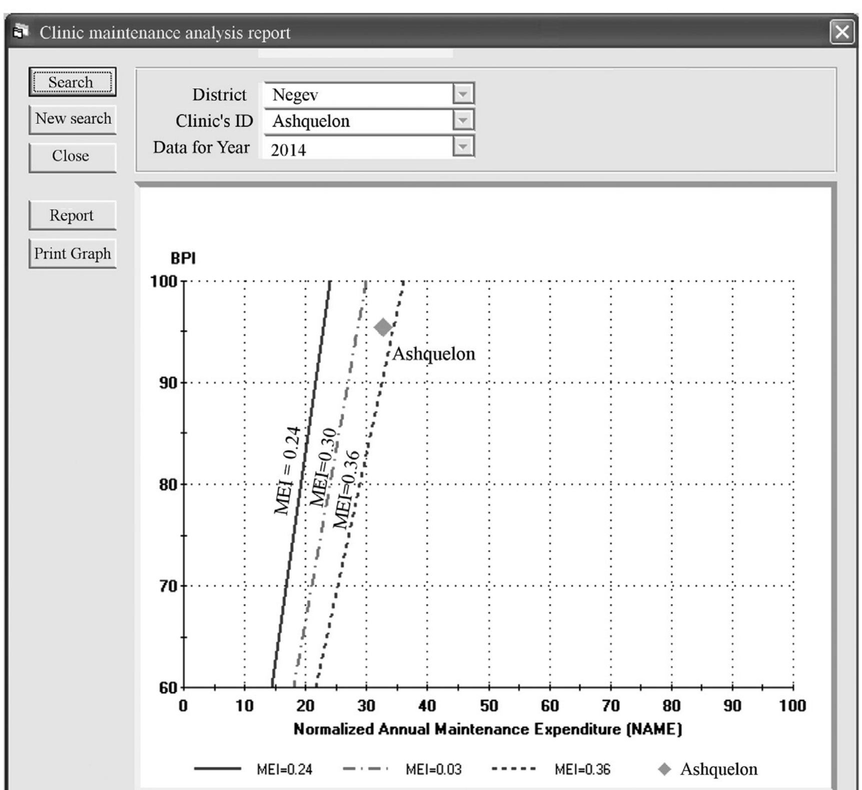

Fig. 6. An example of an analysis report for a clinic.

Table 2
Comparison of the KPIs of the clinics facilities in Phase I and II.

Parameter	Phase I		Phase II	
	Mean	Standard deviation	Mean	Standard deviation
Floor area [sq.m.]	1214	924	1154	1162
Age [years]	11.2	7.5	7.9	6.2
Age coefficient (AC_y)	0.84	0.24	0.75	0.23
Annual number of visitors/sq.m	273	155	258	126
Density coefficient (DC)	1.17	0.15	1.17	0.15
Annual maintenance expenditure (AME) [$/sq.m.]	$33.2	$16.4	$24.2	$13.9
Normalized annual maintenance expenditure (NAME) [$/sq.m.]	$36.3	$19.2	$28.6	$16.0
Maintenance sources ratio (MSR)	60.6%	8.8%	52.7%	17.5%
Managerial span of control (MSC)	7.2	3.2	6.1	2.0
Building performance indicator (BPI)	91.0	5.7	95.5	2.9
Maintenance efficiency indicator (MEI)	0.40	0.21	0.30	0.16

Table 3
Comparison of 95% confidence intervals between Phase I and Phase II.

	BPI		NAME		MEI	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Max	92.8	96.4	$42.3	$33.5	0.46	0.35
Min	89.2	94.6	$30.4	$23.6	0.33	0.25
Mean	91.0	95.5	$36.3	$28.6	0.40	0.30
Improvement ratio		4.9%		21.4%		25.2%
Variability	3.5	1.8	12.0	10.0	0.13	0.10
Improvement ratio		48.9%		16.5%		20.5%

improvement of 25% in efficiency with regard to the allocation and application of resources for clinic maintenance. As 70% of the maintenance resources were labor resources, the better cost-effectiveness was expressed in similar savings in labor. The performance of the clinics improved as well. Through the use of the proposed KPIs and LCC principles, it is also possible to benchmark the asset's performance in relation to other clinics or facilities (inter-organizational benchmarking) and to benchmark the clinic's systems in order to compare the efficiency of the various maintenance crews (intra-organizational benchmarking).

Statistical analysis demonstrated not only enhanced performance but also a 48% reduction in the variability of the performance of the clinics and a 16% decrease in normalized annual maintenance expenditure (NAME). The latter indicates that the performance of the maintenance regime can be significantly improved by using the proposed

Fig. 8. Comparison of the mean and 95% NAME confidence intervals between Phases I and II.

ERP system, thus allowing a public organization to predict and more precisely define the expenditure on clinic maintenance.

The study confirms that the potential benefit of applying ERP systems for healthcare facilities is high and that this route of development could contribute to an improved performance of clinic facilities and to greater cost-effectiveness.

The results of this pilot study are supported by other studies on performance-based maintenance in public offices and residential buildings, where similar results were achieved [16,46,47].

The selected KPIs and particularly the BPI were demonstrated to have the capability to assess the performance of the different levels of maintenance, with the ability to retrieve the performance of each individual system and component and analyze the root cause of any problem with accuracy.

The reliability of the results were also validated through statistical Student *t*-test analysis of cost reduction and performance improvement achieved after the implementation of the ERP system, supporting the first and second hypotheses of this research study.

The ERP system used in this study represents a first step in the revolution of information and knowledge management in the AEC/FM sector. Recent studies [33,38–42] have demonstrated the possibilities of implementing this system within a BIM and integrating a BIM with other information systems, such as building energy management

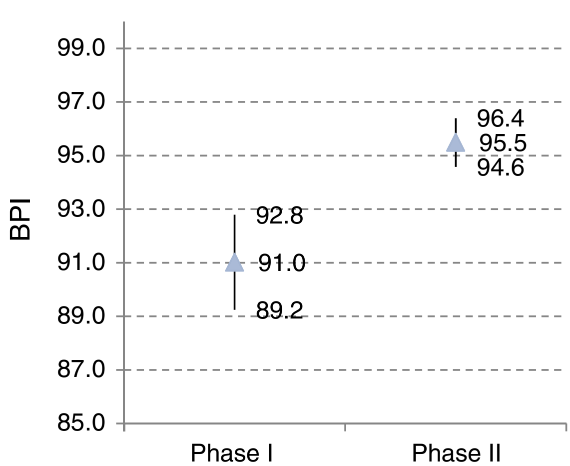

Fig. 7. Comparison of the mean and 95% BPI confidence intervals between Phases I and II.

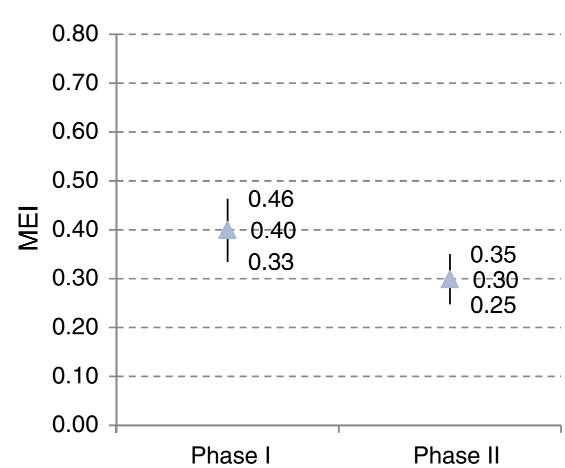

Fig. 9. Comparison of the mean and 95% MEI confidence intervals between Phases I and II.

system or RFID sensor networks. Further possible developments for the FM sector could include:

- Definition of maintenance priorities through an analysis of the performance of a building's components
- Integration of performance evaluation in the BIM of a building, so that the information about the state of the various components can also serve as geospatial data.
- Creation of a common database for all the clinics, to include comprehensive information on possible failures, on corrective interventions, and on the costs and performance of various systems. Such a database would enable maintenance decision-makers as well as maintenance teams to increase their knowledge, to upgrade the effectiveness of maintenance actions, and to plan and program maintenance more efficiently.

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