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An analytic network process model for hospital facilities management performance evaluation

Structured abstract

Purpose

This study aims to establish a rigorous model that can pragmatically evaluate the facilities management (FM) performance of hospitals.

Design/methodology/approach

Among the applicable performance indicators that were identified from extant literature, a focus group study shortlisted ten key performance indicators (KPIs) in four categories (safety, physical, financial and environmental) and verified their practicality. Using the Analytic Network Process (ANP) method to process the focus group's responses yielded importance weightings for the KPIs and developed the intended evaluation model. This model was then validated by a case study.

Findings

From the empirical data collected, two types of FM performance data and two scenarios of KPI scores were identified. To process these data and scores, a robust calculation method was devised and then proved useful in obtaining an overall score for holistic hospital FM performance. The case study confirmed the appropriateness and validity of the model developed.

Research limitations/implications

Through illustrating how the ANP method could be applied to develop an FM performance evaluation model, the study contributes knowledge to the multi-criteria decision-making domain. Despite the geographical limitation of the model established (i.e., centred around a group of hospitals investigated in Hong Kong), the study can serve as a reference for developing performance evaluation models for other buildings or infrastructures globally.

Practical limitations/implications

The model constitutes a practical tool for evaluating the FM performance of hospitals. Using this model on a regular basis will enable performance benchmarking and hence, continuous improvement of FM services.

Originality/value

The ANP model established is the first of its kind tailored for evaluation of hospital FM performance.

Paper type

Research paper

Keywords

AHP, ANP, facilities management, hospital, KPI, performance

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1. Introduction

Hospitals are quintessentially important in every health system because they are responsible for delivering healthcare services and treatments to patients (WHO, 2021). Provision and uninterrupted continuity of quality hospital services require not only capable healthcare practitioners but also reliable hospital facilities (Kagioglou and Tzortzopoulos, 2010). To ensure that hospital facilities are managed effectively, consideration must be given to identify or develop a means for evaluating facilities management (FM) performance. For example, the Health Information and Quality Authority (2013) published guidance on how to develop key performance indicators (KPIs) for monitoring healthcare services. Academic studies have also been conducted to identify key performance indicators (KPIs) applicable to measuring certain hospital performance aspects such as maintenance management (e.g. Lavy and Shohet, 2004). In recent years, other studies have further strived to develop KPIs for evaluating the holistic FM performance of hospitals (e.g. Amos et al., 2020a, d; Lai and Yuen, 2021), and the KPIs studied include those in different aspects such as physical, safety, environmental and financial. Whilst KPIs are regarded as useful performance evaluation measures (Lavy et al, 2010; Meng and Minogue, 2011), the excessive usage of numerous KPIs will incur exorbitant costs to gather data for calculating the KPIs, thus making the performance evaluation process inefficient or at worst, inaccurate. Conversely, using too few KPIs will make the evaluation result partial and hence, produce an incomplete picture of how well the hospital's facilities have been managed. Therefore, it is imperative that an optimal number of KPIs are used to monitor the most essential performance attributes (Lai and Yuen, 2021).

Since a plethora of attributes are often applicable to performance evaluation, selecting the optimal number of essential attributes as KPIs is not straightforward. Even after selection of appropriate KPIs, the determination of suitable weightings and scores for the KPIs remains challenging. To tackle this problem, a variety of multi-criteria decision-making (MCDM) methods can help. Notable examples include the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) developed by Saaty (1980, 2005), which have been widely applied in various research disciplines (cf. Sipahi and Timor, 2010; Darko et al., 2019; Kheybari et al., 2020). Moreover, applications of these methods to healthcare research have continued to increase (Schmidt et al., 2015).

In principle, having identified an optimal set of KPIs, it is feasible to develop a model for evaluating hospital FM performance by applying an appropriate MCDM method to determine the KPIs' importance weightings. This then logically leads to the following research questions: What are the KPIs appropriate for measuring hospital FM performance? Which MCDM method should be applied to determine their importance weightings? How to conduct this application process? More importantly, what types and extent of empirical FM data constitute model development? To address these research questions, this study sought to develop a model that is both rigorous and pragmatic for evaluating hospital FM performance. Concomitant objectives are to: develop a practical model for optimizing the evaluation of FM performance; in realizing the previous, augment health care services to engender greater patient care; and lower the prohibitive costs of conducting a comprehensive evaluation process.

2. Hospital facilities management

Hospital facilities must be properly designed, constructed and managed to support medical operations; this requires apposite incorporation of specialized systems for delivering healthcare services (Salah et al., 2018). Such systems are wide ranging, including but not limited to: electricity supply and lighting system; heating, ventilating and air-conditioning system; medical gases system; nurse call and bed head trunking system; fire fighting and alarm system; and lift and/or escalator system (Yik et al., 2012). Over the life cycle of hospital facilities, FM is an essential activity which embodies daily maintenance works to preserve operations but also satisfying long-term development needs by: extending the usage life of the facilities; keeping abreast of professional quality to ensure medical operation standards; and maximizing the operational performance to suit users' demands (Salah et al., 2018). In recent decades, the concept of FM has been increasingly accepted and applied in holistic hospital management. FM performance evaluation has become a systematic approach to assessing and monitoring the effectiveness in managing hospital facilities (Amos et al., 2020a, c, d).

The planning and management activities for hospital facilities are premised upon both the medical operational needs and feedback from hospital stakeholders (e.g. staff, members of the public, government and independent auditors). Thus, facilities performance data and stakeholders' opinions have been increasingly valued and analyzed in hospital facilities studies (cf. Becker and Parsons, 2007). To improve the performance of hospital facilities and to support future hospital facilities planning and management, perceptions of hospital stakeholders have been increasingly collected as empirical evidence for facilities performance evaluation (Becker and Jones-Douglas, 2006).

2.1 FM performance evaluation and KPIs development

Amaratunga and Baldry (2002) produced early research on FM performance evaluation and recommended that structured performance management system is needed to guide an organization towards a strategic direction for future development. A conceptual framework for FM performance measurement was subsequently proposed (Amaratunga and Baldry, 2003), which covers five performance categories, namely: 1) customer relations; 2) FM internal process; 3) learning and growth; 4) financial implication; and 5) strategic performance measurement. Since then, a range of FM performance evaluation tools have been developed. For example, Meng and Minogue (2011) utilized KPIs to underpin a novel FM performance evaluation tool. A set of KPIs for facilities operation and maintenance were identified through a thorough literature review and a focus group study (Lai and Man, 2018a, b). In the hospital sector, further development of KPIs for FM purposes started with the study of Shohet (2003), where KPIs for maintenance of healthcare facilities were discussed. Shohet and Lavy (2004a, b) attempted to understand healthcare facilities management from a systematic manner and develop an integrated healthcare facilities management model based on a state-of-the-art review. Furthermore, Shohet (2006) developed 11 KPIs to evaluate strategic healthcare facilities maintenance from four perspectives: 1) asset development; 2) organization and management; 3) performance management; and 4) maintenance efficiency. Pitt and Tucker (2008) provided in-depth discussion on FM key issues evaluation and examined the effective application of benchmarking systems. Lavy et al. (2014) adopted a simulation approach to create multiple scenarios for an education facility and used a number of identified FM KPIs to examine the simulated scenarios to analyse the effect of the FM KPIs. Li et al., (2019) developed a comprehensive conceptual benchmarking framework with a focus on five dimensions of hospital FM performance (i.e., cost-effectiveness; customer satisfaction; energy and resource efficiency; management efficacy; and operation and maintenance efficiency), and used a case study of 23 Shanghai municipal hospitals to demonstrate how the benchmarking framework can be implemented. Recently, Amos et al. (2020a, b) adopted the conceptual framework of Amaratunga and Baldry (2003) and developed KPIs for hospital FM performance evaluation. Lai and Yuen (2021) made reference to international FM performance evaluation frameworks (relevant studies in the UK, Germany, Canada and Malaysia, and the phase-hierarchy (P-H) model for classifying KPIs (cf. Lai and Man, 2018a)) and developed a KPI framework for evaluating hospital FM performance in six categories: 1) safety; 2) financial; 3) physical; 4) patient experience; 5) functional; and 6) environmental.

In previous KPI studies, a desktop literature review (including international building or FM performance evaluation schemes) was often taken as a first step to identify applicable KPIs (cf. Shohet and Lavy, 2004a; Lai and Yuen, 2021). The identified KPIs then underwent a shortlisting process, and the methods commonly used for this purpose include focus group meetings and expert interviews. Focus group meetings (Lai and Man, 2018b) and expert interviews (Amos et al., 2020c) are qualitative methods that help develop a deeper understanding of the identified KPIs' fitness in the respective context.

2.2 Multi-criteria decision-making (MCDM) in hospital management evaluation

Studies that have used MCDM methods to investigate FM-related matters in hospital environments are ubiquitous and cover focused areas such as: waste management system (cf. Brent et al., 2007; Hariz et al., 2017; Thakur and Ramesh, 2017; Aung et al., 2019; Amos, et al., 2020a, b; Pradenas et al., 2020); technology adoption and assessment (cf. Hummel et al., 2000; Ritrovato et al., 2015; Howard et al., 2019; Alrahbi et al., 2021); risk management (cf. Yucel et al., 2012; Zhang et al., 2015; Tervonen et al., 2015; Corvino et al., 2021); facility layout and design (cf. Fogliatto et al., 2019; Lin and Wang, 2019; Corvino et al., 2021; Fan et al., 2021); maintenance management (cf. Shohet, 2003; Sweis et al., 2014; Karimi et al., 2020); and supply chain management (cf. Larimi and Yaghoubi, 2019; Leksono et al., 2019; Hossain and Thakur, 2020). To support management decision-making or evaluate the performance of certain types of management processes, the AHP method and the ANP method are commonly-used MCDM tools.

2.2.1 The AHP method

Developed by Saaty (1980), the AHP method is a powerful tool in solving complex decision problems (Zaim et al., 2012). It provides a systematic approach for a problem to be transformed into a hierarchy, consisting of critical criteria for decision making. The logical relationships between attributes within the hierarchy enable the decision-makers to secure a comprehensive understanding of the problem. The AHP method facilitates pairwise comparisons to be made on the importance of attributes under investigation, and the mathematical treatment on calculating the consistent ratio associated with the comparisons helps remove any irrational judgement. Given its versatility, the AHP method has gained popularity in evaluating decision-making processes in the built environment development or management. Examples include: safety evaluation and management in construction sites (cf. Teo and Ling, 2006; Li et al., 2013); green building rating (cf. Ali and Al Nsairat, 2009; Chang et al., 2007); construction management (cf. Das et al., 2010; Wu et al., 2007); and post-occupancy evaluation of hostels (cf. Hou et al., 2020).

2.2.2 The ANP method

Compared with the AHP method, the ANP method (Saaty, 2005) provides a more accurate means to address the interactions among the criteria/sub-criteria and alternatives in a problem under investigation (Zaim et al., 2012). An essential distinction between the two methods is that the ANP method takes into account the interactions, interdependences and feedbacks in the decision-making system. Specifically, the inter-relationships between the sub-criteria in each cluster under the decision-making system are considered. As the ANP method gives advantage in mapping out the hierarchical relationships and the interactions among sub-criteria, it is commonly used in decision-making processes that require a high level of fuzzy logic. In the Architecture, Engineering, Construction and Operation (AECO) industries, the ANP method has been increasingly adopted to facilitate decision-making (cf. Cheng et al., 2005; Cheng and Li, 2007; Chen et al., 2014; Mavi and Standing, 2018; Hatefi and Tamošaitienė, 2019; Kar and Jha, 2020). Given that FM performance evaluation covers multiple performance aspects such as customer relationship management, financial management and human resource management (cf. Amaratunga and Baldry, 2003)) and that the importance weightings of the KPIs intended for measuring hospital FM performance need to be scientifically determined, the ANP method was adopted in this present study.

3. Materials and Methods

The above shows that various relevant studies have been undertaken, but there remains a research gap for establishing a credible model for the evaluation of hospital FM performance. To plug this gap, initially, Lai and Yuen (2021) conducted a desktop review of relevant literature and found 61 indicators to be applicable to hospital FM performance evaluation. These indicators were subsequently used as a basis for questions posed at a focus group study - the findings of which identified the selection of 18 indicators as being essential. Through a questionnaire survey on hospital building practitioners, which was conducted at the preceding stage of this study (Lai et al., 2020; 2021), the importance levels of these selected indicators were solicited. The questionnaire survey results were taken for review in a focus group meeting that involved eight FM experts. The ensuing parts of this present paper report on the research tasks and findings drawn from this focus group meeting.

All being veterans and holding positions such as senior hospital facilities manager and hospital facilities manager, the focus group experts had on average over 22 years hospital FM work experience. The meeting, with an interim comfort break in the middle, was held for one and half hours. Upon commencement, all the meeting participants were informed of the research aim and objectives. In addition to the ethics approval given by the Human Subjects Review Committee of the principal investigator's institution, informed consent was obtained and the participants were given assurances that a strict ethical protocol would be adhered to: specifically, confidentiality and anonymity of participants was assured; and the results of the study would be made available to the participants upon request (cf. Zheng and Lai, 2018; Fisher et al., 2019; Ahmed et al., 2021). Then, the study team showed a relationship diagram of the selected indicators, briefed the participants about the interdependencies and influences between the indicators, and invited them to express their opinions and discuss the information shared with them. The discussion comprised two parts: 1) whether each of the performance indicators should be included in the subsequent analysis; and 2) the influences between the indicators and their performance categories.

Referring to the relationship diagram, a series of comparisons between the indicators and/or their respective performance categories are needed to determine their importance weightings according to the ANP method. For this comparison purpose, the 9-point rating scale (Saaty, 1980) was used, with "1" indicating the two items being compared are of equal importance and "9" indicating one of the two items as of absolute importance. Figure 1 presents two examples of the comparisons: (a) between pairs of categories; and (b) between pairs of indicators, and the study team explained these examples to the participants before asking them to make comparisons on the items being studied. In total, 16 pairwise comparisons were made. The responses for such comparisons given by each of the focus group experts were recorded and immediately input to the SuperDecision software. Among all of the pairwise comparisons, the largest matrix was 3-by-3, for which the allowable consistency ratio is 0.05 (Saaty, 2005). Whenever a computed consistency ratio exceeded this acceptable limit, the respective participant was requested to reconsider the response given and adjust the corresponding comparison judgment. This step repeated until the computed consistency fell within the acceptable limit.

"Insert Figure 1 here"

Based on the computed importance weightings pertaining to each of the focus group experts, the average weighting of each performance category (i.e. physical, environmental, financial and safety) was calculated using Equation 1. Likewise, the average weighting of each KPI in its own category was calculated using Equation 2. Multiplying these two sets of calculated weightings (Equation 3), the score weighting of each KPI was obtained.

$$C_i = \frac{\sum_{j=1}^{n} C_{ji}}{n} \quad (1)$$

$$E_i = \frac{\sum_{j=1}^{N} E_{ji}}{N} \quad (2)$$

$$W_i = C_i \times E_i \quad (3)$$

where

C_i = average weighting of category i

C_{ji} = weighting of category i by expert j

~~C_{ji}~~E_{ji} = weighting of KPI_i in its category by expert j

E_i = average weighting of KPI_i in its category

n = number of categories

N = number of KPIs

W_i = score weighting of KPI_i

After obtaining the above-mentioned weightings, a series of interviews were held with the experts to collect FM record data for scoring each of the KPIs. In total, data from 20 hospitals that the experts managed were gathered. Data gathered included: facilities maintenance work orders; operational incidents and statutory orders served by government departments; energy consumption and carbon emissions; and O&M and energy costs of the hospital buildings. The data fell into two types: percentage data and numeric data.

For percentage data where the KPI's possible performance levels lie within a bounded scale (e.g. 'availability of lift service', which ranges from 0 to 100%), the actual value of the record data was taken as the performance score. For KPIs whose best performance levels are some target values (e.g. 'actual costs within budgeted costs'), the best performance is attained when the actual level hits the budgeted level. According to the experts, any level of the actual costs falling below or above the budgeted level means that the best performance has not been attained, because underspending of any budgeted amount implies that not all the planned activities (e.g. facilities upgrade) have been implemented. Conversely, a budget overrun shows failure in financial control. Ergo, two scenarios (**Error! Reference source not found.**2) were considered in determining the performance score (S_i) of KPIs of this type and Equations 4 and 5 were used respectively: (A) the actual data value was taken as the performance score of the KPI if the data value is below or equal to the target value; and (B) the difference between the actual data value and the target value was considered in calculating the performance score if the data value exceeds the target value.

"Insert Figure 1 here"

"Insert Figure 2 here"

Scenario A:

$$S_i = D_{ai} \quad (4)$$

Scenario B:

$$S_i = D_{ti}\cancel{100\%} - |D_{ai} - D_{ti}\cancel{100\%}| \quad (5)$$

where
S_i = performance score of KPI$_i$
D_{ai} = actual data value of KPI$_i$
D_{ti} = target value of KPI$_i$

For numeric data where the KPI's possible performance levels are not bounded by definite limits (e.g. 'No. of incidents', which ranges from zero to virtually an unlimited value), one of the following two methods could be used for the determining the performance score for the concerned KPI. In cases where the lower the KPI value, the better the performance level: the actual data value was normalized with respect to the best performance data value (i.e. minimum value among the sample data) and the worst performance data value (i.e. maximum value among the sample data). The performance score of the KPI was calculated using Equation 6. Likewise, in cases where the higher the KPI value, the better the performance level: the actual data value was normalized with respect to the best and the worst performance data values, and the performance score of the KPI was calculated using Equation 7.

$$S_i = \left(\frac{D_{max,i} - D_{ai}}{D_{max,i} - D_{min,i}}\right) \times 100\% \quad (6)$$

$$S_i = \left(\frac{D_{ai} - D_{min,i}}{D_{max,i} - D_{min,i}}\right) \times 100\% \quad (7)$$

where
S_i = performance score of KPI$_i$
D_{ai} = actual data value of KPI$_i$
$D_{min,i}$ = minimum value among all sample data of KPI$_i$
$D_{max,i}$ = maximum value among all sample data of KPI$_i$

Then, the overall facilities management performance (FMP) score (c.f. Lai and Yik, 2011), which reflects how well the facilities in a hospital have been managed, was calculated by summation of the weighted performance scores of all the KPIs (Equation 8).

$$S_T = \sum_{i=1}^{T} S_i \cdot W_i \quad (8)$$

where

S_T = FMP score
S_i = performance score of KPI_i
T = total number of KPI_i
W_i = score weighting of KPI_i

4. Results and Discussion

Findings and discussion focused on four distinct areas, namely: interrelationships between the performance categories and indicators; importance weightings of performance categories and indicators; overall FM performance; and implications and future work. By reporting upon these areas, a richer and deeper knowledge and understanding of the subject under investigation could be secured.

4.1 Interrelationships between the performance categories and indicators

A relationship diagram of the 13 indicators shortlisted from the earlier questionnaire survey was constructed using the SuperDecisions software (Figure 3). For comparisons to be made on the relative importance between the 13 performance indicators, a total of 24 judgements are needed. After deliberation, the focus group experts considered it impracticable to make such a large number of pairwise comparisons. Then, the representation of the indicators was reviewed and their interrelationships scrutinized. Upon the experts' consensus, eventually three of the indicators were removed. The first indicator removed was "Average age of major facilities", the reasons being the following practical difficulties: (1) there is no authoritative definition of what facilities are regarded as major; and (2) different facilities may be replaced at different times, which renders their ages variable. The second indicator removed was "Maintenance cost per building area" because it is covered by another indicator listed - "O&M cost per building area (HK$/m^2)". The last indicator removed was "Annual maintenance expenditure as a percentage of total replacement value" because determining the total replacement value is not straightforward - the scope and cost of facilities to be replaced are often hard to determine.

"Insert Figure 3 here"

Figure 4 depicts the interrelationships between the remaining 10 performance indicators. For illustration purposes, the interrelationships between the environmental performance indicators and the indicators in the remaining performance categories are explained:

1) Within the environmental performance category, the two indicators - E1 and E2 - are interrelated because, for example, a larger energy use (i.e. higher E1) will result in a larger carbon emission (i.e. higher E2) and vice versa.
2) Between the environmental and financial performance categories, there exists a bilateral influence. For example, a higher investment into facilities maintenance would result in a better energy efficiency and hence, lower energy use of the facilities, thereby

a higher environmental performance. With the facilities using less energy, a lower operating cost is anticipated, leading to a higher financial performance.

3) Between the environmental and physical performance categories, there exists a unilateral influence. For example, a higher work request response rate will enable energy-inefficient facilities to be rectified faster. This would reduce energy wastage, thus attaining a higher environmental performance.

"Insert Figure 4 here"

4.2 Importance weightings of performance categories and indicators

Based upon the responses of the focus group experts, the importance weightings of the four performance categories were calculated (refer to Table 1). On average, the financial category (with a weighting of 0.4353) was considered as the most important. The other performance categories, in descending order of importance are: safety (0.4027), environmental (0.0970) and physical (0.0650). Referring to the values of standard deviation (*SD*), the largest amount of dispersion of the important weightings was found with the environmental category (0.0618) while the least-varied important weightings belonged to the financial category (0.0225).

"Insert Table 1 here"

Table 2 displays the calculated importance weightings of the KPIs. The *SD* values show that the important weightings of indicator F1 "actual costs within budgeted costs" dispersed the most (0.2540), while the counterparts of indicator F3 "energy cost per building area" were the least-varied (0.1045). Both indicators are in the financial category. Among all the KPIs, the top-rated one is S2 "No. of statutory orders per year", which recorded an average importance weighting of 0.5608. The second and third most important indicators are: E1 "energy utilization index" (0.5411) and F1 "actual costs within budgeted costs" (0.4837). At the other end of the spectrum is F3 "energy cost per building area", whose average important weighting was the lowest (0.2085).

"Insert Table 2 here"

Combining the results in Tables 1 and 2, the score weighting of each KPI was calculated. As summarised in Table 3, the score weightings range from 0.0148 (P1) to 0.2259 (S2). Figure 5 further diagrams the proportions of the score weightings of the KPIs. The largest proportion, pertaining to S2, is 22.6%. Notably, the five largest proportions of the score weightings all belonged to KPIs in the safety and financial categories – in descending order: S2, F1, S1, F2, and F3. Their aggregate proportions amount to 83.9%, which prevail over the counterpart of the KPIs in the remaining two categories – environmental and physical.

"Insert Table 3 here"

"Insert Figure 5 here"

4.3 Overall FM performance

Of the hospitals investigated, one of the largest hospitals in Hong Kong was taken for a case study. This hospital, offering a full complement of services to people in the city, operates a 24-hour Accident and Emergency service and a range of specialist services. Providing medical care in both inpatient and outpatient services, the hospital has over 1,900 beds, 13 clinical departments and a staff force of over 6,800, serving an effective population of about 900,000. From this hospital's FM records, annual data of the ten KPIs were retrieved (refer to Table 4). Among the KPIs, four (viz. P1, P2, P3 and F1) are with a bounded range of values (0 – 100%), while the range of values of the remaining six (S1, S2, E1, E2, F2 and F3) are not bounded.

"Insert Table 4 here"

Using the record data (D_a) of the case study hospital and with the KPIs' maximum (D_{max}) and minimum (D_{min}) data values identified from the 20 hospitals, the weighted performance scores (S_iW_i) of the ten KPIs were calculated following the foregoing calculation procedures. These calculated results, alongside the scores (S_i) and weightings (W_i) of the KPIs, are summarized in Table 5.

"Insert Table 5 here"

Data values for four of the KPIs, viz. P1, P2, P3 and F1, were bounded between 0 and 100% and hence, were directly used for calculating their corresponding weighted performance scores. Given the relatively low importance weightings of P1 to P3, their weighted performance scores were small - from 1.26% to 2.76%. While for F1, which is a financial indicator, its importance weighting is high (21.05%). With the actual costs being the same (100%) as the budgeted costs, the weighted score of F1 is 21.05%, which represents a significant portion of the overall FMP score.

The other two financial indicators, viz. F2 and F3, are different from F1 in that their data values are not bounded. In terms of O&M cost, the case study hospital performed well, as reflected by the high score of F2 (88.95%). But when measured based on energy cost, the hospital's performance was low because the score of F3 was only 32.79%. Fortunately, the weighting of F3 was low (9.08%) and thus, the respective weighted score was also small (2.98%), contributing to a low proportion of the overall FMP score. Conversely, the weighted score of F2 (11.92%) contributed significantly to the overall FMP score, given the significant importance weighting (13.40%) and high score of F2.

The two safety KPIs, S1 and S2, both scored 100% because there were no accidents or statutory orders served upon the case study hospital. The weighted scores of S1 and S2, by virtue of their high importance weightings (17.69% and 22.59%), collectively contributed to a large proportion of the overall FMP score.

The data values of the two environmental KPIs (E1 and E2), akin to the two financial KPIs (F2 and F3), are virtually unbounded. With an annual EUI being 1,800 MJ/m^2, the performance score of E1was 30.14%. The environmental performance of the hospital, when measured by carbon emissions per building area (E2), was higher (41.48%). Due to the relatively low importance weightings of E1 and E2, the aggregate weighted scores of these two KPIs only contribute to a small amount of the overall FMP score.

Totalling the weighted performance scores of the ten KPIs gives 85.91%. This overall FMP score reflects that the FM performance of hospital was high. The major contributors to this high overall performance, according to the weighted performance scores, are the hospital's performance in the safety (S1 and S2) and financial (F1 and F2) aspects.

4.4 Implications and future work

Hospital facilities have become increasingly sophisticated and the demand for effective management of the facilities is growing. While many studies have developed KPIs for hospital FM and the applications of MCDM methods in built environment research have continued to expand, a credible means for evaluating the performance of hospital FM was still lacking. In addressing this need, the present study sought a scientific approach to establish a pragmatic evaluation model. Through demonstrating how the theoretical principles of the ANP method could be applied to process empirical hospital FM performance data, the study contributes to the existing body of knowledge in the MCDM domain.

The ANP model established, which is novel in the hospital FM context, is a practical tool that enables FM managers and decision-makers to determine not only the overall FM performance level of their hospitals but also the performance of individual constituent elements, thus allowing the stakeholders to understand how effective the FM services for their hospitals have been managed. Using the model to evaluate a hospital's performance on a regular basis (e.g. annually) will produce evaluation results based upon which internal performance benchmarking can be undertaken. Extending the model's application to evaluate a cluster of hospitals (e.g. multiple hospitals in a district or region), the performance evaluation results can be used for external benchmarking purposes (John and Eeckhout, 2006). Such performance benchmarking results will help the hospitals to continuously improve their FM services.

As observed during the data collection process, the FM data spread across different performance aspects including physical, safety, environmental and financial. The different types of such data were either recorded manually or electronically in a specific system (e.g. a computerized maintenance management system (CMMS) that recorded the facilities maintenance work orders). To enable effective implementation of the model established in this study, an integrated electronic platform in this era of Industry 4.0 (Edwards et al., 2017;

Hossain and Thakur, 2020; Newman et al., 2020) needs to be developed to automatically log the relevant FM data, process the data logged, and compute the performance evaluation result.

5. Conclusions

Developed from an optimal set of KPIs and the application of the ANP method, the performance evaluation model established in this present study is novel in the context of hospital FM. The KPIs were rigorously selected through a desktop literature review followed by a focus group study. The KPIs' practicality in real-world hospital buildings was verified by the focus group experts, and the importance weightings of the KPIs were determined using the ANP method. Covering four key performance aspects (safety, physical, financial and environmental), the ten KPIs' importance weightings were dominated by the safety indicators.

Unlike traditional studies where assumptions or simulations were made to assign scores for the KPIs, this present study's research team managed to obtain real performance data that were retrieved from empirical FM records and used such data to score the KPIs. A key finding from this process was the classification of two data types: data with bounded values, and data with unbounded values. Another important finding was the identification of different scenarios where the score of a KPI is higher (or lower) when the respective performance data value is higher (or lower) than the target KPI value. In handling these different scenarios and the two data types, the robust calculation method devised was useful for obtaining the FMP score, which reflects the overall FM performance of the hospital.

The model's applicability was validated by a case study on a large hospital. In addition to revealing the FM performance of the hospital in the safety, physical, financial and environmental aspects, the holistic FM performance of the hospital, represented by the calculated FMP score, was determined. The level that each of the KPIs contributed to the overall FM performance was also identified. A limitation of the current study ascribes to the fact that the model was established based on the group of hospitals investigated in Hong Kong. For future research, the model can be taken to conduct similar FM research work on other hospitals. By then the outcomes will help hospital stakeholders realize how well their facilities have been managed and, when more evaluation results of this kind are available, both internal and external performance benchmarking can be made for hospitals, for the betterment of the healthcare sector. Following the approach of this study can also establish similar performance evaluation models for managing the facilities in other types of buildings or infrastructures.

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1. With respect to "**Physical**" node in "Categories" cluster, choose the perceived relative importance between:			
1.1	Safety performance	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Environmental performance
1.2	Safety performance	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Financial performance
1.3	Environmental performance	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Financial performance

(a) Comparisons between pairs of categories

2. With respect to "**Physical**" node in "Physical performance" cluster, choose the perceived relative importance between:			
2.1	Work request response rate	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Availability of fire services system
2.2	Work request response rate	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Availability of lift system
2.3	Availability of fire services system	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Availability of lift system

(b) Comparisons between pairs of indicators

Figure 1 Examples of pairwise comparisons

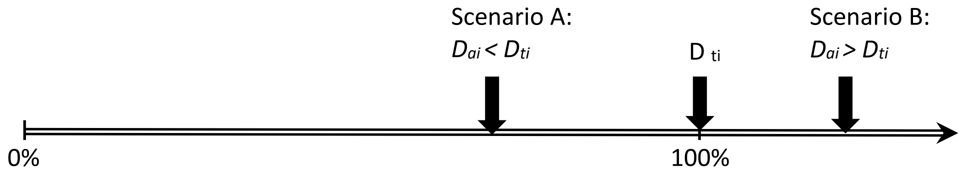

Figure 2 Scenarios of performance scores for percentage data

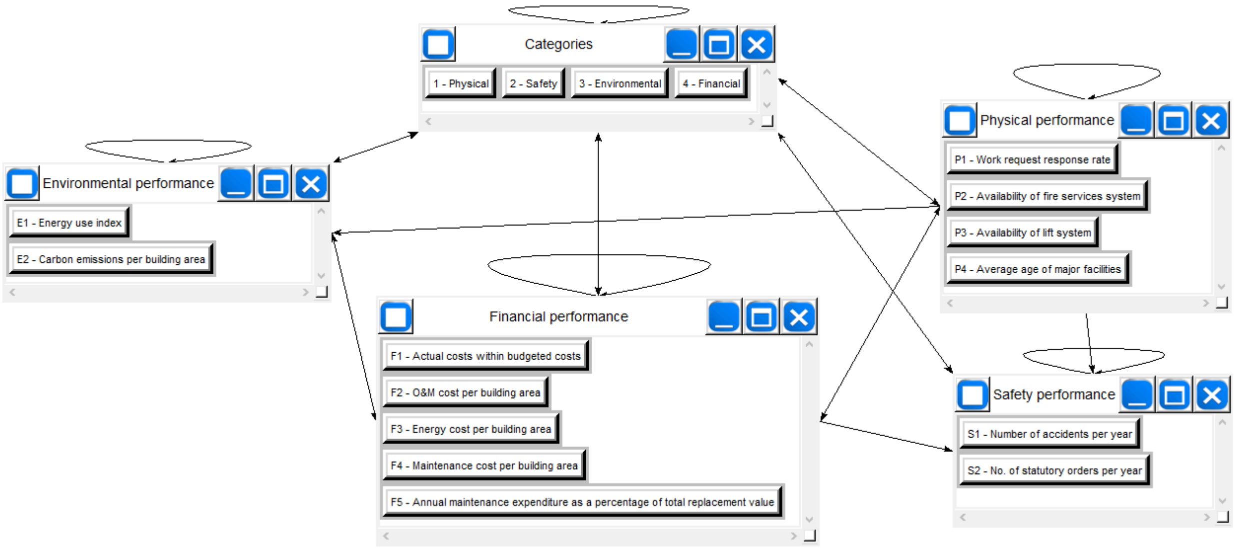

Figure 3 Relationship diagram of the 13 performance indicators

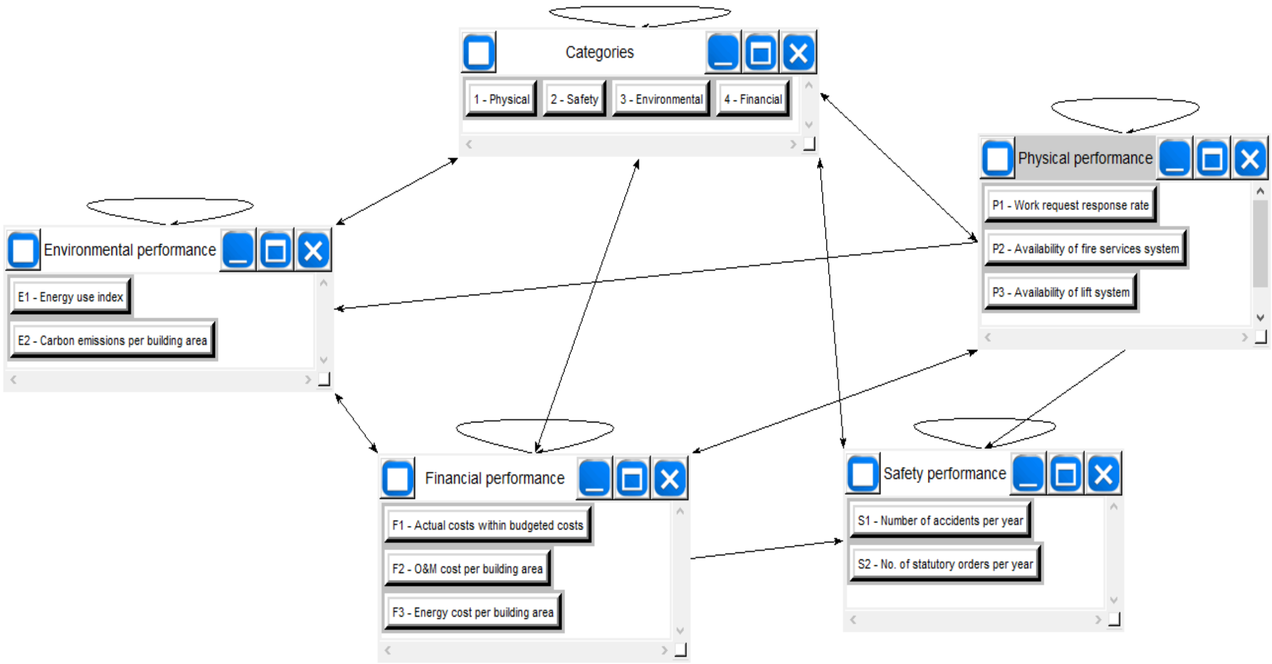

Figure 4 Relationship diagram of the 10 performance indicators

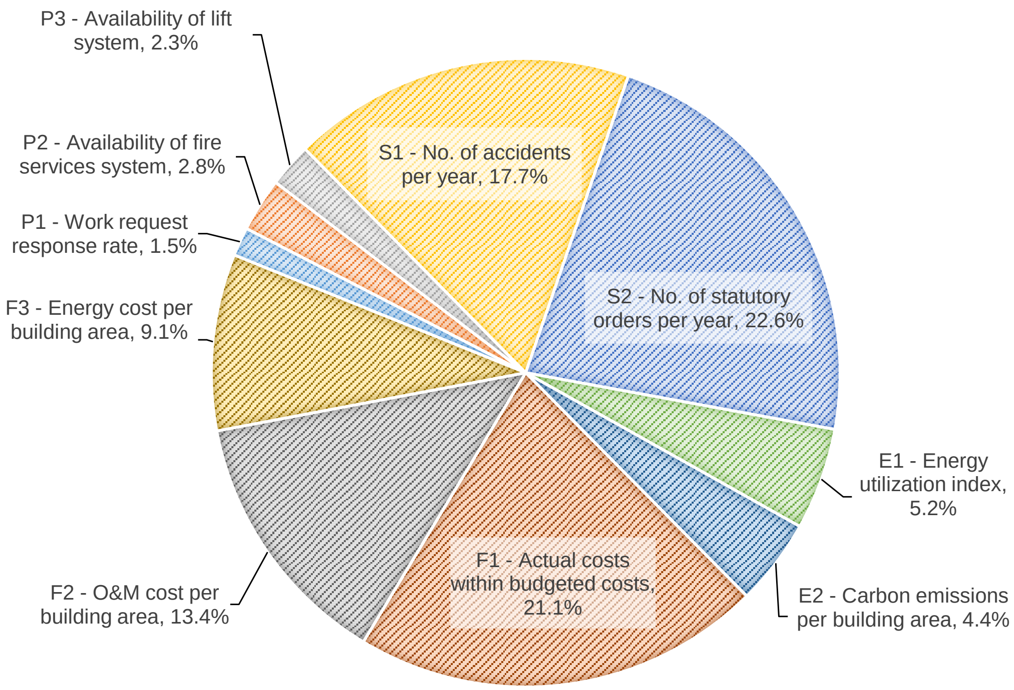

Figure 5 Score weighting distribution of KPIs

Table 1 Importance weightings of performance categories

	Physical (P)	**Safety (S)**	**Environmental (E)**	**Financial (F)**
Participant A	0.0328	0.3308	0.2032	0.4332
Participant B	0.1063	0.4158	0.0362	0.4418
Participant C	0.0359	0.3868	0.1737	0.4037
Participant D	0.0484	0.3769	0.1096	0.4651
Participant E	0.0666	0.4253	0.0682	0.4400
Participant F	0.0910	0.4185	0.0890	0.4015
Participant G	0.0579	0.4422	0.0440	0.4559
Participant H	0.0815	0.4257	0.0518	0.4411
SD	0.0264	0.0361	0.0618	0.0225
Mean (C_i)	0.0650	0.4027	0.0970	0.4353
Rank	4	2	3	1

Table 2 Importance weightings of KPIs

	P1 - Work request response rate	**P2 - Availability of fire services system**	**P3 - Availability of lift system**	**S1 - No. of accidents per year**	**S2 - No. of statutory orders per year**	**E1 - Energy utilization index**	**E2 - Carbon emissions per building area**	**F1 - Actual costs within budgeted costs**	**F2 - O&M cost per building area**	**F3 - Energy cost per building area**
Participant A	0.5214	0.2393	0.2393	0.4000	0.6000	0.6673	0.3327	0.2141	0.4668	0.3191
Participant B	0.1764	0.4259	0.3977	0.6207	0.3793	0.6788	0.3212	0.7699	0.1367	0.0934
Participant C	0.1509	0.5457	0.3034	0.6166	0.3834	0.4286	0.5714	0.1692	0.5813	0.2495
Participant D	0.1994	0.5134	0.2872	0.5566	0.4434	0.6308	0.3692	0.6087	0.2162	0.1752
Participant E	0.2160	0.2738	0.5103	0.3714	0.6286	0.1579	0.8421	0.6518	0.2410	0.1072
Participant F	0.1765	0.6294	0.1941	0.6041	0.3959	0.6443	0.3557	0.1680	0.4398	0.3922
Participant G	0.1770	0.4233	0.3997	0.1564	0.8436	0.5396	0.4604	0.6843	0.1667	0.1490
Participant H	0.2026	0.3524	0.4450	0.1876	0.8124	0.5816	0.4184	0.6035	0.2138	0.1827
SD	0.1204	0.1346	0.1083	0.1908	0.1908	0.1751	0.1751	0.2540	0.1640	0.1045
Mean (E_i)	0.2275	0.4254	0.3471	0.4392	0.5608	0.5411	0.4589	0.4837	0.3078	0.2085
Rank	9	6	7	5	1	2	4	3	8	10

Table 3 Score weightings of KPIs

KPI	**Score weighting (W_i)**	**Rank**
P1 - Work request response rate	0.0148	10
P2 - Availability of fire services system	0.0277	8
P3 - Availability of lift system	0.0226	9
S1 - No. of accidents per year	0.1769	3
S2 - No. of statutory orders per year	0.2259	1
E1 - Energy utilization index	0.0525	6
E2 - Carbon emissions per building area	0.0445	7
F1 - Actual costs within budgeted costs	0.2105	2
F2 - O&M cost per building area	0.1340	4
F3 - Energy cost per building area	0.0908	5

Table 4 Record data of the KPIs

KPI	Record data	Possible range
P1 - Work request response rate	85.00%	0 – 100%
P2 - Availability of fire services system	99.80%	0 – 100%
P3 - Availability of lift system	99.60%	0 – 100%
S1 - No. of accidents per year	0	0 – unlimited
S2 - No. of statutory orders per year	0	0 – unlimited
E1 - Energy utilization index (EUI) (MJ/m^2)	1800	0 – unlimited
E2 - Carbon emissions per building area (tonnes CO_2-e/m^2)	0.238	0 – unlimited
F1 - Actual costs within budgeted costs	100%	0 – 100%
F2 - O&M cost per building area (HK$/$m^2$)	530	0 – unlimited
F3 - Energy cost per building area (HK$/$m^2$)	520	0 – unlimited

Table 5 Calculation results of the KPIs

KPI	D_a	D_{max}	D_{min}	S_i	W_i	S_iW_i
P1 - Work request response rate	85.00%	N/A	N/A	N/A	1.48%	1.26%
P2 - Availability of fire services system	99.80%	N/A	N/A	N/A	2.77%	2.76%
P3 - Availability of lift system	99.60%	N/A	N/A	N/A	2.26%	2.25%
S1 - No. of accidents per year	0	8	0	100%	17.69%	17.69%
S2 - No. of statutory orders per year	0	1	0	100%	22.59%	22.59%
E1 - Energy utilization index	1800	2347	532	30.14%	5.25%	1.58%
E2 - Carbon emissions per building area	0.238	0.3298	0.1085	41.48%	4.45%	1.85%
F1 - Actual costs within budgeted costs	100%	N/A	N/A	N/A	21.05%	21.05%
F2 - O&M cost per building area	530	3992	100	88.95%	13.40%	11.92%
F3 - Energy cost per building area	520	680	192	32.79%	9.08%	2.98%
					FMP score (S_T) =	85.91%