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Performance Assessment Framework for Healthcare Facilities

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Abstract: Accurate performance assessment of building systems is essential for efficiently prioritizing necessary capital-renewal works to sustain the performance of healthcare facilities. One of the main difficulties associated with inspection and renewal decisions, however, is the lack of clear performance indicators that are related to healthcare facilities. Traditionally, physical condition has been used as the main performance indicator, overlooking other important aspects such as level of service, sustainability, and risk of failure, which are crucial for hospital buildings. This paper introduces a practical performance assessment framework for supporting the efficient planning of capital renewal programs for healthcare facilities, particularly hospitals. The framework divides the hospital building into three zones that serve different functions: clinical, nursing, and support. It also assesses the performance of hospital subsystems using four key performance indicators (KPIs): physical condition, level of service, risk of failure, and sustainability. To accurately assess level of service, the framework assesses the service quality (temperature, lighting, noise, etc.) within the key spaces of each hospital zone. Based on the proposed multi-criteria assessment approach, priority index for each subsystem is computed for renewal purposes. A survey among hospital maintenance experts has been used to verify the proposed framework and collect real-life data for its development. The paper discusses the proposed prioritization approach, and the potential benefits of the proposed framework to improve capital renewal decisions for hospitals.

1. Introduction

In recent years, the demand for healthcare facilities has been increasing as a result of increasing population and, accordingly, an accelerated demand for medical services. Due to the intensive use and aging of many public hospital buildings, effective maintenance has become essential for sustaining the operation of these facilities. In addition, the decreasing budgets have placed additional pressure on the managers of healthcare facilities to reduce operational costs and maximize the return over capital renewal (rehabilitation) dollars. Generally, healthcare facilities include a wide range of types, ranging from small medical clinics to large and complex hospitals, as shown in Figure 1. These facilities are among the most important and complex civil infrastructure assets to manage, operate, and maintain (Lavy and Shohet 2009). They are also expected to provide efficient and sufficient services at all times.

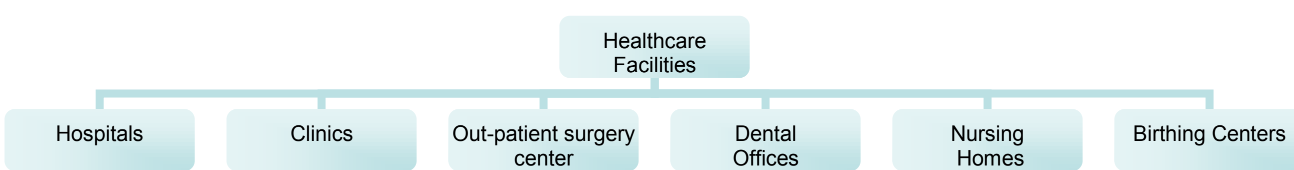


Figure 1: Healthcare facilities

To help prioritize capital-renewal works, many asset management tools exist either for a specific type of asset (e.g., buildings) or for a specific type of component (e.g., only roofs). For example, The engineered management systems (EMSs) implemented by the US Army Corps of Engineers handle individual asset types, e.g., PAVER (Shahin 1992), ROOFER (Bailey et al. 1989), and BUILDER (Uzarski 2002). Other general purpose systems, e.g., ReCAPP (PPTI 2006) and TOBUS (Brandt and Rasmussen 2002), are also available commercially. For healthcare facilities, commercial systems such as VFA.(VFA 2013) and Archibus (FCI 2013) also have specialized asset management systems. A survey of asset management systems used at the municipal level (Halfawy et al. 2005) revealed that the vast majority of such systems focus primarily on supporting day-to-day management activities, and an extremely small number of them offer limited support for long-term renewal planning. Moreover, many fundamental asset management functions, such as performance modeling and repair prioritization, are not supported by many systems with the lack of the decision support, the key decision on fund allocation is not properly guided. As an example, to allocate hospital renewal funds, Ministry of Health and Long-Term Care (MHLTC) uses a simple allocation model that is a direct percentage of the hospital operating funds in past years (MHLTC 2008). This simple model does not consider important performance indicators such as stakeholders' satisfaction with hospital services, the availability of newer technology to improve services, patient demographics at a specific hospital location, energy-saving, environmental issues, and the business value retained and passed on to subsequent generations. Typically, little guidance is given to individual hospitals with respect to key performance indicators that support internal decisions about when and how to renew components to avoid the risk of critical equipment failure and to increase the level of service satisfaction for all stakeholders, including patients and staff. This paper, therefore, aims at discussing the key performance indicators for hospital buildings and that are to prioritize capital renewal works.

2. Performance Assessment Methodology

The proposed performance assessment methodology has been designed to incorporate three main aspects (Figure 2) that facilitate rigorous priority analysis for capital renewal: (1) defining proper hierarchy of hospital systems/spaces; (2) identifying and properly assessing the key performance indicators that are applicable to various systems/spaces; and (3) performing detailed priority analysis. These aspects generate properly prioritized list of subsystems for capital renewal purposes. A key consideration in the proposed methodology is to account for the key aspects related to hospitals, including: the diverse zones/spaces and their varying relative importance; the specialized equipment within the hospital; and the different types of assessments that provide good performance evaluation. The details of the framework functions are discussed in the following subsections.

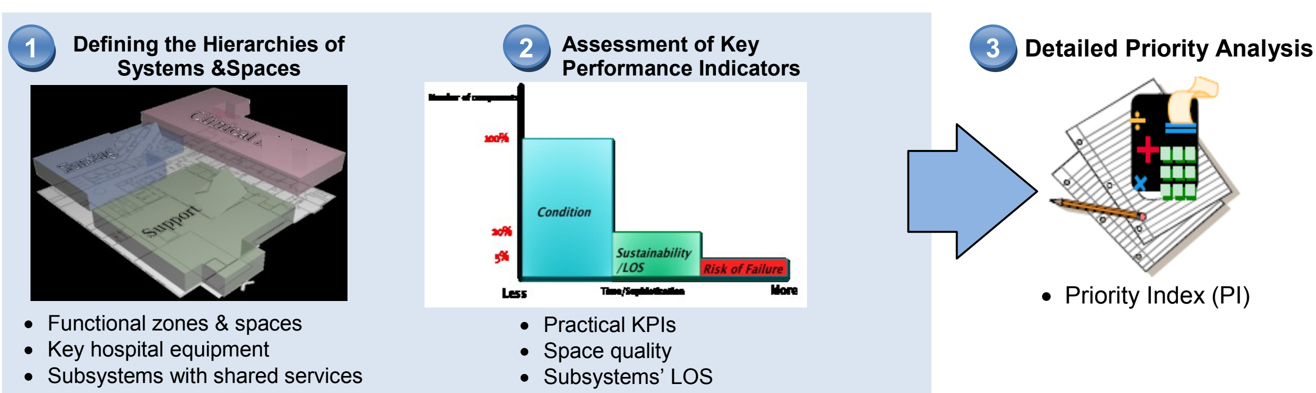


Figure 2: Main functions in the proposed performance assessment methodology

2.1. Hierarchies of Hospital Systems and Spaces

To facilitate accurate, speedy, and structured performance assessment of hospitals, the proposed framework defines a detailed hospital hierarchy and introduces three unique features that are important to hospitals: (1) defining two hierarchies for the hospital; one for the systems and their subsystems and the other for the important zones/spaces; (2) providing special focus on the key hospital equipment; and (3) providing special focus on the hospital subsystems that provide shared services to multiple zones.

The basic hierarchy of systems and subsystems in hospitals uses the Uniformat II classification (UNIFORMAT II, 2005), as shown in the top part of Figure 3. An additional fifth category "Equipment" has been added, by the authors, to the four main physical systems (Civil, Architectural, Electrical and Communications, and Mechanical). This category relates to specialized (costly) equipment that has been separated from regular mechanical systems because of the importance of keeping them well renewed in hospitals. They include MRI, CT Scans, and kitchen equipment. The standardized subsystems in the hierarchy facilitate data integrating among various functions (e.g., preventive maintenance, capital renewal, material/equipment management, etc.).

Because of the diversity of space functions in hospitals, a separate hierarchy for hospital spaces has been defined in the proposed framework, with three main functional zones (bottom of Figure 3). Each zone includes a group of spaces that share similar functional characteristics, as follows: (1) Clinical zone consisting of operating rooms, intensive care unit (ICU), etc. (2) Nursing zone comprising of inpatient rooms, nursing stations, etc.; and (3) Support zone comprising administration, kitchen, workshops, storage areas, etc. Defining these zones (and their relative importance) is a unique advantage of the proposed system that will lead to better prioritization of assets. For example, assuming the clinical zone is the most important, then, the priority of renewing the same subsystem (or component) must be higher in the clinical zone. Similarly, it is important to identify the building subsystems that provide shared services to the three zones in the hospital (bold in Figure 3), and accordingly, assign them more weights, to give them higher priority than the same components that are local within individual zones.

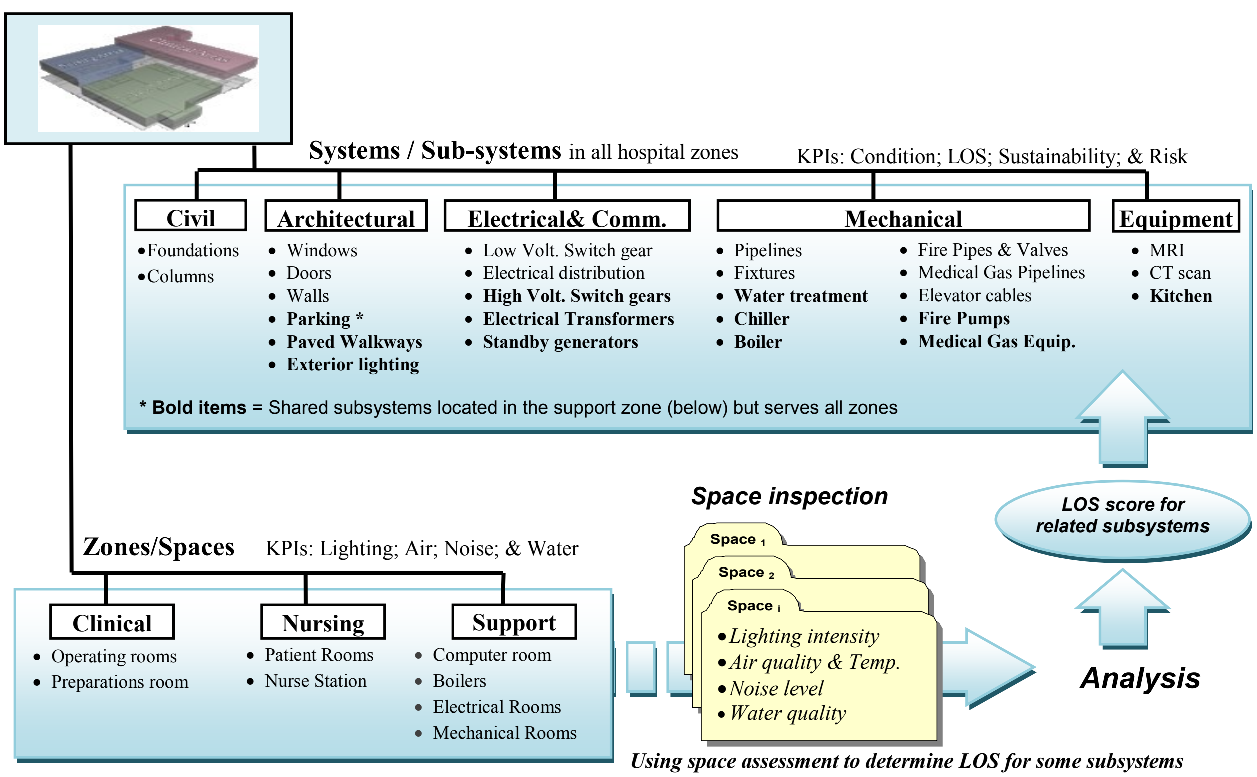


Figure 3: Main Systems and Functional Zones

2.2. Key Performance Indicators (KPIs)

The aim of performance assessment is to measure not only the physical condition but, more generally, the performance of each component in the hospital building with respect to a variety of performance criteria. Extensive research has been carried out in a number of diverse directions that have been pursued mostly in isolation from one another. These directions include: identifying the key performance indicators (KPIs) to use in multi-criteria evaluations, methods of physical condition evaluation, level-of-service evaluation, risk and reliability assessments; and sustainability assessments.

Due to importance of spaces in buildings, recent research (Eweda et al. 2010) presented a condition assessment model that considers space as the principle evaluated element. As such, their model evaluates all the systems within every space and then accumulates the information for all the physical systems of the building. However, assessing all the spaces in a complex building indiscriminately is costly and time consuming. Also, considering condition as the only performance indicator does not suit hospital buildings, which face enormous challenge due to the complexity of the electro-mechanical equipment (Shohet 2003) and the significant differences among the functional spaces within the buildings. There is a need, therefore, for a performance assessment approach that integrates physical condition with other important key performance indicators such as the level of service (LOS) observed at various spaces, sustainability aspects, and the risk of service failure. In the literature, various efforts have examined some of these aspects individually, including: multiple-criteria performance analysis (Shohet 2006; Shohet and Lavy 2004); LOS attained by multiple stakeholders (Nasser 2007); risk/reliability analysis (Christodoulou et al. 2009; Moubray 1997); and social/economic/environmental sustainability (Lützkendorf and Lorenz 2005); and indoor environment quality of building space (Eweda et al. 2010). Maintenance management of hospital buildings is an enormous challenge due to the complex nature for the hospital buildings that embody a number of interrelated physical systems, diverse functional spaces (e.g., operating room, patient wards, labs), and special systems (e.g., medical gas systems, nurse call systems, etc. all of which must be managed within a limited maintenance budget. Therefore, both systems and spaces represent important interrelated entities within hospital facilities. Generally, the quality of physical systems greatly affects the quality of the indoor environment (e.g., temperature, lighting, and sound) inside the various functional spaces (Eweda et al. 2010), which directly impacts both patients and staff. Therefore, this paper introduce a practical and comprehensive performance assessment approach which incorporates multiple key performance indicators (condition, LOS, sustainability, and risk); indoor space quality on systems' LOS; and appropriately prioritizes the various systems for renewal action.

2.3. Assessing the KPIs

Both the system hierarchy and the zones/spaces hierarchy, combined, enable a comprehensive assessment of hospitals. In the proposed framework, the system hierarchy enables performance assessment of building subsystems based on four key performance indicators (KPI)s: Condition; LOS; sustainability; and risk. For some of the subsystems that affect the quality of spaces (HVAC, water distribution, electrical distribution, etc.), however, evaluating the LOS is not a simple task. For these subsystems, the space hierarchy makes it possible to determine a proper LOS value based on assessing the various spaces in terms of four quality-related KPIs (Lighting intensity; Air quality & Temperature; Noise level; and Water quality). For example, when several spaces show inadequate water quality/quantity, it implies low LOS for the water supply system (as highlighted on the bottom right corner of Figure 3).

For assessing the hospital subsystems, the four KPIs (condition, LOS, sustainability, and risk) vary in their assessment complexity and in their applicability to various subsystems, for example, the overall performance for the water pipeline can be best represented by the four KPIs, with different importance, as shown in figure 4. Generally, however, condition assessment is the easiest to evaluate and can be applied to all subsystems. Sustainability and LOS, on the other hand, are more difficult to evaluate but apply to a small group of subsystems. The risk of failure is also the most difficult to assess and applies to major equipment and subsystems within the hospital. As such, it was initially expected that risk of failure analysis applies only to about 5% only of hospital subsystems, involving major electrical and mechanical systems. As shown in Figure 4, the condition for all subsystem is to be assessed visually using a direct rating approach (Good; Fair; Poor; or Critical), which provides a sufficient level of detail for renewal purposes (Uzariski 2007)**.** The LOS, on the other hand, assesses the quality of service offered to stakeholders, irrespective of physical condition. For example, old equipment that scores high in the condition KPI may score poorly in LOS due to its old technology and its inability to serve the current workload. For some specific subsystems (HVAC, Water distribution, and Electrical distribution), as mentioned before, the LOS assessment will be determined after assessing the quality of indoor environment in various spaces. Sustainability also applies to a small subset of the hospital subsystems using a direct rating process. The last type of assessment (risk) applies to key subsystems whose failure affects health, safety, or the environment. In the absence of historical data on failure rates and consequences, a direct rating approach is used in this research.

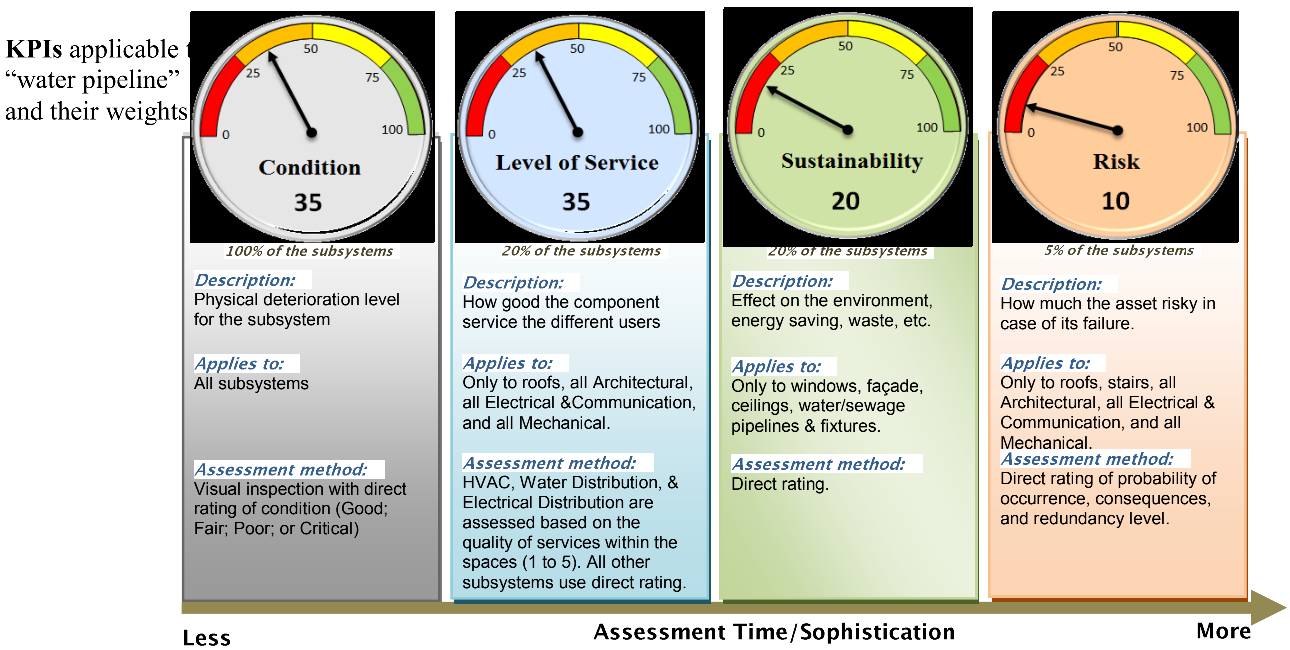


Figure 4: Applicability and weights for the various KPIs

For each hospital subsystem, therefore, the first step in the assessment process is to define the applicable KPIs that best measure the performance of that subsystem (obtained from the survey discussed later). For example, foundations are assessed based on condition only; whereas, the water system needs to be assessed in terms of condition, level of service, sustainability, and risk as shown in Figure 4. This process, as such, focuses the assessment effort and saves the time and cost of indiscriminate assessments with respect to all the KPIs.

3- Multi-criteria Priority analysis

The proposed assessment framework incorporates a priority analysis for all subsystems renewal purposes that takes into account two important parameters: the overall subsystem importance (OSI) of a subsystem within its system and zone; and the overall subsystem deficiency (OSD) determined from field assessment of related KPIs. The calculation of the subsystem Priority Index (PI) is represented graphically, as shown in Figure 5. The overall subsystem importance (OSI) of a subsystem is determined by multiplying the relative importance factors for the zone, system, and subsystem. As such, when a subsystem is in a more important zone or system, then, its OSI becomes higher, and accordingly, the PI becomes higher, i.e., more eligible for renewal.

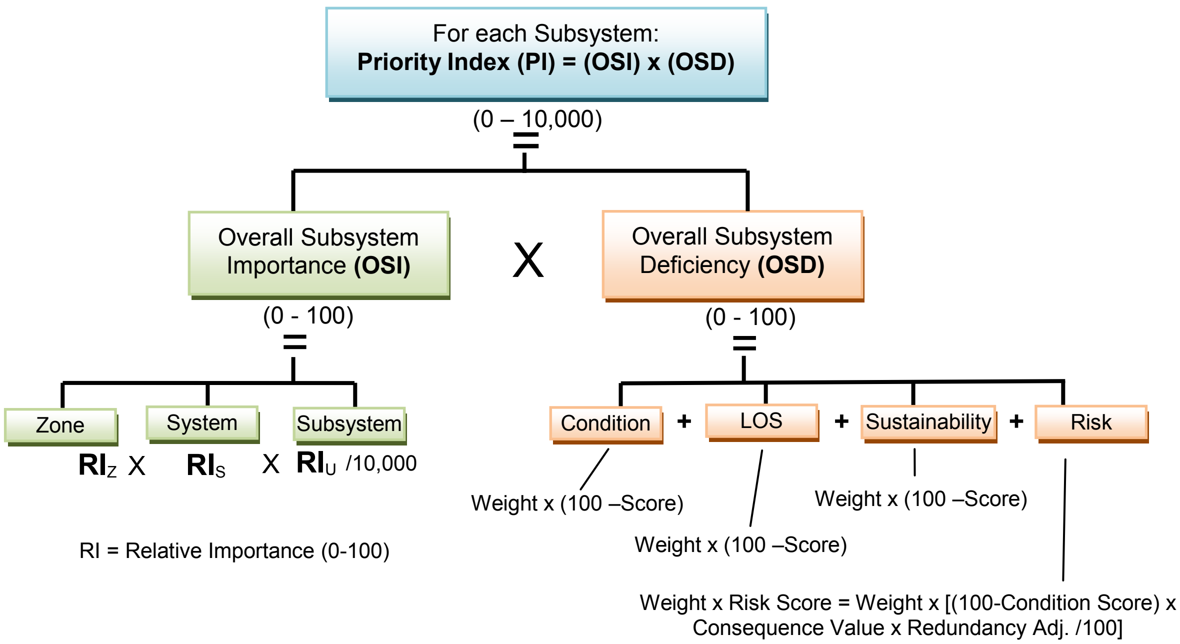
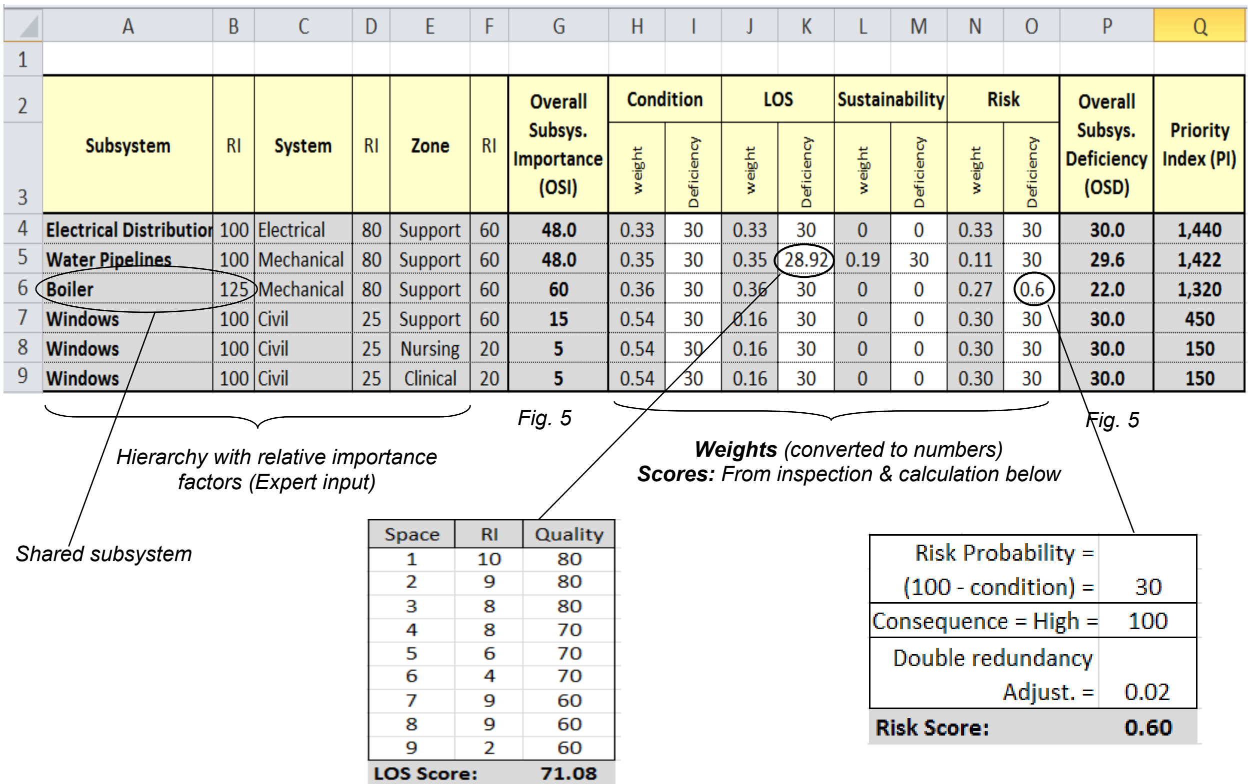


Figure 5: Subsystem's priority index calculation

Calculating the overall subsystem deficiency (OSD), however, requires special care to avoid misrepresentation. Once the subsystem is assessed in the field and the scores for its Condition, LOS, Sustainability (all from 0 to 100) are determined, the subsystem's OSD value is then determined as the weighted sum of these scores, as shown in Figure 5. The equations in Figure 5, however, show careful use of the score values. For example, for the first three indicators (condition, LOS, and sustainability), the value used in the equation is (100-score). i.e. deficiency. As such, when the subsystem's condition score, for example, is high, then using (100-score) in the equation results in a small OSD value, and accordingly, low priority index (PI) for renewing this subsystem. Risk, however, is dealt with in a different manner. To facilitate risk calculations, the value of subsystem risk is determined based on its probability of failure (assumed to be 100-condition score), multiplied by the consequence score (High = 100; Medium = 70; and Low = 40), and multiplied by an adjustment value for the existing redundancy level of the subsystem (Partial = 50%; Full = 10%; and Double = 2%). Using this formulation, the impact of condition, consequence, and redundancy properly affect the PI calculation. When the PI for a subsystem is zero, it indicates that its performance is high, i.e., the subsystem has a low renewal priority. On the other hand, when the subsystem is at a high deficiency level that makes its condition below its minimum acceptable condition, this subsystem will have a higher priority for renewal.

To demonstrate the proposed prioritization analysis, a hypothetical example involving six different subsystems (boiler, water pipelines, electrical distribution, and three windows sections) has been considered. The priority analysis calculation is shown in Figure 6, with each of the analyzed subsystems in a separate row. Among these subsystems, the boiler is considered as a shared subsystem (i.e., part of the support zone and serves all zones, as highlighted in Figure 3). Also, the three windows sections related to the three zones in the hospital (clinical, nursing, and support). These six subsystems have been selected to demonstrate different competing subsystems from different zones and systems, and involve shared and non-shared subsystems, involve some subsystems that have an impact on indoor quality of spaces, and also involve subsystems that are sensitive to the risk of failure and different minimum acceptable conditions.



Subsystem	RI	System	RI	Zone	RI	Overall Subsys. Importance (OSI)	Condition weight	Condition Deficiency	LOS weight	LOS Deficiency	Sustainability weight	Sustainability Deficiency	Risk weight	Risk Deficiency	Overall Subsys. Deficiency (OSD)	Priority Index (PI)
Electrical Distributior	100	Electrical	80	Support	60	48.0	0.33	30	0.33	30	0	0	0.33	30	30.0	1,440
Water Pipelines	100	Mechanical	80	Support	60	48.0	0.35	30	0.35	28.92	0.19	30	0.11	30	29.6	1,422
Boiler	125	Mechanical	80	Support	60	60	0.36	30	0.36	30	0	0	0.27	0.6	22.0	1,320
Windows	100	Civil	25	Support	60	15	0.54	30	0.16	30	0	0	0.30	30	30.0	450
Windows	100	Civil	25	Nursing	20	5	0.54	30	0.16	30	0	0	0.30	30	30.0	150
Windows	100	Civil	25	Clinical	20	5	0.54	30	0.16	30	0	0	0.30	30	30.0	150

Space	RI	Quality
1	10	80
2	9	80
3	8	80
4	8	70
5	6	70
6	4	70
7	9	60
8	9	60
9	2	60
LOS Score:		**71.08**

Risk Probability = (100 - condition) =	30
Consequence = High =	100
Double redundancy Adjust. =	0.02
Risk Score:	**0.60**

Figure 6: Priority index calculations for subsystems

The left side of the figure shows the hierarchy of the subsystems, systems, and the zones, with their relative importance (RI) factors determined from the survey (Expert inputs). Accordingly, column G shows the calculated OSI of each subsystem, following the formulation in Figure 5. The middle part of the Figure 6 also shows the weights of the KPIs, obtained from the experts at the hospital, and the deficiency for the KPIs related to each subsystem. All the deficiencies for the condition, LOS, and sustainability KPIs are determined using (100-condition score). But the LOS KPI for the subsystems that are related to the indoor quality factors and Risk, however, required detailed calculations. As an example, the circled (100 – 71.08 = 28.92) score for the LOS of the water pipelines was determined from the assessment of spaces, as shown at the bottom of Figure 6. Also, the circled 0.6 score for the Boiler's risk assessment is calculated as shown on the bottom right corner of Figure 6. Accordingly, following the calculation scheme in Figure 5, the overall priority index for the six subsystems are calculated in the last column of Figure 6 and sorted in a descending order, with the top subsystem (Electrical Distribution) being the one most eligible for renewal action. Looking at the PI values in Figure 6, the proposed prioritization framework demonstrates logical computation and ability to differentiate among competing subsystems.

4. Summary and Concluding Remarks

Accurate performance assessment of buildings is essential for prioritizing the many building components that compete for limited renewal funds. Traditionally, physical condition has been used as the main indicator of performance. To provide a more comprehensive assessment of building components, this paper uses three other key performance indicators (KPIs): level of service, sustainability, and risk of failure. The proposed assessment methodology has been designed to incorporate rigorous priority analysis for capital renewal based on two hierarchies of hospital systems/spaces and a multi-criteria performance assessment that determines subsystems' priority indices considering the applicable KPI's. The proposed methodology structures the assessment process and makes it suitable for quantifying the level of service that is important to healthcare facilities.

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