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# MAINTENANCE COST ANALYSIS FOR LARGE HOSPITAL BUILDINGS

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**ABSTRACT:** Large hospitals such as medical centers provide not only medical services, but also carry the responsibilities for emergency refuges, medical researches and education. The function of large hospitals is as important as other infrastructure systems such as highways, bridges, and utilities. When disasters occur, the hospitals have to provide emergency medical services for victims and support the patient's needs of health. In order to keep a smooth operation of hospitals, the maintenance management of hospital buildings should be carefully investigated. However, there are few researches focused on maintenance management issues of hospital buildings.
This paper investigated the National Taiwan University Hospital (NTUH) and established a maintenance cost database. The NTUH is the best-known and most high-renowned medical center in Taiwan in which more than 4,000 employees serving approximately 2,000 in-patients and 7,000 out-patients daily. The data were collected from the NTUH which consisted of 16,228 maintenance records in the past ten years. This paper analyzed these data to obtain various characteristics of maintenance records, and revealed the key items of maintenance cost for large hospital buildings, which can provide the facility manager of hospital buildings to execute a proper maintenance policy for hospital buildings.

*Keywords: Maintenance Cost; Hospital; Building*

## 1. INTRODUCTION

With the increasing demands on healthcare facilities and services, hospital buildings have gradually matured to become large capacity and numerous complex facilities. Hassan [1997] pointed out that the increase in sophistication and complexity of medical services within the health service is reflected in the sophistication and complexity of buildings, their finishes, fittings, contents and service. However, in the situation of ever-growing demands and decreasing operational budget, facilities managers of hospital have to ensure that facilities are properly maintained without compromising their performance. In order to integrate the medical service and resources and provide an appropriate environment in such a high-complex building, the key maintenance items should be carefully analyzed and executed as well as proper decisions for maintenance budget allocation.

To achieve this goal, historical maintenance data are vital for this study. Few researches can provide sufficient and reliable maintenance records of hospital buildings, neither the key items of maintenance for allocating the limited maintenance budget. More than 16,000 maintenance records of the National Taiwan University Hospital (NTUH) from 1998 to 2006 are collected and analyzed in this study.

## 2. LITERATURE REVIEW

Uhlik and Hinze (1998) sent questionnaires throughout the Unites States to investigate matters concerning the maintenance of existing health care facilities. The majority of the maintenance work consisted of HVAC (including plumbing, 53%) and roofing projects (20%) Neely and Neathammer's (1991) research focused on American defense facilities, subdividing them into 34 building types (hospital buildings being one of the 34 subcategories). They found that the majority of the maintenance budget in hospitals was spent on interior finishing and interior construction (32%), and on heating, ventilation, and air-conditioning (HVAC) was 29%. The rest of the budget (39%) was spent on electricity, exterior envelope, water and plumbing, and other electricity systems, such as communications and low-voltage systems. Nesje (2002) examined the distribution of FM expenditures at St Olavs Hospital in Norway, and found that maintenance, energy and cleaning costs each account for one third of the total operation costs of the hospital.

For the above aforementioned researches, most studies utilized questionnaires to identify key maintenance items. This study tries to base on real life cycle maintenance data to analyze the key maintenance items for various life cycle stages of large hospital buildings, i.e. medical centers.

## 3. BACKGROUND OF CASE STUDIES

This study investigates the maintenance records of National Taiwan University Hospital (NTUH) for the past decade. The NTUH is the most prestigious and historical healthcare center and is one of the most representative medical centers in Taiwan. The NTUH consists of two main buildings: the West-Site building and the East-Site building. The service ages of these two main buildings are significantly different. The West-Site building has passed towards 86th years, but the East-Site building operated only for 17 years. The sickbed capacity of NTUH is more than 2,700. The very different stages in building's life cycle should display different physical deterioration degree and require different maintenance needs. This study analyzes the key maintenance items according to the historical data of each site and provides maintenance cost allocation individually.

According to the interview results, three types of maintenance work are identified, periodic maintenance, repair, and demand changes. Periodic maintenance deals with regular or routine works to maintain the basic functions and requirements of building service. Repair maintenance occurs when the physical components are either damaged, broken, or deteriorated, resulting in malfunction of building services. Demand changes may arise from altering space allocation, medical market changes, and customer requirement changes. Typical cases such as bio-safety level wards, cancer and health management center, and plastic surgery et al. Seven major maintenance items are identified by hospital staff: structure, interior/exterior, electricity, drainage, machinery, fire prevention, and others. Combined with the three categories described above, the work breakdown items of hospital maintenance works are listed in Table 1

**TABLE 1. Work Break Down Items of Hospital Maintenance Works**

| Items | Category | | |
|---|---|---|---|
| | Periodic | Non-periodic | |
| | Periodic maintenance | repair | Demand change |
| Structure | none | A1 building demolition<br>A2 building additions<br>A3 structure reinforcement | A1 building demolition<br>A2 building additions<br>A3 structure reinforcement |
| Interior/Exterior | b1 painting<br>b2 surgical lead door | B1 roof<br>B2 building hardware<br>B3 interior finishes<br>B4 outdoor<br>B5 external walls<br>B6 doors and windows | B1 roof<br>B2 building hardware<br>B3 interior finishes<br>B4 outdoor<br>B5 external walls<br>B6 doors and windows |
| Electricity | c1 high voltage<br>c2 low voltage<br>c3 uninterruptible power supply (UPS) | C1 high voltage<br>C2 low voltage<br>C3 thunder prevention system | C1 high voltage<br>C2 low voltage<br>C3 thunder prevention system |
| Drainage | d1 water supply equipment<br>d2 water treatment unit | D1 drainage equipment<br>D2 sewage treatment facilities | D1 drainage equipment<br>D2 sewage treatment facilities |
| Machinery | e1 HVAC<br>e2 boiler<br>e3 elevator | E1 HVAC<br>E2 boiler and steam engine<br>E3 elevator | E1 HVAC<br>E2 boiler and steam engine<br>E3 elevator |
| Fire prevention | none | F fire fight equipment | F fire fight equipment |
| Others | g1 medical air facility<br>g2 medical facility<br>g3 ward facility (Electro-motion medical Bed)<br>g4 kitchen facility<br>g5 logistic facility<br>g6 testing for pollution source | G1 medical air facility<br>G2 medical facility<br>G3 ward facility<br>G4 kitchen facility<br>G5 logistic facility<br>G6 design / technical service | G1 medical air facility<br>G2 medical facility<br>G3 ward facility<br>G4 kitchen facility<br>G5 logistic facility<br>G6 design / technical service |

## 4. COMPARISON OF ANNUAL MAINTENANCE COST

There is a big difference in the ages of the East Site and the West Site buildings. The West Site building has been in operation since 1921, while the East Site building started operating in 1991. Regarding the life cycle of buildings, West Site and East Site buildings represent the old adult and young adult stage, respectively. Although periodic maintenance and demand change are required for old buildings, these expenditures are much less than the cost of repairs. For the East Site building, repair is also the major category of maintenance cost and demand change is relatively less than periodic maintenance. The maintenance cost per year per square meter of floor area for West Site and East Site buildings are calculated and listed in Table 2.

**TABLE 2. Comparison of Maintenance Cost Dollar/$m^2$ (per year)**

| Dollar/$m^2$ (per year) | periodic | repair | demand change | total |
|---|---|---|---|---|
| West Site | 3.9 | 22.7 | 2.9 | 29.5 |
| East Site | 5.4 | 8.0 | 2.0 | 15.4 |

It is very meaningful to compare the unit maintenance cost for old adult and young adult buildings. For

periodic maintenance, West Site building spent $3.9/ sq m (per year) and East Site building spent 5.4 dollar/ sq m (per year). The difference is not very obvious. For repair, the older West Site buildings' cost was nearly 3 times ($22.7 vs. $8.0) the cost of the young adult East Site building. For demand change, the older West Site buildings spent $2.9 / sq m (per year) comparison with $2.0 / sq m (per year) of the East Site buildings. The West Site has been operating for more than 80 years. Although periodic maintenance may have been done in the past eight decades, the facility's functions still can not meet the increasing modern requirements of patients' needs. The lifespan of HVAC, pipelines, and other equipment is much shorter than the building structure. A lot of interior finishes renovations, facility repair, and space enlargement resulted in these maintenance expenditures. On the other hand, the demand change requirements of the young adult East Site building are comparatively less than the requirements for the older West Site. The total average maintenance cost per square meter per year for the older West Site is about twice that of the young adult East Site ($29.5 vs. $15.4).

It may be meaningful to compare the periodic maintenance and repair for different stages of the building's life cycle. For the older West Site, the repair cost is about 5.8 times than the periodic maintenance ($22.7 vs. $3.9). For the younger East Site, this ratio is only about 1.5 times ($8.0 vs. $5.4). It is a reasonable assumption that the older the building age, the higher the ratio will be if regular maintenance works are not periodically executed. However, since there are only two sites analyzed in the study, the relationship between the building age and the ratio of repair/periodic maintenance can not be clearly identified. Nevertheless, the ratios of repair/periodic maintenance for the older West Site and younger adult East Site provide valuable references for the other hospital buildings and future analysis.

## 5. KEY MAINTENANCE SUB-ITEMS

### 5.1 Key sub-items for periodic maintenance

The investigation of maintenance and repair cost distribution helps to reveal the key sub-items for hospital facility managers.

As shown on Table 3, for the old West Site building, the top three most costly sub-items are high voltage (26.1%), HVAC (25.9%), and elevators (15.9%) respectively. For the young adult East Site building, the top three sub-items are quite similar: HVAC (26.2%), high voltage (22.1%), and elevators (13.9%). Regardless of the different life cycle stages, the key sub-items of periodic maintenance for these two buildings are almost identical. The high voltage, HVAC, and elevators provide essential support for hospital functions. Although these three sub-items account for more than 60% of the periodic maintenance cost, the hospital facility managers need to ensure that these three sub-items are well maintained.

**Table 3. Key Sub-items of Periodic Maintenance**

| West Site | | East Site | |
|---|---|---|---|
| Major sub-items | Percentage | Major sub-items | Percentage |
| c1 high voltage | 26.1% | e1 HVAC | 26.20% |
| e1 HVAC | 25.9% | c1 high voltage | 22.10% |
| e3 elevator | 15.9% | e3 elevator | 13.90% |
| Sum | 67.9% | Sum | 62.20% |

### 5.2 Key sub-items of repair

Table 4 shows the top three sub-items of the old West Site building are interior finishes (67.3%), low voltage (10.6%), and HVAC (5.1%) respectively. For the young adult East Site building, the top three sub-items are quite similar: interior finishes (43.4%), HVAC (24.7%), and low voltage (9.3%). Regardless of the different life cycle stages, key sub-items of periodic maintenance for these two buildings are also identical. For the old West Site building, the interior finishes comprise more than two-thirds of the repair costs.

Five major sources for repairs have been identified as 1. space requirements for medical records, cashiers and examination department, 2. psychiatric department, 3. tumor and radio surgery department, 4. obstetrics/gynecology department, 5. increased in-patient wards. These space remodeling require the replacement of many interior finishes. Low voltage and HVAC system account for the other repair costs for the older West Site building. Although the interior finishes is also the number one sub-item of repair cost for the young adult East Site building, the percentage (43.4%) is comparatively less than that of the old West Site building (67.3%). On the other hand, significant portions (24.7%) of repair costs in the young adult East Site building have been spent on the HAVC system. HVAC is clearly the top sub-item of periodic maintenance for East Site building. However, due to the lifespan of the HVAC system, the 17 year-old East Site building still requires significant expense on HVAC repair.

**Table 4. Key Sub-items of Repair**

| West Site | | | East Site | | |
|---|---|---|---|---|---|
| Items | Major sub-items | | Items | Major sub-items | |
| Interior / Exterior | B3 interior finishes | 67.3% | Interior / Exterior | B3 interior finishes | 43.4% |
| Electricity | C2 low voltage | 10.6% | Machinery | E1 HVAC | 24.7% |

| | | | | | |
|---|---|---|---|---|---|
| Machinery | E1 HVAC | 5.1% | Electricity | C2 low voltage | 9.3% |
| Sum | | 83.0% | Sum | | 77.4% |

### 5.3 Key sub-items of demand change

For the older West Site building, the key sub-items of demand change are identified as low voltage (52.7%), boiler and steam engine (31.3%), and interior finishes (11.1%), as shown on Table 5. The security system rehabilitations account for the low voltage sub-item in the old West Site building and comprise more than half of the demand change cost. The boiler and steam engine replacement as well as gas line installation account for about one third of the demand change. The Center for Human Appearance was established in 2002, and related facilities were renovated in 2003. The interior finishes were designed with a balanced mix of contemporary and classic style to provide guests with a private and homey environment, professional aesthetical medical consultations, and warm hospitality

For the younger adult East Site building, the key sub-items of demand change are identified as interior finishes (29.9%), low voltage (27.6%), HVAC (17.9%), and elevator (16.0%). The relocation of chief doctors' offices resulted in significant costs for interior finishes and low voltage replacement. The outbreak of SARS in 2003 forced NTUH to renovate the emergency center for crisis management. Follow-on reallocation and redesign of the East Site building continued in 2004. The addition of a cooling tower and elevators also resulted in considerable demand change cost.

**Table 5. Key Sub-items of Demand Change**

| West Site | | | East Site | | |
|---|---|---|---|---|---|
| Items | Major sub-items | | Items | Major sub-items | |
| Electricity | C2 low voltage | 52.7% | Interior / Exterior | B3 interior finishes | 29.9% |
| Machinery | E2 boiler and steam engine | 31.3% | Electricity | C2 low voltage | 27.6% |
| Interior / Exterior | B3 interior finishes | 11.1% | Machinery | E1 HVAC | 17.9% |
| Machinery | E1 HVAC | 4.1% | Machinery | E3 elevator | 16.0% |
| Sum | | 99.2% | Sum | | 91.4% |

## 6. DISCUSSION

This study provides essential data analysis and key items of maintenance costs by examining 9,410 historical maintenance records of the 2400-bed medical center NTUH in Taiwan. An 86 year–old West Site building and a 17 year-old East Site building were compared. The results of this study can provide significant references for the hospital facility managers around the world. Three major findings are discussed as follows.

In Shoet's study in 2003, 17 hospitals in Israel with an average age of 38 years and 658 sickbeds were analyzed. The mean annual maintenance budget is $37.20 per square meter and about half of this was spent on permanent maintenance staff. Thus, the mean annual maintenance cost will be less than $18.60 per square meter. For the case study of NTUH, which has a much larger scale (2400 beds vs 658), the average annual maintenance costs were $29.50 per square meter for the older West Site building and $15.40 for the younger adult East Site building. For different building life cycle stages, it is reasonable that the older the buildings, the higher the maintenance cost. The findings of the NTUH study provide valuable information about the maintenance costs during various life cycle stages. In Shoet's later study in 2004, a 23 year-old hospital building with 1065 beds was studied and the annual maintenance expenditure was $38.50 per square meter (half was for maintenance staff). Combining the results of NTUH with Shoet's studies, the relationship between the age of hospital buildings and the annual maintenance costs is be plotted as in figure 8. Although this relationship may require further detailed analysis, this finding provides precious information for hospital facility managers in making decisions regarding maintenance budgets.

Regarding to the key sub-items and associate maintenance cost percentage, in Uhlik and Hinze's study, the questionnaire showed that the majority of the maintenance work consisted of HVAC (including plumbing, 53%) and roofing projects (20%). Neely and Neathmmer (1991) identified interior finishes (32%) and HVAC (29%) as the major maintenance sources. This research on the NTUH demonstrated different key items of maintenance work for the older West Site building and East Site building accordingly. As discussed in section 5, the key sub-items for periodic maintenance, repair, and demand change are identified respectively. For various life cycle stages, the key sub-items may be different. However, it's interesting to note that HVAC and low voltage systems remain the key sub-items for all the periodic maintenance, repair, and demand change categories. Regardless the various life cycle stages of the West Site and East Site buildings, these two sub-items continue to be essential items for hospital maintenance work. This finding coincides with the results of Uhlik's studies. However, the percentage of HVAC in NTUH's historical maintenance data is relatively low compared to Uhlik's questionnaire results. Another difference is that the low voltage system identified in this research was not significant in Uhlik's study. Lack of the information of building age in Uhlik's questionnaire, the electrical system only occupied about 5% of the total maintenance cost. In Neely's study, the electricity system accounted for about 13% of the maintenance cost. The findings of this research are closer to the findings of Neely's study.

The interior finishing has also been identified in NTUH as a major key maintenance item. In the older West Site building, the deterioration and space remodeling results in high expenditures on interior finishes. For the younger adult East Site building, the demand change of chief doctors' offices also results in considerable costs for interior finishes. This finding is similar with Neely's study that interior finishes account for 32% of the total maintenance cost. The roofing projects identified by Uhlik's questionnaire was not a significant item in either the NTUH, or Neely's study. This difference may be due to different roof design system or weather conditions in the different countries.

## 7. CONCLUSIONS

Hospital isolation wards and operation rooms have many special design requirements, including pressure, ventilation, climate control and air filtering. The ventilation system must be well managed to maintain proper room pressure, contamination removal and temperature. Therefore, the items E1 and e1 both should be of great concern. Hospitals often vary the interior finishes because of the demands of space change. In addition, the large-scale of hospital buildings may result in a variety of interior finishes. Nurse calls, monitoring, broadcast and telecom, internet, and security require the low voltage in hospital building. The high percentage of the low voltage also requires attention in non-periodic repair.

Since most life-support equipment depends on machinery and electricity systems, an uninterrupted power supply for continual operation is of upmost importance. The energy supply in a hospital is so important that it is subject to many official regulations designed to ensure its permanent availability.

The major conclusions of this study can be summarized as follows:

This study provides a comprehensive data analysis of historical maintenance records for the NTUH. It is not easy to get such a complete maintenance records for medical center during the life cycle span. Although the NTUH is a case study in Taiwan, the representative status and its large scale make the NTUH a good experience and lessons for managing hospital facilities.

The average annual maintenance costs per square meter is analyzed in this study. Compared to questionnaire

results, the unit maintenance cost provides facility managers an actual value to examine their maintenance budgets.

This study identifies key items and sub-items in three maintenance categories (periodic, repair, demand change) respectively. High voltage, HVAC, and elevators, are the key sub-items for periodic maintenance. Interior finishes, low voltage, and HVAC are the key sub-items for repair. Low voltage, interior finishes, HVAC, and other machinery (boiler, stem engine, and elevators) are the key sub-items for the demand change.

Regarding the life cycle of buildings, this study compares older and younger adult hospital buildings for maintenance cost distribution. Although different building ages may influence the maintenance cost, none of previous studies had conducted comparisons for various life cycle stages. This study reveals the differences between the old and young adult hospital buildings. The results can provide facility managers with useful maintenance information concerning the life cycle stages of hospital buildings.

The results and the findings of this study have been discussed in detail with the findings of previous studies. Although the results in the United States and Israel may not be similar to the NTUH in Taiwan, this study provides valuable knowledge exchange with the other countries. For the medical technology level in Taiwan, the NTUH undoubtedly is one of the most advanced medical centers in the world. The research findings of this study provide useful lessons and information for the other medical centers worldwide.

## REFERENCES

[1] Hassan Al-Zubaidi （1997） Assessing the Demand for Building Maintenance in a Major Hospital Complex. Property Management, Volume 15, Number 3, pp. 43–50.

[2] Uhlik, F., and Hinze, J., 1998. Trends in the Construction Needs of Hospital Facilities, Journal of Architectural Engineering, ASCE, 4(4).

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

[4] Nesje, A., 2002, Management, operation and maintenance costs of hospital buildings, Proceedings of the International Federation of Hospital Engineering, Bergen, 290-296.

[5] Shohet, I.M., 2003. Building evaluation methodology for setting priorities in hospital buildings, Construction Management and Economics, 21(7), 681-692.

[6] Shohet, I.M., Lavy-Leibovich, S., Bar-On, D., 2003, Integrated maintenance monitoring of hospital buildings, Construction Management and Economics, 21(2), 219-228.