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Multi-Criteria Decision Analysis for Evaluating Sustainable Lifts Design of Public Hospital Buildings

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Sustainability is a big trend in today’s building industry. For instance, energy use, resource efficiency, materials selection, safety, and life-cycle management are all important considerations in making the transition to greener buildings. In the past, lifts have been overlooked in green building planning yet including them is a useful way to improve overall building functionality and efficiency. Lifts use a relatively small amount of energy compared to the overall energy consumption of a building yet they provide both daily carrier service for user and so they should be included in sustainability planning. With so many building products being marketed with a sustainable angle, lifts also need to be included in this improvement. Building process has become complex due to the involvement of multiple benchmark like social, economic and environmental dimensions. A significant challenge for those involved in the building industry is identifying and incorporating sustainable features into each of the building stage. This in turn puts constrains to decision makers in selecting the finest decision in achieving sustainable goal for every aspect of building processes. This paper investigates the multi-criteria decision analysis for sustainable lifts design, namely; criteria selection, criteria weighting, evaluation and final aggregation. Decision analysis plays a vital role for designing the systems by considering various criteria. The criteria were grouped based on economic, environmental and social dimensions. Technique for order preference by similarity to ideal solution (TOPSIS) methods were employed to rank the most important criteria that need to be considered in making the decision. A design team from hospital project specifically from mechanical and electrical department have been chosen for this study due to their expertise in planning and designing the mechanical aspects for a project. As a result, it shows the process of decision analysis and provides the direction for sustainable lifts criteria selection which has a significant effect on the design. The result shows the preference dimension for sustainable lift design is economic aspect including its criteria required as decision analysis output for planning and designing lifts systems for public hospital buildings.

1. Introduction

Sustainable is not passing fad – it will continue to become an increasingly important consideration for everyone involved in building design. Paucity has been given to the importance of ensuring the sustainability of hospital building in Malaysia (Sahamir and Zakaria, 2014). There are various criteria that need to be considered before the decision can be made in selecting the appropriate lifts design for a building particularly for hospital buildings (Sahamir et al., 2017). Different building owners would have different requirements in evaluating and supporting their decision-making processes. Nowadays, the lift system has been a significant vertical transportation device for high-rise buildings and has brought human convenience and efficiency for daily routine. Technological development enables the construction of high-rise buildings with advance technological equipment provided alongside. Urbanisation and the expansion of urban areas motivate hospital buildings to be constructed in multi-storey design. The rapid increase in number of buildings and the heavy

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passenger traffic within the buildings caused the need for the lifts to increase. Particularly for the hospital buildings where during the peak time, the usage will increase three-fold from the regular working routine.

2. Lift system for building

In a modern building, the requirement of the latest technology is an essential. Recent advances in intelligent technologies enable a plenty of smart living services in people daily lives. For example, in a smart building environment, various physical information such as temperature, humidity, motion, light, and sound can be collected from sensors, and then transferred immediately to the building control system (Kwon et al., 2014).

2.1 Economic issues

There are high costs related to a highly developed healthcare system, but without investments, an unhealthy population in working age will contribute to large annual expenses (Nedin, 2013). According to Larssen (2011), hospital buildings only serve one purpose: assisting the healthcare services to be as functional as possible. The performance of hospital buildings depends to a large degree on the efficiency of building design. A more strategic life cycle planning, involving both adaptability and life cycle cost (LCC), need to be a part of hospital building projects of the future (Hareide et al., 2015). The focus needs to be given to assessment of life-span qualities such as low operational costs, adaptability, long-lasting materials and on how the hospital building supports the healthcare services over time (Bjørberg and Verweij, 2009). This highlights the issue of poor development of the hospital buildings, as there will be problems if no actions are rendered.

2.2 Environmental concern

Energy efficiency for lift system has not been a major market and technological driver in the building sector. Other design options like space restrictions, reliability and safety, riding comfort, etc. have been the central concerns of the vast majority of manufactures (ISR, 2010). The last few years have witnessed a change of course with a company introducing energy efficient technologies for competitive reasons and, at the same time, to help in saving energy and money (ISR, 2010). The development of energy efficient technologies is of high importance today and should be considered due to moral and financial aspects. It is said that lifts use a relatively small amount of energy compared to the overall energy consumption of a building. In Rider (2017) article quoted from Jorge Chapa (Head of market transformation at Green Building Council Australia), “lifts can be a significant portion of the energy consumption of a building. It depends on the type of building, but it is usually 5 to 10 percent of their energy use.” The usage of different smart strategies and different technologies can lead to low energy efficiencies and is therefore of high importance in the world today. One way of reducing energy consumption is to have a lift which operates using a smart and energy efficient control strategy, but at the same time tries to minimize the waiting time for passengers. The energy (electrical power, crude oil for example) has been consumed and exploited greatly for many years. The energy consumption of the lift system is the most part in the power consumption of tall buildings. Hospitals are enormously complex buildings with many unique requirements. The energy demand for hospital buildings are not similar compared to the other types of building as it operates 24 hours. Research about the amount of energy consumed in the buildings demonstrates that the energy consumed by the elevators and the escalators constitute between 5 % and 25 % of the total energy consumption of the building (Liu et al., 2010).

2.3 Social features

There are several performance criteria of vehicle lift scheduling systems need to be considered such as minimising the waiting time, the riding time, and the energy consumption. Most existing studies have focused on minimising the average waiting time since passenger’s dissatisfaction grows rapidly as the waiting time increases (Brand and Nikovski, 2004). Conventionally, there is one lift car moving within each hoistway, which is inefficient from a transportation traffic point of view, as easily indicated by a railway system. On a rail, there are multiple trains moving on different sections of the rail. The idea of having more cars to serve one hoistway is not new. By using more cars. The handling capacity of one hoistway could be increased as more passengers can be handled at the same time but the motion control tends to be more complicated (So et al., 2016). In an age of rapid urbanisation, safety and evacuation become more complex as designers aspire upwards, by their very nature, size and large footprint on the ground, raise the question of economic feasibility and environmental sustainability (Sisson, 2017).

2.4 Lift selection criteria

Lifts have come a long way since the first passenger lift was installed by Elisha Otis at New York’s Haughwout Building some 160 years ago (Rider, 2017). Today, specifiers have access to a diverse range of energy efficient lift options which incorporate functions like regenerative drives, machine-room-less (MRL) technology, standby mode, destination dispatch, and energy efficient lighting. As illustrated in Figure 1, eco-friendly elevators, utilising telescoping jack systems, eliminate jackholes and avoid the potential for below-ground oil leaks whereas compact, lightweight, gearless machines deliver greater energy efficiency in machine room-less (MRL) elevators (Schindler, 2017). Machine-room-less (MRL) lifts have also proven to be a big saver on energy and emissions for buildings (Rider, 2017). Specifying a sustainable lift does not go beyond just its energy consumption and emissions (Rider, 2017). It should also involve consideration of materials used, which includes things like interior paints, flooring, control panels, lighting, and HVAC systems. This could fall under the criteria of Indoor environment quality and materials. Table 1 shows the summary of important criteria that need to be taken into account in order to look at the main preference of lift design for hospital buildings.

Figure 1: Eco-friendly elevators that utilising telescoping jack systems (left); Machine room-less (MRL) elevators (right) (Schindler, 2017)

Table 1: Criteria identification in selecting the best design of lift systems for public hospital buildings

Dimensions	Criteria
Environmental	Type of lifts
	Technology
	Design (Lift strategy)
	Materials
	Specification
Social	Minimum noise
	Minimum vibration
	Minimum waiting time
	Maximum speed
	Safety
	Indoor environmental quality
Economic	Brand
	Low initial cost
	Economic functional size
	Low energy consumption
	Lifespan
	Low operation and maintenance cost

3. Research Methodology

Multi-Criteria Decision Analysis (MCDA) include the process of establish decision goals, formulation of alternatives, identification of criteria, assigning the criteria scores, normalisation. Technique for order preference by similarity to ideal solution (TOPSIS) technique has been adopted in this study. TOPSIS is part of the decision-making process which the decision maker task is to solve a multiple criteria decision making (MCDM) problems. It helps decision maker(s) (DMs) organise the problems to be solved, carry out analysis, compare, and rank the alternatives. Classical MCDM method was first developed by Hwang and Yoon (1981). A MCDM problem can be concisely expressed in matrix format as shown in Figure 2 (Chen, 2000). Decision making is the process of finding the best option from all the feasible alternatives. Multicriteria evaluation of alternatives belongs among the basic decision problems of multicriteria decision making with very large possibilities of real applications (evaluation of investment alternatives, evaluation of credibility of bank clients, rating of companies, consumer goods evaluation and many others) (Shih et al., 2007).

$$\begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{array}$$

$$W = \quad [w_1 \;\; w_2 \ldots w_n]$$

Figure 2: Multi-criteria decision making (MCDM) matrix

where $A_1, A_2, ..., A_m$ is the set of alternatives among which decision makers have to choose. $C_1, C_2, ..., C_n$ are criteria which alternative performance are measured. x_{ij} is the rating of alternative A_i with respect to criterion C_j. W_j is the weight of criterion C_j.

3.1 Technique for order preference by similarity to ideal solution (TOPSIS)

TOPSIS has been chosen for this analysis due to it works for fundamental ranking, makes full use of allocated information and the information need not be independent (Kumar et al., 2017). TOPSIS is a method to identify solutions from a finite set of alternatives based upon the shortest distance from the positive-ideal solution (PIS) and the longest distance from negative ideal solution (NIS) or nadir (Hwang and Yoon, 1981). The most important function of TOPSIS was, it can incorporate relative weights of criterion importance. The operations of the TOPSIS process include: decision matrix normalisation, distance measures, and aggregation operators. The multi-criteria evaluation of alternatives problem is usually defined by criterion matrix as indicate in Figure 2. There are two important items that need to be evaluated by using this technique, namely; alternatives and criteria. Alternatives are the options used to be evaluated for selection of the best while criteria will give impact to the selection of alternatives. Weights are used to estimate relative importance of criteria (r_{ij}). To compare the alternatives on each criterion, the normalised process is usually made column-wise. Eq(1) shows the linear normalisation methods that has been used for this study while closeness coefficient (CC_i) formula is shown in Eq(2).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \tag{1}$$

$$CC_i = \frac{S_i'}{S_i^* + S_i'} \qquad i = 1, 2, \ldots., m \tag{2}$$

where $0 \leq CC_i \leq 1$, Si^* is the positive ideal solution, and Si' is the negative ideal solution. The larger the index value, the better the performance of the alternative.

3.2 Expert decision

30 experts among the design team for public hospital building have been identified. These experts were assigned with the task of weighting each criterion that has been established from literature search. The TOPSIS for group decision-making approach has been used to analyse the result.

4. Result

There are three dimensions that have been evaluated to achieve the aim of the study. These dimensions have been evaluated against certain criteria as shown in Table 2. Multiple preferences of more than one Decision Makers (DM) and the separation measure by taking the geometric mean of the individuals for TOPSIS is used

(Shih et al., 2007). Normalisation of the criteria is important part for the TOPSIS analysis that reveal the real problem solution of the criteria selection as shown in Table 3.

Table 2: Preference aggregation for TOPSIS in the group decision environment

Dimensions	Criteria	Criteria Code	Weights (W)	Decision makers (DM)	Weights (W) Rank-order weighting method
Environmental (EN)	Types of lift	C1	4	30 numbers of respondent from public hospital design team (mechanical and electrical engineers).	W = (1 – 5) 1 = not at all important 2 = slightly important 3 = important 4 = fairly important 5 = very important
	Technology	C2	2		
	Design (Lift strategy)	C3	2		
	Materials	C4	5		
Social (SO)	Minimum noise	C5	4		
	Minimum vibration	C6	5		
	Minimum waiting time	C7	2		
	Maximum speed	C8	2		
	Safety	C9	3		
	Indoor environmental quality	C10	5		
Economic (EC)	Low initial cost	C11	5		
	Low energy consumption	C12	4		
	Low operation and maintenance cost	C13	4		

Table 3: Criteria normalisation

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
EN	0.577	0.426	0.371	0.391	0.577	0.492	0.371	0.686	0.298	0.530	0.662	0.566	0.566
SO	0.577	0.640	0.557	0.651	0.577	0.615	0.743	0.514	0.745	0.662	0.530	0.424	0.424
EC	0.577	0.640	0.743	0.651	0.577	0.615	0.557	0.514	0.596	0.530	0.530	0.707	0.707

Table 4 shows that economic element has the highest closeness coefficient (CC_i) for the lift criteria selection based on PIS and NIS identification. The ranking process was then conducted in identifying the highest closeness coefficient (CC_i) that represents the best selection. The process is important to show the preference when considering the three elements of sustainability. Incorporating green lifts designs is complex and not every option is suited to every project, but creating a sustainable building is very rewarding in terms of building efficiency and user experience. Environmental, economic, and social dimensions of the sustainability set the performance standards of the building requirement and the attainment of these standards sets the practical solutions in building design.

Table 4: Identification of positive ideal solution (PIS) (S_i) and negative ideal solution NIS (S_i') in ascending order.*

Solution	Alternatives		
	EN	SO	EC
S_i*	2.498	1.804	1.154
S_i'	1.094	2.277	2.511
$S_i* + S_i'$	3.592	4.081	3.665
$CC_i = S_i'/(S_i* + S_i')$	0.305	0.558	0.685
Ranking	3	2	1

5. Conclusions

Based on the result of the study, the task of solving these problems is largely that of initial cost, energy consumption, maintenance cost that meet the performance standards in the most economical way. The designer must know the limits within which their choices must be made in terms of the considered criteria (i.e. materials selection, design principle, associated cost and others) and of the economics of the end result, and these will drive to the sustainability lifts design. In the past, a limited number of available technology resulted in a limited number of design process which, after a long period became fully developed and standardised in practice. Traditionally, development processes are difficult to handle due to lack of available building technology. This has encouraged the search for new method which will fulfil the same or even greater decision towards sustainability. Such problems and many others need to be solved with the aid of empirical knowledge and even require a scientific approach. For this reason, building has been to a large extent transformed to a modern technology with its repository of knowledge based on scientific principles applied to the problems of building. Technology can free designers from the big-box model of buildings and lead to more efficient and economical building designs. It is observed that multi-criteria decision analysis is part of the important process that can be used by project stakeholder to achieve the sustainable objective. It eases the process of deciding the criteria that need to be seen entirely before the other process can be proceeded. It is said as a practical tool for solving problems faced by many industries.

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