Indian Journal of Science and Technology, Vol 8(25), DOI: 10.17485/ijst/2015/v8i25/80839, October 2015
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

A Study on Improving Safety Performance through Efficient Prioritization for Fire and Evacuation Safety in Commercial Buildings

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Abstract

In recent years, many nations around the world, including the Republic of Korea, have shown keen interest in the regeneration of cities as a viable solution to a host of environmental issues the world is facing today. As such, development of various regeneration methods is being undertaken. One integral part of the said initiatives is the recycling of existing buildings that are aging, though the focus is being placed on improving the internal and external aesthetics and structural performance rather than on enhancing fire safety performance of buildings. Reflecting such trends, relatively fewer studies have been conducted to address the ways to improve the safety performance during disasters such as fire which lead to fatality and massive property losses. Given the rationale, this study proposed a building owner/manager-friendly comprehensive and effective way to improve the safety performance of aging commercial buildings during fire/evacuation incidents so as to address the particular susceptibility exhibited by such buildings during disasters that result in large casualties and property damages. Statistical techniques were used to establish the buildings' properties relating to fire and evacuation. Also AHP analysis was performed to calculate property-specific weightings. In consideration of the calculated weightings and condition of buildings, the study proposed a logic and decision-making tool for the owner/manager such that a comprehensive improvement can be made about the fire/evacuation performance.

Keywords: Commercial Building, Decision-Making, Fire Safety Attributes, Prioritization

1. Introduction

By characteristics, buildings do not respond quickly to changes in society or lifestyle or to technological advances, and deterioration of the physical performance of buildings takes place gradually over time. To come up with ways to troubleshoot, various studies and research projects are actively under way about remodeling which entails basic repair and revamp/reinforcement of buildings. Recycling of existing buildings, however, focus on aesthetics, both inside and outside, as well as recovery of structural performance, as such relatively less emphasis being put on the study of restoring safety performance of buildings against disasters such as fires that claim fatality and massive damage to properties. Such safety performance-particularly in the case of aging commercial buildings - poses a whole array of problems in terms of safety performance (evacuation, flame containment, etc.) because they often exist as multi utility or purpose space (business, commerce, education/training, accommodation, etc.) and as such their purpose or interior use has been subjected to frequent modification. Furthermore, fire safety systems and mechanical systems of the buildings, which must guarantee failure-proof performance during emergency, worsen over time, exhibiting increased chances of mechanical failure, more leaks in piping, and other deteriorations in facility functioning. Such deteriorations increase the uncertainty of the fire safety systems' performance during actual fire incidents. Hence, aging commercial buildings

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in densely populated districts in the urban area show decreased fire-safety performance compared with newly erected buildings. In certain cases, the compromised functioning acts as a threat to the safety of the entire city. Each city's safety against fire needs to be ensured, so does the stable recycling of existing commercial buildings that continue to age. To that end, it is necessary to establish ways of logical and comprehensive fire safety assessment/evaluation regarding step-wise restoration of safety performance of aging commercial buildings, with emphasis on the fire susceptibility of such buildings.

2. Establishment of Fire and Evacuation Safety Properties of Commercial Buildings

Assessment/evaluation of the fire and evacuation safety and risk of buildings utilizes fire/evacuation safety assessment/evaluation methods for existing buildings, such as establishing a quantifiable weighting for fire system operability as well as building utility and assessment/evaluation items through professional intervention. The aforesaid approach, however, limits assessment/evaluation items that suit the particular purpose(s) harbored by each organization or company. For the purpose of this study, literature review was conducted to identify the properties that are related to evacuation during fire in commercial buildings. The review included investigation and analysis of the previous studies on fire safety assessment/evaluation on buildings and of the assessment/evaluation items relating to building fire safety that are either being enforced or have been proposed. Though the assessment/evaluation items and methods examined through literature review vary, Table 1 has organized them into groups by focusing on the content thereof.

To identify the assessment/evaluation items addressing the fire safety performance of commercial buildings and to establish an objective weighting for the identified items, this study carried out two rounds of surveys and interviews with

Table 1. Comparing building fire safety performance evaluation items

Properties relating to commercial buildings' fire safety performance		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Total**
Prevention and facility management	Organizational setup and drills				v					v	v		v		4
	Inspection/monitoring and recordkeeping				v					v	v		v	v	5
	Inflammables control (organization & housekeeping)	v			v					v	v			v	5
	Security and patrol				v					v					2
	Fire source (individual equipment) control	v		v											2
	Fire equipment (boiler, etc.) facility management	v		v	v	v	v			v					6
	Electrical facility management	v			v	v	v			v					5
	Hazardous facility management	v			v	v	v			v					5
	Disaster control center location and structure			v	v					v					3
Fire extinguishing system	Fire extinguisher	v	v	v	v					v	v		v	v	8
	Indoor fire hydrant	v	v	v	v	v	v			v	v		v	v	10
	Outdoor fire hydrant	v	v	v	v	v	v			v	v				8
	Special fire extinguishing system	v		v	v					v		v			5
	Sprinkler	v	v	v	v	v	v	v		v	v	v	v		11

(*Continued*)

Table 1. (*Continued*)

Properties relating to commercial buildings' fire safety performance		1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Fire alarm system	Automatic fire detection system	v	v	v	v	v	v	v		v	v		v	v	11
	Automatic notification system	v			v					v	v				4
	Emergency public announcement system	v	v	v	v	v	v			v	v	v	v	v	11
	Alarm system (short circuit and gas leaks)	v			v					v					3
Firefighting system	Water supply & spray system	v		v	v	v	v			v					6
	Emergency EV (Elevator)			v		v	v	v		v				v	6
	Wireless communication and emergency power outlet	v			v					v					3
	Smoke control for halls and auxiliary rooms	v	v	v	v			v	v	v	v	v	v	v	11
	Firewater system				v					v	v				3
Evacuation system	Exit lights and Inducement signs	v	v	v	v	v		v		v					7
	Evacuation instrument	v	v	v	v			v		v					6
Fire compartmentation	Safety of horizontal/vertical fire compartmentation	v	v	v	v	v	v	v	v	v	v	v	v	v	13
	Balcony installation condition and compartmentation						v	v							2
Fire protection zone	Fire resistant structure of key structures		v	v		v	v		v		v	v	v		8
	Interior finish materials		v	v		v	v	v	v		v	v	v		9
Potential risk & hazard	Fire load										v			v	2
Evacuation route	2-way evacuation		v	v		v	v	v		v		v	v	v	9
	Evacuation route safety (distance, dead end, etc.)		v	v		v	v	v	v	v		v	v	v	10
	Appropriateness of exits		v	v						v		v		v	5
Evacuation stairs	Structure and condition of (designated) evacuation stairs	v	v	v	v	v	v	v	v	v				v	10
External environment	Condition of surroundings, and accessibility		v	v		v	v	v						v	6
	Distance between fire location and fire station					v	v				v		v		4
Internal environment	Area, no. of floors/levels, and sectional configuration							v			v	v	v	v	5
Fire station/officer capability	Fire station's containment capability Area to be covered by fire station Individual fire officer's capability							v			v		v		3

a large number of professionals/specialists in disciplines relating to fire safety. The first such round surveyed 40 professionals in fire safety fields (e.g., academics [professors and graduate students in architecture/firefighting], civil servants in firefighting disciplines, and fire safety monitoring personnel). The survey utilized the Liker's Scale, which is widely used in various kinds of survey questionnaires, resulting in assessment/evaluation items for fire safety performance of commercial buildings. For the second round of surveys, 20 professionals/specialists were subjected to AHP (Analytic Hierarchy Process) wherein the 1st survey-identified assessment/evaluation items are grouped into units having homogenous properties to form homogenous hierarchies. Thus, a weighting for each of the fire-safety properties was established. Figure 1 shows the step-wise analytical processes that were used to identify property-specific weightings relating to fire safety performance of commercial buildings.

3. Establishment of Fire Safety Assessment/Evaluation Items and Weightings in Commercial Buildings

3.1 Overview of Study Participants

The Table 2 summarizes the general information about the professionals/specialists who participated in the surveys. A total of two survey tests were conducted, with the first such survey performed on 40 individuals who are researchers in disciplines relating to architecture and firefighting and those working in the field. Of these individuals, 20 were selected for advanced career and/or academic background and given the second surveys.

3.2 Identification of Key Assessment/ Evaluation Items (1st Survey)

The first survey questions were constructed such that the participants were presented with the fire safety

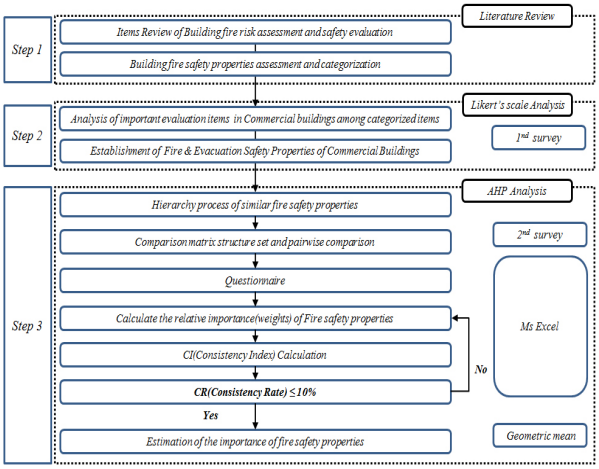

Figure 1. The step-wise analytical processes of property-specific weightings relating to fire-safety performance of commercial buildings.

Table 2. General information of study participants

Professional field Survey Target(person)	Architectural engineering	Electric engineering	Mechanical engineering	Chemical engineering	Safety of fire fighting
	16[10]	5[1]	7[5]	4[1]	8[3]
Education Survey Target(person)	BACHELOR	MASTER	PH.D	-	-
	18[4]	13[7]	9[9]	-	-
Profession Survey Target(person)	Graduate school,	Fire/Fire-fighting officer	Professor (Fire, Safety, etc.)	Public enterprise (Fire, Safety, etc.)	Senior researcher (Fire, Safety, etc.)
	6[1]	10[4]	7[7]	15[6]	2[2]
Length of experiencen Survey Target(person)	3~5years	5~10 years	10~15years	20~25years	-
	16[0]	14[10]	3[3]	7[7]	-

* [ ] is a secondary subjects

performance assessment/evaluation items for commercial buildings as indicated in Table 1; the participants were then asked to rate the importance on each item. For the rating, a five-level Likert's scale was used. Developed in 1992 by Likert, the Likert-type scale is roughly divided into two categories: (a) a summated ratings scale, where a number of items on the same subject are arranged and presented to the participants who rate them for the intensity of agreement on a constant sum scale with 3 to 7 levels, and the sum of such rated agreement is used to assess/evaluate the subject; and (b) an attitude scale which is based on the item analysis technique incorporating internal consistency scale. Data on each question item that were collected through the survey questionnaires were converted into values (i.e., average index) by using Formula (1). The calculated average indexes were placed into the rating as shown in Table 3.

$$Average\ Index = \frac{\sum(\mu \times n)}{N} \quad (1)$$

μ : *Ordinal-scale priority value (1-5)*
n : *Item response frequency*
N : *Total response*

The first survey questions were constructed such that the participants were presented with the fire safety performance assessment/evaluation items for commercial buildings as indicated in Table 1; the participants were then asked to rate the importance on each item. For the rating, a five-level Likert's scale was used. Developed in 1992 by Likert, the Likert-type scale is roughly divided into two categories: (a) a summated ratings scale, where a number of items on the same subject are arranged and presented to the participants who rate them for the intensity of agreement on a constant sum scale with 3 to 7 levels, and the sum of such rated agreement is used to assess/evaluate the subject; and (b) an attitude scale which is based on the item analysis technique incorporating internal consistency scale. Figure 2 illustrates the 4-level rating system that was used in this study and the level of intensity given to each of the 4 levels. It above presents the average index/rating given to each of the identified fire safety properties. For the purpose of this study, those properties with average index/rating III or above were defined as key assessment/evaluation items related to fire safety performance of commercial buildings.

Table 3. Rating Scale For Average Index

Raring Scale (5-Pts scale)	Average Index Rang
1	0.00 ≤Ai< 1.50
2	1.50 ≤Ai< 2.50
3	2.50 ≤Ai< 3.50
4	3.50 ≤Ai< 4.50
5	≤Ai< 5.00

3.3 Calculation of Weighting for Fire Safety Properties (2nd Survey)

Using the results of the 1st survey conducted, the fire safety performance assessment/evaluation items identified for commercial buildings were grouped into 11 areas for each fire safety domain and were defined as the fire-safety properties in commercial buildings (hereinafter referred to as the "Property" or "Properties"). To establish a weighting for each Property, this study used the AHP (Analytic Hierarchy Process) technique which is one of the most commonly used analytical methods for MADM (Multi-Attribute Decision Making). For AHP analysis, sub-hierarchies were established for each Property, with hierarchical systems established as shown in Figure 2 to allow for pairwise comparison. The 2nd survey test (interview) was carried out on selected 20 participants (professionals/specialists), during which the participants were given full explanation of the Properties being pair-compared and of the inter-Property intensity scale before they responded. For said pair comparison, 9-level analysis was used (see Table 4).

As shown in Table 5, depending on the intensity scale, results of the pair comparison can be subjected to constructing of the matrix for each hierarchy. The matrix is a reciprocal matrix wherein all elements of the main diagonal line are '1.' The said pair-comparison matrix is

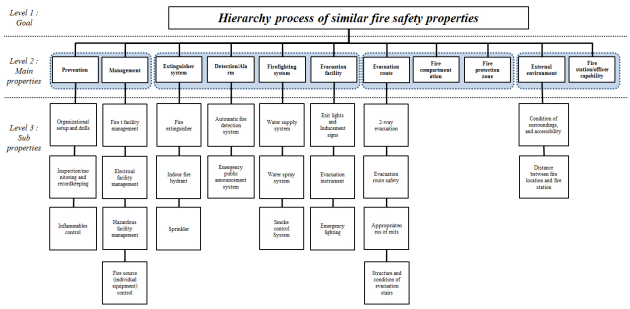

Figure 2. Hierarchy process of similar fire safety properties.

Table 4. AHP pair-wise comparison scale

A 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 B	
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	Absolutely more important.
2, 4, 6, 8	Intermediate values

subjected to internal matrix multiplication so that the mutual intensity (weighting) can be established mathematically. There are several methods for calculating weighting, such as arithmetic mean, geometric mean, least square, and eigenvector. The technique using eigenvector offers merits such that the extent of matrix consistency can be measured[12]. The same technique was adopted for this study to calculate the weightings. The method allows for the calculation of CR (Consistency Ratio) for each matrix, where the CR range was set at 0.05 for max. 3 × 3 matrix; 0.08 for 4 × 4 matrix; and 0.1 or less for min. 5 × 5 matrix. Any matrix that exhibit CR 0.1 or above was excluded from intensity calculation[13].

Tabulated information in Table 5 indicates the 2nd survey respondents' pair comparison matrixes and CRs. The summation of the weighted values were attained by Saaty's geometric mean method[14]. Table 6 shows the results that calculated and compiled Property-specific relative intensity ratings (weightings) based on the 2nd survey results.

4. Method for Estimating Aging Commercial Buildings' Fire/ Evacuation Performance Improvement

To improve the fire performance of existing commercial buildings that are aging, priorities -if under normal circumstances- would have to be given to the Properties with greater intensity as defined in Section 3. Applying this rule of thumb uniformly, however, has its limits. For instance, in the case of carrying out performance improvement per the intensity defined in Section 3, the first such task would be to improve "organizational setup and drills" under "prevention and facility management," i.e., a key Property category with the highest intensity given. If the building's organizational setup and drills are under good care, the improvement priorities will have to be changed. Hence, estimation of the priorities given to fire/evacuation performance improvement as mentioned herein should be subjected to a technique that uses subjective assessment/evaluation by the said building's manager and the intensity rating on each Property.

Figure 3 illustrates the basic logic behind the technique of estimating performance improvement priorities. For the Properties most urgently requiring performance improvement, priorities have been established such that the highest priority is assigned to the Property that is poorly managed by the building and yet scores high on intensity rating, whilst the lowest priority is given to the Property that is being well managed but has relatively lower intensity

Figure 4 indicates this study's proposed approach for estimated prioritization for performance improvement, where:

Step 1: Present to the building manager its fire/evacuation Properties and inform him/her about the key features of the Properties.

Step 2: Evaluate the condition and management status of the defined Properties for the building.

Step 3: Shows the processes wherein each Property's intensity is converted/calculated. The value is attained through each Property's intensity (see Section 3) and by arithmetic calculation of the diagnosis/assessment results as examined in Step 2.

Step 4: Summation of the ratings (scores) assigned to the Properties prioritizes hem by descending order and is given to the building manager.

Further,

Step 1: The Properties are defined as per the DB (Table 7. Property-Specific Intensity Rating of building fire/evacuation safety) as addressed in Section 3.

Step 2: The Properties defined in Step 1 are applied to diagnosing/evaluating of the commercial building in question. The rating is proposed as 'Good,' 'Average,' or 'Poor' as shown in Table 8, which depends on the concerned system, facility or task's condition.

Additionally, any performance diagnosis or assessment must be carried out by a party or parties with professional knowledge and qualification relating to fire safety management.

Step 3: There are a total of 26 fire/evacuation Properties in the commercial buildings. Results of the diagnosis/assessment performed by the manager in Step 2 are converted into weightings (1) through the formula shown in Table 8.

Table 5. Respondents' pair comparison matrixes and CR (Consistency Ratio)

Matrix	20 professionals/specialists subject																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A(11×11)	0.03	0	**0.34**	0.06	0.06	0.01	0.02	0.01	0.01	0.08	0.06	0.18	0.03	0.04	**0.09**	0.01	**0.43**	0	0.01	0.03
B(3×3)	0	0	0.01	0.03	0	0	0.04	0.01	0	0	0.04	0.07	0.03	0.02	0	0	0	0.01	0.02	0.04
C(4×4)	**0.24**	0	0.01	0.04	0.07	0.01	0.02	0	0.02	0	0.04	0.03	0	0.01	0	0	0.01	0	0.03	0.06
D(3×3)	0	0.01	0	**0.31**	0.04	0.03	0.02	0	0.04	0	0.02	0.02	0.01	0	0.03	0.01	0	0	0	0.01
E(2×2)	0	0.01	0	0.01	0	0	0	0	0	0.01	0	0	0	0	0.02	0	0	0	0	0
F(5×5)	0.07	0.03	0	0	0.01	0.3	0.01	0.04	0.02	0	0.07	0.08	0.04	0	0.03	0	0.13	0.04	0.03	0
G(3×3)	0.03	0	0	0	0.03	0.02	0.01	0	0	0	0.03	0.02	0.01	0	0	0	0	0	0	0.01
H(3×3)	0	0.01	0.03	0	0	0	0.01	0.1	0	0.01	0	0	0.04	0.01	0.05	0	0.03	0.01	0	0.01
I (2×2)	0	0	0	0	0	0	0	0	0.01	0	0	0.02	0	0	0.01	0	0	0	0	0

Table 6. Importanment(Weighting) of Fire safety Properties in Commercial Buildings

Fire safety Properties		Weighting (%)	
Main Properties	**Sub Properties**	**Sub Properties**	**Main Properties**
Prevention	Organizational setup and drills	34.6	12.8
	Inspection/monitoring and recordkeeping	21.3	
	Inflammables control (organization & housekeeping)	44.1	
Facility management	Fire source (individual equipment) control	24.3	11.4
	Electrical facility management	19.8	
	Hazardous facility management	28.3	
	Fire equipment (boiler, etc.) facility management	27.6	
Firefighting system	Fire extinguisher	16.7	11.3
	Indoor fire hydrant	10.9	
	Sprinkler	72.4	
Detection/Alarm	Automatic fire detection system	89.8	8.7
	Emergency public announcement system	10.2	
Firefighting system	Water supply & spray system	20.3	8.2
	Smoke control for halls and auxiliary rooms	58.9	
Evacuation facility	Exit lights and Inducement signs	40.4	8.6
	Evacuation instrument	31.3	
	Emergency lighting	28.3	
Evacuation route	2-way evacuation	26.4	10.8
	Evacuation route safety (distance, dead end, etc.)	18.3	
	Appropriateness of exits	23.2	
	Structure and condition of evacuation stairs	32.1	
Fire compartmentation	Safety of horizontal/vertical fire compartmentation	100	12.2
Fire protection zone	Fire resistant structure of key structures	100	9.2
External environment	Condition of surroundings, and accessibility	73.6	4.2
	Distance between fire location and fire station	26.4	
Fire station/officer capability	Fire station's containment capability	100	2.6

Figure 3. Logic structure for priority derived.

Table 7. Criteria for Property Diagnosis/Assessment for the Building

Good	Average	Poor
Showing no defects, or exhibit defects that hardly affect the fire safety or the emergency fire prevention measures	Showing defects that considerably affect the fire safety, or fairly serious problems are foreseen against the fire prevention measures during emergency	Defects seriously affect the fire safety, or the emergency fire prevention measures are not effective

The established converted weightings (1) are further converted into the weighted values (2) using Formula (2) are finally expressed as the rating scores relating to the concerned commercial building's performance improvement.

$$Convert\ Weight\,(2) = M.P.W \times Convert\ Weight\,(1) \qquad (2)$$

M.P.W : Main Properties Weight

Step 4: Priorities are given to the concerned building's Properties by descending order and then provided to the manager. This final information offers the manager objective data upon which he/she will make decisions about performance improvement.

5. Conclusion

This study proposed a way to objectively and reasonably improve the performance of aging commercial buildings in relation to their fire safety performance. The study utilized the Likert-type scale as well as logic-based analytical statistic techniques such as AHP (Analytic Hierarchy Process) to define the properties of fire safety performance (the "Properties") and to examine the intensity rating thereto. Based on the results, a decision making tool was proposed to the owner or manager of the building concerning their attempts to actively improve the fire/evacuation performance of the buildings. It is considered that the results can be used as a viable method to achieve step-wise restoration and safer recycling of aging commercial buildings that are susceptible to fire hazards. Furthermore, recommendations are made for future studies that may combine engineering-based examination of fire/evacuation performance in detailed assessment/evaluation items. Such enhancement would offer further examination of detailed performance restoring methods.

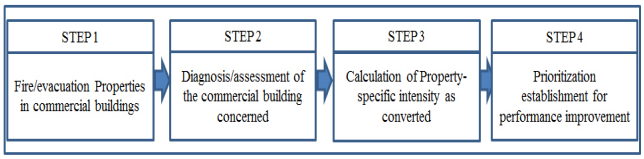

Figure 4. Procedure for improved performance.

Table 8. Calculation of Property-specific intensity as converted

	Good	Average	Poor
Convert Weight(1)	$\frac{S.P.W}{3}$	$(\frac{S.P.W}{3}) \times 2$	$S.P.W$

S.P.W : Sub Weight, 26 fire/evacuation Properties

6. Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(NRF-2011-0025645).

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